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**FINAL REPORT
ON EVALUATION OF CYCLOCRAFT SUPPORT
OF OIL AND GAS OPERATIONS IN WETLAND AREAS**

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EXECUTIVE SUMMARY

The cyclocraft is a proven hybrid aircraft, capable of VTOL, lifting heavy and bulky loads, highly controllable, having high safety characteristics and low operating costs.

Mission Research Corporation (MRC), under Department of Energy sponsorship, is evaluating the potential use of cyclocraft in the transport of drill rigs, mud, pipes and other materials and equipment, in a cost effective and environmentally safe manner, to support oil and gas drilling, production, and transportation operations in wetland areas. Based upon the results of an earlier parametric study, a cyclocraft design, having a payload capacity of 45 tons and designated H.1 Cyclocraft, was selected for further study, including the preparation of a preliminary design and a development plan, and the determination of operating costs. The H.1 Cyclocraft design has the following major characteristics:

Maximum weight	128.2 tons
Empty weight	77.6 tons
Overall cyclocraft	length 345 feet
	height 170 feet
	width 151 feet
Aerostat volume	3,637,230 cubic feet
Installed power	5,404 SHP

This report contains all of the results derived from the program to evaluate the use of cyclocraft in the support of oil and gas drilling and production operations in wetland areas. The program completed by MRC and LSU for DOE had the following objectives:

- (a) Define transport requirements to support oil and gas operations in wetland areas.
- (b) Develop a cyclocraft preliminary design capable of meeting both the transport and the environmental requirements.
- (c) Validate cyclocraft performance by conducting subscale free-flight tests.
- (d) Determine ground support requirements for the cyclocraft operations.
- (e) Determine environmental impacts of the operations.
- (f) Evaluate the costs, risks and benefits associated with the cyclocraft operations,
- (g) Prepare a prototype cyclocraft development plan.
- (h) Transfer technology developed to all relevant organizations.

The scope of the evaluation program included a determination of the environmental impact of operating cyclocraft in wetland areas. In addition, validation of the aircraft's operational capabilities was obtained through subscale flight tests. A prototype H.1 Cyclocraft development plan was also included, together with a technology transfer program, to ensure that the results obtained from implementation of the program, were communicated to all government agencies, educational institutes and business entities, that might benefit from the program.

The results of the cyclocraft evaluation program show that:

(a) There is a very real need for a system that can transport heavy loads in wetland areas, economically and with no permanent adverse environmental impact.

(b) Cyclocraft operations in wetland areas appear to be very practical and should result in a high level of reliability. Required payloads of 45 tons are well within the cyclocraft's capability.

(c) The cyclocraft has the potential of supporting oil and gas drilling and production operations in wetland areas, far more economically than any other airborne system, including helicopters.

(d) The environmental impact of operating heavy-lift cyclocraft is projected to be both low and temporary, and far less than that caused by other options available to support oil and gas drilling and production operations in wetland areas.

As discussed above, there is a high potential value of utilizing cyclocraft to support oil and gas drilling and production operations in wetland areas. Further, based on results obtained, MRC considers that cyclocraft technology is well established and that the risks associated with the development of cyclocraft, large or small, manned or unmanned, are clearly understood and that those risks are both low and acceptable. This contention is not fully understood by some of the potential end-users however. Further, a significant investment would be required to realize the potential of large payload cyclocraft, such as the H.1 Cyclocraft. Consequently MRC and LSU personnel have formulated a three phase program to develop a smaller cyclocraft, designated P.1 Cyclocraft, which would be a "pilot" version of the 45 ton payload H.1 Cyclocraft:

- o Phase I: System Design and Program Planning
- o Phase II: System Detailed Design and Manufacture
- o Phase III: Wetlands Operation and Evaluation

Essentially, the program is aimed at designing and building a P.1 Cyclocraft which is capable of carrying 4 to 6 personnel and demonstrating its utility to operate properly in the wetlands environment. Specific applications of the P.1 Cyclocraft would include aerial monitoring of environmental changes and personnel transportation. To exploit the considerable potential that cyclocraft offer in wetland areas, it is recommended that development of the P.1 Cyclocraft be initiated with minimum delay.

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1. Introduction.

The cycloplane hybrid aircraft was developed by Aerolift, Inc. at Tillamook, Oregon from 1978 through 1990. Aerolift demonstrated the technical viability of the single-rotor version of the aircraft by the accomplishment of several developmental programs, including the successful manned free-flight operations of the two-ton payload demonstration Cycloplane X.2, shown in Figure 1.

Figure 1. X.2 Cycloplane in Flight

In 1990 Aerolift, Inc. performed a program to determine optimum USAF mission opportunities for hybrid aircraft technology, under a SBIR phase I contract with Wright-Patterson AFB, ASC/XRX. Subsequently AeroLift ceased its operations. In November, 1990, Mission Research Corporation (MRC) reached a formal agreement with AeroLift, Inc., whereby MRC obtained all rights to follow-on SBIR programs. In addition MRC acquired the use of the cycloplane technology, hired the principal investigator and obtained the support of several of the engineers experienced in cycloplane development. MRC introduced the generic term "cycloplane", which is applicable to all aircraft whose configurations combine cycloplane and aerostats.

The initial development phase of an unmanned dual-rotor cycloplane was conducted recently by Mission Research Corporation under a SBIR phase II contract with Wright-Patterson AFB, ASC/XRX, Contract No F33657-91-C-2133. The program, completed in December 1993,

comprised conceptual definition of a near term prototype cyclocraft that could perform a broad range of selected missions, preliminary design of the prototype aircraft, the design and construction of a subscale model for unmanned flight tests, preparation of a follow-on development plan and parallel mission effectiveness assessments.

Mission Research Corporation is also currently under contract to the United States Department of Energy, Pittsburgh Energy Technology Center, to utilize its cyclocraft technology base of theoretical and empirical data to evaluate use of the cyclocraft in the support of drilling and production of oil and gas in wetland areas. The results of the cyclocraft evaluation study reported herein were obtained from that DOE-sponsored program.

A major contribution to the U.S. Department of Energy's Enhanced Oil Recovery (EOR) Research Program would be the development of a means to extract oil and gas from wetland areas in a cost effective and environmentally safe manner. Past activities have resulted in significant adverse environmental effects and the US Government has affirmed no net loss of wetlands as a national goal.

Traditionally the helicopter, with its vertical take-off and landing (VTOL) capability, has been used for transport of drill rigs by air when surface transport is prohibitive. The helicopter is not a satisfactory solution however because of its poor operating economics, limited payload, limited adverse weather capability, poor reliability/maintenance, poor safety and high downwash.

The cyclocraft is a proven hybrid aircraft that utilizes aerostatic and aerodynamic lift. This type of aircraft has considerable payload capacity, VTOL capability, high controllability, low operating cost, low downwash and high safety. The benefits of using a cyclocraft to transport drill rigs and materials over environmentally-sensitive surfaces would be significant. Specifically its advantages over the helicopter include the following:

- (a) Considerable reductions in cost and time associated with drill rig breakdown and reassembly, due to high payload capacity, e.g., 100,000 lb.
- (b) Lower operating costs, due to substantially reduced maintenance and fuel costs.
- (c) Smaller drill site areas required, due to the small amount of drill rig reassembly required.
- (d) Reduced lost time, due to the aircraft's ability to operate in more adverse weather conditions.
- (e) Enhanced safety for flight crews, due to the inherent fail-safe characteristic of the cyclocraft.
- (f) Improved safety and efficiency of ground crews working under the aircraft, due to very low downwash.

In the recently completed program a careful evaluation was made of the applicability of the cyclocraft to transport drill rigs, mud, pipes and other materials and equipment in a cost effective and environmentally safe manner to support oil and gas drilling and production operations in wetland areas. Because of the significant potential applications of a heavy-lift cyclocraft, opportunities will be also explored for cost-sharing for the prototype aircraft development.

The scope of the planned evaluation program included a determination of the environmental impact of operating cyclocraft in wetland areas. In addition, validation of the aircraft's operational capabilities was obtained, through subscale flight tests. The latter utilized a 42 ft cyclocraft, designed, built and flight tested under a US Air Force program. Figure 2 shows the cyclocraft being prepared for flight. The preparation of a plan for a long-term development program was included, together with a technology transfer program. The latter ensured that the results obtained from implementation of the program, were communicated to all government agencies, educational institutes and business entities, that might benefit from the program.

Figure 2. 42 ft Subscale Dual-Rotor Cyclocraft

To support the accomplishment of the Department of Energy objectives, the following major program tasks were performed:

- Task 1 Environmental Considerations
- Task 2 Transport Requirements
- Task 3 Parametric Analysis
- Task 4 Cyclocraft Preliminary Design
- Task 5 Subscale Tests
- Task 6 Ground Support
- Task 7 Environmental Impacts

Task 8 Development Plan
Task 9 Operating Costs
Task 10 Technology Transfer
Task 11 Reports

This report addresses the work accomplished under all of the above tasks that constituted the DOE-sponsored program. Results of the work accomplished under each of the individual tasks are presented in more detail in References 1 through 8 respectively.

2. Cyclocraft Background and Concept of Wetland Operations

2.1. Evolution of Cyclocraft

To understand both the design configuration and the operational potential of the cyclocraft, it is instructive to review its evolution.

The conceptual approach for cyclocraft was generated in the early 1970s in response to a need for an economic, short haul, heavy lift aircraft for harvesting timber in remote areas of the Pacific Northwest. The two aerial approaches that were being tried, i.e. large helicopters and tethered balloons, did not provide a viable economic solution. Payloads of up to 20,000 lb were hauled over distances of about 1/2 mile. The helicopters were mobile but not economic; the balloons provided low-cost lift but were also uneconomic due to lack of mobility.

The perceived solution was to combine the best features of the two basic approaches, resulting in the first hybrid aircraft, the aerocrane. This aircraft utilized the basic rotor of the helicopter with the aerostat of the blimp. Figure 3 illustrates the structural integration of the two features, which resulted in rotation of the aerostat about its vertical axis. Airfoils, called "wings", were fixed to the rotor blade tips, to provide horizontal forces, without having to reorient the aircraft. The arrangement of wings and blades, termed a "cyclorotor", was tip-driven to avoid the transmission problems of the helicopter. The aerostat was spherical in shape and the payload was suspended on cables beneath it. The ability of the aerocrane to hover in a controlled manner, as required for the pickup and delivery of timber, was demonstrated successfully by subscale models. Poor speed capability, due to high drag associated with the aerostat shape and magnus effect, became apparent and the aerocrane development was abandoned in favor of the cyclocrane.

The cyclocrane, also illustrated in Figure 3, was based on the aerocrane configuration, but incorporated the following four differences:

- (a) The axis of rotation was along the flight path, eliminating the magnus effect.
- (b) The aerostat was aerodynamically shaped, with a 2:1 fineness ratio, to reduce drag.
- (c) Both cabin and payload were suspended by cables from the nose and tail of the aircraft.
- (d) A tail was added for directional stability.

From 1978 through 1990 AeroLift developed the cyclocrane with programs of analytical and empirical work, culminating in the successful operations of the two ton payload X.2 demonstration aircraft. The X.2, shown in Figure 1, was flown both manned and unmanned from 1984 through 1989, and the operations provided a considerable amount of both qualitative

Figure 3 Evolution of Cyclocraft

and quantitative technical data. All of the AeroLift work, including the X.2 programs, was based on the single-rotor aircraft. Contributors to the cyclocrane development programs included USAF, US Navy, US Army, ARPA, SDIO, US Forest Service, The Aerospace Corporation, Northrop Aircraft, the Forest Research Institute of Canada, Princeton University, Titan Corporation and ILC Dover, Inc.

Figure 4 shows how cyclocranes are able to handle payload pickup and delivery, by utilizing aerodynamic lift capability, both positive and negative. The experimental X.2 cyclocrane, shown in Figure 1, successfully demonstrated the precise pickup and delivery of two ton payloads, operating in hover. Quantitative data derived from X.2 tests, subscale tests and theoretical work, confirmed the economic operation of cyclocranes. Substantial work was done in determining and demonstrating the requirements for facilities, equipment and personnel to provide ground support for cyclocrane operations. These requirements proved to be significantly less than for blimps. Nonetheless, attempts were continued to simplify the ground handling, maintenance and operational facets of the system. These efforts resulted in the non-rotating aerostat design of the dual-rotor configuration.

Cyclocraft, developed from cyclocranes and illustrated in Figure 3, also utilize the weight

Figure 4 Cyclocraft Lifting Capability

change process shown in Figure 4. They embody the following features, which differ from those of cyclocranes:

(a) The central single cyclorotor is replaced by one cyclorotor located at the nose of the aircraft and one at the tail.

(b) The tail is removed.

(c) The aerostat is non-rotating.

(d) Located at the underside of the aerostat, depending on the mission requirements, may be the crew cabin, payload accommodations and landing pads or wheels.

Cyclocraft utilize their blades to generate propulsive thrust. Because of the low disc loading, propulsive efficiency, i.e. thrust/power, is very high compared with that of other aircraft, including blimps. Lift efficiency is maximized by limiting aerodynamic lift to that needed for weight excursions and control forces and by maximizing the aerostatic lift contribution.

The non-rotating aerostat and the dual-rotor configuration have both design and mission related advantages over the single-rotor aircraft, in addition to facilitation of ground handling and maintenance activities, for example:

(a) Both aerodynamic and structural efficiencies are enhanced.

(b) More attractive options are available for crew and payload accommodations.

- (c) Total aircraft controllability is increased.
- (d) C.G. location is no longer critical.
- (e) The non-rotating ballonnet and other aircraft subsystems are simplified.

The advantages of the dual-rotor cyclocraft over its single-rotor counterpart are considered significant and relevant to the current program to support wetlands operations. Consequently the dual-rotor was selected for the parametric study reported herein.

2.2 Cyclocraft Operational Attributes

The cyclocraft's technology is generally applicable to the following operating envelope:

Speeds:	up to 120 knots
Altitudes:	up to 25,000 ft continuous; up to 50,000 ft short periods.
Payloads:	up to 100 tons.
Endurances, without refueling:	up to 12 days.

The flight capabilities and characteristics of the cyclocraft are a product of the operation of its cyclorotor(s) and aerostat. To hover, or rise and descend vertically, the rotor wings and blades are pitched perpendicular to the longitudinal axis of the craft, causing the cyclorotor(s), and the aerostat of single-rotor aircraft, to rotate. Wing angle of attack determines whether positive or negative lift or sideforce is provided. Figure 4 illustrates how both loaded and unloaded lift are achieved. For level flight, the wings, blades and engines may be rotated 90° to be parallel to the longitudinal axis. Hull rotation would then cease for the single-rotor aircraft, which would move forward much like a conventional aircraft. Normal cruise is performed with rotation of the cyclorotors however, utilizing the high propulsive efficiency of the blades and ensuring maximum effectiveness of the control system.

The X.2 cyclocrane and other cyclocraft programs reported in References 1 through 36, and 42, have established a very large technology base comprising analytical, empirical and correlated data. During the original X.2 cyclocraft test program, ground-handling procedures and equipment were developed. As a result of this work, it was demonstrated that all ground-handling tasks associated with cyclocraft operations could be accomplished efficiently without resorting to the use of expensive facilities or to large ground crews. The ground-handling tasks tested included refueling, crew boarding and exit, helium purification, mooring and total system maintenance activities. The testing determined that these ground-handling procedures are readily adaptable to field conditions. This is particularly advantageous for applications of the aircraft in remote locations and in difficult terrain.

As noted above, cyclocraft exploit the best attributes of helicopters and aerostats to provide very

flexible aircraft. The flexibility permits a broad mix or family of missions to be performed by a single cyclocraft platform. The missions could range from heavy lift short haul payload movements at low altitude, to higher altitude, e.g. 25,000 feet, surveillance with a modest sensor suite, loitering on station for days at locations hundreds of miles from base. An individual cyclocraft platform would have an operational envelope constrained by the gross weight established during the aircraft design phase. A user could then employ the aircraft in any mix of operating parameters within that envelope.

Such flexibility is achievable by conventional fixed-wing aircraft, helicopters and LTA aircraft for, generally, a much narrower range of mission parameters than those which cyclocraft could provide. Some examples are given below:

(a) Conventional fixed-wing aircraft do not have VTOL capability; although they could handle range versus payload trade-offs, they would be unable to achieve the very long times on station. It is noted however that there are unique fixed-wing UAVs, like Condor, which have long times on station, are not VTOL and have very high cost.

(b) Helicopters have VTOL and could also handle range versus payload needs, but could not meet the altitude or the time on station.

(c) Conventional LTAs would be competitive for moderate altitude and stable payload conditions, but lack the ready capability for picking up or depositing payloads, are not VTOL, have limited controllability and are constrained at higher altitudes.

The additional attributes of cyclocraft are summarized below in general terms:

(a) VTOL capability, the aircraft can hover with more effective control from its rotors than that of a conventional helicopter, and with a small fraction of the helicopter's downwash.

(b) Transition from hover to forward flight merely by altering the positions of the wings and blades of the rotor, i.e. no re-orientation of the aircraft.

(c) It can accept near instant weight changes, e.g. short time disposal or pickup of a mission payload, due to its ability to control weight changes by aerodynamic controls and power settings.

(d) Depending on the particular configuration, the cyclocraft generally has a low acoustic signature and, with composites, a low radar signature. Further, its IR signatures are minimized by its high lift/power ratios, and the possible temperature gradients of the helium in a large aerostat can be mitigated through an appropriate design approach.

(e) It is highly survivable with respect to on-board failures, e.g. engine failure, results in progressive decay of aircraft performance, permitting considerable reaction time. In fact, by adjusting its buoyancy fraction, the aircraft can be biased toward either a rising or descending mode upon failure of ability to generate aerodynamic lift, as desired.

(f) It is also highly survivable to a range of weapons impacting the aerostat, as the helium pressure is just a few inches of water over atmospheric; further it has few critical components that render the aircraft vulnerable to a K-kill, much like a helicopter's vulnerability.

(g) Cyclocraft can be programmed for "neutral buoyancy" operation, like a conventional LTA, thereby providing for very long range operation, i.e. strong ferrying attribute that could be very important with respect to world wide deployment needs.

(h) It has wide flexibility in ground operations, e.g. location options for operations and requisite maintenance, over land or water. Further the integration of its structure and aerostat permit the cyclocraft to withstand considerably greater wind loads and hence greater wind speeds, obviating many of the base provisions required by the blimp.

(i) Cyclocraft can be manned or unmanned, as demonstrated in X.2 flight tests.

The design parameter that dominates the range of altitudes at which a cyclocraft can operate on a single mission, is the ratio of ballonnet volume to aerostat volume. By inflating the ballonnet with air at the operating base, the altitude change during the mission becomes the limitation. When a cyclocraft is operating from a base located at high altitude, the aircraft's altitude capability is correspondingly increased.

Based on ground tests made on the cyclocrane, and engineering evaluations, cyclocraft can be safely deployed at any unprepared site on land. The aircraft can be parked on the ground or attached by a single line tether to a ground anchor, utilizing its buoyancy. Similar techniques could be used for maritime basing. Because of their ability to generate substantial aerodynamic lift, through their rotors, cyclocraft can be safely tethered in significantly higher winds than balloons. In fact, the cyclocraft could be powered on a tether, e.g. through an RF link, and the rotors energized to improve the stability on the line significantly.

Maintenance requirements for cyclocraft are considered to be small by aircraft standards. Simple ground support equipment (GSE) would be needed for depot type operations and home base needs would include minimal GSE for disassembly, and housing. Hangars would not be required for normal, long term operations.

From the operational characteristics of cyclocraft presented above, it is apparent that cyclocraft have a significant capability for flexibility of use. In general cyclocraft have much more operating flexibility than conventional fixed wing or the more traditional LTA vehicles. With its inherent VTOL capability, cyclocraft comparisons are more relevant to those of helicopters. In this comparison, the cyclocraft's speed ranges are comparable, but it has greater altitude capabilities and is much superior in the areas of endurance and payload.

Because cyclocraft have low power/weight ratios and simple subsystems compared with VTOL type aircraft, they have significantly lower acquisition and operating costs. In addition, the cyclocraft's low signature levels, give it a lower probability of detection than other aircraft.

Because of their utilization of aerostatic lift, cyclocraft are frequently confused with blimps, and their associated operational shortcomings. Blimps are not VTOL aircraft; they cannot accommodate substantial weight changes, e.g. payload recovery or weapon deployment; they cannot keep station in gusty conditions; they require a large ground crew to support operations; they have poor ground handling, mooring and docking characteristics; they have poor controllability and lack maneuverability; they lack high propulsive efficiency and they cannot be refueled easily in the air. Cyclocraft overcome all of the operational shortcomings of blimps, yet they retain the economy of aerostatic lift.

2.3 Cyclocraft Applications

The attributes discussed in Section 2.2 above combine to make cyclocraft economic, effective aircraft for many US Government, local government and commercial applications. References 1 through 36, and 42, contain results of past cyclocraft application studies. The majority of those applications were focused on heavy-lift roles, but, as noted in the preceding section, cyclocraft have the flexibility to be employed over a wide range of operations. In fact, subsequent studies have identified a very broad range of applications for cyclocraft, including roles as small UAVs, in addition to manned and unmanned cyclocraft with moderate to very heavy lift and wide range of performance, e.g. altitude, speed and endurance.

For example, commercial heavy lift applications include aerial selective harvesting of timber; support of drilling operations, where ground transportation systems are impractical or unacceptable; support of building and highway construction projects, in remote and congested locations; support of pipeline construction and repair, in remote locations.

For the military, potential heavy lift missions for cyclocraft include ASW, deploying heavy sensors and weapons; mine countermeasures, operating independently of support ships; ship-to-shore container conveyance system; logistics over the shore; damaged aircraft recovery; transport of space vehicle subsystems; recovery of space vehicles and boosters; cargo airlift.

Beyond these, the current cyclocraft development program for USAF is focussed on relatively small, unmanned cyclocraft, which address candidate applications in which moderate payloads and corresponding low gross weights, are required. The resultant configurations for these missions would be of such a modest size that very low risk and moderate cost R & D programs could be structured for full scale developments. References 9 through 16, and 42, address studies performed on a small unmanned cyclocraft.

As reflected in the above summaries of possible applications, cyclocraft have considerable potential. Although broad mission capabilities could be cited for other government and commercial uses, the following presents a generic set of military missions that could be accomplished readily by cyclocraft:

- (a) Transport of equipment or personnel for overt or covert operations.

- (b) Interdiction type roles, with the aircraft having on-board sensors and/or weapons.
- (c) A variety of surveillance modes, with low or high altitude locations, with varying needs for stationkeeping and communications with other units.
- (d) As an unmanned aerial vehicle (UAV), or a relay for UAVs, transferring command from base to forward locations.
- (e) Aerial command post at altitude, for control of all mission assets.

It is noted that refueling capability is readily facilitated in cyclocraft. The aircraft's long range potential can be extended by refueling from other cyclocraft outfitted as tankers, or by low speed, conventional aircraft tankers.

2.4 The Problems and Opportunities

The South Louisiana land area is one of the largest oil & gas producing areas in the United States. These oil & gas fields are located in areas defined as wetlands. Protection and preservation of these wetland areas has been a rising subject of concern from a variety of regulatory agencies over the past 10 to 15 years. The collective impact of this steady increase in regulatory pressure, combined with steadily declining market conditions is, simply, forcing the reduction of that regional industry.

CONOCO, for example, has no new sites in the continental U.S. scheduled for drilling. UNOCAL has a new deep drilling project of potentially great economic value in South Louisiana, but considers the project to be too risky in today's market. TWO R DRILLING in Houma, Louisiana, currently owns 7 barge type drilling rigs, but can only keep one or two rigs working.

Although difficult to access without adverse environmental impact, there is a great deal of oil & gas still to be found in South Louisiana. It is well known that the Miocene formations and the Selma Chalk and Tuscaloosa Trend geologic zones contain great volumes of oil & gas. Table 1 shows the amount of oil and gas produced in Louisiana in 1991. Table 2 summarizes active Louisiana drilling rigs in September, 1992. Table 3 gives numbers of oil and gas drilling permits issued by Louisiana since 1981.

The South Louisiana oil industry grew successfully by using low cost dredging of new water channels to reach new drilling sites. To make use of these channels, fabricators along the Gulf Coast designed and built special drilling rig configurations known as posted barge drilling units. Posted barges, usually 50 ft wide, 220 ft long, 15 ft deep and 5 to 8 ft in draft, cut new water channels 70 ft wide and 10 ft deep to accommodate the posted barge drill.

Table 1. Louisiana Oil and Gas Production in 1991.

	Crude Oil (bbls)	Natural Gas (mcf)
North Louisiana	21,475,000	345,858,000
South Louisiana	68,118,000	997,974,000
Offshore, 3 mile limit	21,910,000	126,660,000
Total, Louisiana	111,503,000	1,470,492,000

Table 2. Number of Active Drilling Rigs in September 1992.

Item	Number
South Louisiana Land Drill Rigs	25
South Louisiana Inland Barge Drill Rigs	15
Louisiana & Federal Offshore Drill Rigs, combined count	50
Total Active Rigs	90

Table 3. New Oil & Gas Drilling Permits Issued by Louisiana.

1981 - 6260	1984 - 7631	1987 - 2422	1990 - 1707
1982 - 5181	1985 - 5410	1988 - 1850	1991 - 1309
1983 - 5490	1986 - 2282	1989 - 1690	1992 - 1100 (est.)

Government agencies have, however, stopped issuing dredging permits in South Louisiana. The future of the dredging business along the Gulf Coast is very bleak.

Barges can be used as temporary floating logistic bases in order to reduce overall airlift expenses. The Canal Barge Company of New Orleans is one of several Gulf Coast operations that provide rental and sales of barges and tugboats. Equipment is available in Houston, Galveston, Lake Charles, Morgan City, Houma, Venice, New Orleans and Mobile.

The largest ABS-Classed Offshore deck barges that can pass through the Intracoastal Lock System are 260 feet long x 72 feet wide x 20 feet deep, with an empty draft of 5 feet and freeboard of 15 feet. These barges have a rated capacity of 5,000 tons with a 1,500 pound-per-square-foot deck load limit. Offshore barges of this size rent for \$700 to \$900 per day.

Purchase prices of new barges range from \$900,000 to \$1,250,000. A 1800 hp to 2400 hp tugboat is required, renting for \$2000 to \$2200 per day plus fuel. Fuel consumption is 75 gallons per hour when running at 5 knots.

Small inland barges are available to serve as temporary floating logistic bases. Inland barges are typically 120 feet long and 30 feet wide. They are not Coast Guard certified and cannot be used offshore. Inland barges are rated at 450 to 500 tons, with a deck load limit of 1,000 pounds per square foot. Rental rates are \$75 per day. A 600 hp tugboat is required, renting for \$80 per hour including fuel.

New oil & gas wells in Southern Louisiana range in depth from a shallow 6,000 ft to a maximum of 19,000 to 22,000 ft. An average well depth of 16,000 feet has been used for the purpose of this research, as current trends are towards deeper wells.

Since dredging is so heavily restricted, a standard 16,000-foot depth-rating land drill rig configuration has been selected as the basis for this research. Land drill rigs with high hook load and depth ratings are readily available along the Gulf Coast. Inland barge drilling contractors have the option of dismantling drill rig components from their barges, so that they can be airlifted.

The only viable solution to restoring the production of existing wells and obtaining production from new wells, in a manner that is acceptable both environmentally and economically, is to utilize an economic aerial system. Helicopter-portable rigs are not a viable contender for drilling contracts in the South Louisiana market for the following reasons:

1. The \$12,000 daily contract rate is too expensive.
2. The majority of heli-portable rigs are Parker model TBA 2000. The biggest of these models only have an 800,000 pound static hook load rating, which is insufficient for this market.
3. The Parker AT2000-E rig is one-of-a-kind. Currently located in Burma, it represents a \$10 Million investment. The rig breaks down into 7,200-lb components.
4. The hook load and depth rating of the Parker AT2000-E rig is inadequate for the majority of drilling contracts in this market.

2.5 The Wetlands Role of the Cyclocraft

The cyclocraft is an ideal candidate as a new aerial barge for the South Louisiana oil industry. The cyclocraft can replace the dredge barge and posted barge drills by airlifting drilling equipment directly to a new drilling site, from either a land logistic base or from a utility barge logistic base. Cyclocraft are economic, compatible with the payloads to be carried and have minimal basing requirements, with vertical takeoff and landing capability.

From an operational base at New Iberia, the cyclocraft could service the St. Martin, Lafayette and Vermillion Parishes. The old blimp base at Houma, Louisiana, could serve as a practical cyclocraft base for operations in the Terrebonne, LaFourche, St. James and Assumption Parishes. Cyclocraft bases could be relocated at any time to keep the aircraft within a maximum 30 mile one-way flight distance from work areas.

The cyclocraft fleet would occasionally have to be relocated before starting the next airlift contract. For example, after completing contract operations in the Sabine National Wildlife Refuge near Lake Charles, the fleet may have to be flown to a temporary base at Port Sulphur to begin operations in Breton Sound. It is logical to consider New Iberia as the main operational base. Each contract price would include both a mobilization cost from New Iberia to a temporary base and a de-mobilization cost back to New Iberia. Basing of the cyclocraft is addressed in References 5 and 6.

Daily working flight distances will range from a minimum of 1 mile to a maximum of 25 miles from the nearest truck/barge landing point. A conservatively estimated annual average one-way working flight distance would be 15 statute miles.

If flight distances from a land logistic base become too lengthy, MRC has the option of using inland utility barges and inland tug boats to create a temporary floating logistic base. Given the extensive network of canals and waterways in South Louisiana, the cyclocraft can be kept within a 1 to 3 mile working flight radius of any new drilling site. Daily personnel transport to and from the barge base, by either helicopter or crew boat, would be an added expense.

In addition to ferry flights, mobilization flights and working flights, the following non-revenue flights will occur:

1. Pilot training flights
2. Weather avoidance flights
3. Post-maintenance check flights
4. Sales demonstration flights

The minimum aircraft airspeed will be dictated by the need to maintain useful ground speeds in a variety of wind conditions. Southerly breezes of 10 to 20 mph, with gusts pushing the highest winds to 35 mph, are very common in South Louisiana. An aircraft airspeed of 55 to 65 mph is considered appropriate.

Southern Louisiana experiences a variety of weather, including a number of work-stopping events. Weather statistics are summarized below:

1. Temperature ranges: +16° F winter to +115° F summer.

2. Steady-state 20 mph winds out of the South are normal Gulf breezes for most of the year. Additional wind gusts of 5 to 15 mph will occasionally push the total wind speed to 25 or 35 mph.

3. Fog on winter mornings usually burns off before noon.

4. Rain of 60 ins to 80 ins per year, occurs in the spring and fall.

5. Severe thunderstorms in the spring and fall have high vertical shear winds and microbursts. Duration of the most severe winds over a single point on the ground is usually no longer than 20 to 30 minutes.

6. Squall Lines are fast moving, 30-50 mph cold fronts tracking south-southeast into the Gulf of Mexico. These winter "blue-northers" can bring 75 mph gusts in the advance winds ahead of the front. Frontal passage is usually completed in 2 to 3 hours. Cold air behind the front is turbulent for several days.

7. Hurricanes can stop all work for up to 10 days. It would be planned to fly the cyclocraft to northern Louisiana or Texas for the duration of hurricanes.

8. Off-shore water spouts always look menacing, but usually have very little destructive power. Duration is typically one hour.

The following provisions would be made for the cyclocraft to handle inclement weather:

1. Hurricanes would be avoided by transit to any safe open field.

2. Severe thunderstorms would be avoided in a similar manner and would be detected by onboard radar.

3. The cyclocraft would be designed to withstand tropical downpours of rain.

4. The cyclocraft would also be designed for safe mooring in wind speeds of up to 80 mph.

5. The cyclocraft control system would be designed for rapid response to side gusts of up to 30 mph.

For the purpose of this study, it is assumed that a land drill rig can be used in place of an inland barge drill rig. The land rig's daily contract rate is \$3,500 to \$4,000 per day lower, compared to the barge drill. This creates an economic opportunity for the cyclocraft to operate without contract price back-pressure from the oil companies. Assuming a 90 day average contract period, it is expected that a minimum amount of \$315,000 to \$360,000 will be available from offset costs, for funding cyclocraft operations for each well. Additionally, the oil companies may be

willing to pay a reasonable premium for cyclocraft services to minimize their contributions to a new mitigation program being established by the State of Louisiana. The oil companies may have to pay into the program an amount equal to \$8,000 per acre of marsh land impacted by drilling operations. The cost study, reported in Section 8, shows that the costs associated with cyclocraft operations are well within those acceptable to the industry.

3. Transportation Requirements

3.1 Inbound Requirements

3.1.1 Drilling Rig

For the purpose of this report, a standard drilling rig is defined as a readily available, 16,000 ft depth-rated, land drilling rig with a 1,500,000 lb static hook load rating and a zero-discharge drilling mud system. Table 4 lists all necessary drilling equipment and materials as broken down into individual, easily transportable components.

Table 4. Drilling Rig Weight Summary.

Item	Weight (lb)
Mast Substructure, Driller's side	85,000
Mast Substructure, Off-driller side	85,000
150' Mast/Derrick, fully assembled (Mast breaks down to 15 pieces, with heaviest at 20,000 lb, includes standpipes & mud hose)	130,000
Mast Crown Block Oilwell 760 ton	16,000
Drawworks 3,000 hp National 1625-DE, with 11 ins diameter wireline.	87,000
Drawworks back-porch with 3 electric drive motors	30,000
Drawworks front-porch with controls	10,000
Rotary Table Oilwell 491 ins 800 ton driven mechanically by draw works	26,000
Traveling Block Oilwell 750 ton	35,000
Hook 650 ton	10,000
Swivel 650 ton	7,000
Diesel Electric #1: CAT D399 1200 hp	90,000
Diesel Electric #2: CAT D399 1200 hp	90,000
Diesel Electric #3: CAT D399 1200 hp	90,000
S.C.R. Electric Control House	85,000
B.O.P. stack: 20" Hydril 2000 psi	45,000
13 5/8" Hydril 5000 psi	18,000
13 5/8" Cameron U single 10000 psi	11,000
13 5/8" Cameron U double 10000 psi	20,000

Koomey B.O.P. Accumulator 160 gal with 25 hp triplex & 2 remote control stations	10,000
Mud Pump skid #1 with electric drive	85,000
Mud Pump skid #2 with electric drive	85,000
Mud Pit #1 1000 barrel, active	75,000
Mud Pit #2 1000 barrel, active	70,000
Mud Pit #3 1000 barrel, reserve	70,000
Mud Pit #4 1000 barrel, cuttings	70,000
Dual Tandem Shale Shaker, Harrisburg	6,000
Mud Cleaner #1 800 g.p.m.	5,000
Mud Cleaner #2 800 g.p.m.	5,000
Mud-Gas Separator	10,000
Mud Desilter 24 cone	5,000
Mud Desander 2 cone	2,000
Mud mixing pump #1 & electric motor	4,000
Mud mixing pump #2 & electric motor	4,000
Mud 200 bbl. treatment & slugging tank	20,000
Cables, wires, hoses, tools, slips	50,000
Tongs & Power Supply, Elevators	50,000
Container style stackable liquid storage tanks: Tanks: 8 ft cylinder x 45 ft long with steel external frame & interlocking corners, 17,000 gallons = 400 barrels, (17,000 lb empty weight).	
Fuel Tanks, 5 each = 2,000 bbls.	85,000
Potable Water, 3 each = 1,200 bbls.	51,000
Drill Water, 11 each = 4,400 bbls.	187,000
Liquid Mud, 3 each = 1,200 bbls.	51,000
Bulk Storage, mud & cement 5000 cu.ft.	30,000
Stiff Leg Derrick Crane, 270 ft swing, 50 ft reach, 10,000 lb cap., electric	15,000
Dog House	30,000
PORTA-KAMP portable quarters for 40 man crew: 10 ft wide x 9 ft high x 24 ft long modules can be airlifted individually or bolted together for group lifts.	
4-Man sleeper modules @ 14,000 lb, 10 each	140,000
Private stateroom module for 2 men, 1 each @ 14,000 lb	14,000

Office module	14,000
Kitchen module	16,000
Freezer/Cooler/Dry Storage module	16,000
Diner modules @ 14,000 lb ea, 2 each	28,000
Bathroom module	16,000
Sewage treatment module	22,000
Trash Container module 8000 lb, 2 each	16,000
Helicopter Deck module	6,000
Emergency Power, Diesel 250 KW w/fuel	20,000
Pipe racks, cat walks	7,000
Pipe slides	10,000
Total Weight, Drilling Rig only	2,370,000

3.1.2 Drill String.

The safest method for the cyclocraft to transport drill pipe and collars is in pipe baskets that can be pre-loaded with quantities equal to the aircraft's payload capacity. The pipe lengths are defined as Range 2, or 30 ft long. A steel pipe basket is 8 ft wide x 40 ft long x 5 ft high, with interlocking corners to allow vertical stacking. The 10,000 lb empty weight of the pipe basket will have to be deducted from the cyclocraft payload capacity for each size of aircraft examined in the trade-off studies. Thus, a 50 Ton cyclocraft will be capable of lifting a 10,000 lb basket containing 90,000 lbs of pipe. Weight summary for a 16,000 ft drill string is given in Table 5.

Table 5. Drill String Weight Summary.

Item	Weight (lb)
5 ins Grade E @ 19.50 lb/ft, 15,000 ft	292,500
5 ins Grade G @ 19.50 lb/ft, 2,000 ft	39,000
5 ins Heviwate @ 46 lb/ft, 2,000 ft	92,000
9½ ins x 3 ins Collar @ 6,500 lb/30 ft jt, 5 ea	32,500
8 ins x 2 13/16 ins Collar @ 4,520 lb/30 ft jt, 5 ea	22,600
6½ ins x 2 13/16 ins Collar @ 2,768 lb/30 ft jt, 5 ea	13,840
6¼ ins x 2 13/16 ins Collar @ 2,520 lb/30 ft jt, 3 ea	7,560
Total Weight, Drill String only	500,000

3.1.3 Mud Program

Table 6 lists water-based products supplied by the M.I. Drilling Fluids Company of Lafayette, Louisiana for drilling a 16,200 ft well. Barite mud is handled by a new design of bulk tank equipped with flexible augers, replacing the heavier pneumatic system tanks used on inland barge drills. Each tank weighs 1000 lb empty and will hold 40 each of the 100 lb sacks. Total loaded weight per tank is 5000 lb. For a 16,200 ft well, 160 tanks will be required. Bulk tanks are stackable, two high, and are 48 ins wide x 52 ins deep x 72 ins high. Bulk tank weights are also given in Table 6.

Table 6. Water-Based Products Weight Summary

Water-Base Products	Weight (lb)
BNIT 420#/bbl, 142 gl bbl, 65 ea	27,300
Caustic Soda, 50 lb sack, 491 ea	24,550
Defoam-X 45 lb can, 5 gal can, 13 ea	585
Kwik Seal M, 100 lb sack, 20 ea	2,000
Lime, 50 lb sack, 176 ea	8,800
M-I Barite, 100 lb sack, 455 ea	45,500
M-I Gel, 100 lb sack, 1,226 ea	122,600
PLUG Fine, 50 lb sack, 25 ea	1,250
POLYPAC, 50 lb sack, 7 ea	1,350
PRSL, 50 lb sack, 150 ea	7,500
SPERSENE, 50 lb sack, 584 ea	29,200
Sodium Bicarbonate, 100 lb sack, 2 ea	200
TANNATHIN, 50 lb sack, 1,047 ea	52,350
THERMPAC U.L., 50 lb sack, 29 ea	1,450
M-I Barite, 100 lb sack, 6,385 ea	638,500
Bulk Tank, 70 Cu.Ft., 169 @ 1,000 lb ea	160,000
Total Weight, Mud Program	1,123,135

3.1.4 Casing Equipment.

After the drill rig is set up and before actual drilling can begin, a large diameter conductor casing is driven into the ground. A large flange is attached at the surface as a mounting base for

the Blow Out Preventer (B.O.P.) stack. Required casing crew equipment is listed in Table 7.

Table 7. Casing Crew Equipment

Item	Weight (lb)
Hydraulic Power Pack, 2 each @ 60,000 lb	120,000
Tongs, 2 each @ 10,000 lb	20,000
350 Ton tools, 3 each @ 2,500	7,500
Elevator	2,500
Spider	2,000
Conductor Casing 20 ins Dia, 300 ft @ 133 lb/ft.	40,000
Total Weight, Casing Equipment	192,000

3.1.5 Inbound Requirements Summary.

Table 8 gives a weight summary for all inbound transportation requirements.

Table 8. Inbound Transportation Requirements Weight Summary.

Item	Weight (lb)
Drilling Rig	2,370,000
Drill String	500,000
Mud Program	1,123,000
Casing Equipment	192,000
Total Weight - Inbound	4,185,000
Total Weight - Tons	2,092.5

3.2 Liquid Supply Requirements

3.2.1 Flight Options.

Liquids used during drilling operations may be either flown in to the drilling site from a land base, or hauled by inland barge to within 3 miles of the drilling site and then either airlifted or pumped through temporary Poly Pipe pipelines between the inland barges and the drilling site.

If Poly Pipe is used, the cyclocraft's high drawbar pull capacity would be employed to pull the

pipeline over the top of the wetland area. Poly Pipe has been used in the Mid-Continent U.S. since 1975 as water flow lines and gathering lines for gas and oil. The Corps of Engineers indicates that permission to use pipelines can be included as part of the overall drilling permit. Three-inch diameter, ½ ins wall thickness Poly Pipe is available in reels of 1,500 ft, weighing 2 lb/ft in and costing \$1.00 per ft. Each 3 mile long temporary pipeline will have a one-time material cost of \$20,000.00 and a weight of 32,000 lb. The Poly Pipe is reusable for several years. The cyclocraft should be able to pull each pipeline into position within 3 hours flight time and remove it within the same time.

3.2.2 Potable Water

A 5,000 lb potable water tank holds 5000 gallons and weighs 45,000 lbs. At 8 lb per gallon, the total loaded weight per tank is 45,000 lb. There is a 1,200 A.P.I. barrel, or 51,000 gallon, water storage capacity on the drill rig. Total potable water requirement for the 90 day drilling period is estimated at 1,000 gallons per day, or 90,000 gallons. This amounts to 18 tank loads. Potable water weights are summarized in Table 9.

Table 9. Potable Water Weight Summary.

Item	Weight (lb)
Potable water @ 8 lb/gal x 90,000 gal	720,000
Transport tank @ 5,000 lb x 18 tanks	90,000
Total Weight - Potable Water	810,000

This airlift requirement can be eliminated by use of the Poly Pipe pipeline.

3.2.3 Drilling Water.

Similar 5,000 lb tanks can be used for transporting drilling water. Approximately 16,000 A.P.I. barrels, or 672,000 gallons of water are required to drill a 16,000 ft well. This amounts to 135 tank loads. There is a 4,400 barrel, or 185,000 gallon, drill water storage capacity on the drill rig. Drilling water weights are summarized in Table 10.

Table 10. Drilling Water Weight Summary

Item	Weight (lb)
Drilling water @ 8 lb/gal x 672,000 gal	5,376,000
Transport tank @ 5,000 lb x 135 tanks	675,000
Total Weight - Drilling Water	6,051,000

This airlift requirement can also be eliminated by using the Poly Pipe pipeline.

3.2.4 Fuel

A 16,000 ft rated drilling rig consumes an average 2,500 gallons per day of Diesel fuel. At 7.25 lb/gal, 18,125 pounds of Diesel fuel is required daily. Over a 90 day drilling term, 1,631,250 lb, or 225,000 gallons, is required. There is a 2,000 barrel, or 84,000 gallon, fuel storage capacity on the drill rig. There will be 45 tank loads required to supply fuel. Diesel fuel weights are summarized in Table 11.

Table 11. Diesel Fuel Weight Summary.

Item	Weight (lb)
Diesel Fuel	1,631,000
Transport tank @ 5000 lb x 45 tanks	225,000
Total Weight - Diesel Fuel	1,856,000

This airlift requirement can be eliminated by using the Poly Pipe pipeline.

3.2.5 Drill Cuttings Slurry

To comply with new zero discharge environmental regulations, it is necessary to remove all drilling fluids and cuttings from the well site. In addition to the drilling water volume of 16,000 barrels, 2,000 barrels of drilling mud and cuttings must be removed, totalling 18,000 barrels, or 756,000 gallons of slurry. Weighing 18 lb per gallon, approximately 3000 gallons of slurry can be safely contained in a 5,000 lb flight tank. Drill cuttings slurry weights are summarized in Table 12.

Table 12. Drill Cuttings Slurry Weight Summary

Item	Weight (lb)
Cuttings slurry @ 18 lb/gal x 756,000	13,608,000
Transport tank @ 5,000 lb x 252 tanks	1,260,000
Total Weight - Drill Cuttings Slurry	14,868,000

This airlift requirement can be eliminated by using the Poly Pipe pipeline.

3.2.6 Liquid Products.

Liquid product weights are summarized in Table 13.

Table 13. Liquid Product Weight Summary

Item	Weight (lb)
Potable Water	810,000
Drilling Water	6,051,000
Fuel	1,856,000
Drill Cuttings Slurry	14,868,000
Total Weight - Liquid Products	23,585,000

3.3 Non-Liquid Supply Requirements

3.3.1 Open Hole Logging

After the well is drilled, open hole logging is performed to determine whether the well will produce economic quantities of oil and gas. The SCHLUMBERGER F Unit is a portable system currently in use for this work. Table 14 summarizes component weights for the SCHLUMBERGER F Logging Unit.

Table 14. SCHLUMBERGER F Logging Unit Weight Summary

Item	Weight (lb)
F Unit, with cable	34,000
Power Unit, with fuel	1,500
Logging Tools, 2 Pallets @ 8,000 lb each Pallet: 50' long x 6' wide x 8' high	16,000
Crew Box	5,000
Total Weight - Open Hole Logging	56,500

3.3.2 Casing Program

If open hole logging is successful, the remainder of the casing is installed. Table 15 summarizes intermediate and production casing weights.

Table 15. Intermediate and Production Casing Weight Summary

Item	Weight (lb)
1st Intermediate Casing String: 2,000 ft x 16 ins dia @ 109 lb/ft.	218,000
2nd Intermediate Casing String: 4,000 ft x 13 3/8 ins dia @ 84 lb/ft.	336,000
Production Casing String: 16,000 ft x 9 5/8 ins dia @ 53.5 lb/ft.	856,000
Total Weight, Casing Program	1,410,000

3.3.3 Cementing Program

Cement is pumped down through the casing string and back up through the outer annular area to hold the casing in place. HALLIBURTON and DOWELL-SCHLUMBERGER are the two major cement service companies. Weights of cementing program components are summarized in Table 16.

Table 16. Cement Program Weight Summary

Item	Weight (lb)
Halliburton Mixing & Pumping skid	50,000
Halliburton HCS Pumper, Diesel power	37,000
Cement, 4,200 x 100 lb Sacks	420,000
Additives, 200 x 100 lb Sacks	20,000
Cement Bulk Tanks for 4,400 Sacks: 40 Sacks per Tank = 110 tanks @ 1,000 lb each	110,000
Total Weight, Cementing Program	637,000

3.3.4 Closed Hole Logging

After the production casing string has been cemented in, an electric wireline rig is used to perforate the casing from the inside along the depths determined to be producing zones. The electric wireline will also perform depth measurement and bottom hole pressure measurement. The SCHLUMBERGER French Unit is typical of the closed hole logging systems currently used. Closed hole logging component weights are summarized in Table 17.

3.3.5 Production Tubing and Equipment

Production tubing is installed to transfer the oil and gas to the surface. A 16,000 ft well uses

2-7/8 in. tubing, weighing 8.7 lb/ft. As described above, a pipe basket is the preferred means of airlifting pipe. In normal operations, the drill rig would move off-location, so that a cheaper & lighter drill rig could be used to set the tubing string. For the purpose of this report, however, it assumed that the big rig will be left in place to complete the well. Table 18 summarizes production tubing weight and equipment weights.

Table 17. Closed Hole Logging Weight Summary

Item	Weight (lb)
Computer Cab	11,000
Power Pack	6,200
.22 Cable Skid	8,400
Generator Box	2,500
Pressure Package	9,000
Workstation	7,000
TDT-P Pallet	1,000
PLT Pallet	2,000
Total Weight, Closed Hole Logging	47,100

Table 18. Production Tubing and Equipment Weight Summary

Item	Weight (lb)
2 7/8 ins Tubing @ 8.7 lb/ft, 16,000 ft	139,000
Pipe Basket @ 10,000 lb, 2 flights	20,000
Christmas Tree	20,000
Total Weight, Production Tubing & Equipment	179,000

3.3.6 Non-Liquid Requirements Summary

Supply flight weight totals are summarized in Table 19.

3.4 Outbound Requirements

Table 20 gives a weight summary for all outbound transportation requirements.

Table 19. Supply Flight Weight Summary

Item	Weight (lb)
Open Hole Logging 56,500 lb, round trip	113,000
Casing Program	1,410,000
Casing Equipment, outbound	152,000
Cementing Program	637,000
Cementing Equipment, outbound	197,000
Mud Tanks, empty & outbound	160,000
Closed Hole Logging 47 x 100 lb, round trip	94,000
Production Tubing & Equipment	179,000
Total Weight, Supply Flights	2,942,000
Total Weight, Tons	1,471

Table 20. Outbound Transportation Requirements Weight Summary

Item	Weight (lb)
Drill Rig	2,370,000
Drill String	500,000
Unused Mud	50,000
Total Weight, Outbound	2,920,000
Total Weight, Tons	1,460

3.5 Production Requirements

3.5.1 Production Equipment

Once a well is determined to be a gas producer, the drill rig is moved off and additional production equipment is transported to the drill site. A weight summary for this equipment is given in Table 21.

3.5.2 Permanent Gathering Pipelines

After the production equipment has been set up at the gas well site, a pipeline construction

Table 21. Production Equipment Weight Summary

Item	Weight (lb)
Line Heater	10,000
Oil/Water Separators	30,000
Glycol Unit	40,000
Tank: 2 - 500 Bbl./ Oil & Condensate	20,000
Tank: 500 Bbl./ Salt Water	10,000
Total Weight, Production Equipment	110,000

contractor will install permanent gathering pipelines to deliver oil and gas to the nearest trunk pipeline. These lines are buried four feet deep using draglines working on marsh mats. Permanent gathering pipeline equipment weights are summarized in Table 22.

Table 22. Permanent Gathering Pipeline Equipment Weight Summary

Item	Weight (lb)
Crane marsh mats: 20 each @ 2,000 lb	40,000
50 Ton Crane: 3 lifts; 10,000 lb mast, 80,000 lb crane & 50,000 lb counterweights	140,000
Welding Machine skids 2 @ 10,000 lb	20,000
Gas Pipeline 4 ins @ 15 lb/ft, 20,000 ft	300,000
Oil Pipeline 4 ins @ 12 lb/ft, 20,000 ft	240,000
Salt Water Flowline 4 ins @ 12 lb/ft, 20,000 ft	240,000
Total Weight, Pipelines	980,000

3.5.3 Production Requirements Summary

Required production equipment weights are summarized in Table 23.

3.6 Summary Requirements

Transportation requirements, with and without the use of Poly Pipe pipelines, including maximum flight times, are summarized in Table 24.

Table 23. Production Equipment Weight Summary

Item	Weight (lb)
Production Equipment	110,000
Permanent Pipelines	980,000
Construction Equipment, outbound	200,000
Total Weight, Production	1,290,000

Table 24. Transportation Requirements Summary

Phase	Without Poly Pipe	With Poly Pipe	Maximum Time Allowed to Complete Flights
Inbound	4,185,000	4,185,000	5 days
Supply	26,527,000	2,942,000	80 days
Outbound	2,920,000	2,920,000	5 days
Production	1,290,000	1,290,000	30 days
Total Weight (lb)	34,922,000	11,337,000	
Total Weight (Tons)	17,461	5,668.5	

4. Environmental Considerations

4.1 History of Oil and Gas Activities in Coastal Zone

The most intensive petroleum development in the nation's coastal and offshore area is concentrated in Louisiana. The success in petroleum activity is due to Louisiana's geologic history which is characterized by optimal geological conditions for forming petroleum resources. Commercial development of petroleum resources in Louisiana's coastal zone, shown in Figure 5, has contributed to Louisiana's place as the second leading producer of natural gas and the third leading producer of oil in the nation. Today, most petroleum activity in Louisiana occurs offshore and in south Louisiana which contains 41% of the nation's coastal wetlands. Besides petroleum, Louisiana's economy and culture rely heavily upon renewable resources of the coastal zone such as finfish, shellfish, and fur. Louisiana is also a world leader as well as the nation's leader in OCS development and has historically produced 91% (57 billion barrels) of the nation's OCS oil and 94% (6 TCF) of the nation's OCS gas.

Figure 5. Location Map of Coastal Louisiana

Because oil and gas activities and other resources in the coastal zone are so important to Louisiana, an overview of historical events and activities relating to oil and gas development in south Louisiana is presented.

4.1.1 Early History

Early history of petroleum development is presented in Reference 37 and the following is a summary of the information contained in that report. The Indians knew of the existence of petroleum in south Louisiana long before it was commercially exploited. The first well drilled in the state was in southwest Louisiana around 1868, but it was not until 1901 that the first successful well was drilled in Jennings, Louisiana. Exploration was then concentrated in northern Louisiana where giant gas fields were discovered at Caddo and Monroe in 1906 and 1916, respectively. Interest in the coastal zone was stimulated after the success of Spindletop in Texas marshes in 1901. The first successful well in the coastal zone was drilled at Sweetlake in Cameron Parish in 1926; following this success, interest in the coastal zone became widespread. Since then oil and gas exploration has been extremely successful in the coastal zone.

With major discoveries in the wetlands in the 1930s, innovative techniques such as the submersible drilling rig were developed to exploit petroleum in the wetlands. As discoveries moved further south and into open water, over-water drilling structures were developed. Over-water structures were first used in this country in Caddo Lake in 1910. This success made the first unprotected offshore drilling structure in the Gulf of Mexico near Creole, Louisiana possible in 1938. In 1939, the first offshore field was discovered, the Creole Field, and freestanding platforms proved successful. Then in 1947, Kerr-McGee completed the first successful well out of sight of land, marking the beginning of OCS development. Since that day the oil and gas industry has rapidly developed in the coastal zone and offshore Louisiana. The development of steel pilings, the submersible drilling rig, and tender equipment made drilling offshore physically possible as well as economically profitable. Seaplanes and helicopters as well as boats and barges became extremely important in servicing crews and platforms in the 1950s. By 1955 more than 40 offshore platforms were operating offshore. Pipelines became important aspects of the industry to provide transportation of the products to land based operations. In 1951, the first large-diameter, concrete coated pipeline was laid offshore in the Gulf of Mexico. By December 1990, there were 17,727 miles of pipelines offshore Louisiana alone (Minerals Management Service 1992) and about 12,000 miles onshore Louisiana.

4.1.2 State Oil and Gas Regulation

The oil and gas industry grew rapidly and the need for regulatory guidelines and regulations became apparent as careless and wasteful drilling practices were developed. During the early period of oil and gas production, Louisiana wasted more of these resources than any other state. For example, the Caddo field in North Louisiana had a wild gas well for five years wasting at least 27 BCF of gas (Conservation Commission 1914).

The first oil and gas legislation in Louisiana was passed in 1906: Act 71, which prohibited

waste. Then in 1912, Act 127 created the Conservation Commission to administer oil and gas operations within the state. Several acts followed which provided regulations for waste practices, taxing, well spacing, and unitization and also, the Conservation Commission issued rules governing practices of extraction, escape of oil and gas, and sealing and plugging of wells. However, many of these acts and rules only applied to specific areas or fields and were not observed statewide. Table 25 presents all of the state legislation and statewide orders pertinent to oil and gas regulation.

Inconsistent administration practices and corruption led to the need for broader regulations and resulted in passage of the Oil and Gas Conservation Law of Louisiana (Act 157) in 1940. It was the first statewide comprehensive oil and gas conservation statute in the nation. It regulates the use and conservation of natural resources within the state and mandated the Commissioner of Conservation to regulate oil and gas exploration, development, and production. Title 30 R.S. 1950 contains the mandates of the Office of Conservation and the rules now governing mineral resources.

The Office of Conservation also issues permits to drill once prospective land is leased. Besides a permit to drill, other state and federal permits may be required. For example, all activities in the coastal zone require a coastal use permit (CUP) from the state Coastal Management Division (CMD) of the Department of Natural resources. For certain activities in wetlands such as dredging and spoil disposal, and obstruction or alteration of waterways, the U.S. Army Corps of Engineers requires permits to comply with Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act.

4.1.3 Leasing

Leasing state lands for natural resources began in 1915 and was initially handled by the Governor with assistance from the Register of State Lands. The State Mineral Board was created by Act 93 in 1936 after misuse of power, lack of cooperation, and other factors made it clear that leasing should be consolidated under one agency. When the board was created, only 124 leases had been established but virtually all of the state's waterbottoms had been leased: some of these leases covered 500,000 acres (Reference 37). These practices led to lease size limits of 5,000 acres in 1940 and a further decrease to 2,500 in 1976.

Lease sales were held annually until the 1950s and 1960s when leasing occurred irregularly throughout the year. Finally in 1969, a monthly schedule was established. Today the state follows that monthly schedule.

Today the Mineral Board and two agencies within the Department of Natural Resources, the Office of Mineral Resources and the Office of Conservation are the main bodies governing leasing and oil and gas regulatory activities. The Mineral Board, a governor-appointed body, has jurisdiction for granting, supervising, and enforcing oil and gas mineral leases on state lands and water bottoms. The Office of Mineral Resources technically assists the Mineral Board on leasing matters and maintains lease records. The Office of Conservation regulates oil and gas

Table 25. Historical Highlights of the Oil & Gas Industry in Coastal Louisiana

- 1866** -The first well in Louisiana was drilled about 15 mi west of Lake Charles.
- 1902** -The first oil exploration well in the coastal zone was drilled at Hackberry Island. This well encountered oil at two depths, but not in commercially significant quantities.
- 1908** -The first natural gas pipeline was laid in Louisiana from Caddo field to Shreveport.
- 1910** -The first over-water drilling in America occurred in Caddo Lake.
- 1921** -The first coastal zone acreage lease under Act 30 of 1915 was awarded to W. T. Burton in the area of Black Lake Bayou in Cameron Parish.
- 1926** -The first commercial oil producer in the coastal zone was brought in at Sweet Lake Field, Cameron Parish.
- 1933** -The first well was drilled in the Gulf of Mexico in 12 ft of water approximately 3,000 ft off the beach near Creole, Louisiana. This well did not produce oil.
- 1938** -Creole, the first offshore field in open, unprotected waters in Louisiana, was discovered. The field was located 1.5 mi offshore Louisiana in 26 ft of water.
- 1946** -Magnolia Petroleum Company built the first platform to use steel pilings.
- 1947** -The offshore oil and gas industry began when the first successful well was drilled completely out of sight of land on Ship Shoal block 32, 45 mi south of Morgan City.
- 1948** -Main Pass field was discovered near the mouth of the Mississippi River.
- 1949** -Four major offshore fields were discovered: Eugene Island Block 32, Bay Marchand Block 2, and Vermillion blocks 39 and 76.
- 1950** -South Pass field was discovered.
- 1954** -With the discovery of West Cameron field, the western limit of Louisiana oil and gas production was established.
- 1959** -Severance taxes on oil and gas rose above \$100 million in Louisiana for the first time.
- 1970** -Louisiana oil production peaked at 905 million bbl, and the state's gas production peaked at 8 TCF.
- 1973** -The offshore industry created Clean Gulf Associates, a cooperative stockpiling of the most sophisticated oil spill containment and cleanup equipment available. The equipment is on call today in several coastal Louisiana cities.
- 1982** -Lease and royalty income paid by the oil and gas industry to the state of Louisiana soared to an all-time record of \$624,529,812. Oil and gas severance taxes in Louisiana hit an all-time record of \$971,677,140.
- 1983** -Approximately 165,000 oil industry jobs supported over 600,000 Louisianians.

development on both state-owned and private lands, manages unitization of fields and maintains production and exploration records.

Louisiana has been leasing state lands since 1915, although leasing in the coastal zone did not begin until 1921. In 1945 Louisiana held its first offshore lease sale. By 1983 Louisiana had issued 11,112 leases statewide with 55% of them in the coastal zone. From 1921 to 1983, about 75% of all leased acreage was in the coastal zone: a total of 11.6 million acres were leased and an average lease size was 6,481 acres. The lowest statewide leasing occurred in 1931, when 12,620 acres were leased. In the coastal zone, leasing activity reached its low in 1926 with 1,000 acres leased. The most active year, both statewide and in the coastal zone, was 1927, when 1.7 and 1.6 million acres were leased, respectively.

Interest in leasing was erratic from the 1920s through the 1950s, with sales ranging from none to more than 1.7 million acres. Since 1950, total acreage leased in the state and the coastal zone has remained less than 0.5 million acres annually. However, most of this acreage—about 75%—still falls in the coastal zone. Leases were largest during the 1920s and 1930s before the Mineral Board was established. Lease size averaged 3000 acres statewide and 33,000 acres in the coastal zone during that period. Lease sizes were limited by the Legislature to 5000 acres in 1941, and then to 2500 acres in 1977 by the Mineral Board, thus decreasing lease size significantly. Nevertheless, the average lease size in the coastal zone remains about twice as large as the rest of the state.

4.1.4 Production

In a study on oil and gas development in Louisiana's coastal zone, Reference 37, it was found that 55% of the oil production and 47% of the gas production has occurred in fields in the coastal zone. The study also identified 471 fields in the coastal zone out of the state's total 1600 fields. A complete list of these fields that produced oil and gas between 1926 and 1983 may be found in that publication. These fields are located partly onshore, partly in state waters, in bayous, ponds, lakes, and bays, as well as in marshes and swamps.

The Sweetlake field in southwestern Louisiana, discovered in 1926, was the first commercial success in the coastal zone. An average of six new oil fields and nine new gas fields have come to production each year in the coastal zone since that time.

Production of oil in Louisiana began in 1902. Oil production increased sharply beginning in the 1940s when 100 million barrels of oil was exceeded. Improved technology and increased demands for petroleum led to a peak in state production in 1969 at 842 million barrels. This peak was followed by a very rapid decline to one-half that level in 1974 then to one-fourth in 1979. Since 1979 production has been relatively stable at about 200 million barrels (Figure 6).

Coastal zone oil production began in 1926 with 11,000 barrels, less than 1% of the state's total, but increased steadily thereafter. Since 1952 the coastal zone has contributed to more than one-half the state's annual production. Peak production in the coastal zone occurred in 1970 (513 million barrels) one year after the state peak, followed by a rapid decline to production of less than one-fourth the peak in 1983 (Figure 6).

Figure 6. Oil production in Louisiana, 1926-1987

Natural gas reserves were first discovered in 1870 near Shreveport Louisiana, but gas was not produced until 1913. In addition, records of gas production were not kept until 1934 since gas was not a drilling target before that time, but a by-product of oil. Generally gas was burned or flared because there was little use for it. Therefore, records of gas production in the coastal zone only became available in 1934.

State gas production rose steadily from the 1930s and then in 1950 it reached 1 BCF and doubled every six years until it peaked in 1970 at 7.8 BCF and then sharply declined to 2 BCF by 1983 (Figure 7).

Figure 7. Gas production in Louisiana, 1926-1987

The coastal zone proved to be a significant area for gas production. In 1934 less than 1% of the state's gas production occurred in the coastal zone; by 1952 one-fourth of the state's gas came from the coastal zone. Production steadily rose reaching 1 BCF in 1960 and peaked in 1970 at 3.8 BCF (Figure 7). Annual production has since declined to about 1 BCF in the coastal zone and remains about one-half of the state's production.

4.1.5 Revenues

The state receives revenues from bonuses, rentals, royalties, and severance taxes from leases on state lands and waterbottoms. On private lands, the state receives severance taxes on production only. More than \$12 billion in revenues has been generated from leases and production in the coastal zone from 1926 to 1983. Leases in the coastal zone have yielded more than \$6.2 billion in severance taxes, \$3.8 billion in royalties, \$1.4 billion in bonuses, and \$0.7 billion in rentals. About 1/2 of the revenue is from severance taxes, 32% from royalties, 12% from bonuses, and 6% from rentals.

4.2 Wetland Habitats in Southern Louisiana

Wetlands are land areas, often transition zones which have unique features from upland habitats. The distinguishing features of a wetland are the presence of standing water, unique wetland soils and vegetation adapted to or tolerant of saturated soils. Wetlands include marshes, swamps, bogs, wet meadows, potholes, sloughs, and river outflow lands.

Wetlands vary in depth and duration of flooding, size (from small potholes to expansive wetland several hundred km²), and location (coastal to inland). Since they are transitional areas between deepwater and terrestrial upland systems, they are influenced by both of these very different systems. Human influence on wetlands varies in each region as well.

The legal definition of a wetland is extremely important for management purposes. The U.S. Army Corps of Engineers (USACE) and EPA use the definition under Section 404 of the Clean Water Act which defines wetlands as:

"those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, fens, and similar areas." (33CFR 323.2C; 1984).

For research as well as management purposes the U.S. Fish and Wildlife Service and Louisiana Coastal Management Division (CMD) use the definition described by Cowardin et al. (1979):

"Wetlands are transitional areas between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. Wetlands

must have one or more of the following attributes: 1) at least periodically, the land supports predominantly hydrophytes, 2) the substrate is predominantly undrained hydric soil, and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."

While CMD uses the Cowardin definition of wetlands, the definition described in Louisiana Coastal Resources Program Final Impact statement (1980) is as follows:

"Wetlands are open water areas or areas that are inundated or saturated by surface or ground-water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life under saturated conditions"

While these working definitions are very similar there are cases in the coastal zone where USACE may not require a permit under Section 404 but CMD would.

Louisiana's coastal land contains approximately 40% of our nation's wetlands. The entire coast of Louisiana is fringed with wetlands, some of which extend up to 50 miles inland. Within this wide band of wetlands, several distinct wetland habitats occur. These habitats have variable environmental conditions and variable flooding, tidal regime, and salinity as well as diverse plant communities. The Natural Heritage Program has identified several distinct marine, estuarine, lacustrine, palustrine, riverine, and terrestrial communities which are found in the coastal zone (Table 25).

Louisiana's coast contains marshes and swamps which make up about 75% of the habitat in the coastal zone. The remaining 25% of the land area is mostly classified as developed or agricultural/ pasture land. Major marsh habitat types and their areal extent include fresh, intermediate, brackish, and salt marshes which are so divided depending upon the salinity and the dominant plant communities. These marsh types succeed from salt to brackish, to intermediate, to fresh marsh habitat from the shoreline inland.

Forested wetlands include cypress-tupelo swamps and mangroves and bottomland hardwoods. The focus, for the purposes of this study will be on these six major habitat types. Other habitats such as natural and spoil shrub/scrub communities and submerged and aquatic vegetation are not described here.

4.2.1 Importance of Wetlands

Generally wetlands are important for a variety of reasons. They provide flood damage protection, protection from storm and wave damage, water quality improvement, and they recharge aquifers. They also provide critical habitat for all or part of life stages of plants, fish, shellfish, and wildlife.

The Louisiana coastal zone contains over 8 million acres of swamps, marsh, cheniers, barrier islands, open bays, bayous, and other water bodies. These habitats are important to the state

Table 26. Natural Communities in Coastal Louisiana

Marine	
Marine Subtidal Open Water	
Deepwater	
Shallow Water	
Marine Intertidal Beach/Bar	
Intertidal Sand/Mud/Shell Beach/Bar	
Marine Aquatic Bed	
Submergent Algal Vegetation	
Submergent Vascular Vegetation	
Estuarine	
Intertidal Emergent Vegetation	
Salt Marsh	
Brackish Marsh	
Intermediate Marsh	
Subtidal Aquatic Bed	
Submergent Vascular Vegetation	
Submergent Algal Vegetation	
Intertidal Flat	
Intertidal Sand/Shell Flat	
Intertidal Mud/Organic Flat	
Vegetated Pioneer Emerging Delta	
Intertidal Mollusk Reef	
Intertidal Saltwater Swamp	
Subtidal Open Water	
Bay	
Tidal Channel/Creek	
Tidal Pass	
Lacustrine	
Littoral Open Water	
Marsh Lake	
Swamp Lake	
Palustrine	
Emergent Vegetation	
Freshwater Marsh	
Herbaceous Bog (Flatwood bog)	
Aquatic Bed	
Submerged Algal Vegetation	
Submerged/Floating Vascular Vegetation	
Scrub/Shrub Wetland Vegetation	
Scrub/Shrub Swamp	
Shrub Swamp	
Forested Wetland	
Cypress-Tupelo Swamp	
Cypress Swamp	
Tupelo-Blackgum Swamp	
Batture (Riverfront pioneer)	

Table 26. Natural Communities in Coastal Louisiana (Continued)

	Bottomland forest
	Overcup Oak-Water Hickory
	Hackberry-American Elm-Green Ash
	Sycamore-Sweet Gum- American Elm
	Sweet Gum-Water Oak
	Forested Canebrake
	Live Oak Forest
	Bayhead Swamp
	Slash Pine-Cypress/Hardwood Forest
	Riparian Sandy Branch Bottom
	Riparian Forest (Small stream floodplain forest)
Riverine	
	Riverine Subtidal Channel
	Tidal Mud Flat
	Subtidal Open Water
	Riverine Lower Perennial Channel
	San/Gravel Beach/Bar
	Mud Bar
	Lower Perennial Open Water
	Aquatic Bed
	Submerged/Floating Vascular Vegetation
Terrestrial	
	Tallgrass Grasslands
	Coastal Dune Grassland
	Coastal Prairie
	Shrub Thicket
	Coastal Dune Shrub Thicket
	Deciduous Forests
	Coastal Live Oak-Hackberry Forest (Chenier maritime forest)
	Beech/Magnolia Forest (Hardwood slope forest)
	Mixed Evergreen/Deciduous Forests
	Mixed Hardwood-Loblolly Forest
	Pine Flatwoods
	Slash Pine/Post Oak Forest
	Pine Savannah
	Live Oak-Pine-Magnolia Forest

because of their recreational, aesthetic, and commercial value. They provide habitat and food for numerous fish, shellfish, birds, mammals, and other wildlife. Wetlands provide nutrients for plants to grow and buffer zones which protect populated areas from storms and hurricanes.

Louisiana has some of the richest wetlands in the world. They produce 33% of the United States' seafood, 40% of its fur harvest, and 40% of its alligators. Many commercially and recreationally important species spend all or part of their life cycle in the Louisiana wetlands. It has been estimated that as much as two-thirds of all commercial fishery species rely upon

coastal marsh habitat during some or all of their life cycles.

Louisiana marshes support over five million migrating ducks and geese. Eleven federally listed endangered and three threatened species are found in coastal Louisiana. These include bald eagles, brown pelicans, and several species of sea turtles and whales. Forty-five eagles' nests are found in coastal Louisiana along with over 150 water bird colonies.

Because Louisiana wetlands were formed through recent sedimentation of the Mississippi River, oil and gas deposits are common in the coastal area. Louisiana's coastal area has been more extensively developed for oil and gas production than any other place in the country. One-half of Louisiana's oil and gas production occurs in coastal marshes, where over 10 billion barrels of oil and 65 trillion cubic feet of gas have already been produced (Reference 37).

Wetland loss has become a serious problem in south Louisiana where the natural process of subsidence of deltaic deposits coupled with man's activities has caused high land loss rates. Causes of land loss include regional and local subsidence, sea level rise, leveeing of the Mississippi River, saltwater intrusion, and drainage of wetlands. As a result of natural and human induced alterations, Louisiana has lost about 30-40 mi² of wetlands a year between 1956 and 1978. Recent studies show an increase of land loss rates during the 1970's, and a decrease in loss rates in the 1980's (about 30 mi²/yr) down from estimates of 39-42 mi² in the 1970s.

4.2.2 Marshes

4.2.2.1 Salt Marsh

Salt marshes are the habitat closest to the Gulf of Mexico and may range from 1 to 15 miles wide in coastal Louisiana. Salt marshes covered 455,044 acres of the coastal zone in 1978. Because of the proximity to the Gulf and regular tidal cycles, the salinity level varies from almost fresh to hypersaline (0.6 to 52 ppt). However, the mean salinity for salt marshes is about 16 ppt and generally ranges from 11 to 19.

Salt marshes are often monospecific with smooth cord grass (*Spartina alterniflora*) as the dominant plant. This very productive, salt- and flood-tolerant plant can be found in pure stands or intermixed with the other 16 species of plants found in Louisiana salt marshes. Some other common species which may occur with *S. alterniflora* in salt marshes include black needle rush (*Juncus roemerianus*), salt grass (*Distichlis spicata*), and wire grass (*Spartina patens*) (Table 27). In areas where elevations and soil salinity are slightly higher, species such as sea oxeye (*Borrchia frutescens*) and saltwort (*Batis maritima*) are more frequently found.

Salt marshes support 99 species of birds, 7 species of mammals, 5 species of reptiles, and no amphibians (Lindstedt 1990a). Raccoons (*Procyon lotor*) are probably the most common mammal found in Louisiana salt marshes. The most common birds that live in the salt marsh are the clapper rail (*Rallus longirostris*), seaside sparrow (*Ammodramous maritimus*), night heron (*Nycticorax sp.*), laughing gull (*Larus atricilla*), Foster's tern (*Sterna forsteri*), royal tern

(*Thalasseus maximus*) and caspian tern (*Hydroprogne caspia*).

Table 27. Common plants of wetland habitats in Louisiana.

Salt Marsh	
Black needle rush	<i>Juncus roemerianus</i>
Salt grass	<i>Distichlis spicata</i>
Saltwort	<i>Batis maritima</i>
Sea oxeye	<i>Borrchia frutescens</i>
Smooth cord grass	<i>Spartina alterniflora</i> *
Wire grass	<i>Spartina patens</i>
17 species of plants have been found in the salt marshes of Louisiana.	
Brackish Marsh	
Big cord grass	<i>Spartina cynosuroides</i>
Black needlerush	<i>Juncus roemerianus</i> *
Bulrush	<i>Scirpus robustus</i>
Dwarf spikerush	<i>Eleocharis parvula</i>
Salt grass	<i>Distichlis spicata</i> *
Seashore paspalum	<i>Paspalum vaginatum</i>
Smooth cordgrass	<i>Spartina alterniflora</i>
Three cornered grass	<i>Scirpus olneyi</i>
Water hyssop	<i>Bacopa monnieri</i>
Widgeon grass	<i>Ruppia maritima</i>
Wire grass	<i>Spartina patens</i> *
61 species of plants have been found in the brackish marshes of Louisiana.	
Intermediate Marsh	
Alligator weed	<i>Alternanthera philoxeroides</i>
Bultongue	<i>Sagittaria falcata</i> *
Common three square	<i>Scirpus americanus</i>
Cow pea	<i>Vigna repens</i>
Deer pea	<i>Vigna luteola</i>
Giant Bulrush	<i>Scirpus californicus</i>
Roseau cane	<i>Phragmites australis</i> *
Seashore paspalum	<i>Paspalum vaginatum</i>
Spikerush	<i>Eleocharis spp.</i>
Switch grass	<i>Panicum virgatum</i>
Three cornered grass	<i>Scirpus olneyi</i>
Water hyssop	<i>Bacopa monnieri</i>
Wire grass	<i>Spartina patens</i> *
54 species of plants have been found in the intermediate marshes of Louisiana.	

* Dominant plant of that habitat

† Common to floating marsh habitat

Table 27. Common Plants of Wetland Habitats in Louisiana (Continued)

Fresh Marsh

Alligator weed	<i>Alternanthera philoxeroides</i>
Arrowhead, Duck potato	<i>Sagittaria latifolia</i> *
Bladderwort	<i>Utricularia</i> spp.
Bultongue	<i>Sagittaria falcata</i> *
Cattail	<i>Typha latifolia</i> *
Giant cutgrass	<i>Zizaniopsis miliacea</i>
Grass	<i>Eleocharis</i> spp.
Maidencane	<i>Panicum hemitomon</i> *†
Marsh fern	<i>Thelypteris palustris</i> †
Pickereel-weed	<i>Pontederia cordata</i>
Roseau cane	<i>Phragmites australis</i> *
Royal fern	<i>Osmunda regalis</i> †
Southern wildrice	<i>Zizaniopsis Miliacea</i>
Spike sedge	<i>Eleocharis</i> spp.
Tear thumb	<i>Polygonum sagittatum</i>
Vine	<i>Vigna luteola</i>

93 species of plants have been found in the fresh marshes of Louisiana.

Swamp

American snowbell	<i>Styrax americana</i>
Ash	<i>Fraxinus tomentosa</i>
Bald cypress	<i>Taxodium distichum</i> *
Black willow	<i>Salix nigra</i>
Buttonbush	<i>Cephalanthus occidentalis</i>
Green ash	<i>Fraxinus pennsylvanica</i>
Pumpkin ash	<i>Fraxinus profunda</i>
Red maple	<i>Acer rubrum</i> var. <i>drummondii</i>
Swamp blackgum	<i>Nyssa sylvatica</i>
Virginia willow	<i>Itea virginica</i>
Water elm	<i>Planera aquatica</i>
Water locus	<i>Gleditsia aquatica</i>
Water tupelo	<i>Nyssa aquatica</i> *

143 species of plants have been found in swamps in Louisiana.

Bottomland Hardwood Forest

American elm	<i>Ulmus americana</i> *
Boxelder	<i>Acer negundo</i> *
Hackberry	<i>Celtis laevigata</i> *
Peppervine	<i>Ampelopsis arborea</i>
Poison ivy	<i>Rhus radicans</i>
Red maple	<i>Acer rubrum</i> var. <i>drummondii</i>
Sweet gum	<i>Liquidambar styraciflua</i> *
Vines	<i>Smilax</i> spp.
Virginia creeper	<i>Parthenocissus quinquefolia</i>

149 species of plants have been found in bottomland hardwood forests in Louisiana.

4.2.2.2 Brackish Marsh

Brackish marshes are generally found between salt and intermediate marshes where salinity averages 8 ppt (Lester 1988) but can reach 28 ppt. However, salinity usually ranges from 4 to 12 ppt. Brackish marshes are irregularly tidally flooded and dominated by salt-tolerant plants. Plant diversity and organic matter in the soil are higher than in the salt marsh but lower than fresh and intermediate marsh. The brackish marsh community covered 909,481 acres of the coastal zone in 1978.

Because many species overlap brackish and intermediate marshes, these two habitats are often combined in the literature as brackish. Approximately 61 plant species have been found by various authors in the brackish marshes of Louisiana. The dominant species of the brackish marsh is wire grass, (*Spartina patens*), which is extremely productive and is the basis of the brackish marsh food web. Other common species include saltgrass (*Distichlis spicata*), black needle rush (*Juncus roemerianus*), three-cornered grass (*Scirpus olneyi*), dwarf spikeweed (*Eleocharis parvula*), bulrush (*Scirpus robustus*), widgeon grass (*Ruppia maritima*), seashore paspalum (*Paspalum vaginatum*), water hyssop (*Bacopa monnieri*), smooth cordgrass (*Spartina alterniflora*), and big cordgrass (*S. cynosuroides*) (Table 27).

Brackish marshes support 101 species of birds, 17 species of reptiles, 10 species of mammals, and 5 species of amphibians. Common mammals in brackish marshes include the muskrat (*Ondatra zibethicus*), raccoon (*Procyon lotor*), mink (*Mustela vison*), and otter (*Lutra canadensis*).

Loons, grebes, and cormorants often winter in brackish marshes. Common ducks are gadwall (*Anas strepera*) and mottled duck (*Anas fulvigula*). Other birds such as the great egret (*Casmerodius albus*), great blue heron (*Ardea herodias*), marsh hawk (*Circus cyaneus*), night heron (*Nycticorax spp.*), clapper rail (*Rallus longirostris*), and seaside sparrow (*Ammodramus maritimus*) frequent brackish marshes.

4.2.2.3 Intermediate Marsh

In Louisiana, intermediate marsh forms an extensive transition zone between brackish and fresh marshes. This oligohaline habitat where salinity averages about 3 pp has been classified as brackish or fresh marsh in some studies. Mean salinity ranges from 2 to 5 ppt but has been recorded as high as 10 ppt.

This marsh type covered 426,386 acres of the coastal zone in 1978. The tidal regime is irregular and the vegetation is composed mainly of narrow-leaved species. Plant diversity and organic content of the soil are not as high as fresh marsh but are higher than in the brackish and salt marsh.

Reference 38 provides a list of the 97 plant species that have been found by several authors in intermediate marshes in Louisiana. Species that are common to both fresh and brackish marshes

may be found together in intermediate marshes. Broad-leaved plants and vines as well as grasses are common. The dominant plants are wire grass (*Spartina patens*), roseau cane (*Phragmites australis*), and bulltongue (*Sagittaria falcata*). Other species commonly found in intermediate marshes are listed in table 2, the spikesedge (*Eleocharis spp.*), water hyssop (*Bacopa monnieri*), three-cornered grass (*Scirpus olneyi*), giant bulrush (*S. californicus*), common threesquare (*S. americanus*), seashore paspalum (*Paspalum vaginatum*), cow pea (*Vigna repens*), deer pea (*V. luteola*), switch grass (*Panicum virgatum*), and alligator weed (*Alternanthera philoxeroides*) (Table 27).

The intermediate marshes in Louisiana support 98 species of birds, 19 reptiles, 10 mammals, and 6 amphibians, all of which are listed in Reference 38. Mammals common to intermediate marsh are the muskrat (*Ondatra zibethicus*), raccoon (*Procyon lotor*), mink (*Mustela vison*), and otter (*Lutra canadensis*). White-tailed deer (*Odocoileus virginianus*) are also found in intermediate marshes, especially along ridges and levees.

Several ducks may be found in intermediate marshes, including mottled duck (*Anas fulvigula*), which is a permanent resident, and migratory ducks such as the mallard (*Anas platyrhynchos*), blue-winged teal (*Anas discors*), and green-winged teal (*Anas crecca*). Other birds include the great egret (*Casmerodius albus*), great blue heron (*Ardea herodias*), marsh hawk (*Circus cyaneus*), and common snipe (*Capella gallinago*).

4.2.2.4 Fresh Marsh

Fresh marshes occupy the northernmost extent of coastal marshes in Louisiana. In 1978, 653,636 acres of fresh marsh covered the coastal zone. In Louisiana, fresh marshes are located adjacent to intermediate marshes and swamps or at the mouth of major rivers such as Atchafalaya and the Mississippi. Frequency and duration of flooding and salinity are the primary factors governing species distribution. Secondary factors such as substrate, current flow, and competition affect species distribution as well. Fresh marsh has the greatest plant diversity and the highest soil organic content of all the marsh types. Salinity in fresh marshes is usually less than 2 ppt and may reach 7 ppt.

Species composition in fresh marshes is extremely diverse and is dominated by broad-leaved, flowering plants, grasses, reeds, and sedges. Reference 38 compiles a listing of 150 plant species which have been found in the fresh marshes of Louisiana by several authors.

Two types of fresh marshes may be found in Louisiana--emergent and flotant. Both emergent and flotant marshes have many of the same species but these communities are anchored differently. Emergent marshes are anchored in the sediments whereas flotant marshes are anchored in a dense mat of roots, sediment, and detritus which floats on a layer of water and moves with the tides and water level.

The dominant plants in emergent fresh marsh communities are broad-leaved plants such as arrowhead (*Sagittaria latifolia*) and bulltongue (*S. falcata*), and grasses such as maiden cane

(*Panicum hemitomon*), roseau cane (*Phragmites australis* formerly *P. communis*), and cattail (*Typha latifolia*). Table 27 lists other common species.

Flotant marsh is dominated by maidencane (*Panicum hemitomon*), which is a grass that grows on the floating but firm organic substrate. The plant community is diverse and capable of supporting vegetation that is less flood tolerant than other marsh vegetation since water does flood the vegetation. These species such as the marsh fern (*Thelypteris palustris*) and the royal fern (*Osmunda regalis*) are unique to flotant marshes. Other plants common to this community include the vine (*Vigna luteola*), a grass (*Eleocharis spp.*), and tear thumb (*Polygonum sagittatum*).

Fresh marshes support 90 bird species, 33 reptile species, 19 amphibian species, and 14 mammal species (Lindstedt 1990a). The muskrat (*Ondatra zibethicus*) and nutria (*Myocastor coypus*) are common commercial furbearers in fresh marsh. Other mammals, such as the raccoon (*Procyon lotor*), mink (*Mustela vison*), otter (*Lutra canadensis*), white-tailed deer (*Odocoileus virginianus*), and harvest mouse (*Reithrodontomys fulvescens*) also live in fresh marshes.

Common birds in fresh marshes include loons, grebes, and cormorants. Other common species include anhingas (*Anhinga anhinga*), gallinules (*Porphyrio maritima*, *Gallinula chloropus*), and king rails (*Rallus elegans*). Bald eagles (*Haliaeetus leucocephalus*), which are federally endangered, nest in trees in and around fresh marshes. The mottled duck (*Anas fulvigula*) is a permanent resident while other ducks such as mallards (*Anas platyrhynchos*), blue-winged teal (*Anas discors*), and green winged teal (*Anas crecca*) are common migratory waterfowl. Wading birds, such as the great egret (*Casmerodius albus*) and great blue heron (*Ardea herodias*), are the most common birds found in fresh marshes.

4.2.3 Forested Wetlands

Wetland forests in Louisiana are primary composed of two types: freshwater and saltwater swamps. Freshwater swamps include the deepwater or cypress-tupelo swamp and bottomland hardwood forests. The difference between these forested areas is the tree species and how often they are flooded and how long the flooding lasts. The cypress-tupelo swamp mainly consists of cypress, water tupelo, and maple trees, while bottomland hardwoods contain a variety of species of trees, including elms, sweet gum, and maple. Mangrove swamps are the forested wetlands in the salt water environment.

4.2.3.1 Mangrove Swamp

Mangroves or saltwater swamps in Louisiana occur mostly behind barrier islands or on slightly elevated stream edges. The black mangrove (*Avicennia germinans*) is the only mangrove species found in Louisiana. They are mainly found along the bayou edge of *S. alterniflora* marshes where marsh elevation is slightly higher. In Louisiana mangroves do not always form a thick swamp but are often found as a marsh in association with *S. alterniflora*. Because Louisiana is in the northern edge of its range, freezes cause diebacks of this plant, preventing large

established stands here therefore these plants seldom exceed 1.5 meters. The brown pelican (*Pelecanus occidentalis*) and white-faced ibis (*Plegadis chihi*) nest in this habitat.

4.2.3.2 Bottomland Hardwood Forest

Bottomland hardwood forests flank rivers and bayous and serve as a transition zone from swamps and marshes to drier upland areas. In the classification of habitats in the Louisiana coastal zone, forests occupy 199,577 acres and bottomland hardwoods occupy most of this area. This habitat type has the least-flooded, best-drained soils in wetland areas. These areas were once natural levees that were dominated by upland hardwood trees; they have since subsided and are now dominated by flood-tolerant species. Because many of these areas are so well drained, they have been cleared and used for residential areas, roads, industry, and agriculture. The lower portions of the natural levee are less well drained and are usually the sites of the bottomland hardwoods, which grade into cypress-tupelo swamps.

Bottomland hardwoods are flooded each year for several weeks to a few months, usually in the winter and early spring. During the rest of the year the water table is near or just below the soil surface. Salinity is virtually zero in these areas. They are important natural communities for maintaining water quality and for providing habitat for a variety of fish and wildlife.

Bottomland hardwoods are dominated by hardwood trees and woody shrubs in which 149 plant species have been reported. Reference 36 compiled a list of these species. The most common species are the American elm (*Ulmus americana*), sweet gum (*Liquidambar styraciflua*), hackberry (*Celtis laevigata*), and red maple (*Acer rubrum* var. *drummondii*). The woody understory is composed mainly of red maple (*A. rubrum* var. *drummondii*) and box elder (*A. negundo*) saplings (Table 27).

A variety of herbaceous plants is found in bottomland hardwood forests as well, especially along the edges and in open areas. The most common herbaceous plants and vines found in Louisiana bottomland hardwoods are poison ivy (*Rhus radicans*), and other vines such as *Smilax* spp., pepper vine (*Ampelopsis arborea*), and Virginia creeper (*Parthenocissus quinquefolia*).

4.2.3.3 Swamp

Cypress-tupelo swamps are the primary forested wetlands in fresh, poorly drained areas where the soil is saturated or covered with water for at least one month during the growing season. Cypress-tupelo swamps covered 342,425 acres of the coastal zone in 1978. The dominant species found in the swamp are the bald cypress (*Taxodium distichum*) and the water tupelo (*Nyssa aquatica*). Often swamps are composed of pure stands of one of these species or a mixture of the two trees. Conner found 146 species of plants in Louisiana swamps. Other trees that may be commonly found in the swamp are ash (*Fraxinus tomentosa*), green ash (*F. pennsylvanica*), pumpkin ash (*F. profunda*), black willow (*Salix nigra*), water elm (*Planera aquatica*), water locust (*Gleditsia aquatica*), swamp blackgum (*Nyssa sylvatica*), and the red maple (*Acer rubrum* var. *drummondii*). Common species found in the woody understory include

saplings of the red maple (*A. rubrum* var. *drummondii*), Virginia willow (*Itea virginica*), buttonbush (*Cephalanthus occidentalis*), and American snowbell (*Styrax americana*).

Tupelo-blackgum swamps are also forested wetlands where the dominant overstory is composed of gums (*Nyssa* spp.). Common species associated with these communities are similar to cypress and cypress-tupelo swamps.

Other common plants in swamp habitat are floating aquatic and emergent plants. The most common floating aquatics include duckweed (*Lemna minor*), water hyacinth, (*Eichhornia crassipes*), water fern (*Azolla caroliniana*), and American frogbit (*Limnobium spongia*). The most common emergent plants include lizard tail (*Saururus cernuus*) and smart weed (*Polygonum punctatum*).

Common mammals found in Louisiana swamps are the opossum (*Didelphis virginiana*), bobcat (*Lynx rufus*), fox squirrels (*Sciurus carolinensis*, *S. niger*), cottontails and swamp rabbits (*Sylvilagus floridans*, *S. aquaticus*), nutria (*Myocastor coypus*), and white tailed deer (*Odocoileus virginianus*).

Birds common to the swamp are anhingas (*Anhinga anhinga*), gallinules (*Porphyryla maritima*, *Gallinula chloropus*), wood duck (*Aix sponsa*), red shouldered hawk (*Buteo lineatus*), barn owl (*Tyto alba*), great horned owl (*Bubo virginianus*), barred owl (*Strix varia*), black vulture (*Coragyps atratus*), and turkey vulture (*Cathartes aura*). The endangered bald eagle (*Haliaeetus leucocephalus*) nests in swamps of Louisiana.

Amphibians and reptiles are especially common in swamp forest communities, especially the alligator (*Alligator mississippiensis*) and cottonmouth snake (*Agkistrodon piscivorus*).

4.2.3.4 Other Wetland Forest Communities

There are several lesser known and common forest communities where soils are inundated or saturated part of the year and could be classified as wetland habitat. These areas occur in the coastal zone of Louisiana and are under jurisdiction of the Coastal Zone Management Act. These communities are the overcup oak-water hickory community, the hackberry--American elm--green ash community, the sycamore--sweet gum--American elm community, and the sweet gum--water oak community. These communities are dominated by the species for which they are named and are found along low ridges and along banks of rivers and streams, and on floodplains.

4.2.4 Endangered Species

There are eleven federally listed endangered and three threatened species in Louisiana's coastal zone. Three of the endangered and two of the threatened species are sea turtles and three are endangered whales which do not frequent inland wetlands of the state. Those endangered species which do inhabit Louisiana marshes and swamps are the piping plover (*Charadrius*

melodus), bald eagle (*Haliaeetus leucocephalus*), brown pelican (*Pelecanus occidentalis*), red-cockaded woodpecker (*Picoides borealis*), Florida panther (*Felis concolor coryi*), and the west Indian manatee (*Trichechus manatus*). There are 45 bald eagle nests in the coastal zone. More detailed information on endangered and threatened species may be found in Reference 39.

In addition, the Natural Heritage Program, with the Louisiana Department of Wildlife and Fisheries maintains a list and a data base of state threatened and endangered species. There are 50 plants, 15 birds, 11 reptiles, 2 amphibians, 3 fish, and 16 mammals on this list.

4.3 Wetland Access Practices

Exploration and development of petroleum resources in wetlands pose several logistical problems for transportation and operation of equipment to the drilling sites. Prior to the 1930's problems of access were easily solved because roads were used for land based operations however, open water environments and wetlands proved to present different transportation problems. In open water areas, access by boat or barge is direct and relatively easy if the water is deep enough. In wetlands and shallow water environments, traditional access methods by land (roads) and by water (boat, barge) are not feasible. Equipment used for upland areas or open water access is not suitable for wetland environments. Therefore new technology and methods of access were required to proceed in these difficult areas. Historically, there have been only two successful methods of access in wetlands, canals and board roads. Both are modifications of conventional access methods on firm land or navigatable water. Both are the conventional methods for site access in use today in wetlands.

The high water and organic content of wetland soils and thus low bearing capacity pose major problems for transporting and operating heavy drilling equipment in wetlands. Early access to wetland sites were either by natural waterways, or roads built on adjacent upland. However, as the industry grew and wetland areas proved productive to the industry, alternate methods of access were required. In order to produce in these areas, roads needed to be built through wetlands and new waterways (canals) needed to be constructed.

4.3.1 Canals

Since canal and road construction in wetlands is expensive and time consuming, roads on firmer marshes were used where possible and canals were built in areas that could not support roads. In areas accessed by canals, early drilling sites were either constructed on pilings similar to open water sites or on wooden mats which were placed on the marsh surface. By 1931 the floating barge rig was invented followed by the submersible drilling barge in 1934 which eventually proved to be cheaper and more efficient than the previous site preparation methods.

Once the submersible barge was in use, there was a need for a more efficient method of digging access canals through the marsh. By 1938 barge mounted bucket dredges were used as were hydraulic dredges. Sometimes these were used in combination because the bucket dredge was

more efficient in removing the vegetative layer and the hydraulic dredge would remove the underlying substrate. By the mid 1950's bucket dredge technology improved and they became more efficient than hydraulic dredges. By the early 1960's few hydraulic dredges were used, and today conventional bucket dredges are almost solely used. With advances in dredging technology from the 1930's to the 1950's and the economics, canals became the common access method to drilling sites in coastal Louisiana.

Typically a canal is dredged to about 8 feet and the dredged spoil is deposited along the sides of the newly created canal. The dredged canal is about 70 feet across the bottom and may be greater than that at the surface depending upon the stability and slope of the spoil bank sediments. The deposited material forms a continuous spoil bank which is usually about 70 feet wide. The spoil is deposited along both sides of the canal with a 25 foot berm between the canal and the spoil bank. In cross section, a swath of at least 260 feet wide is necessary to construct a canal and its associated spoil bank.

The size of the access canal is dependent upon the size of the equipment that will be used. Access canals are typically 70 feet wide and 9 feet deep with a terminus about 160 feet wide which is needed to accommodate work barges and the submersible platform (dimensions 180 to 220 feet long and 45-55 feet wide. These access canals are often referred to as the keyhole because the shape of the canal and terminus resembles a keyhole especially when viewed from the air. The keyhole itself is approximately 345 feet long. It is clear that access by canal has been successful and economical because today Louisiana's coastal zone has an extensive network of canals which has been built in the last 50 years.

4.3.2 Road Dump/Board Roads

Road dumps or board roads are used to access the drill sites by land. Early roads were created with both shell and planks as materials. An additional access method was a piling supported board road which was used to access a site in open water.

For drilling access by land in wetland environments it is necessary to build roads to transport and operate drilling equipment. In marsh areas where access by water is not used, a road dump is constructed of dredged material "borrowed" from the adjacent marsh or swamp. Hence the name "borrow ditch or borrow pit". The dumped material is then surfaced with layers of temporary boards. The typical road dump requires a 30 feet wide road and a 30 feet wide borrow ditch.

In the standard construction procedure a dragline, which is supported by wooden mats as temporary supports, moves over the marsh surface. The mat consists of timbers about 1 by 16 feet long wired together to form a mat 4 to 6 feet wide and 16 feet long. As the dragline progresses, it moves the mat forward and "walks" across the marsh. Generally the dragline dredges marsh material from one side and deposits it on the other to form the road dump. Generally only one dragline is necessary. However, if conditions are poor (low clay and high water and organic content) draglines on each side of the road dump may be necessary.

Not all marsh areas are suitable for board roads. One out of 100 sites along the Texas and Louisiana coasts are not suitable for road dumps. The specific site conditions are the controlling factors rather than the marsh type. Depth to the underlying clay layer and percent organic matter determine the size of the road dump, borrow ditch, and disturbed area.

The dredged material is piled up to create a surface 5 feet above the marsh level. The width of the level road surface is about 30 feet. The borrow ditches are usually 30 feet wide, 5 feet deep, and 300 feet (maximum) long, alternating on either side of the road dump. The width and depth of the borrow ditches varies with the fill requirement of the road dump. For example, less fill is required for soils with high clay content and more for soils with high water and organic content.

In forested wetlands construction varies somewhat because the access route must be cleared of trees before building the road dump. Stumps in the borrow ditch site must also be removed prior to dredging, and stumps on the road dump site are left in place to provide support.

After dredged spoil is deposited to form the road, a sediment filter cloth or plastic sheeting is placed on the fill to allow the material to dewater and solidify. After the material has formed a hard surface, the boards are placed on the elevated site. Several layers of boards are hand placed at right angles to each other on the dumped material. The boards are usually 4 by 8 inches and 16 feet long. The first layer of boards, (mud boards), is laid directly on the fill material lengthwise (in the direction of travel). The next layer of boards is laid perpendicular to the mud boards, each subsequent layer is laid perpendicular to the layer below it. Three or four layers of boards are laid before the top layer (tread boards) is placed in the direction of travel. The tread boards are positioned where truck tires will travel. The total number of board layers depends upon the soil conditions and the size of the drilling rig and equipment at the site.

Board roads are often temporary measures to access a site. Since the road is designed to be removed if the site is unsuccessful, the boards are usually rented by the drilling company for 90-180 days. If the operation extends beyond 180 days before the site is abandoned, the road is considered permanent. When a site is successful, the road becomes permanent by placing shell or limestone on top of the boards. Maintenance of the permanent road usually requires additional deposits of shell or limestone.

Road dumps constructed prior to 1953 are visible on aerial photographs. The earlier road dumps used a continuous borrow ditch unlike the alternating ditch that is used today. The continuous ditch alters hydrology more so than an alternating ditch. Abandoned sites showed little restoration of road dumps or borrow ditches, but the routes are revegetated. Some of the continuous borrow ditches have developed into boat routes and many of the roads have revegetated and appear as an elevated anomaly.

4.4 Impacts of Oil and Gas Development

The oil and gas industry has had and will continue to have long-term impacts on coastal Louisiana. Beneficial and detrimental effects of the industry are evident in the state's economy and in the coastal zone. Although the state's economic security has declined with declining production, the industry remains the most important one in the state today (Reference 37). The effects on the wetlands of oil and gas activities are permanent and will continue to alter natural processes long after the area is no longer actively producing oil and gas. Because canals and board roads are the most significant activities related to wetland access, the question of impact is addressed separately for them.

Since the 1950s, south Louisiana's population has grown steadily and has shifted from remote rural areas in the marshes to more densely settled communities where employment with the petroleum industry has been available. The coastal parishes have grown more quickly than the northern ones, but the concentration of petroleum activities in the coastal zone has required coastal communities to develop roads and other public services.

High, dry land suitable for residential, commercial, and community use is limited in the coastal zone, therefore, wetlands have been reclaimed for such activities. Support bases, supply yards, and related industries in the coastal zone are located as close as possible to the development and production areas. As a result, heavy concentrations of petroleum-related industries are found in the coastal parishes and surrounding areas. For example, in 1990 there were 26 service bases, 21 heliports, 9 pipe coating yards, 14 platform-fabrication yards, 26 gas processing plants, 17 oil refineries, and 50 separation facilities in south Louisiana (Minerals Management Service 1992). These facilities require from 1 to over 1000 acres for construction and operation.

Canals and navigational channels have a major impact on Louisiana's coastal wetlands. They alter hydrology by changing an area's drainage patterns from numerous small, sinuous channels to one large, straight, deep channel. These channels are one cause of saltwater intrusion and subsequent loss of freshwater vegetation in the state.

Pipelines are another by-product of oil and gas development. Pipelines have been laid throughout Louisiana and are especially concentrated in south Louisiana and offshore. For example, it is estimated that 4500 miles of pipelines crossed wetlands in Louisiana in the 1960's. This does not include canals. By the late 1980's it was estimated that there were approximately 12,000 miles of pipelines in Louisiana's coastal zone and the Minerals Management Service (1992) reported 16,000 miles of pipeline offshore in 1990.

Pipeline installation displaces bottom sediments, causes accidental spills. In coastal wetlands, pipelines destroy habitat and the surrounding biota. They also interfere with drainage, and straight channels allow saltwater intrusion and dewatering of the marsh (Minerals Management Service 1992). The extent of the impact of a pipeline is dependent upon the method of installation and the mitigation measures taken if any. The degree of impact depends upon whether the right of way is backfilled, the stability of the location, and the sediment supply to

the system.

The petroleum industry's contribution to land loss may be devastating to coastal fisheries and may have legal implications as well. Land loss can adversely affect fisheries production because some species use the sheltered marsh coastline for food and protection during part of their life cycles. Spoil banks can also affect feeding and spawning activities of fish and other indigenous species that move in and out of the marsh and the adjacent waterbodies with the water level. Because canals and board roads are the most significant activities related to access these are discussed separately in this section.

4.4.1 Canals

The most obvious and significant ecological impacts of the oil and gas industry in the coastal zone are related to dredging. Miles of pipeline and well access canals, along with major navigational channels, interlace the coastal zone. These canals are often cited as the major human-induced cause of land loss.

Canals and spoil banks affect wetlands in both direct and indirect ways. Direct effects are the immediate loss of habitat i.e. conversion of marshes to open water and conversion of marshes to spoil bank (shrub/scrub) habitat. Indirect effects are chronic which occur over a long and extended period of time and result in a change in ecological processes because of a physical change.

When canals and road dumps are constructed, marsh habitat is directly converted into either open water or spoil bank habitat. These new habitats alter the hydrological regime of the marsh. The total area impacted by a canal includes the channel itself and the associated spoil bank. The spoil bank on each side of the canal alters more than twice the area than the actual channel does and results in a total impacted area 5.5 times as wide as the canal itself. Other studies have estimated that 48 to 56 acres of wetlands may be altered for every mile of access canal. This change in habitat is apparent and widespread. The area of spoil banks present in the coastal zone was 19,866 acres in 1956 and increased to 93,973 acres in 1978. In addition, habitat classified as artificial water which includes canals, channels and impounded areas, mostly used by industry, increased from 77,042 acres in 1956 to 145,072 acres in 1978.

Hydrologically canals are more efficient and rapid than natural bayous. Faster runoff decreases the potential of the marsh to filter nutrients and pollutants effectively thus decreasing water quality lower in the estuary where eutrophication occurs more quickly. The increased runoff also causes rapid fluctuations in the water table and lowers it as well causing more frequent dry periods which in turn affects soil/water chemistry and the ability of plants to respond to wider ranges of environmental conditions.

Finally, canals also provide more routes for salt water to move further inland thus changing marsh communities significantly. Increases in salinity causes change in marsh habitat and the distribution of oysters. Depending upon the location, an increase in salinity causes different

reactions. In freshwater swamps and float marshes the habitat is usually converted to open water and fresh and brackish marshes change into brackish and salt marshes respectively.

Once a canal is completed the area which it alters continues to change with boat traffic which continuously erodes the sides of the canal. The canal widens and spoil and marsh are converted into open water. Access canals are widened from 3.1 to 7.4 feet/year and widening in some canals can range from 2 to 15% annually causing the canal to double in width every 5 to 35 years. It is estimated that widening of old canals can almost equal the area of new canals added each year.

According to the most recent studies, conversion of marsh directly into open water and spoil habitat from dredging canals accounts for 5 to 10% of the total land lost each year in coastal Louisiana. The subsequent widening increases land loss to 10 to 20% of the total. Previous studies have also linked density of canals with land loss rates and have implicated canals responsible for up to 90% of the land loss because of the indirect influence on coastal subsidence.

The habitat created by spoil disposal is much different from the natural levee found along the banks of natural streams. The artificial levee or spoil bank has a lower soil organic content, a higher bulk density, and is typically much wider than a natural channel berm. After deposition, dewatering and oxidation of organic matter causes spoil banks to shrink up to 50% within the first six months. The invading vegetation on these spoil banks is upland shrub/scrub communities dominated by woody terrestrial vegetation such as shrubs and trees which are not found in coastal marshes except along natural levee banks.

In addition, the change in elevation itself is critical in Louisiana coastal marshes because small changes in surface elevation influences hydrology and plant succession. Most spoil banks are continuous and therefore interfere with hydrology by providing a barrier to sheet flow and drainage of surface waters across the marsh. Continuous artificial levees prevent drainage and/or can delay drainage of the surrounding marsh increasing flooding duration. Prolonged inundation then affects soil/water chemistry which then affects plant growth and species composition.

Spoil banks can also alter subsurface water flow and drainage since the weight of the spoil can compress the organic layer of marsh to approximately 60% of its original thickness. Therefore the below ground flow has a smaller more restricted area to flow through and flow rate is then reduced. Spoil banks can block tidal flooding and reduce sediment and nutrient supplies to the marsh thus affecting the rate of vertical accretion, a critical problem in Louisiana's naturally subsiding marshes.

The dredged water habitat that is formed from canal dredging is also different from the natural water habitat of the area. Canals are usually straight rather than meandering, they are deep (8-9 feet) rather than shallow, and the soft organic bottom is often replaced by a hard clay bottom, reducing the amount of suitable benthic habitat available. Dredging also resuspends nutrients

and pollutants and returns them to the marsh surface thus decreasing water quality. Water turnover rates and water quality can be variable. Oxygen depletion and thus decreased population size or fish kills may result from little turnover combined with an accumulation of organic debris in semi-open or closed canals.

4.4.2 Road Dumps/Board Roads

Road dumps disrupt ecological processes and indirectly cause wetland alteration or loss. Studies provide an evaluation of the effects road dumps have on wetlands. Environmental consequences such as habitat alteration (physical and ecological impact and altered physical processes) and impact on biota have been documented. Road dumps destroy habitat, create barriers to water movement and alter inundation and sediment distribution patterns. Borrow ditches which connect different salinity regimes may promote salt water intrusion. Alteration to wetland processes in turn reduce organic production and vertical accretion. Acute and chronic environmental impacts of road dump access are less than those of canal access however, the construction cost is higher for road dumps.

Road dump construction like canal construction converts marsh into open water and spoil habitat but the area affected by a road dump is less. The total area altered by borrow ditches equals the area altered by the road dump and alters approximately 0.137 acres of marsh for every 100 feet of road. Since the USACE allows a maximum of 1100 feet of access road, up to 1.5 acres of marsh are altered to provide access to drill locations by this method. There is no quantitative data on the total area directly converted from wetlands to road dumps and borrow pits.

The area altered by the ring levee/drill pad is about 400 by 400 feet maximum (preferred size is 300 by 300 feet under USACE General Permit NOD-13) and alters about 5.2 acres of marsh. When compared with a canal of 1500 feet, which alters 10.3 acres of habitat, road access alters half that of a canal. For longer canals and road dumps the difference in impact is greater with 67% less altered habitat from the road dump. In addition, the open water created by the road construction is shallower than canals (5 vs 8 feet).

Road dumps alter hydrologic regime by creating a barrier to sheet flow as do spoil banks. However, installation of culverts at periodic intervals is required for road dumps therefore water movement across the marsh is not impeded as much. This configuration creates new channels because water becomes funneled to the culvert sites. Effects on hydrology are minimized but not eliminated. The orientation of the road dump can influence hydrology. For example, if the road is perpendicular to the water movement, a hydrologic head may develop alternately on either side with the rising and falling tides. With inundation and drainage patterns and frequency changes, plants may become stressed or species composition altered.

As in spoil banks, subsurface water flow and drainage are altered by the weight of the road which compresses the underlying organic layer. Feeding and spawning habits of species inhabiting the marsh may be interrupted because of the road barrier. However, these impacts may be less severe than spoil banks because of the required culverts. As with canal

construction, water turbidity increases and water quality may decrease due to resuspension of toxic substances and nutrients during excavation and deposition of sediments at construction.

4.4.3 Management Techniques

Management techniques have been developed that avoid impacts to surface features and functions during construction canal site access. These techniques include using alternate access methods such as board roads, hovercraft, and helicopters, timing construction so that breeding and nesting activities of coastal birds do not coincide with drilling, moving the drilling location elsewhere if birds are breeding and nesting, using existing access routes, using directional drilling, or using a combination of avoidance techniques. They also suggest methods to minimize impacts to the surface. These are; regulate canal dimensions and use minimum feasible dimensions, minimize canal depth, and align canals in relation to local drainage patterns, existing canals, and surface features. They also suggest methods to minimize the effects of spoil disposal. These are: deposit spoil in a discontinuous spoil bank, haul the spoil away, dispose of spoil in open water, or use hydraulic dredging techniques such as jet spray or low pressure disposal.

Various techniques have been developed that avoid or minimize wetland impacts during road dump construction. Some are similar to these presented for canals. To avoid impacts, operators should use land access instead of canals, existing road dumps, natural levee sites, public or private roads, or alternate access methods. Other suggestions to avoid impacts include time construction to occur during nonbreeding seasons of bird colonies, relocate drill site, use directional drilling techniques, or combine avoidance techniques. To minimize impacts they suggest that operators minimize width, height and length of road, align the road parallel to sheet flow, install 24 inch culverts at proper marsh elevation at all streams crossed by the route, alternate borrow pits along the road every 300 feet, leave a 50 foot gap between successive pits in areas where a continuous pit is necessary, and reroute streams where culverts are not feasible.

4.4.4 Alternate Access Methods

Other methods of access which are available but are not used today are hovercraft and helicopters. Hovercraft have been evaluated as an alternative to marsh buggies but this method has not been seriously considered by industry because technological developments are lacking.

It appears that hovercraft have little impact on the marsh surface because their loading ratio is low and the impacts that do occur are not permanent. Transportation of the drilling equipment to a site by hovercraft or helicopter has not been tried therefore the cost and feasibility of this access method is unknown.

4.5 Summary of Environmental Considerations

The oil and gas industry has operated productively in the coastal zone since 1921. Oil and gas fields have been developed in all coastal habitats in Louisiana including barrier islands, open

water and bays, salt, brackish, intermediate, and fresh marshes, swamps, and bottomland hardwood forests. Historically 75% of all leased acreage has fallen within the coastal zone. The coastal zone now carries 50% of the leasing in the state and more than one-half the production. This area has contributed \$12 billion of the more than \$28 billion in state revenues generated from oil and gas activities. This accounts for more than 40% of the state's mineral revenues which have been generated in only one-sixth of its area.

Although Louisiana has benefitted economically from the oil and gas industry, there have also been some long term detrimental environmental effects. Oil and gas activities in the coastal zone has contributed to land loss in Louisiana. Louisiana loses about 40 square miles of wetlands annually, and it is estimated that 40-80% of this is related to dredging. Although natural processes of wetland loss are at work in the coastal zone, canals, pipelines, navigation channels, road dumps, and other activities which serve the industry also contribute to direct and indirect causes of wetland loss. Since wetland loss is a serious problem the state and industry are now aware that impacts to coastal habitats must be avoided or minimized when human activities occur there.

5. Parametric Cyclocraft Study

5.1 Parametric Study Ground Rules

To obtain the most realistic evaluation of the economics associated with operating cyclocraft to support oil and gas drilling and production in wetland areas, the following ground rules were selected for performing the parametric study:

- (a) Average distance from supply barge to drill site is 15 statute miles
- (b) Daily duration of cyclocraft operations varies from 8 hours to 12 hours, with an average of 10 hours.
- (c) Out of the average daily operation of 10 hours, one hour is lost in the morning and one in the afternoon, for transit from base to supply barge and return. In addition, 20 minutes is lost for each refueling of the cyclocraft.
- (d) The time taken for cargo handling varies with the payload size. The resulting average round trip delivery time is as follows:

<u>Payload Capacity</u>	<u>R.T. Time</u>
(lb)	(mins)
90,000	75
120,000	80
150,000	85

- (e) The average weight carried is 90% of payload capacity.
- (f) Each aircraft operates productively for 180 days per annum. This is based on an analysis of provisions required for scheduled maintenance, unscheduled repairs, inclement weather and awaiting payload/well availability.
- (g) The basis for computing the Ownership Costs of the cyclocraft operations is given in Table 28.
- (h) The basis for computing the Annual Operating Costs of the cyclocraft operations is presented in Table 29.
- (i) Table 30 provides the basis used for computing the Hourly Operating Costs for the cyclocraft operations.

Table 28. Basis of Cyclocraft Ownership Cost Analysis

Number of Aircraft in Fleet	6	
Taxes	4% on all acquisition items	
Depreciation - Straight Line	Period	Residual Value
Aircraft	10 Years	10%
Spares	no depreciation	
Ground Support Equipment	20 Years	5%
Insurance Rates		
Aircraft, based on replaceable value - \$500,000	2.5% per annum	
Personnel liability	\$2,000 per annum	
Spares & Ground Support Equipment, replaceable value	1.5% per annum	
Annual Licenses and Taxes		
Aircraft, based on depreciated value	1.223% per annum	
Spares & Ground Support Equipment, depreciated value	1.223% per annum	
Operating Base		
Rent	\$25,000 per aircraft per annum	
Taxes	\$10,000 per aircraft per annum	

Table 29. Basis of Cyclocraft Annual Operating Cost Analysis

Pilots - Chief Pilot's Salary & Fringe Benefits	\$60,000		
- Other Pilot's Salary & Fringe Benefits	\$45,000		
- One Chief Pilot in Fleet			
- Maximum Annual Flying Hours/Pilot	1,000		
- Two Pilots used for each Flight			
Mechanics - Chief Mechanic's Salary & Fringe Benefits	\$55,000		
- Other Mechanic's Salary & Fringe Benefits	\$42,000		
- One Chief Mechanic in Fleet			
- Mechanics Assigned to Each Aircraft:			
Payload	90,000 lb	120,000 lb	150,000 lb
No. of Mechanics	3	4	5
Dispatcher - One in Fleet; Salary and Fringe Benefits	\$35,000		
Ground Operations Directors - One plus Two per Aircraft			
- Salary and Fringe Benefits (Each)	\$40,000		
Helium - 12% Annual Replenishment of Aerostat Capacity;	10 Cents/Cubic Foot		
- Annual Purification Service	\$5,000 per million cub ft volume per cyclocraft		

Table 30. Basis of Cyclocraft Hourly Operating Cost Analysis

Fuel - Consumption	0.05543 Gallons/Installed SHP/Flight Hour
- Price	\$2.00/Gallon
Oil	1.5% Fuel
Scheduled Maintenance - Engines	\$0.0525/Installed SHP/Flight Hour
- Other	\$2.50/Empty Weight (Tons)/Flight Hour

5.2 The Parametric Model

In performing the parametric study, MRC utilized a computerized parametric design model, which incorporates algorithms that relate the design characteristics of a cyclocraft to its operational capability. The model incorporates a broad range of mission stages from which complete mission profiles may be constructed, e.g. climb, accelerate, cruise, hover, climb, decelerate, cruise and descend. The model has iterative loops so that, by inputting a set of operational requirements and design constraints, it will iterate automatically until a point design solution is obtained. The model has been used extensively to derive cyclocraft designs to meet different military and commercial mission requirements. The modularized structure of the parametric model is shown diagrammatically in Figure 8.

As the primary purpose of the subject analysis was to perform parametric studies on a very simple mission profile, the Parametric Design Model was simplified. The simplified mission profile was assumed to comprise a single segment, i.e. cruise. In other words, the fuel required for a mission was computed from operating at the cruise airspeed at the design altitude for the full endurance capability of the aircraft. In the parametric studies the installed shaft horsepower was computed from the greater of the power required to achieve a maximum airspeed of 60 mph at the maximum cyclocraft weight and that required to hover at maximum weight.

The algorithms, which have been tailored to represent cyclocraft having a dual-rotor configuration, quantify the weight components, buoyant lift, aerodynamic lift, power requirements and costs. The algorithms have been derived from a correlation of theoretical data, e.g. Reference 20, and empirical data acquired from X.2 and subscale testing, e.g. References 19, 33 and 35. The parametric expressions given below are applicable to a large heavy-lift cyclocraft, with an onboard crew and of a dual-rotor configuration. The algorithms would be substantially different for a small unmanned military aircraft, for example. The equations are based on an aerostat fineness ratio, i.e. length/beam, of 2 and a cyclorotor having four blades and four wings, each with an aspect ratio of 6.

The weight components of large manned dual-rotor cyclocraft, having aerostats of length/beam = 2, are projected as follows, in lb:

Figure 8. Cyclocraft Parametric Design Model Structure

Aerostat, ballonnet and external cables	$0.00556VOL_A + 0.7101VOL_A^{2/3}$
Internal structure	$0.00903 VOL_A$
Wings and blades	$0.9 L_{MA}$
Engines, nacelles and propellers	$1.1 SHP_{MAX}$
Fuel system	$0.1 W_F$
Controls, actuators and wiring	$0.13 L_{MA}$
Landing skids	$0.00044 VOL_A$
Bearings	$0.081 L_{MA}$
Cabin, Crew (4)	1,800 lb

Payload Handling

$0.2 W_P$

Payload, W_P

mission dependent

where,

L_{MA} is maximum aerodynamic lift, lb.
 SHP_{MAX} is maximum shaft horsepower.
 VOL_A is aerostat volume, cu ft.
 W_F is maximum fuel weight, lb.

Summing the above component weights,

$$W_E = 1,800 + 0.01533 VOL_A + 0.7101 VOL_A^{2/3} + 1.111 L_{MA} + 0.1 W_F + 0.2 W_P + 1.1 SHP_{MAX}$$

$$W_G = W_E + W_F + W_P$$

where,

W_E = aircraft empty weight, lb.
 W_P = payload + ballast weight, lb.

Aerostat buoyancy is a function of maximum design altitude, which determines ballonnet/aerostat volume ratio. Based on an assumed 95 % helium purity and 15°F superheat, the relationship between buoyant lift and maximum design altitude is given below:

Buoyancy (lb/cu ft)	Maximum Design Altitude (1000 ft)
0.0602	Sea level
0.0585	1
0.0567	2
0.0518	5
0.0444	10
0.0378	15
0.0321	20
0.0274	25
0.0233	30
0.0091	50

Allowing for aerostat blockage, in hover,

$$L_A = 0.002093 \sigma V_w^2 C_{LW} A_w$$

where,

L_A is aerodynamic lift, lb.
 σ is relative air density,
= 1 at sea level
 V_w is wing airspeed, ft/sec.
 C_{LW} is wing lift coefficient
 A_w is plan area of each wing, ft²

Based on $C_{LMAX} = 1$,

$$L_{MA} = 0.002093 \sigma V_w^2 A_w$$

In hover, and in rotating cruise,

$$L_A = 0.0023 \sigma V_w^2 C_{LW} A_w$$

Based on $C_{LMAX} = 1$

$$L_{MA} = 0.0023 \sigma V_w^2 A_w$$

In non-rotating cruise,

$$L_A = 0.0023 \sigma V^2 (C_{LW} A_w + C_{LB} A_B)$$

where,

V is aircraft speed, ft/sec.
 C_{LB} is blade lift coefficient
 A_B is plan area of each blade, ft²

Power requirements are based upon:

$$\text{aerostat length/beam} = 2$$

$$\text{airfoil aspect ratio} = 6$$

In hover,

$$SHP = 0.098 L_A \sigma^{-1}$$

In non-rotating cruise,

$$SHP = SHP_A + SHP_{WB} + SHP_I, \text{ where}$$

$$\begin{aligned} \text{SHP}_A &= 11.16 \cdot 10^{-8} \sigma V^3 \text{VOL}_A^{2/3} \\ \text{SHP}_{WB} &= 1.7 \cdot 10^{-8} \sigma V^3 L_{MA} \\ \text{SHP}_I &= 3.65 \sigma^{-1} V^{-1} L_A \end{aligned}$$

where,

$$\begin{aligned} \text{SHP}_A &\text{ is profile power of aerostat, tail and nacelles} \\ &= 11.75 \cdot 10^{-8} \sigma V^3 \text{VOL}_A^{2/3} \end{aligned}$$

$$\begin{aligned} \text{SHP}_{WB} &\text{ is profile power of wings and blades} \\ &= 1.65 \cdot 10^{-8} \sigma V^3 L_{MA} \end{aligned}$$

$$\begin{aligned} \text{SHP}_I &\text{ is induced power} \\ &= 3.32 \sigma^{-1} V^{-1} L_A \end{aligned}$$

The acquisition cost of cyclocraft components and phases in the development program, are expressed in the following manner:

$$\text{Cost of each component/function} = \$ (1,000 \cdot x + y \cdot \text{vol} + z \cdot \text{SHP})$$

The values of the coefficients x, y and z for a prototype heavy lift cyclocraft are shown in Table 31. Note that the cost coefficients given in Table 31 are for a commercial craft with no FAA certification. A cyclocraft designed to meet military standards would cost substantially more.

5.3 Scope of Parametric Study

The ground rules defined in Section 5.1 restrict some of the variables that usually are addressed in a parametric study of this nature. For example, in this application there is no need for higher altitude. Hence 2,000 feet altitude was selected as being well in excess of the mission requirement. Should higher altitudes ever be required of this cyclocraft, they can be achieved by changing the ballonnet to one of greater volume.

With regard to airspeed, it is found that, for a cyclocraft of this nature, by installing sufficient power to have a hovering capability at maximum weight, the cruise speed requirement of 60 mph can be accomplished. Hence there is no need to consider different values of altitude capability or maximum airspeed capability.

The two primary variables to be addressed in the parametric study are maximum payload capability and fuel capacity; the latter being addressed in terms of flying time between refuels, i.e. endurance. It was found from the payload requirements analysis, reported in Reference 2, that the minimum practical payload capacity is 90,000 lb. To utilize aircraft that have less than this payload capability would require break down of the heavier equipment for each move, a time-consuming and expensive procedure, or to be limited to helicopter-portable drill rigs. A

90,000 lb payload-carrying capability would not have these problems however.

Table 31. Cost Coefficients for a Prototype Heavy Lift Cyclocraft

Component/Function	x	y	z
Project Management	120	0.45	0
Engineering/Design	340	0.65	0
Aerostat	236	1.55	0
Structure	100	0.90	0
Cyclorotors	140	0.48	590
Propulsion	70	0	380
Controls	140	0.20	215
Crew Cabin	50	0.02	20
Landing Gear	10	0.10	0
Assembly	100	1.20	50
Helium	0	0.09	0
Payload Handling	55	0.05	0
Flight Test	120	0.60	50
Total Aircraft	1,481	6.29	1,305
G.S.E.	50	0.105	10
Spares	40	0.045	80
Total System	1,571	6.44	1,395

The parametric study was planned on the basis of two phases:

Phase I Variations in Payload and Endurance as shown below:

Parameter	Parametric Values Studied		
Payload, lb	90,000	120,000	150,000
Endurance, hrs	4	8	12

In Phase I, all combinations of payload and endurance, i.e. nine cases, were studied.

Phase II Using a selected value of Payload, based on the results of Phase I, further variations in Endurance are studied to determine the optimum cyclocraft design, which is to be used as a baseline design in Task 4, Preliminary Design.

The criterion chosen to determine the baseline design is the minimum total cost incurred in the transport of one ton of payload, under the specified operational conditions addressed in Section 5.1. Total cost includes all of the ownership, annual operating and hourly operating costs.

5.4 Phase I Study Results

In the Phase I study a parametric cyclocraft design was derived for each of the nine combinations of payload and endurance studied. Some of the major characteristics of the nine cyclocraft designs are given in Table 32. The table shows the growth of cyclocraft dimensions, weights and installed power with increase in payload and endurance.

Table 32. Design Parameters of Cyclocraft Derived in Phase I

Design Parameter	90,000 lb			120,000 lb			150,000 lb		
	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr
Aerostat Volume, cub ft	3,612,790	3,917,050	4,284,590	4,733,730	5,136,680	5,623,460	5,848,170	6,349,430	6,955,030
Aerostat Length, ft	380.8	391.2	403.0	416.6	428.1	441.3	447.1	459.5	473.7
Installed Power, SHP	5,286	5,790	6,399	7,048	7,720	8,532	8,811	9,650	10,665
Empty Weight, lb	154,975	167,380	182,357	202,177	218,565	238,345	249,010	269,360	293,920
Fuel Weight, lb	8,140	17,830	29,560	10,850	23,770	39,410	13,565	29,710	49,260
Gross Weight, lb	253,915	276,010	302,715	333,830	363,140	398,560	413,370	449,870	493,980
Aerostatic Lift, lb	204,840	222,100	242,940	268,400	291,250	318,850	331,590	360,010	394,350
Max Aerodynamic Lift, lb	50,870	55,715	61,580	67,830	74,290	82,105	84,780	92,860	102,630

The acquisition costs of the nine cyclocraft studied in Phase I, together with their spares and ground support equipment (GSE) costs, are tabulated in Table 33. The costs are presented as an average unit cost for a fleet of six cyclocraft. The table shows that the costs are very sensitive to payload, but substantially less so to endurance. The annual utilization, which is independent of payload, for the cyclocraft designs studied in Phase I, is given below:

Endurance (hours)	4	8	12
Annual Utilization (hours)	1,680	1,740	1,800

The Ownership, Annual Operating and Hourly Operating Costs were determined for the nine parametric designs. These are presented in Tables 34, 35 and 36 respectively. The Total

The Ownership, Annual Operating and Hourly Operating Costs were determined for the nine parametric designs. These are presented in Tables 34, 35 and 36 respectively. The Total Operating Costs, i.e. the sum of the Ownership, Annual Operating and Hourly Operating Costs, are presented in Table 37, in terms of Cost per Operating Hour.

The Productivity of the nine cyclocraft; given in terms of the number of round trips operated per annum and the total load delivered per annum, is provided in Table 38. The latter is based on an average load factor of 90 %, as discussed in Section 5.1.

Table 33. Acquisition Costs of Cyclocraft Derived in Phase I

Payload (000lb)	Endurance (hr)	Aircraft Cost (\$millions)	Spares Cost (\$millions)	G.S.E. Cost (\$millions)	System Cost (\$millions)
90	4	24.5339	0.2593	0.2586	25.0518
	8	26.5867	0.2811	0.2805	27.1483
	12	29.0665	0.3082	0.3063	29.6810
120	4	31.9821	0.3382	0.3374	32.6577
	8	34.7061	0.3681	0.3656	35.4398
	12	37.9969	0.4043	0.3997	38.8009
150	4	39.4005	0.4178	0.4152	40.2335
	8	42.7928	0.4551	0.4502	43.6981
	12	46.8928	0.5002	0.4926	47.8856

Table 34. Ownership Costs of Cyclocraft Derived in Phase I
(\$/operating hour)

Element	90,000 lb			120,000 lb			150,000 lb		
	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr
Depreciation	1,374.49	1,438.14	1,519.86	1,791.78	1,877.33	1,986.81	2,207.38	2,314.74	2,451.94
Insurance	377.95	395.99	419.06	494.69	518.85	549.70	610.96	641.23	679.83
Licenses & Taxes	112.85	118.08	124.79	147.11	154.14	163.13	181.24	190.06	201.33
Operating Base	20.83	20.11	19.44	20.83	20.11	19.44	20.83	20.11	19.44
Total	1,886.12	1,972.32	2,083.15	2,454.41	2,570.43	2,719.08	3,020.41	3,166.14	3,352.54

Table 35. Annual Operating Costs of Cyclocraft Derived in Phase I
(\$/operating hour)

Cost Element	90,000 lb			120,000 lb			150,000 lb		
	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr
Salaries - Pilots	95.24	96.26	93.06	99.71	96.26	93.06	99.71	96.26	93.06
- Mechanics	80.46	77.68	75.09	101.29	97.80	94.54	126.29	121.94	117.87
- Others	55.06	53.16	51.39	55.06	53.16	51.39	55.06	53.16	51.39
Helium & Purif'n	36.56	38.27	40.47	47.90	50.19	53.11	59.18	62.03	65.69
Total	267.32	265.37	260.01	303.96	297.41	292.10	340.24	333.39	328.01

Table 36. Hourly Operating Costs of Cyclocraft Derived in Phase I
(\$/operating hour)

Cost Element	90,000 lb			120,000 lb			150,000 lb		
	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr
Fuel	586.01	641.88	709.39	781.34	855.84	945.86	976.79	1,069.80	1,182.32
Oil	8.79	9.63	10.64	11.72	12.84	14.19	14.65	16.05	17.73
Engine Maint'nce	277.52	303.98	335.95	370.02	405.30	447.93	462.58	506.63	559.91
Other Maint'nce	193.72	209.23	227.95	252.72	273.21	297.93	311.26	336.70	367.40
Total	1,066.04	1,164.72	1,283.93	1,415.80	1,547.19	1,705.91	1,765.28	1,929.18	2,127.36

Table 37. Total Operating Costs of Cyclocraft Derived in Phase I
(\$/operating hour)

Cost Category	90,000 lb			120,000 lb			150,000 lb		
	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr
Ownership	1,886.12	1,972.32	2,083.15	2,454.41	2,570.43	2,719.08	3,020.41	3,166.14	3,352.54
Annual Operating	267.32	265.37	260.01	303.96	297.41	292.10	340.24	333.39	328.01
Hourly Operating	1,066.04	1,164.72	1,283.93	1,415.80	1,547.19	1,705.91	1,765.28	1,929.18	2,127.36
Total Cost / Hour	3,219.48	3,402.41	3,627.09	4,174.17	4,415.03	4,717.09	5,125.93	5,428.71	5,807.91

Combining the cost and productivity data contained in Tables 37 and 38 respectively, the cost per ton of equipment/materials delivered is computed. This parameter, which is the basic criterion for selection of the cyclocraft design, is given in Table 39.

Table 38. Productivity of Cyclocraft Derived in Phase I

Payload (000lb)	Endurance (hr)	Number of Round Trips per Annum	Number of Tons Delivered per Annum
90	4	1,056	42,768
	8	1,104	44,712
	12	1,152	46,656
120	4	990	53,460
	8	1,035	55,890
	12	1,080	58,320
150	4	932	62,910
	8	974	65,745
	12	1,016	68,580

Table 39. Total Cost per Ton Delivered for Phase I Cyclocraft

Cost Category	90,000 lb			120,000 lb			150,000 lb		
	4 hr.	8 hr	12 hr	4 hr	8 hr	12 hr	4 hr	8 hr	12 hr
Ownership	74.09	76.75	80.37	77.13	80.02	83.92	80.66	83.79	87.99
Annual Operating	10.50	10.33	10.03	9.55	9.26	9.02	9.09	8.82	8.61
Hourly Operating	41.88	45.33	49.53	44.49	48.17	52.65	47.14	51.06	55.84
Total Cost / Ton	126.47	132.41	139.93	131.17	137.45	145.59	136.89	143.67	152.44

From the results contained in Table 39, two conclusions were drawn:

1. For the targetted application, there is no economic benefit in utilizing a cyclocraft that has a payload carrying capability greater than the minimum value of 90,000 lb.
2. The most economic cyclocraft would have a relatively low endurance, i.e. less than 8 hours.

5.5 Phase II Study Results

Based upon the results of the Phase I study, it was decided to limit the Phase II work to the minimum acceptable payload of 90,000 lb. Because Phase I results indicated that the optimum cyclocraft would not be encumbered with a large fuel weight, the additional values of endurance selected for study, to determine the optimum fuel weight at a payload of 90,000 lb, were 2 hours, 3 hours, 5 hours and 6 hours.

The key design characteristics of the 90,000 lb payload cyclocraft studied are given in Table 40.

Table 40. Design Parameters of 90,000 lb Payload Cyclocraft Studied

Design Parameter	Endurance						
	2 hours	3 hours	4 hours	5 hours	6 hours	8 hours	12 hours
Aerostat Volume, cub ft	3,479,500	3,544,750	3,612,790	3,683,860	3,758,110	3,917,050	4,284,590
Aerostat Length, ft	376.0	378.3	380.8	383.2	385.8	391.2	403.0
Installed Power, SHP	5,065	5,174	5,286	5,404	5,526	5,790	6,399
Empty Weight, lb	149,540	152,200	154,975	157,875	160,900	167,380	182,357
Fuel Weight, lb	3,900	5,970	8,140	10,400	12,760	17,830	29,560
Payload, lb	90,000	90,000	90,000	90,000	90,000	90,000	90,000
Gross Weight, lb	244,240	248,970	253,915	259,075	264,470	276,010	302,715
Aerostatic Lift, lb	197,290	200,990	204,840	208,870	213,080	222,100	242,940
Max Aerodynamic Lift, lb	48,750	49,790	50,870	52,000	53,180	55,715	61,580

The system acquisition costs, based on a fleet of six aircraft, for each of the seven 90,000 lb payload parametric designs evaluated in Phase II, are presented in Table 41. The annual utilizations of the seven 90,000 lb payload cyclocraft are given below:

Endurance (hours)	2	3	4	5	6	8	12
Annual Utilization (hours)	1,500	1,620	1,680	1,725	1,740	1,740	1,800

The Ownership, Annual Operating and Hourly Operating Costs for the 90,000 lb payload cyclocraft, are tabulated in Tables 42, 43 and 44 respectively. By summing these cost components, the Total Operating Costs were determined; these are presented in Table 45. All operating costs are given in terms of dollars per operating hour.

Table 41. Acquisition Costs of 90,000 lb Payload Cyclocraft

Endurance (hr)	Aircraft Cost (\$millions)	Spares Cost (\$millions)	G.S.E. Cost (\$millions)	System Cost (\$millions)
2	23.6345	0.2499	0.2487	24.1331
3	24.0758	0.2545	0.2536	24.5839
4	24.5339	0.2593	0.2586	25.0518
5	25.0139	0.2642	0.2638	25.5419
6	25.5136	0.2694	0.2693	26.0523
8	26.5867	0.2811	0.2805	27.1483
12	29.0665	0.3082	0.3063	29.6810

Table 42. Ownership Costs for 90,000 lb Payload Cyclocraft (\$/operating hour)

Cost Element	Endurance						
	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr
Depreciation	1,482.98	1,398.78	1,374.49	1,364.83	1,380.10	1,438.14	1,519.86
Insurance	407.52	369.17	377.95	375.42	379.75	395.99	419.06
Licenses & Taxes	121.76	114.85	112.85	112.06	113.31	118.08	124.79
Operating Base	23.33	21.60	20.83	20.29	20.11	20.11	19.44
Total	2,035.59	1,904.40	1,886.12	1,872.60	1,893.27	1,972.32	2,083.15

Table 43. Annual Operating Costs for 90,000 lb Payload Cyclocraft (\$/operating hour)

Cost Element	Endurance						
	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr
Salaries - Pilots	91.67	94.14	95.24	92.76	96.26	96.26	93.06
- Mechanics	90.11	83.44	80.46	78.36	77.68	77.68	75.09
- Others	61.67	57.10	55.06	53.62	53.16	53.16	51.39
Helium & Purification	39.43	37.20	36.56	36.30	36.72	38.27	40.47
Total	282.88	271.88	267.32	261.04	263.82	265.37	260.01

Table 44. Hourly Operating Costs for 90,000 lb Payload Cyclocraft
(\$/operating hour)

Cost Element	Endurance						
	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr
Fuel	561.51	573.59	586.01	599.09	612.61	641.88	709.39
Oil	8.42	8.60	8.79	8.99	9.19	9.63	10.64
Engine Maintenance	265.91	271.64	277.52	283.71	290.12	303.98	335.95
Other Maintenance	186.92	190.25	193.72	197.34	201.13	209.23	227.95
Total	1,022.76	1,044.08	1,066.04	1,089.13	1,113.05	1,164.72	1,283.93

Table 45. Total Operating Costs for 90,000 lb Payload Cyclocraft
(\$/operating hour)

Cost Category	Endurance						
	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr
Ownership	2,035.59	1,904.40	1,886.12	1,872.60	1,893.27	1,972.32	2,083.15
Annual Operating	282.88	271.88	267.32	261.04	263.82	265.37	260.01
Hourly Operating	1,022.76	1,044.08	1,066.04	1,089.13	1,113.05	1,164.72	1,283.93
Total Cost / Hour	3,341.23	3,220.36	3,219.48	3,222.77	3,270.14	3,402.41	3,627.09

The Productivity of the 90,000 lb payload cyclocraft studied in Phase II, presented in terms of the number of round trips operated per annum and the total weight of equipment and materials delivered each year per cyclocraft, is given in Table 46. Again note that the delivered loads are 90 % of the cyclocraft payload capacity.

Combining the results contained in Tables 45 and 46, the cost per ton delivered, for each of the 90,000 lb payload cyclocraft studied, is calculated and is given in Table 47. The total cost per ton delivered is presented graphically in Figure 9. The figure shows that the cyclocraft that can perform the wetlands support mission most economically, has an endurance between refuels of about 5 hours, i.e. one mid-day refuel in a 10 hour day. The scatter in the points shown in the graph of Figure 9 are due to the use of integers rather than fractions or decimals in the computations, e.g. the ten-hour cyclocraft work day is interrupted by zero, one or two refuels, not 1.33. Thus an endurance of 5 hours is more compatible than one of either four or six hours.

Table 46. Productivity of 90,000 lb Payload Cyclocraft

Endurance (hr)	Number of Round Trips per Annum	Number of Tons Delivered per Annum
2	912	36,936
3	1,008	40,824
4	1,056	42,768
5	1,104	44,712
6	1,104	44,712
8	1,104	44,712
12	1,152	46,656

Table 47. Total Cost per Ton Delivered for 90,000 lb Payload Cyclocraft

Cost Category	Endurance						
	2 hr	3 hr	4 hr	5 hr	6 hr	8 hr	12 hr
Ownership	82.67	75.57	74.09	72.25	73.68	76.75	80.37
Annual Operating	11.49	10.79	10.50	10.07	10.27	10.33	10.03
Hourly Operating	41.54	41.43	41.88	42.02	43.32	45.33	49.53
Total Cost / Ton	135.70	127.79	126.47	124.34	127.26	132.41	139.93

5.6 Baseline Design Selection

From an analysis of the study results reported in Section 5.5, the cyclocraft that has a payload capacity of 90,000 lb and an endurance between refuels of 5 hours, was selected as the baseline design. The primary selection criterion employed was the minimum cost incurred in the delivery of a payload. Secondary criteria used in the selection are identified below:

- (a) Minimum investment to put the required system operational capability in place.
- (b) Minimum calendar time to put the required operational capability in place.

(c) Minimum risk associated with program accomplishment.

(d) Minimum requirement for logistics support in the defined cyclocraft operations.

The ability of the selected baseline cyclocraft design to meet the primary and secondary selection criteria, is better than that of the other candidates. Design and operational characteristics of the selected baseline design, designated H.1 Cyclocraft, are addressed in Section 6.

Figure 9. Total Cost per Ton Delivered for 90,000 lb Payload Cyclocraft

6. H.1 Cyclocraft Preliminary Design

6.1 System Requirements

The unmanned prototype for the USAF has been designated, by MRC, as the U.1 Cyclocraft and the heavy-lift configuration for the DOE application in oil/gas recovery is designated as the H.1 Cyclocraft.

6.1.1 Basic Requirements

The basic requirements postulated for the operation of the H.1 Cyclocraft in wetland areas are summarized below:

1. Operation of the H.1 Cyclocraft, together with the deployment of its support systems, must result in no long-term adverse impact on the wetlands environment.
2. The H.1 Cyclocraft must be able to transport all items of standard equipment and materials that are utilized in oil and gas drilling and production operations, without resorting to expensive and time-consuming breakdown of components.
3. The H.1 Cyclocraft shall be able to pick-up and deposit its payloads while in a hover mode of operation.
4. The H.1 Cyclocraft shall perform its support operations at a cost that is acceptable to industry.
5. The H.1 Cyclocraft shall be able to operate from any cleared level area, without the provision of expensive facilities and/or support equipment.
6. The H.1 Cyclocraft shall be able to avoid or withstand all adverse weather conditions that may exist in the designated areas of operation.
7. The risks associated with developing the H.1 Cyclocraft, so that it will perform its defined duties in a reliable and economic manner, shall be minimal.

The MRC approach is to ensure that the H.1 Cyclocraft fully meets all of the above mandatory requirements, together with design optimization that provides for minimum operating cost.

6.1.2 Initial Baseline Design Parameters

Within the framework of the above requirements, MRC, in pursuit of DOE program Tasks 1, 2 and 3 developed specific design information with respect to the anticipated needs associated with the oil/gas developments of interest. From this work, initial determinations have been made

on the desired minimum payload capabilities, e.g. 45 tons; the nominal transport distances, e.g. 15 miles; maximum airspeeds required, e.g. 67 mph; and desired times between fuel stops, e.g. 5 hours. These underlying criteria were developed using the existing dual-rotor parametric model of MRC's for the trade-offs and related design evaluations and the activities are covered in References 1 through 3. The H.1 Cyclocraft that will satisfy those initially established parameters has the basic characteristics listed below. Note that some changes are made to the baseline design derived in Section 5, due to refinements made in the design data.

Cyclocraft Length	345	ft
Aerostat Volume	3,637,230	cu ft
Installed Power	5404	SHP
Empty Weight	155,231	lb
Fuel Weight	10,400	lb
Payload	90,000	lb
Gross Weight	256,431	lb
Aerostatic Lift	206,231	lb
Max Aerodynamic Lift	52,000	lb

During the system engineering phases of the formal design process in the development program, further trade-offs and judgments will be made by MRC before the detailed design specifics of the desired system evolve completely. For example, even though the very detailed analyses performed by MRC in the parametric evaluations of Section 5 clearly indicated the most cost-effective payload to be 90,000 lbs, that conclusion was based on a series of assumed ground rules, e.g. average distance of supply barge to drill site, specific cost factors of importance and times for handling various payloads. As the program evolves, other considerations, e.g. actual locations for home base and field operations or the design chosen for picking up or depositing payloads by the H.1 Cyclocraft, might alter the guiding criteria for items such as payloads, speeds or times between fuel stops.

6.2 System Definition

The H.1 Cyclocraft System will, ultimately, comprise the cyclocraft and all equipment, related facilities, material, software, services, personnel and support required to ensure that the aircraft can accomplish its intended operational role effectively. This document addresses the preliminary design of the H.1 Cyclocraft with an overview of the support needed in the operational environment, rather than the total system. The work being performed under Task 6, Ground Support, and Task 8, Development Plan, addresses all facets of support, e.g. home base facilities, specific requirements for ground handling equipment and needed personnel for system support.

Figure 10 depicts the basic components of the planned H.1 Cyclocraft System, together with a preliminary listing of the ground support equipment. The latter is addressed more completely in Sections 7 and 8.

Figure 10. Elements of the H.1 Cyclocraft System

6.3 H.1 Cyclocraft Geometry

As noted previously, the principal H.1 Cyclocraft characteristics were determined through MRC's utilization of its parametric model, in response to identified transport requirements for oil and gas hardware, Reference 2. Further details of the geometry of the dual-rotor H.1 Cyclocraft are presented in Table 48.

Note that the H.1 Cyclocraft has an aerostat volume of 3,637,230 cu ft, which is approximately 11 times that of the successfully flown X.2 Cyclocrane, i.e. 330,000 cu ft. MRC notes that this aerostat size is well within the state of the art however. The linear dimensions of the H.1 Cyclocraft are approximately 2.2 times those of the X.2.

A two-view sketch of the H.1 Cyclocraft is shown in Figure 11. Comparison with the two-view sketch of the U.1 Cyclocraft, given in Reference 11, shows marked similarity, with notable

differences being in the strength and the amount of structure internal to the aerostat and the provisions for the payload. Initial thoughts on the payload handling are presented in Section 6.6.1.3, Structure Subsystem.

Table 48. H.1 Cyclocraft Geometry

Overall Aircraft Dimensions	
Length	345.0 ft
Height	170.0 ft
Width	151.4 ft
Aerostat Geometry	
Volume	3,637,230 cu ft
Length	302.9 ft
Diameter	151.4 ft
Ballonet	15.5 %
Cyclorotor Geometry	
Diameter	132.0 ft
Wing area (each)	760 sq ft
span	67.5 ft
chord	11.2 ft
aspect ratio	6.0
Blade area (each)	400 sq ft
span	40.0 ft
chord	10.0 ft
aspect ratio	4.0

6.4 H.1 Cyclocraft Weights & Balance

Summary weights data for the H.1 Cyclocraft are given in Table 49. The table shows that the disposable weight, comprising payload, fuel and personnel, is approximately 40 % of the cyclocraft's gross weight. The aircraft's Center of Gravity range is from 140 ft to 150 ft aft of the nose of aerostat.

6.5 H.1 Cyclocraft Performance

As noted earlier, MRC has used its computer based parametric model to derive expected performance capabilities for the defined H.1 Cyclocraft depicted in Figure 11. The power

Figure 11. Two-View Sketch of H.1 Cyclocraft

Table 49. H.1 Cyclocraft Weights

Subsystem	Weight (lb)
Aerostat	37,017
Cyclorotors	46,800
Internal Structure	32,844
Propulsion	5,944
Controls	6,760
Fuel	1,040
Bearings	4,212
Landing Gear	1,614
Cabin	1,000
Payload Handling	18,000
Empty Weight	155,231
Payload	90,000
Fuel, Oil	10,400
Personnel	800
Gross Weight	256,431

required to maintain different airspeeds is shown in Figure 12. At 2,000 feet altitude and at a gross weight of 250,000 lb, the figure shows that a maximum airspeed of 68.4 mph can be achieved at the maximum power of 5,404 SHP, with no allowance for the aerodynamic drag associated with an external payload. With an external payload frontal area of 100 sq ft and a drag coefficient of 0.6, the figure shows that the maximum attainable airspeed is reduced to 65.8 mph. As expected, the increment in power requirement associated with the aerodynamic drag of the external load, drops off dramatically at the lower cruise speeds.

Figure 13 depicts the effect of gross weight on the maximum attainable airspeed at 2,000 feet altitude, with and without an external payload. The figure shows that the cyclocraft weight at which the highest speed is achievable is 206,231 lb, i.e. the gross weight at which aerodynamic lift is zero. At this optimum weight, with and without an external payload, the maximum airspeed is 82.0 mph and 85.3 mph respectively.

The relationships between endurance, payload and cruise speeds achievable with the cyclocraft, are presented in Figure 14. The figure shows that the H.1 Cyclocraft, carrying a 90,000 lb external payload at 2,000 feet altitude, has a five hour endurance capability, while cruising at 40 mph. Figure 14 shows further that by reducing payload and adding fuel, with full allowance for added fuel system weight, the endurance capability of the H.1 Cyclocraft is increased considerably. For example, at a cruise airspeed of 30 mph and a payload of 20 tons, the H.1 Cyclocraft has an endurance of over 42 hours. The figure illustrates one aspect of the operational flexibility of the cyclocraft. With an internal payload the endurance is improved further.

Figure 12. Effect of Cruise Airspeed on Power Requirement

Figure 13. Effect of Weight on Maximum Airspeed

The data contained in Figure 14 was also used to prepare Figure 15, which shows the relationship between operating range, payload and cruise airspeed for the H.1 Cyclocraft, at 2,000 feet altitude and still air. It is seen from the figure that the airspeed that results in maximum range for a given payload varies from about 45 mph at the lower payloads to 65 mph at the maximum payload of 45 tons.

The impact of altitude on the range versus payload at a cruise airspeed of 50 mph is shown in Figure 16. Because the aerostat displaces air of lower density as altitude increases, aerostatic lift is reduced and the combined weight of payload and fuel is correspondingly reduced. The figure shows that this results in lower payload at a given range and lower range at a given payload, at the higher altitudes. To operate at altitudes higher than the design altitude of 2,000 feet, the H.1 Cyclocraft would be modified by the installation of a larger ballonnet. The latter could be accomplished in a relatively short period of time at low cost, illustrating again the operating flexibility of the cyclocraft.

Although the data contained in Figures 12 through 16 are not directly applicable to the planned primary application of the H.1 Cyclocraft, i.e. support of drilling in wetlands, the data do show that the H.1 Cyclocraft has operational capabilities far beyond those required for its primary mission. This broad capability is considered significant in providing assurance that the annual utilization of operational H.1 Cyclocraft would be high, should its primary use not require high utilization.

Figure 14. Payload, Endurance and Cruise Airspeed Relationships

The two lift systems, i.e. aerostatic and aerodynamic, have the capability to generate the following lift forces:

Aerostatic lift	206,306 lb
Maximum aerodynamic lift	52,000 lb

The maximum rate of climb and maximum rate of descent are each limited to 500 ft/min by the fans and vents in the aerostat. Aerodynamic forces could be generated to provide greater climb and descent rates, should they be required.

In addition to lifting heavy payloads, the H.1 Cyclocraft is able to tow even higher payloads. Examples of its towing utility are given in Section 6.7. The towing capability of the H.1 Cyclocraft is shown in Figure 17, in terms of towing speed. When towing, the H.1 Cyclocraft would not normally carry a payload and its lift exceeds its weight by 39,800 lb, when carrying full fuel. As fuel is consumed the excess lift increases and approaches 51,200 lb, as the aircraft nears an empty condition. When towing, the cyclocraft's excess lift is used to lift the tow cables and to relieve the bearing load of the towed equipment/material on the wetlands' surface. All of the cyclocraft's power is utilized in generating propulsive thrust, which overcomes the aerodynamic drag and provides the drawbar pull, given in Figure 17. The figure shows that at 5 mph towing speed, the cyclocraft generates a vertical component of tension in the tow cables

Figure 15. Payload, Range and Cruise Airspeed Relationships

Figure 16. Effect of Altitude on Payload and Range

of 39,800 lb and a horizontal tension component of 84,720 lb. Note that the payload being towed will itself be many times the tension in the cables.

Figure 17. H.1 Cyclocraft Towing Capability

6.6 H.1 Cyclocraft Subsystem Designs

As noted earlier, there is a plethora of data/information from previous and ongoing programs with respect to design factors for both the original X.2 configuration and the current dual-rotor approach. For the latter, the 42 ft model, which was still being evaluated in the USAF SBIR Phase II program, was to be upgraded to reflect considerations relevant to the H.1 Cyclocraft design and then tested further. Those results, given in Section 10, as well as continuing engineering analyses by MRC must be completed before enough solid information/data is in-hand to provide a firm position for establishment of details for specific subsystem hardware designs of the H.1 Cyclocraft. It is further noted, however, that the subsystems of the X.2, those defined for the USAF's U.1 Cyclocraft and the present H.1 Cyclocraft being considered, have many areas of commonality, e.g. the airborne computer subsystem for the U.1 Cyclocraft was an upgrade of the X.2's and essentially the same hardware can be utilized in the H.1 Cyclocraft. Except for size of components, the hydraulic subsystems will also be very similar. Most of the other subsystems are also similar, with the exceptions being related to size, e.g. the wing, blade and stalk designs for the U.1 Cyclocraft are basically scaled up for the H.1 Cyclocraft.

Nonetheless the contents of this section are preliminary in nature and they will undergo

considerable, further definition, before the initiation of the contemplated development program. On that basis, the following material briefly addresses the expected hardware facets, for each of the subsystem areas for the H.1 Cyclocraft, identified in Figure 10.

6.6.1 Lift Group

As depicted in Figure 10, this Group consists of the Aerostat, Aerodynamic and Structure Subsystems.

6.6.1.1 Aerostat Subsystem

The H.1 Cyclocraft utilizes aerostatic lift that is approximately equal to the maximum gross weight of the aircraft minus one half of the sum of the max payload and fuel weights. This approach ensures that, in a typical operation in which there is no change in payload, the average of the aerodynamic lift forces required, both positive and negative, is minimized and the fuel consumed is also minimized.

The operational requirements of the H.1 Cyclocraft that impact aerostat and ballonnet design were determined by MRC through estimations of the conditions that might be expected in the Louisiana regions of interest, together with exercising MRC's parametric model, as follows:

Rate of climb	500 ft/min
Rate of descent	500 ft/min
Superheat temperature	+10 °F
Supercool temperature	-10 °F
Maximum operating altitude	2,000 ft
Upper operating temperature	115 °F
Lower operating temperature	16 °F
Design helium purity level	97 %

The selection of the dual-rotor cyclocraft configuration, and the associated non-rotating aerostat, significantly simplified the design of the aerostat/ballonnet components. In particular the need for an axisymmetric ballonnet, as utilized by the X.2, was eliminated and the number of structural penetrations through the aerostat surfaces were greatly reduced from those previously required in the single-rotor X.2.

The selected ballonnet configuration comprises two cylindrical bags, located above the lower aerostat surface and running along the aerostat's length. This arrangement provides for longitudinal balance of the aircraft for most operations, without utilizing the aerodynamic balance that is attainable with the cyclorotors.

Based upon the successful previous history of actual hardware and subsequent engineering of the U.1 Cyclocraft, the shape of the aerostat for the H.1 Cyclocraft will be the same, two semi-ellipsoids with an overall aerostat fineness ratio of 2:1. In consideration of aerostat center of

pressure and aerodynamic drag, the location of the major diameter of the semi-ellipsoids will be at 40 % length behind the aerostat nose. The volume of the aerostat is 3,637,230 cu ft with a length of 302.9 ft and diameter of 151.4 ft.

The volume of ballonnet required for a 20 °F temperature excursion is 3.85 % of initial helium volume; for an altitude change of 2,000 ft, it is 6.17 % of initial helium volume. For maximum and minimum temperature excursions of 20 °F and a full temperature ceiling of 2,000 ft altitude, the required total ballonnet volume is

$$(2 \times 3.85) + 6.17 = 13.87 \% \text{ helium volume,}$$

i.e. required ballonnet volume = 12.2 % aerostat volume.

The total aerostatic lifting capacity, with helium at ambient temperature, is given by:

$$\text{Lift} = (\text{aerostat vol in cu ft}) \times (\text{helium volume fraction}) \times \text{purity} \\ \times (\text{unit lift in lb/ cu ft})$$

Specifically for the H.1 Cyclocraft,

$$\text{Lift} = 3,637,230 \times 0.878 \times 0.97 \times 0.0666 = 206,306 \text{ lb}$$

For the H.1 Cyclocraft, the change of helium volume with altitude, to maintain a given pressure differential between aerostat and atmosphere, is 98.5 cu ft/ft. At a maximum climb rate of 500 ft/min the ballonnet vents require a total flow rate of 821 cu ft/sec. For vent valves having a discharge coefficient of 0.6 and at a maximum pressure of 6 in. water, the minimum required vent area is 8.45 sq ft. Four ballonnet vent valves of 20 in diameter meet this requirement.

At a descent rate of 500 ft/min, the ballonnet must be inflated at a total flow rate of 821 cu ft/sec, i.e. each ballonnet compartment requires a fan capable of delivering 411 cu ft/sec, at a pressure of 6 in water.

Access is provided for entry into the aerostat to inspect all components of the system and to repair the ballonnet. As discussed in Section 6.7 there will also be a requirement for a tunnel from the flight crew cab along the bottom of the aerostat to the load/aerostat interfacing structure for payload handling. There would also be an annular portion from the load handling structure of a depth of 10-15 ft to allow for handling operations, addressed in Section 6.7, by assigned personnel.

It is projected that the cyclocraft helium will require purifying semi-annually, raising the purity from 95 % to 99 %. It is further projected that, in the purification process, the helium required is twice the amount of air removed. Thus the purifying makeup volume required every six months is $2 \times 3,637,230 \times 0.04 = 290,978$ cu ft. Standard helium trailers would be utilized for the replenishment or replacement of helium.

The material requirements for the aerostat, i.e. strength, helium permeability and ultraviolet protection, pose no special concerns. The X.2 was built by ILC Dover using circa 1980 fabrics and adhesives, and the planned H.1 Cyclocraft will employ 1990 technologies, e.g. laminated tedlar, mylar and dacron with Hytrel or other suitable adhesives.

6.6.1.2 Aerodynamic Subsystem

This subsystem is comprised principally of the wings and blades which are mounted on the stalks, which in turn are part of each of the two cyclorotors for the H.1 Cyclocraft. The main frames of the cyclorotors are part of the Structure Subsystem, discussed later.

Although the blades and wings are much larger than those previously employed in the single rotor X.2 configuration or planned for the U.1 Cyclocraft, they are essentially identical in design, the main design difference with the X.2 being one of aspect ratio, i.e. 6 versus 4 for wings and 4 versus 3 for the blades. The higher aspect ratio of H.1 Cyclocraft wings was selected to reduce the required angular movement of the rotating cyclorotors for achievement of the aerodynamic flow pattern associated with maximum lift, i.e. the smaller chord length permits earlier establishment of the flow pattern. Thus the maximum percentage of attainable aerodynamic lift is significantly increased over that obtained in the earlier X.2 Cyclocrane.

It should be noted that in rotational forward flight, an apparent aerodynamic twist occurs, resulting in a variation of the effective angle of attack across the span of the wing. This effect would be reduced with a wing of lower aspect ratio and MRC will evaluate remedies to minimize those twist effects, e.g. anhedral, reduced aspect ratio. In the final selection of wing geometry, consideration will be given to the results of this study.

The design of the wings and blades is premised on standard fixed wing aircraft criteria and result in very simple, proven and cost effective aerodynamic control surfaces. The detailed design of these units is a straight forward approach. The dimensions for the wings and blades are as follows:

	Wings	Blades
area	760 sq ft	400 sq ft
span	67.5 ft	40.0 ft
chord	11.2 ft	10.0 ft
aspect ratio	6.0	4.0
airfoil section	TBD	TBD

6.6.1.3 Structure Subsystem

The Structure Subsystem includes the central structure, i.e. the cyclocraft's longitudinal members and the beams/cables that provide the necessary ties between them and the Aerostat Subsystem, the two very large bearings on which the cyclorotors will be mounted, the main structure of

those cyclorotors, the underside cabin/pod for the flight crew and a selected suite of hardware, arrangement for landing gear/legs and provision of structure and accessories for picking up, carrying and depositing oil/gas related hardware for which the H.1 Cyclocraft is targeted.

Internal Structure and Load Handling. For this heavy payload configuration there are obvious interrelationships amongst the central structure, ties to the aerostat, the payload pickup and release mechanisms and the payload itself. For the pioneer, X.2 single-rotor configuration, the total aircraft was an integration of structural members and a number of cables, which were always under tension. It was light weight and very efficient. The main longitudinal member was a series of in-line simple trusses pin connected to each other, with cables from other portions of the aircraft tied to those pin connections to maintain the central beam's alignment. That truss/cable arrangement was further tied to the center cyclorotor for fore and aft stability, which was augmented by strut braces in the plane of the rotor. The payload and the crew cab, however, were slung beneath the X.2 via cables from the forward and aft portions of the central, longitudinal members, located outside of the aerostat on bearings, to allow for a non-rotating environment. The slings, therefore, had the rotating X.2 between their upper terminal connections and the ends of the X.2's cyclorotor passed over the slung crew cab and payload positions.

In the dual-rotor configuration of the H.1 Cyclocraft, the aerostat does not rotate and a slung payload from the extreme tips of the longitudinal, structural member does not offer a reasonable solution for a vehicle the size of the H.1 Cyclocraft. Such a slung payload would likely be some 500+ ft below the bottom of the aerostat and the pendulum action of a 45 ton payload, with the much separated H.1 Cyclocraft, could cause severe dynamic problems. In addition, and as noted in the transportation needs, Section 3, there are a wide variety of payloads involved which will cause many variations in relative center of gravity locations for the payload/aircraft combination and a closely coupled package would facilitate the attainment of requisite stability.

Varying payload weights and sizes also dictate requirements for flexibility in the attachment to the H.1 Cyclocraft, while maintaining some reasonable positioning with respect to the aircraft's center of gravity. In addition, those attach points should be such that movement, or "swaying" of the payload during any of the H.1 Cyclocraft's pickup, transport or placing of that load, does not result in damage to the aerostat through the attachment lines. Beyond these factors, the payloads must be attached to points that can handle the load and transmit it effectively to appropriate structural elements of the H.1 Cyclocraft itself.

There have been a number of preliminary evaluations with respect to large cyclocraft and the handling of very heavy payloads, e.g. during the Army A.35 Cyclocrane preliminary design development, reported in Reference 20, and a variety of other approaches, References 21 through 32, and 36. Most of these studies resulted in the conclusion that the support of heavy payloads, slung (other than the nose/tail slings of the X.2, noted above) or otherwise, had to be effected at or very near the underside surface of the aerostat by structure, not the "skin" of the aerostat. The attachment approaches utilized in conventional blimps, e.g. patches on the aerostat's surface, are not an option. Of note is the fact, that the only times LTA concepts have

been involved with very heavy payloads was through the use of semi-rigid or rigid configurations and recent new approaches, e.g. the Hindenburg with its large payload of passengers and associated facilities, and the concept being employed in the battleship surveillance blimp of the US Navy, with its large crew/equipment gondola and internal radar. In neither example, however, are the basic payloads separable for ready pick-up or delivery, nor are they as large as the payloads contemplated for the H.1 Cyclocraft.

Figure 18 presents an approach being considered by MRC. The H.1 Cyclocraft is 345 ft long with a height of some 170 ft, while the aerostat, itself, is 302.9 ft long with a diameter of 151.4 ft. There are a very extensive array of payloads which will be involved in the oil/gas operations planned, Reference 2, and fairly small drill sites within the wetlands, wherein delivery and pick-up scenarios will be performed. The load handling is addressed in Section 6.7.

Figure 18 shows that the central longitudinal member of the H.1 Cyclocraft could be a combination truss and circular shaft arrangement, i.e. the truss would be composed of tubes/cables to form an efficient beam for loads imposed near its center, where it would have the most depth, and the end portions would have circular sections, for the emplacement of the bearings and for the installation of the two cyclorotors. It is planned to have mounting structure on the outboard sides of each cyclorotor's bearings for the mounting of the engines and fuel tanks.

Dropping down from the center portion of that truss there would be direct attachments made to circular or rectangular, structural members which would be flush with the skin of the aerostat and attached to the aerostat with flexible connections. Those members, or load attachment frames, would likely be a 50-75 ft diameter circle or rectangle and would have a number of attachment points to facilitate the pick-up and release of a number of different oil/gas loads. By release, MRC expects that mechanisms can readily be devised to have a number of "load attachment links" which have quick disconnect features which can be manually and electrically triggered for separation or attachment of the payloads.

In that regard, it is expected that there would be one or two load handling individuals which would be part of the crew and they would have access through the tunnel to the load handling area, as addressed in Section 6.7.

The concept shown is very preliminary in nature and considerable trade-offs are yet to be made through the system engineering processes during the initial phases of the development program. All of those trades must also be played against the operational scenarios in much more detail than that outlined in Reference 3 for the potential oil/gas applications. It is noted that all pick-up and depositing of the heavy payloads involved will be accomplished while the H.1 Cyclocraft is in a hover mode. This means that payloads must be prepared prior to the cyclocraft being brought over it for attachment. Further, that attachment process must be structured such that quick acquisition of the attach cables can be made, then secured to the load frame.

Figure 18. H.1 Cyclocraft Internal Structure Option

With respect to the internal structure, MRC is also of the opinion that the central truss structure might well be, as shown, attached by a line of cables from its topside directly above to the aerostat itself. In essence, a catenary curtain from the top longitudinal centerline of the aerostat to the beam, with the attachment cables under tension. This would guarantee that the aerostat's buoyant forces would be acting upward on the center beam as opposed to the end points of that beam. This would tend to cause the payload weight to be distributed more equally over the aerostat, whose lift equates to the H.1 Cyclocraft's empty weight plus half of the max payload. The end points of the central structure also handle the forces for the balance of the payload and the H.1 Cyclocraft control inputs, generated by the aerodynamic forces from the cyclorotors. It is further noted that the structural weights, which might thereby end up somewhat higher than a bare structural solution, could readily be compensated for by a slight increase in the aerostat diameter; this is a strong feature of the cyclocraft, which is not severely constrained to weight budgets as in conventional aircraft. The narrow, longitudinal attachment of this vertical curtain to the aerostat might be effected by (1) through-bolts to a pair of composite strips placed in parallel on the outside, as well as the inside of the bag, or (2) some arrangement of glued fabric to the inside of the aerostat as in current LTA technology, yet to be defined and analyzed.

Cyclorotors, Bearings and Housing. The cyclorotors are to be mounted through large bearings located within a housing, outside of the aerostat, at the front and rear of the aircraft's main longitudinal structure, which is composed of the truss, noted above, and the circular end shafts. Those enclosed housings will not only encompass the cyclorotor bearings, but also other hardware associated with propulsion, hydraulics and electric power. The bearings will be of the order of 4-5 ft diameter and suitable units should be available from existing industrial sources, e.g. shipbuilding. If not available commercially, MRC would design and build tailor made units.

The configuration will likely be a conventional roller bearing approach with the needed races and a number of large, lubricated roller bearings. The purpose of the bearings are to allow for free rotation of the individual cyclorotors as well as for the transmission of applied loads and bending moments from the rotors to the main longitudinal structure of the cyclocraft.

The cyclorotors consist of four stalks converging in a hub or housing, basically an "X" frame mounted on the bearings for rotation around the central shaft. Individual propeller installations will be made on each of the four stalks, along with the installation of the co-sets of wings and blades.

The stalks, below the blades are braced with cables in the plane of the cyclorotor. Rotation of the wings, blades and propellers will take place above the cable bracing positions. The stalks are attached to the hub/housing, which will be a built up aluminum structure. The housing, noted earlier, has the large bearing, hydraulics, some batteries and electric power elements. On the aerostat side of the housing there is planned to be a fiberglass dome, which serves two purposes. It makes the sealing of the center longitudinal shaft/truss structure less complicated and allows the offset moment from the cyclorotor to be distributed into the outer shell of the aerostat in a uniform fashion. Also the dome establishes a firm bulkhead for the dynamic pressures encountered in flight. Outside of the stalks there will be some mounting structure on the, non-rotating central shaft for the engines and fuel tanks of the propulsion for each cyclorotor.

Wings and Blades. Each wing has a span of 67.5 ft and will be constructed as a single unit; both the wings and the blades pivot about their aerodynamic axes. The primary requirements for the wing is a low rotational inertia about the aerodynamic axis, to reduce servo loads, and an aerodynamically smooth surface. These requirements are best met by using a molded outer surface using a sandwich construction of carbon fiber epoxy prepreg, with a high density foam core. The wing has a unidirectional carbon fiber main spar to provide bending strength. The spar is located on the aerodynamic axis, with the structure aft of the spar as light as possible, to reduce the need for ballast. The wing pivot point is built into the wing and attaches to the main spar. The blades are of similar construction to the wings, but without spars, as they rotate on the stalk tubes and are not cantilevered. The blades, with a span of 40 ft, are to be constructed in the same fashion as the wings.

Crew Pod/Cabin. As shown on Figure 11, MRC intends to have the flight crew cabin forward of the front landing gear/pad which is well forward of the load handling structure, although the underside structure of the pod will extend to a connection with the trussed, handling framework. The forward part of the crew compartment will be tied, as well, to structure from the forward section of the longitudinal, main center structure. It is expected that there will be a pilot and copilot and, possibly two load handling personnel. The load related personnel will have access through the aft end of the cabin through a lightweight tunnel, separated, and sealed from the helium, to the load handling area. MRC envisions that the bottom ten to fifteen feet of space surrounding the interconnecting structure between the load handling ring and the center truss of the vehicle will be walled off from the helium to form a cylindrical opening around the load handling ring, where access will be provided for the manual connection and/or disconnection of

the attachment links, discussed earlier. Emergency release of those links would be accomplished electrically from a control within the crew cabin for any in-flight emergency, not pick-up and depositing of a load, wherein the pilot deems it necessary to separate the payload for safety of the flight crew. This would not be accomplished with the load handling individuals in the load handling ring area since such a separation could cause snapback of the attachment links and could be dangerous to any personnel in the ring region. The electrical disconnects for the attachment links have yet to be defined, but MRC anticipates that they would be similar to the release hooks used in helicopters for the same purpose. Handling is discussed further in Section 6.7.

The cabin itself will be of composite materials and will be much the same configuration as those used in conventional LTA aircraft, i.e. flight console with controls and seats for the pilot and copilot, an array of flight hardware, some instrumentation and space for the load handling individuals with an undetermined amount of other space for purposes yet to be defined. The controls will be the usual flight controls, e.g. possibly a collective lever, fore/aft and lateral stick and rudder pedals as in a helicopter, with a series of controls associated with the aerostat. The latter needs include controls for the ballonets, monitoring of pressures, positions of inlet and exhaust valves and a number of sensing devices with respect to temperatures and pressures.

6.6.2 Controls Group

6.6.2.1 Flight Controls

The control of the cyclocraft up to this point has been predicated on the previous X.2 experience, which was tailored to a helicopter-type control system. In fact the last version of the X.2 utilized a modified Huey cockpit for the pilot and copilot. Thus, the controls are aligned to conventional, manual and foot inputs of a helicopter, as tabulated below:

CONTROL	RESPONSE
Fwd/Aft Stick	Pitch Rate
Left/Right Stick	Lateral Velocity
Rudder Pedals	Yaw Rate
Collective Stick	Vertical Velocity
Twist Grip	Forward Velocity

The controls for the H.1 Cyclocraft will utilize the data/information from the X.2 configuration and the approach being employed in the unmanned U.1 Cyclocraft, as they might be modified by the ongoing flight test evaluations of the 42 ft model of the dual-rotor concept. The control system for that remotely piloted cyclocraft model was designed and assembled by C Sys Labs, Inc, (CSL), under subcontract to MRC. A general description of the system, description of the transmitter control functions, software flow diagram with calculations, encoder/modulator circuit board and 12 channel receiver schematics, transponder block diagram and transmitter interface for data collection are contained in the CSL Report, Cyclocraft Model Control System

Documentation Package, Reference 40.

At this point it is expected that there will be two computers in the H.1 Cyclocraft, one for each cyclorotor, generating the positional information for the wings, blades and throttles with respect to the cyclorotor's angular position. This will simplify the task of synchronizing the cyclorotors and allow proper operation in all of the flight modes, i.e. each cyclorotor has a shaft encoder supplying positional information to its respective computer. One of the computers has the master controller; into this controller is fed all of the information for the various flight modes. The two computers are linked with a single fiber optic cable to enable them to operate in unison. The H.1 Cyclocraft has the flight capabilities of both a helicopter and a conventional aircraft. A block diagram of the anticipated H.1 Cyclocraft control system is given in Figure 19.

As to flying qualities, both the static and dynamic stability characteristics of the cyclocraft are such that very conventional control hardware should more than suffice in the provision of a stable platform throughout the performance envelopes of the vehicle. The flying qualities of the H.1 Cyclocraft would be very similar to those of a large helicopter in hover and a conventional fixed wing aircraft in forward flight, with somewhat slower response due to the virtual mass of the aerostat. It should be noted however, that the H.1 Cyclocraft will experience its control forces and moments immediately, as the control surfaces are actuated, whereas both rotary wing and fixed wing aircraft have to experience an orientation of the aircraft, before forces are acquired. For example, for lateral movement, cyclocraft employ a change in the wing pitch cycle giving instantaneous sideforce, but a helicopter must change its rotor pitch cycle, which in turn rolls the aircraft, before a sideforce is experienced. Cyclocraft have first order control; other aircraft have second order control.

It should be noted that the shape of the H.1 Cyclocraft results in inherent aerodynamic instability. The aircraft is stabilized by sensing any deviation of the cyclocraft's longitudinal axis, from the direction of the free airstream, and applying an appropriate pitch or roll moment automatically, using its wings and/or blades, to regain the prescribed aircraft's attitude. Calculations made to date indicate that the strength and response of the cyclocraft's control system would ensure stability, throughout the aircraft's operational envelope, including sharp-edged gusts up to 30 mph. Additional careful stability analysis will be made, prior to finalizing the cyclocraft's design. Should there appear to be any question of adequate stability, consideration will be given to the provision of aerodynamic shaped fins, which would be located on the aft end of the aerostat, for enhanced stability in pitch and yaw.

The Controls Group also includes the Air Computer and the Hydraulic Subsystems which, together, effect the control functions for the cyclocraft. As a means of putting the controls into perspective, Table 50 depicts the modes of expected operation for the H.1 Cyclocraft. Note that cyclocraft do not require roll of the aircraft for turning or lateral motion; consequently roll control would not be provided normally. Roll stability is ensured by locating the cyclocraft's center of gravity below its aerostat's center of buoyancy.

Figure 19. H.1 Cyclocraft Controls Block Diagram

Table 50. H.1 Cyclocraft Control Modes of Operation

Aircraft Maneuver	Control Deployment	
	Control	Movement
Forward Flight	Blades	Collective
Ascent/Descent	Wings	Cyclic*
Lateral Motion	Wings	Cyclic*
Yaw	Wings	Cyclic ϕ
Pitch	Wings	Cyclic ϕ

* Fore and aft cyclorotors operate in unison

ϕ Fore and aft cyclorotors operate differentially

6.6.2.2 Air Computer Subsystem

This subsystem combines, through a fiber-optic or hardwired local area network (LAN), the two

flight control computers and their remote data collection and control units. The computer portion provides formatted commands for control of the blades, wings and stalks, along with the power settings of the propulsion units in response to (1) pilot inputs through his hand and foot controls, and (2) various sensors or data inputs from airborne elements, e.g. positions, rates, accelerations, temperatures, pressures, stalk angles, fuel weight and airspeed over the wings.

The design philosophy to be employed by MRC, is to make the subsystem (1) fail-operational for single failure faults and (2) fail-safe for multiple faults. Basically there will be redundant designs incorporated, such that single failures might occur in each of the major control areas, while the overall system remains totally operational, thereby enhancing reliability. The LANs between the flight computers and the remote data handling/control nodes shall be isolated loops, which allow also for monitoring message continuity and for use in diagnostics. The fiber-optic LANs will likely be 75 Mhz bandwidth broadband nets, using 62.5 micron silica graded index fiber with a Kevlar strength member and a Teflon outer jacket. The topology for the LAN will be star-ring for minimum weight and maximum utility. During early design phases, MRC will address the issues related to "tight" or "loose" buffer construction and, possibly, other ring approaches, e.g. a dual ring. ETHERNET interfaces will be included within the subsystem, to facilitate maintenance and/or diagnostic activities.

The airborne computers shall accomplish all calculations necessary for flight control of the H.1 Cyclocraft. The system status and system variables shall be measured using appropriate methods between the source and the computer(s) and any commands shall be transmitted in like fashion. The developed control algorithms, written in the form of difference equations, are yet to be addressed in detail by MRC. Those algorithms will allocate overall responsibility to one of the two computers, i.e. a master controller function for flight operations, which synchronizes the dual-rotor functions.

For modes such as hover or station-keeping, feedback loops to precisely control lateral, horizontal and vertical platform positions in a stable fashion, shall be implemented within the subsystem. Likewise, stable loop arrangements shall also be incorporated in the pitch and heading channels. In all cases, any unwanted gyroscopic effects within the control logic shall be eliminated, through adequate feedback loops around the angular rates and cyclorotor cyclic inputs. Forward flight control shall consist of loops, which hold the aerostat's hull angle of attack and sideslip angle near zero, with respect to the relative wind direction, along with loops to control altitude, heading and forward speed. Cross feeding yaw rate with pitch commands, and pitch rate inputs to yaw commands, shall be used to eliminate gyroscopic coupling in these channels.

Control of the engine power for each stalk shall be provided by the flight computer and it will be based on the relationships associated with the airspeed over the wings. The algorithms shall be configured to regulate wing airspeeds within 2 knots of a nominal set point, during either normal hover or normal forward flight modes of operation. Airspeed measurements shall be provided through the pitot static sensors installed on selected wing(s) of each cyclorotor.

6.6.2.3 Hydraulic Subsystem

The hydraulic subsystem will probably be composed of two parallel installations for each cyclorotor, to establish inherent control reliability. The subsystem shall be designed to ensure that no single failure will inhibit the aircraft from performing at its minimum required level. The hydraulics shall be configured to facilitate modular replacement of any key component. The actuators utilized will be selected with respect to the maximum rotation rates required for the cyclorotors, i.e. current estimate of 13.9 RPM. The subsystem will operate in the 3000 psi range, with a safety factor of approximately 1.5. Flow rates shall be commensurate with requisite wing/blade/stalk rotation rates and ranges of travel, e.g. wings at $+33^\circ$ to -45° , blades at $\pm 20^\circ$ and stalks from 0° to 60° relative to the aerostat longitudinal axis.

The parallel hydraulic units on each cyclorotor shall be separately driven by pumps mounted within the hub and powered through gearing/shafts from the turbines mounted on the non rotating, central structure.

6.6.3 Propulsion Group

This group is comprised of the Engine, Propeller and Fuel Subsystems, each of which are discussed briefly below.

6.6.3.1 Engine Subsystem

There are a number of detailed engineering evaluations that must be performed by MRC prior to the selection of the power plants for the H.1 Cyclocraft. As noted previously, the parametric model has determined that the 90,000 lb payload aircraft must have effective shaft horsepower of some 5404. The key questions, of course, relate to how that horsepower is provided, e.g. through single engines accompanying each of the four wings per cyclorotor, two engines per cyclorotor installed on diametrically opposed stalks, a remote engine for each cyclorotor with shafting and gears transmitting the power to the individual propellers (four per cyclorotor or even just two per cyclorotor), or a single power source within the aerostat which, through another shaft/gear arrangement, provides power to the propellers selected for both cyclorotors.

These decisions are dependent on a number of considerations, e.g. effects of rotational environments on engines, dynamic balance of the individual cyclorotors, difficulties, or not, of simplistic fuel supplies, weight on stalks and the overall effects on total weights, reliability, maintainability and other operational facets, like noise. With respect to noise, MRC would note that the planned structural approach for handling payloads, and the size of those payloads, indicates that normal concerns for both noise and downwash, e.g. like that of a helicopter, should essentially not exist. The ground handling crew working under the center portion of the H.1 Cyclocraft would generally be more than 100 feet from either cyclorotor. Further, because the disk loading of the cyclorotor will be much less than that of the helicopter, the downwash immediately under the cyclorotor will be much less than that beneath a helicopter rotor.

At this point MRC believes that a single power plant located outside of the hub of each cyclorotor, on non-rotating structure, should be employed to power, through appropriate gearing and shafts, the Hydraulic Subsystem and the four individual propellers to be mounted over each of the wings of both cyclorotors. This propulsion arrangement would eliminate concerns for dynamic balance of the rotating stalks that might occur if each stalk had its own power unit and it would remove the propulsion units from the centrifugal/gyroscopic type forces that might be detrimental to the selected engines. The latter problems could pose serious engine selection difficulties for the anticipated power requirements, i.e. a total of 5404 SHP, some 2700 SHP per cyclorotor needed for take-off and hover at maximum weight and in the most adverse conditions.

Even if the evaluations being made in the testing of the 42 ft model should establish the requirement for a connection between the two cyclorotors, this could be accomplished electronically rather than mechanically, i.e. through the previously described computers for each cyclorotor. In addition, MRC feels that adequate reliability could be established by making the cyclorotor power units redundant, i.e. use a pair of twin turbines for each cyclorotor such that a single, or even two turbine failures would only degrade, rather than cut-off, the power to a cyclorotor. This would obviate, to a very large degree, the concern for "rotor-out" conditions which might require rather extreme corrective measures to ensure safety of flight crews and the H.1 Cyclocraft itself. The Pratt & Whitney PT6T-6 Twin Pac, which is used on S-58T helicopters, weighs 657 lbs and puts out maximum continuous power of 1675 SHP. Two Twin Pacs would provide around 3200 SHP at each cyclorotor, somewhat in excess to the 2702 SHP preliminarily defined to date as being required for the H.1 Cyclocraft. In addition, this arrangement of twin turbines could likely be accommodated within the allocated weight budget for propulsion, given in Table 49, of 5944 lb. MRC has not fully assessed the engine market, to determine availabilities of suitable power plants.

In that regard, MRC believes that considerable, further evaluations need to be performed during the initial phases of the planned R & D program for the prototype H.1 Cyclocraft, to resolve the many issues associated with the total power provision problem. For example, an exhaustive review should be performed to determine what engines, both internal combustion and turbine, are being used in the major fleets of operational helicopters, the problems of concern and the assessment of those operators with respect to using any of their engines in the H.1 Cyclocraft. The principal intent of these assessments would be for MRC to select, if possible, power plants that are already in the oil/gas inventory such that their choice would facilitate overall availability, maintenance and experience factors. To this end, MRC has had discussions with Petroleum Helicopters executives.

The propulsion units would, through four way split right-angle gearboxes, drive the shafts which would go to the wings. At the wings there would be planetary reduction gears to attain the appropriate propeller speeds.

6.6.3.2 Propeller Subsystem

Currently, MRC plans to utilize four propellers per cyclorotor, primarily for balance symmetry.

It is expected that the propellers would be on the order of 12-15 ft diameter, be three bladed and of fixed pitch. MRC believes that controllable pitch propellers, and their added weight, are not likely to be reasonable choices due to the modest airspeed variations expected for the H.1 Cyclocraft in the planned operations. Three bladed propellers avoid any chance of resonant vibration being created by the proximity of the wing leading edge in particular and by the orientation of the blade at 90 degrees beneath it. That T-shaped arrangement of the blades and wings at the ends of the stalks dictates that two and four bladed propellers should be avoided.

The four radial blades of each cyclorotor are designed and controlled to act as large, reversible and controllable pitch propellers. The wing mounted, three bladed propellers, are located at the ends of each cyclorotor's stalks and projected loads from the wings and blades are carried through by the radial stalks to the main cyclorotor bearing.

For vertical take-off while lifting maximum payload, the cyclorotor speed will be at the maximum, e.g. about 14 RPM. Under these conditions, the three bladed props should have a propulsive efficiency of about 60 %, since the propellers will be tracking the cyclorotor periphery at approximately 71 knots. This efficiency will be substantially maintained at all cyclocraft airspeeds, due to the rotation of the cyclorotors, i.e. the wing airspeed experiences minimum variations.

6.6.3.3 Fuel Subsystem

On the assumption of each cyclorotor being powered by engines on the outboard side of each of their hubs, MRC has opted for a single fuel tank to be collocated with the engines. This arrangement is simple, requiring a single fill point for the fuel tank, which could readily be handled by a fuel tender, through a fill connection at bottom center. That same connection can also be used for tank drainage and overflow during maintenance and operational checkouts. It is noted, however, that the fuel tanks at the ends of the center truss are some 70 ft above ground level. MRC anticipates that this can be handled from the personnel access planned at those points for normal installation, removal and maintenance functions for the engines and other hardware located in the fore and aft housings. In addition to the internal tunnel from the crew cab to the load handling structure, personnel access would be provided from the load area to the central truss structure and along that structure to both ends of the cyclocraft. Such access would be required for a number of reasons, including fueling. MRC would build into such tunnel arrangements the necessary safety precautions, in addition to personnel wearing Scott Packs, or similar breathing protection from the helium in the aerostat.

The fuel volume in each cyclorotor's tank will be approximately 105 cubic feet and the fuel subsystem will weigh approximately 520 lb at each cyclorotor location.

6.6.4 Power Group

This subsystem includes the electrical requirements for the H.1 Cyclocraft. The electrical power distribution shall be through redundant wiring/power units on each cyclorotor, the individual

stalks, within the hub and the propulsion locations on the outboard side of the stalks. The generators, which will be mounted on the propulsion units, shall be 400 Hz, 208 V, 3-Phase assemblies. Variable Speed Constant Frequency (VSCF) controls with crystal references shall be used. These power sources, along with other power units, i.e. batteries, shall support the individual stalks, the hydraulic units, elements of aerostat control and unique items within the Crew Pod and/or the load handling area.

MRC expects that power elements shall be connected by Aluminum AWG 4, 41,470 cmil, for the three phase sources and AWG 6, 26,240 cmil, for neutral channels of the distribution network.

6.7 Operational Considerations

6.7.1 Logistics

The H.1 Cyclocraft will have a gross weight of 256,431 lb and an empty weight of 155,231 lb, coupled with overall dimensions of 345 ft by 170 ft. This requires some thought with respect to how and where it is used, how it is transported over what distances and how to address unscheduled termination of a particular H.1 Cyclocraft's operation.

Preliminary evaluations by MRC have determined that initial assumptions would include: (1) the build and checkout location for the H.1 Cyclocraft fleet would be in the coastal zone of Louisiana, e.g. New Iberia, (2) most of the wetland sites would be within 120 miles of the home site and forward bases of operation could be selected to allow for 15-30 mile reach distances to oil/gas operational sites, e.g. Lake Charles, Crowley, Franklin, Houma, Myrtle Grove and Slidell. These assumptions are based on the earlier comments with respect to the fact that the Louisiana coastal zone would be the first opportunity for application.

The obvious mode of transport among the locations assumed above would be by the self-ferry mode and MRC does not intend to consider disassembly of the cyclocraft as an option at this point in time. If a vehicle becomes incapacitated in flight, the repair necessary would be at the nearest reachable location. MRC would also assume that the flight profiles during operational modes would be at such an altitude, e.g. 500-1000 ft, that failures during payload transport would be of such a decaying nature that the pilot could get to one of the forward base locations or the drill site without dropping the payload. If this is not achievable, the aircraft would be set down at the nearest open site.

Although the above approach is viable, MRC expects that there may be alternate applications for the H.1 Cyclocraft at sites thousands of miles from the initial home base, e.g. oil/gas in Alaska, where means other than self ferry might be attractive. For example, it is conceivable that the H.1 Cyclocraft could be attached to a ship and towed to the remote region of interest, with both cyclorotors in place, a single cyclorotor or no cyclorotors. The use of the cyclorotors to achieve the necessary stability would have to be addressed further by MRC, before specific

operational modes could be defined. The planned 42 ft model testing includes some phases to evaluate this potential. It is noted that the experimental X.2 was towed on a 1000 ft single line tether and maintained solid stability throughout various wind speeds.

Beyond the above options, the H.1 Cyclocraft could be configured to attach an auxiliary fuel tank, i.e. add a fuel load nearly equal to the 90,000 lb payload capability, which would give it a range of 3000 miles.

The overall facets of a complete H.1 Cyclocraft System will be addressed during the early phases of the planned development program, i.e. home base facilities and equipment, requisite long distance hardware and equipment, provisioning needs for fuel, helium and hardware spares and the details of checkout equipment for final testing and subsequent field support. The subsections below address the operational handling elements of the H.1 Cyclocraft, which focusses on the needed Ground Support Equipment (GSE), and the anticipated handling procedures for payloads, i.e. the Handling, Helium, Power, Checkout and Data Subsystems.

6.7.2 Handling Subsystem

This subsystem involves three categories of operation, i.e. tie-down of the H.1 Cyclocraft when not in use or when weather is of concern, movement of the cyclocraft while on the ground and take-off and recovery operations. In contrast to the unmanned U.1 Cyclocraft, the H.1 Cyclocraft will be handled in a buoyant configuration at all times except when it picks up, transports and deposits the payloads, which is only done in a flight mode. In all other cases the H.1 Cyclocraft, unless ballast is applied, will be lighter than air at the forward operating base or at its home base. That lightness, when the aircraft is essentially empty, is around 50,000 lb or 25 tons of buoyancy. In essence a counter force of 25 tons is needed to put the vehicle on its wheels or pads. The best solution for the home base, or any of the forward bases, that is both operationally reasonable and economic, has yet to be identified by MRC.

A number of questions need to be resolved with respect to the forward bases, e.g. Lake Charles, Crowley or Franklin, as to topography, i.e. the kind of soil or ground that can be expected for set-down of the H.1 Cyclocraft. If the terrain allows for anchors or very heavy mobile units, e.g. Mississippi Road Service (MRS) off road tractors, each weighing some 19,000 lb, it is possible that a series of helix anchors, or several heavy tractors, could be used to hold the H.1 Cyclocraft to the ground. All of these options need considerable engineering evaluations before a reasonable choice is selected. Further, there are other approaches that might be appropriate, e.g. use of ballast. A metal container could be fabricated that could be filled with water to obtain any desired weights up to 25 tons, with appropriate means for draining the container, as needed. The container could be attached to the load handling structure at the underside of the H.1 Cyclocraft on very short cables to allow the vehicle to sit on its wheels/pads for non-payload operations at the home base or the forward bases. Note that its use is not contemplated at the drill sites. Such a ballast tank would have dimensions in the range of 12 x 12 x 6 feet.

The use of the ballast package as a piece of GSE would allow for all modes of non-flight

operation to be effected at a preset buoyancy value based on the H.1 Cyclocraft's weight, e.g. totally empty, with various levels of fuel on board and other weight related variables other than the actual, operational payloads lifted in flight modes. This would simplify the tie-down mode when the vehicle is not in use, as well as when wind conditions are of concern, below the level of having to leave the region. In the case of severe weather being expected, the H.1 Cyclocraft could readily be powered, with the ballast in place, and flown to safer havens. At this point, MRC has not performed any rigid assessments of the potential routes and such engineering would be accomplished during initial phases of the development program.

The diverse nature of the oil/gas payloads are covered in Reference 2. Handling of those payloads involves (1) preparation of payload packages, (2) attachment of those packages to the load handling structure of the H.1 Cyclocraft, while in a hover mode, (3) transport of that payload to the drill site, (4) returning to hover over the drill site location and either electrically or mechanically releasing the payload gently on the site, (5) picking up another payload and returning to the forward base for its deposit, and (6) initiating another cycle or attaching "ballast" and going out of operation.

It is envisaged that, in order to provide a new drill site with all the liquids required, e.g. fuel, water, the H.1 Cyclocraft would tow a pipeline into place in sections and to supply the fluids to the drill site through the pipeline. A double-lined poly pipe would probably be selected for this purpose; sections of poly pipe can be easily fused together in place. After drilling is complete, the pipeline is used to take away the drill cuttings and then is towed away by the cyclocraft. Subsequently the aircraft would tow the production pipeline into place. A sample sequence of loads transported by the H.1 Cyclocraft in supporting operations at a single drill site, is given in Figure 20.

Figure 21 depicts, to scale, the size of the H.1 Cyclocraft versus the Drill Site, and a possible position of the H.1 Cyclocraft for unloading or loading, that puts the cyclocraft below the height of the 150 ft drill rig. The very responsive and strong controls of the H.1 Cyclocraft would allow for maintaining a hover position readily over the area noted and the lower than rig height drop position would facilitate the controlled precise pick-up and release of equipment and materials.

It is expected that the drilling companies would have their equipment and related elements pre-mounted on steel skids prior to the initiation of the H.1 transport operations. These standard skids have steel lifting stubs at each of the skids four corners, at ground level. The skids themselves are 8 ft wide, with lengths from 10 to 75 ft and their height is somewhat less than 13 ft. The majority of the lengths are 55 ft or less with a portion of the drill rig frame utilizing the 75 ft skid. In addition to the variety of skid sizes, there will also be requirements for handling more than one skid package at a time to fully utilize the 90,00 lb payload capability of the H.1 Cyclocraft.

As shown in Figure 20, after the pilings platform has been constructed at the drill site, the rubber tired crane, which weighs about 40,000 lb, is brought in and is used to move subsequent

Tasks	Tons	No. Flights
Transport Pile Driving Equipment, Crane, Mats, Decking	263	7
Remove Pile Driving Equipment, Crane, Mats	95	3
Bring in Drill Rig, Drill String, Mud, Casing Eqpt	2,092	49
Tow Liquids Pipeline into Position	79	2
Bring in Casing, Cement, Pits, Tubing & Logging Eqpt	1,165	27
Remove Casing, Cementing & Logging Equipment	306	7
Remove Drill Rig, Drill String, Unused Mud	1,460	34
Tow Away Liquids Pipeline	79	2
Bring in Production Equipment and Tow in Pipeline	645	16

Figure 20. Sample Incoming/Outgoing Operational Sequence

payloads to their needed locations at the drill site. The drill rig itself is moved in on the third or fourth load (of some 80 move-in loads) and erected to its full 150 ft height early in the total move-in cycle, and thus must be considered as a long term interference item.

Figure 22 depicts a potential means of handling the various payloads, operating below the 150 ft level of the noted drill rig. The payload handling method shown in the figure, includes the use of (1) an aramid basket weave of rectangular pattern which can be attached to the skid's lifting studs directly, prior to pick-up, (2) a structural frame at the top of the 75 ft deep basket-weave configuration, folded on top of load prior to pick-up, (3) a winch driven cable-hook arrangement which is lowered from the H.1 Cyclocraft during initial hover over load, to hook on to the top of the basket-weave frame, (4) pulling the basket-weave up to its tensioned height, less than twenty feet below the hovering H.1 Cyclocraft's load attachment structure, where (5) the load handling personnel on board the H.1 Cyclocraft attach a number of 20 ft load links to the basket's top frame for H.1 Cyclocraft pick-up and transport. This arrangement of load links and the basket-weave itself should provide reasonable stability during transport, and the length is such that, even if there is motion of the payload, which is extremely unlikely as the load links will always be in tension, the payload could never contact the cyclorotors.

There could be a standard size basket of about 40 ft rectangle, with a 75 ft tensioned length, that could be used for most loads, including one or more skids. In addition there could be a few special arrangements for certain outsized loads, e.g. the 75 ft breakdown portion of the drill rig.

Figure 21. Potential Drill Site / H.1 Cyclocraft Relationships

The common size basket could be carried by the H.1 Cyclocraft and lowered on the fairly modest motor/winch assembly on-board the H.1 Cyclocraft, to the skid(s), which would be ready for pick-up. It would then be quickly attached to the lifting stubs and hoisted for attachment to the load-links, by the airborne handling crew.

Although the above represents realistic options, extensive trade-offs in the system engineering process during the early phases of the planned development program are still required before clearly defined handling techniques can be established.

6.7.3 Helium Subsystem

In this area the requirements include (1) a supply source of helium, (2) means for pumping the required volumes of helium into the aerostat, (3) maintaining high helium purity within the aerostat, and (4) maintaining a log of on-board helium conditions, when the H.1 Cyclocraft is

Figure 22. Option for H.1 Cyclocraft Load Handling

on the ground for extended periods of time, i.e. leakage rates, temperatures, pressures and purity levels. Proven procedures were established during the X.2 program for all facets of the helium-related tasks, as well as the development of helium purification techniques. The supply source was handled by the scheduled employment of standard helium trailers, with compressed helium tanks. The purification was accomplished by a process that utilized multi-pass filtering techniques, which allowed for the attainment of helium purity levels in excess of 99%.

The helium requirements for the H.1 Cyclocraft System are substantial, i.e. 3,637,230 cu ft. The initial helium fill of the aerostat would be done at MRC's home base and any major helium purification activities would likely be performed at that location also. The purifier that was used for the X.2 is not of sufficient size for the quantities involved, and its configuration would have to be enlarged by a factor of 10. The double pass X.2 unit was some 4 x 6 x 6 ft in size.

Replenishment phases of operation, due to aerostat leakage or contamination problems would be handled by (1) closed-loop circulation of the on-board helium through the purifier and back to the aerostat, along with, (2) the insertion of fresh helium for makeup supplies from a standard helium trailer. If concern for purification or resupply surfaced at the forward bases, the H.1

Cyclocraft would be flown back to the home base for the replenishment efforts. Helium would be purchased through the normal commercial channels.

6.7.4 Power Subsystem

At the home base, ground power will consist of a variety of generators, alternators, special electronic power and batteries. The major ground generator will be a three phase, 400 Hz, 440 V crystal controlled mobile unit, that will be utilized to power the helium purifier and, through tapped ranges, input to the cyclocraft and its subsystems. The same power will generally be employed at the individual forward bases.

Smaller auxiliary power units (APUs) will be gasoline driven, AC and DC sources, for specific subsystem ground operations, e.g. activate fuel subsystem for filling, or propulsion subsystem for calibration. Other DC sources will generally be small output devices for calibration of sensors/instrumentation and/or checkout of assemblies, e.g. ballonnet plenum valve assembly.

6.7.5 Checkout Subsystem

MRC does not intend, or need to have, individual consoles of ground checkout for individual subsystems of the H.1 Cyclocraft, as might be encountered for a fighter aircraft. The planned H.1 Cyclocraft System does not require such support, due to its relative simplicity.

For the few subsystems that are complex enough to warrant consideration for a checkout package, e.g. the Air Computer Subsystem, there are plans by MRC to provide built-in checks for the subsystem. This will allow, during any system or subsystem test phase, for the identification of problems at important piece-part levels, e.g. a computer board for ready removal, repair or replacement.

It is anticipated that most subsystems can be handled by the utilization of conventional tools and measuring devices, e.g. wrenches, gauges, voltmeters and oscilloscopes. MRC will plan for the ready availability of an array of this supporting hardware.

6.7.6 Ground Data Subsystem

The Ground Data Subsystem requirements are associated with ambient and predicted weather conditions at the operating site for the H.1 Cyclocraft System. In the Gulf Coast there are more than adequate sources for predicting weather fronts in a timely fashion to alert the operating crew to needs for (1) ceasing operations and tying down the cyclocraft or, (2) ceasing operations and flying to safe havens.

Locally there would be a need for simple measurements of temperature and winds for guidance with respect to a variety of needs, e.g. temperatures with respect to superheat conditions of the aerostat with respect to helium needed, short of unintended dumping during flight, go-no-go conditions relative to tie-down modes for the aircraft when not operating, or cautionary modes

for handling the payloads in the local wind environment. Table 51 contains a summary of the planned provisions for the H.1 Cyclocraft to handle inclement weather conditions.

Table 51. Inclement Weather Provisions

- 1. Hurricanes Avoided by Transit to Any Safe Open Field**
- 2. Severe Thunderstorms Avoided by Onboard Radar Detection**
- 3. Designed to Withstand Tropical Rain Downpours and Hail Storms**
- 4. Designed for Safe Mooring in 80 MPH Winds**
- 5. Designed for Rapid Response to 30 MPH Side Gusts**

7. Ground Support Requirements

7.1 Basic Considerations

From the transportation scenarios studied the major tasks were identified and are listed in Figure 20. The data contained in the figure are based on an average payload of 40.5 tons.

The underlying operational premise by MRC, and its potential industry partners, is that the targeted region for planned oil/gas opportunities is the wetlands of Louisiana. Those coastal wetlands of near term interest, depicted in Figure 5, are in the southern portions of the State and they stretch from Port Arthur, on the western border, to the eastern edge of the state near Slidell. At this time, MRC and its possible team members have identified New Iberia as the location for the final fabrication, assembly and test of an initially planned fleet of six H.1 Cyclocraft. Further, that location will serve as the Home Base for all planned operational activities.

Deployment of H.1 Cyclocraft would be from the Home Base, New Iberia, to Forward Bases which would be located within 50 miles of the targeted drill site for any specific oil/gas operation, e.g. Port Arthur, Lake Charles, Kaplan, Morgan City, Houma, Port Sulphur or Slidell. Figure 23 represents a typical operational scenario showing the anticipated relationships amongst the Home Base, Forward Bases and the specified drill site. The hardware/material to be transported, as shown, is expected to be supplied by other contractors to an intermediate location, termed Truck/Barge Landing.

From the New Iberia, Home Base, one or more of the H.1 Cyclocraft will be deployed to a Forward Base, e.g. Morgan City, from which the intended transport operations would be done. Actual operations would consist of an H.1 Cyclocraft taking off and flying to the defined Truck/Barge Landing for pick-up and then transport of sequential loads in support of the requirements for the selected drill site. The loads would be deposited while the H.1 was in a hover mode and, if available, another load at the site would be picked up for transport back to the Truck/Barge Landing, to another drill site or possibly to the Forward Base itself. As noted, periodic trips would include a return to the Forward Base for requisite refueling during daily operations. Sample move-in and move-out packages are given in Figure 20.

7.2 Home Base Considerations

7.2.1 Selected Facility

As noted earlier, MRC has identified New Iberia as the location for the Home Base of the initial fleet of H.1 Cyclocraft. This selection was based on the detailed discussions with respect to partnership arrangements held with Universal Fabricators Inc. (Unifab), in regard to their participation in the anticipated oil/gas programs, as the major fabrication and assembly member

Figure 23. Typical H.1 Cyclocraft Operational Scenario

of MRC's planned H.1 Cyclocraft operational team. Unifab has extensive, large scale fabrication experience, e.g. offshore structures, and their major facilities are located in New Iberia, Louisiana. Figure 24 is an aerial photograph of these facilities.

The Unifab facilities include a main office building, a variety of process and fabrication shops, maintenance areas, material handling, inspection and storage areas and a number of fabrication and assembly buildings. The large building, 295 x 470 ft, in the lower right would accommodate most of the final subsystem assemblies. An addition to that building would be constructed for the final H.1 Cyclocraft assembly and this is depicted by the sketch in Figure 25. Also shown in Figure 25 is the expected positioning for final checkout and the subsequent, on-site parking area for the cyclocraft fleet, prior to deployment for oil/gas operations.

All items for the final assembly of the H.1 Cyclocraft will feed from a variety of other areas within Unifab's total layout into the main fabrication and assembly building. Large items such as the main frames for the cyclorotors and the central, longitudinal truss of the H.1 Cyclocraft will have their final integration with the aerostat performed in the building extension, while their basic fabrication, assembly and inspections will occur in the existing main building. Similar flow patterns would be followed for the other subsystems, e.g. hydraulics, propulsion, flight controls, power, and any identified GSE, e.g. the few field checkout consoles contemplated for start up

Figure 24. Aerial Photograph of Unifab Complex

operations or trouble-shooting at the Forward Bases. Major components of the subsystems, e.g. hydraulic pumps, flight control computers, power supplies and engines, will have receiving inspection, as well as in-house assessments prior to their final incorporation into the total cyclocraft. For example, the engines will have test stands within the Unifab complex, where normal fit and function checks will be made, as well as assessments of the unit during powered operation, e.g. initial calibration with propellers.

7.2.2 Assembly and Ground Handling Considerations

The final assembly process begins with the integration of the central truss structure and the Aerostat Subsystem. Figure 18 shows how the design may evolve during the initial development program. The erection of the aerostat, in concert with the integration of the shown structure, to allow for sequential assembly of the central structure with the wrap-around aerostat subsystem, which includes access tunnels, ballonets, pressure assemblies, valving, a catenary curtain with its cabling and the 303 ft long aerostat itself.

Although air may be used, during early aerostat erection phases, for limited inflation and testing activities, the aerostat must be filled with helium during the final integration phases with the internal structure. How the helium filling sequence is initiated into the full assembly process still requires detailed system engineering during the contemplated development program for the H.1. Cyclocraft. At this time, however, MRC believes that the load handling portion of the internal

Figure 25. Sketch of Home Base and Deployment Area

structure, as shown in Figure 18, should be mounted on a "ballast" tank at the initiation of the final assembly activities. That tank could then be utilized to provide the needed ballast for maintaining ground contact, as the helium is inserted into the aerostat, regardless of the erection sequence. For example, during final assembly of the aerostat and internal structure, various amounts of helium could be inserted, up to full inflation, as the sequential assembly is carried out, which would be followed by mounting of the cyclorotors.

The water-filled Ballast Tank could be incrementally filled to provide the needed opposition to lift at any point in the final assembly process. The aerostat, when filled with helium, will provide over 206,000 lb of aerostatic lift and this results in a net upward lift of nearly 51,000 lb, when the vehicle is fully assembled, as the total empty weight is less than 155,000 lb. If the helium fill is completed prior to the mounting of the two cyclorotors, and all other components are installed, the net uncompensated lift is about 98,000 lb. However, the most likely positive lift during the assembly phase, with a complete helium-filled aerostat, would be when most of the Aerostat Subsystem, i.e. aerostat, ballonnet, plenum, pressure controls and accessories, is installed, but most of the other hardware is yet to be incorporated, e.g. propulsion, fuel tanks, controls, bearings, landing gear, crew cab, payload handling gear and the cyclorotors. Under this condition, the uncompensated lift would be on the order of 123,000 lb. If the Ballast Tank, and its needed subassemblies, is assigned a weight of 10,000 lb, the remaining 113,000 lb would

require 1890 cubic feet of water, or a tank size of about 7 x 15 x 18 ft.

At this point, and as shown in Figure 25, MRC believes that the Ballast Tank approach for final assembly would also facilitate ground handling phases for the H.1 Cyclocraft fleet, e.g. egress of the cyclocraft from the assembly facility, movement on the tarmac for integration tests and, after free-flight evaluations, subsequent use in the deployment area pens. It would also appear reasonable to fly any H.1 Cyclocraft to a Forward Base with the ballast tank in place so that, on landing at that base, it could be appropriately filled with water to aid on-the-ground stability during non-operational phases. That added application might result in a larger size tank than suggested above. For the final assembly the goal is to hold the vehicle down during the process, i.e. only need to offset the net lift of the helium filled aerostat, at all points in the assembly process. For the noted movement outside the hangar, the application in the holding pens and the use at Forward Bases, the targeted Ballast Tank weight might need to be much more than a neutral buoyancy condition. The criterion for this case would be directly related to the wind environment and the expected modes of ground handling for the H.1 Cyclocraft. All facets of this approach must be addressed in significant engineering detail before firm conclusions can be reached and that will not be accomplished until early phases of the planned development program.

Until deemed otherwise, MRC is proceeding on the assumption that a 7 x 15 x 18 ft Ballast Tank will be employed in the manner discussed above. Further, preliminary assessments have determined that to use such a tank, in the manner suggested, would require some alterations to the basic H.1 Cyclocraft configuration, as shown in Figure 11. Figure 26 depicts the potential arrangement for the inclusion of a Ballast Tank as part of the ground handling processes, which are expected in the intended operational roles.

Rather than four landing skids on the H.1 Cyclocraft, there would be a tricycle arrangement, with a steerable forward wheel and two fixed wheels on the aft struts. The length of the struts and the selection of the wheels would be of a size which would allow for the placement of the empty tank under the aircraft for subsequent winching up to the load handling frame for attachment. That load handling frame would be either a circular or rectangular frame of 50 ft in longitudinal length, with internal mounting frameworks to accommodate the Ballast Tank and, when it is removed, the actual operational loads. It is expected that two, relatively small winches could be employed which would handle either the tank or the requisite lifting associated with the currently planned cargo net approach for operational loads. The tank might be deployed on a suitable dolly at the Home Base and would be detached and left in place on the ground at the Forward Base. At the Home Base, as shown, a suitable tractor, e.g. a Mississippi Road Service (MRS) unit, would be used for towing and the cyclocraft in this mode would be near neutral buoyancy in most cases.

7.2.3 H.1 Cyclocraft Acceptance Tests

After the complete cyclocraft is brought together in the final assembly building, there would be fit and function testing of the total system, short of actual powering-up of the engines for full

Figure 26. Modified H.1 Cyclocraft for Ballast Tank Option

cyclorotor evaluations. It would then be towed to an outside position, as shown on Figure 25, and a full scale system integration test would be performed to accept or buy off the adequacy of the H.1 Cyclocraft system. For that move, the Ballast Tank would be adjusted to establish a desired buoyancy of the aircraft, e.g. make the total system neutrally buoyant so that the H.1 Cyclocraft could be easily towed, on wheels, by the tractor to the outside system checkout position.

At this outside position there would also be fixed anchor locations that would, when needed, be used as tie downs for restraining cables during the system testing process. Those anchors would likely be fluted screw type units which are employed in many industrial applications. The wind limitation criteria for the outside positions of the H.1 Cyclocraft would be targeted for conditions up to a sustained 80 mph. When those conditions are expected to be exceeded, and any of the H.1 Cyclocraft fleet is outside of the main building, they would either be firmly tied to anchors or flown out of the area. As noted earlier, to facilitate tie-down, water would be added to the Ballast Tank to make the H.1 Cyclocraft heavier than air, while anchored.

As part of the acceptance or buy-off procedure, MRC plans to have complete functional runs of each of the subsystems at the beginning of the system integration testing, including run-ups and calibrations of the propulsion subsystem, i.e. the engines and the transmission of power to the individual propellers. After everything is demonstrated to be working properly, a complete pre-flight check-out will be executed. At this point, MRC believes that the H.1 Cyclocraft would be powered up and control inputs would be set at "down", while the Ballast Tank was removed. Then the vehicle will take-off vertically and proceed into a limited free flight evaluation as a

means of obtaining final acceptance on the particular H.1 Cyclocraft's adequacy for operational deployment. That limited flight testing will include full exercising of the nominal control functions, e.g. hover, up/down positioning, right/left transitions, fore and aft movements and forward flight modes up to full velocity attainment, with companion pitch up/down and right/left turn maneuvers. Successful completion of the flight testing will permit the particular H.1 Cyclocraft to be moved to a ready status in the deployment area, noted in Figure 25.

Specific details with respect to FAA requirements for the prototype, and eventual production units, of the H.1 Cyclocraft, are yet to be established. However, it is expected that type certification will evolve through parallel participation of FAA personnel during the fabrication, assembly and system integration testing phases for the initial H.1 Cyclocraft.

FAA requirements will probably dictate the extent of the buy-off flight testing briefly discussed above. It is further expected that the prototype will have at least an experimental certificate, approved for those first flight tests and that full certifications will result on the successful completion of all criteria needed by the FAA. The full FAA certifications for the fleet will certainly require maintenance, quality control and other type manuals in support of the total process, as well as FAA designated pilot(s) involvement in actual testing phases. MRC intends to initiate pre-planning with the FAA during the early phases of the anticipated development program for the H.1 Cyclocraft.

It has been assumed by MRC that the actual, initial flight testing operations could be executed, in part, at the Unifab complex, i.e. over their property and the contiguous Rodere Canal. More extensive flight testing could then be carried out by flights to the southwest of New Iberia, e.g. over Avery Island down to Weeks Bay and Vermillion Bay. There would appear to be 20 to 30 miles of relatively open space in those regions which would be more than ample for any anticipated testing.

7.2.4 H.1 Cyclocraft Deployment Readiness

After successful FAA certification processes, the H.1 Cyclocraft fleet would be positioned for deployment at the Unifab complex in pens, as shown in Figure 25. That pen, i.e. a series of vertical structural members, interconnected with cables and anchored in the paved base, would be installed for the open hangaring of any, or all of the six H.1 Cyclocraft in the fleet. It is expected that an individual H.1 Cyclocraft could be moved to a pen position by a tractor, entering through either end of the pen. Alternatively, the H.1 Cyclocraft could easily be flown into position via the hover mode of operation, upon completion of the flight tests, during system integration. As stated earlier, the Ballast Tank would be in place prior to movement into the pen area.

It is recognized that fully constrained positions lead to the highest loads being imposed for specific wind levels and directions and that a conventional LTA type of nose mooring would result in much lower loads. However, there are several factors that have dictated MRC's approach. The historical nose mooring of LTAs requires considerable space to allow for 360

degree rotation of the vehicle around the moored point, i.e. more than seven times the area needed for a fixed position. Further, a requirement for nose mooring at the Home Base dictates the same approach at the Forward Bases which would impose leveling requirements in the operational scenario, which MRC believes to be unnecessarily restrictive and costly. A more important reason, however, is the fact that the H.1 Cyclocraft is not an LTA. The latter relies on the aerostat itself for its structural strength and anything other than nose mooring requires difficult additions to that configuration, to achieve greater load carrying capabilities. In contrast, and as shown on Figure 18, the H.1 Cyclocraft is an integrated aerostat/structure arrangement, wherein the central structural member and the vertical catenary arrangement from that member, distribute the structural loads in an efficient fashion, such that a major portion of those loads are taken by the central shaft, rather than discrete areas of the aerostat itself.

As shown, the imposed wind loads on the H.1 Cyclocraft in the pen would be taken up by cabling attached to four vertical tie down poles, for each individual aircraft. Those cables would go from the vertical members to the end points of the cyclocraft's centerline structure and to both sides of the load handling structure at the bottom of the aerostat, where the Ballast Tank is attached. It is expected that the attachment points, and their angles of attachment to the noted anchor poles, would keep the H.1 Cyclocraft from moving in either the horizontal or vertical planes and that an appropriately filled Ballast Tank would abet this result. Through preliminary assessments and reviews of related materials, MRC has determined that the worst case load conditions for an individual H.1 Cyclocraft, i.e. sustained 80 mph wind at 90 degrees to center line, would be in the range of 50,000 to 75,000 lb, at each of the three cable attachment points. (Note that the downwind side experiences no load). MRC believes that the integrated design can be readily sized to handle these conditions. Discussions relative to specific ground support considerations at the Home Base are addressed in Section 7.6.

7.3 Other Base Considerations

7.3.1 Forward Base

In the sample scenario shown in Figure 23, Morgan City, which is about 40 air miles from New Iberia, is a Forward Base. One or more H.1 Cyclocraft would be flown to this location from the Home Base, to support drill site operations that might be scheduled within a 50 mile radius of that site, e.g. in Terrebone, Lafourche or St. Mary parishes.

A Forward Base need only have clearings large enough for the desired number of H.1 Cyclocraft to set-down. At the Home Base the Ballast Tank would be partially filled to a point where the H.1 Cyclocraft would be neutrally buoyant for the flight to this base. After touch-down, water would be added to make the aircraft heavy, which, in most nominal wind conditions, would be enough to hold the vehicle without any movement on the ground. If wind conditions become fairly severe, fluted anchors could readily be emplaced, to allow for tethers to be tied to the fore and aft ends of the central H.1 Cyclocraft structure, as well as to the ballast tank for maintenance of position. As at the Home Base, when winds or other weather conditions are

expected which are beyond the normal holding capabilities, the aircraft would be flown to safe areas.

Facilities, equipment and material at the Forward Base must be sufficient to sustain prolonged operations, e.g. could possibly be as long as 6 months to a year, if a number of sequential, or even parallel drilling operations were to be supported within the above noted parishes. Thus there will be facilities for support of air and ground crews, e.g. living quarters and cover for maintenance and repair activities. For the H.1 Cyclocraft there will be storage for requisite spares, along with supplies of helium, water and fuel.

It is expected that the infrequent helium purification activities might be performed at the Home Base, since the replication of the contemplated helium purification system would not appear to be an economic approach at a Forward Base. The everyday checkout equipment at the Forward Base, for the subsystems of the H.1 Cyclocraft, would be a duplication of that utilized at the Home Base during normal deployment readiness cycles, in support of fault finding, repair and rechecking of functional operations.

7.3.2 Truck/Barge Landing

Figure 20 provides a representative listing of all the hardware and material that could be involved in the oil and gas operations being planned for in the wetland areas of Louisiana. The expected location of most of that hardware, with respect to planned H.1 Cyclocraft operations, would be at a Truck/Barge Landing, that would be located from one to 25 miles distance from the planned drill site. The H.1 Cyclocraft would be detached from the Ballast Tank at the Forward Base, for the flights to this landing.

Depending on the locale, the hardware and material would be brought in by truck or by barge to the landing site, e.g. a stable piece of land, a wetlands area with built-up, board or dump roads, or on a canal, where a suitable barge had been positioned for the logistics role. The participating well service company would mobilize all of the drilling or production equipment and materials at one of its major facilities and then it would be transported by truck and/or barge to the selected logistics landing. Most of the equipment, e.g. crew quarters, generators, draw works and mud pumps, would be skid mounted. These skids, which are usually 8 feet wide, nearly 13 feet high and of varying lengths, have lifting lugs on each of the four corners, usually at ground level.

At the Truck/Barge Landing, planning would be necessary to arrange the equipment and material in a fashion that provides ready access, per a pre-determined transport cycle for the targeted oil/gas operations, for the H.1 Cyclocraft to descend, hover and pick-up the designated load. Load handling personnel would be positioned at this site, to provide coordination with the well service operator and to be the interface with the incoming/outgoing H.1 Cyclocraft, e.g. will have a communication net from the ground to the aircraft, to the Forward Base and, possibly, to the drill site. MRC would expect that these personnel would be housed on-site with the service organization.

There are no plans for touchdown or landing of the H.1 Cyclocraft at the Truck/Barge Landing. The intent is to go to that location from either the Forward Base or from the drill site, only for pick-up or deposit of particular loads. The pick-up or placement of equipment and materials are addressed in Section 7.4.

7.4 Transport of Payloads

As shown in Figure 23, the H.1 Cyclocraft will primarily be involved in the transport of equipment and material from the Truck/Barge Landing to the selected drill site and from the drill site to the Truck/Barge Landing. Figure 22 shows a design option for a load handling system to be incorporated into the H.1 Cyclocraft.

The initiation of the transportation cycle begins at the established Forward Base. Figure 27 depicts the fundamental elements of the total transportation process.

The cycle begins at the Forward Base where the H.1 Cyclocraft would (1) have pre-flight check-outs, (2) be powered up in hover mode and separated from the Ballast Tank, (3) then flown at 500 to 1000 ft altitude to the Truck/Barge Landing, (4) hover while the on-board load handling crew uses modest hoists to lower cables for attachment to prepared load, i.e. a cargo net over the load and fixed to the skids pick-up points, (5) then, while still in hover, attach cables to a frame that is upper closure of cargo net, (6) the load handling crew then hoists cables to full stretch position of the cargo net, followed by, (7) attachment of load links, which would be of 10 to 20 ft in length, to the cargo net's upper frame, (8) release H.1 Cyclocraft's hoist cables, and (9) proceed with vertical lift and transport to the drill site, where the pick-up cycle at the logistics landing would be reversed for the placing of the load at the drill site.

The magnified insert in Figure 27 shows how the cargo is attached or detached from the H.1 Cyclocraft's load handling frame. The details of the proposed design have yet to be addressed by MRC and this will be accomplished during the early phases of the contemplated development program. There are a number of questions with respect to the actual configuration of the aramid fiber cargo nets and whether these nets would be carried by the H.1 Cyclocraft and lowered to pick-up loads, or should the sequence be as shown on Figure 27, where the specific skid mounted cargo is prepared at the Truck/Barge Landing. System engineering trade-offs are necessary to develop the most efficient, and thereby the most economic, approach. The illustrated approach for load handling would appear to be the most reasonable solution for the large variety of payloads involved, as listed in Table 52. Other options generally would require a large powered hoist system on-board the aircraft, which would add a considerable weight penalty to the H.1 Cyclocraft, while the shown solution requires modest hoists and the cyclocraft itself would lift the attached load. The sizing of the needed hoists would be guided by the weight of an empty Ballast Tank, which would use them for its positioning at the Home and Forward Bases.

Figure 27. H.1 Cyclocraft Transport Cycle

It does not appear to MRC that a conventional cargo net configuration would be the most desirable. It entails a large, usually rectangular, latticed pattern net to be laid out on the ground and the cargo placed in its center. The net is then brought together at the top, for hook-up to a pick-up device, such as a crane. MRC envisions a four sided column, open at both ends, with the sides being webs of aramid ropes. The bottom end of the column would be attached to the four corners of the load, through an appropriate, light weight frame and the total column would be draped over the load in its relaxed position. Another frame at the top of the web's column would be used for attachment of the H.1 Cyclocraft's load cables. The latter would be lowered by the on-board winches, for subsequent stretching of the complete web column up to a point within 10 to 15 ft of the aircraft's load structure, where the airborne load handling personnel would affix the load links for transport.

7.5 Drill Site

As noted above, at the drill site the H.1 Cyclocraft both delivers and picks up equipment, all in the hover mode of operation. In addition to these basic roles, and as noted in Figure 20, the H.1 Cyclocraft will also be involved in the laying and removal of Poly Pipe, for the provision or removal of liquids to and from the drill site. Figure 28 illustrates how the H.1 Cyclocraft would use its high drawbar pull to drag the pipes into position. An inland barge, loaded with

liquids for support of drilling, would be moved to within three miles of the drill site, where Poly Pipe will be used to pump those liquids to the drill site. In turn, the same pipes will be used to remove all drilling fluids and cuttings from the site.

Figure 28. H.1 Cyclocraft Laying Poly Pipe

The Poly Pipe would likely be three inches in diameter and 1/2 inch wall thickness, which weighs 2 lb/ft and is available in standard reels of 1500 ft in length. As noted, the H.1 Cyclocraft, while in hover, would have a tow line attached to the end of the pipe and then it would transition to forward flight, dragging the pipe over the wetlands surface to its full length. The cyclocraft would then return to drag the next 1500 ft length of pipe into position for connection to the previous pipe. It is noted that lengths of Poly Pipe can easily be fused together, in place. This procedure would continue until the drill site was reached. MRC expects that the tow line for connection to the ends of each segment of pipe would be approximately 75 ft in length and that it would be attached to the center section of the H.1 Cyclocraft's loading frame. The line would be of the order of 1/2 inch in diameter and would consist of an aramid fiber rope jacketed with abrasion-resistant, moisture blocking extruded polymers for wetlands use. At the loading frame, the attachment would be via an eyebolt, affixed to the end of the line, that would fit over an installed hook. The other end would attach in the same fashion to a hook emplaced at one end of a longitudinal, clamshell type sleeve. That sleeve would be several feet in length and would fit over the Poly Pipe and clamped in place via large, locking wing-nuts. Detailed designs would be effected during the early phases of the development program. A 1/2 inch aramid tow line would have a breaking strength in the range of 24,000 lbs, which is well above expected tension loads.

It is expected that one person could handle the attachment of the H.1 Cyclocraft's tow line to the end of the pipe at the reel on the barge; two people would be required to attach and/or detach the clamps and fuse the connections, during the ground laying of the Poly Pipe. The field personnel, depending on the wetland conditions, would need appropriate transportation, e.g. land, water or amphibian vehicle. The drilling operator would handle the attachments at the drill site.

At the drill site, the relationship of the H.1 Cyclocraft to the drilling rig poses some clearance

considerations, which are not of great concern, i.e. the agility and the responsive controls of the cyclocraft allow for accurate positioning during delivery or pick-up of planned payloads. Figure 21 illustrates the relationships between the H.1 Cyclocraft and the Drill Site that will occur while load handling is in process.

As at the Truck/Barge Landing, MRC plans that ground handling personnel will be located at the drill site to coordinate with the drilling operator and to provide communications links with the H.1 Cyclocraft in flight and with the Home and Forward Bases.

7.6 Home Base Ground Requirements

The purpose of this section is to delineate both the personnel and equipment requirements that are necessary to support the operations planned, and discussed, in the previous sections. Those specifics relate to all facets of the planned operations, from the time the H.1 Cyclocraft is in the deployment area at the New Iberia Home Base, through its various operational modes, associated with the transportation of loads, in support of a nominal oil and gas operation in a wetlands environment. In essence, a determination must be made of the requirements to be met in order to perform the daily operation for a single H.1 Cyclocraft, at each of the sites involved, i.e. Home Base, Forward Base, Truck/Barge Landing and the Drill Site, which includes the liquids barge.

In general, the ground personnel, equipment, hardware and material that are needed at the Forward Base, with minor exceptions, can be represented by those required at the Home Base. Other site requirements, e.g. the pipe-laying process from the liquids barge to the drill site and load handling activities at the Truck/Barge Landing and the drill site are much less. This section addresses the Home Base; the other sites are addressed in Section 7.7.

7.6.1 Operational Phases

The major phases of operation at the Home Base are (1) pre-flight checkouts for the System Integration Test, (2) the various test flights of the H.1 Cyclocraft at or near the Home Base, (3) the post-flight evaluations, (4) the bedding down in the pen, (5) pre-flight and take-off from the deployment area and (6) any condition that requires repair of the H.1 Cyclocraft before proceeding. A basic assumption is that the ground needs are being identified for an eight hour day and that the in-flight portions are not being addressed, e.g. there are a pilot, copilot and two load handlers on board the H.1 Cyclocraft in flight.

Of particular import is the fact that the Home Base is where the H.1 Cyclocraft will be assembled and, therefore, there will be considerable experience and expertise developed during that process. Unifab's facilities will have many of the back-up structural and mechanical shops and these will have personnel already trained in the H.1 Cyclocraft's hardware and equipment. In addition, a great deal of occasional support can be provided by Unifab's normal general purpose equipment, e.g. pickup trucks, welding equipment, cranes and support helicopters. Any

major problems associated with maintenance or repair can likely be handled in existing facilities and/or use of special ground support equipment that would be built during subsystem fabrication, assembly and test processes, e.g. fit and function test stand for engines which would suffice for most checks other than major overhaul which would be done at licensed, overhaul facilities.

The H.1 Cyclocraft will have the same fundamental requirements for scheduled maintenance and overhaul as other FAA regulated aircraft, and the details will be developed during the certification process and documented in appropriate manual form. These will include daily preflight and post flight requirements, routine or scheduled inspections, periodic overhaul schedules and, if any, replacement schedules for certain items based on useful life.

With respect to ground operations, e.g. inspections or maintenance, the actual design of the H.1 Cyclocraft can have a significant effect on how they are accomplished. In that regard MRC has determined that, for a vehicle of this size, internal access must be provided in order to facilitate the process. Figure 29 presents a side view of the H.1 Cyclocraft with notations of where special access will be incorporated to facilitate inspection, maintenance and potential repairs and/or replacements.

As shown, there is planned to be a rectangular open cavity at the bottom of the aerostat, just above the load handling framework. At this point, the size of that opening is expected to be 10 ft high x 25 ft wide x 50 ft long and it will have a number of cross members, attachment points or hooks, winches, and cross paths, with handrails for the load handling crew that will be on-board during flight operations. The main access to this area will be via the crew cab, which will be accessible from the ground by a ladder, which will be attached to the forward landing strut, which passes through the aft portion of the crew cab, as shown in Figure 26. Alternative access would be through a ladder attached to the Ballast Tank, also shown in Figure 26, or, in the event that the tank is not in place, to the loading frame itself.

As noted, from the lower bay, there will be personnel access through tunnel type arrangements up the load structure to the central truss and along that center truss to either end of the H.1 Cyclocraft. These tunnels, as well as the wall of the lower bay, will be sealed off from the helium filled aerostat. In addition, for safety, procedures will be established for a "buddy system", with proper communications and Scott type packs for personnel in the tunnels. Not shown are the two ballonnet bags, that will be located in the bottom portion of the aerostat and run nearly the total length of the underside. The ballonnet bags also will have entrances for personnel involved in daily inspections, scheduled maintenance and possible repair operations.

The propulsion units are located outboard of each cyclorotor. The power to the hydraulic subsystem and the propellers is transmitted through gearing and shafts from the propulsion units, through the rotating hubs of the cyclorotors, to the resultant hardware interfaces. Access will be provided from the inner, central tunnels, through the cyclorotors, to the ends of the center structure, where the propulsion units and associated fuel subsystems are located. This will allow for daily inspections, scheduled maintenance functions and removal and replacement, when necessary, for all equipment involved.

Figure 29. H.1 Cyclocraft, Potential Personnel Access

MRC expects that design features will be included at the propulsion mounting points for either (1) disconnection and lowering of the engine with an auxiliary, electric powered winch, or (2) the on-board maintenance individual to guide the hook from a Boom Truck to pickup points on the engine, for removal and placement on a ground dolly. Specific detailed procedures are to be addressed during early development phases.

7.6.2 Ground Personnel Needs

In developing ground crew requirements the above factors, e.g. extant Home Base capabilities and potential access features for the H.1 Cyclocraft, in addition to other features of the planned H.1 Cyclocraft System, must be taken into account. The components of that system were initially defined in the H.1 Cyclocraft preliminary design report, Reference 4, and are summarized in Figure 10.

The subsystems of the H.1 Cyclocraft, listed in Figure 10, are not complex and MRC plans to

have built-in checkout features for the aircraft components that warrant them, e.g. the Air Computer Subsystem. If problems occur, the self check will isolate faults, to the piece-part level, for ready removal, repair or replacement. The general makeup of the equipment dictates the skills required of ground personnel. There is a need for mechanics and technicians that are qualified in propulsion, hydraulics, electronics, structures, aerostats and electrical, as well as personnel for handling, hauling and loading functions. In many cases, the personnel assigned to flight hardware or subsystems would require FAA rating, e.g. A & P rating for power plants. Beyond basic needs with respect to the actual hardware, there are requirements for management and direction of the ground crew in operations, in addition to the need to prescribe and direct the requisite training and safety type attributes that must be developed.

Beyond the considerations above, the size of the vehicle dictates solid ground communications during preflight or postflight checkouts and during the movement of the H.1 Cyclocraft itself, i.e. considerable separation distances between ground crew members and between them and personnel that would be involved on board the H.1 Cyclocraft.

The makeup of the ground crew would vary with respect to the status or phase of operation for the H.1 Cyclocraft at the Home Base, e.g. preflight checks, flight test support, postflight checks, a shut down H.1 Cyclocraft that is tied to anchors in the tarmac, shutdown and located in a pen or readied for deployment and exiting the Home Base. Roles will change with status changes of the aircraft and MRC plans that most ground personnel will have cross-training such that they are not limited to a single facet of ground activity, e.g. a mechanic might be required to checkout or inspect the engines for preflight, directly participate in the placement and attachment of the Ballast Tank to the load frame, be responsible for setting null positions on the cyclorotor blades and might even be assigned as designated Safety Officer during a pre-flight operation. All elements of the ground crew makeup, training and roles will be addressed in much detail during the development program and the cross coordination with the FAA.

At this time, the following is the preliminary identification of the personnel required for a minimal ground crew for daily checkout of the H.1 Cyclocraft, or the complete preflight checkout and preparation of the aircraft for flight, its flight and its return to base for checkout and storage. In general this requires checkout and operation of each airborne subsystem identified in Figure 10 and includes the application of at least all the items noted under the ground subsystems. Table 52 depicts the required personnel, with a brief annotation of responsibilities.

The above Ground Crew would be sufficient to do all preflight checking on the tarmac, support take-off of the H.1 Cyclocraft with a dummy payload, i.e. removal of the Ballast Tank and attachment of the payload, return landing, post flight check and movement of the vehicle, after switching the dummy with the Ballast Tank, to an anchored position on the tarmac or move to the pen location for dormant tie-down. It is noted that the Ballast Tank might be the dummy payload.

Table 52. Ground Crew Composition

Type of Personnel	Number of Personnel	Responsibilities
Ground Director	1	Ground Crew Direction
Mechanical Crew Chief	1	Directs Aerostat, Structure, Handling, Helium, Power, Cargo, Fueling and Platforms
Mechanic	2	Supports Handling, Helium and Platforms
Mechanic	2	Supports Structure, Engine, Power, Cargo and Fueling
Technician Crew Chief	1	Directs Aerodynamic, Air, Computer, Propeller, Checkout and Data
Technician	2	Supports Aerodynamic, Air Computer, Propeller, Checkout and Data
Total	9	All Ground Support

During a physical move of the H.1 Cyclocraft, the Ground Director, through hands free radio communications with all members of the ground crew, directs the process, which primarily relates to the hook-up of a suitable tractor to the forward landing gear, the posting of personnel for surveillance and other factors pertinent to the safety of the operation. For that movement there would likely be the Ground Director, a mechanic on the tractor, a crew member at the rear and both sides of the aircraft, with one well forward to aid in guidance of the tractor driver. The remaining three crew members would be involved in a variety of unscheduled tasks such as getting a readout on weather from the Data Station or running errands with a pickup for the fix of a problem, etc.

Both mechanics and technicians would have cross training, so that they can handle multiple responsibilities, as noted above. When the vehicle is anchored or housed in the pen, only a caretaking role is required, e.g. one individual for security, while also recording periodic measurements of helium purity levels. The balance of the ground crew during those downtime periods would be involved in other items, e.g. scheduled maintenance and daily checkouts.

The actual running levels of total ground support would depend on the size of the fleet, the sequence of operations and the interaction with H.1 Cyclocraft employed at other sites. Those factors are considered in Section 9, Operating Costs.

7.6.3 Ground Equipment Needs

As noted earlier, MRC developed a first cut at potential ground support hardware in the H.1 Cyclocraft Preliminary Design, reported in Reference 4, which is listed in Figure 10. Since that time, and through ongoing evaluations of the utilization of the H.1 Cyclocraft in the wetlands for oil and gas developments, this list is being modified to include other items and to expand on the definition of certain items. The ground support of interest is that required to support operations, after assembly and checkout in the main Unifab facility, i.e. integration testing and FAA certification work at New Iberia and operations in the field in support of oil/gas developments. The "field" being the Forward Base Truck/Barge Landing, liquids barge/pipe laying and drill site.

The Home Base will have complete maintenance and routine repair facilities, including structural and mechanical work short of major overhauls, i.e. required by the engines and to be done at the manufacturer or licensed overhaul facilities. Normally it will not be necessary to do major maintenance in the field, e.g. remove and replace engines. The H.1 Cyclocraft would be able to return to the Home Base if one engine was out. Repairs in the field that involve small parts, minor structural damage, minor aerostat damage, instrumentation, computer board, hydraulic valve, etc., would be considered as part of normal field operations and would be repaired at the site. MRC will develop a maintenance framework during the development program, which meets the needs of the FAA and recognizes the easy access of the Home Base facilities. For example, there would likely be an annual requirement to move a specific H.1 Cyclocraft back into the main assembly facility, to do a complete assessment of the aerostat, including its upper surface.

The headings for Ground Support Equipment (GSE), shown on Figure 10, are utilized below to present the currently identified needs.

Handling Subsystem

1. Ballast Tank	o one per H.1 Cyclocraft, used in assembly, on tarmac, in pen and during transit between Home Base and Forward Baseo sized to handle water ballast from zero to approximately 120,000 lbo interfaces with load frame at underside of H.1 Cyclocrafto tank strong enough to support empty weight of H.1 Cyclocrafto special links with load cells for measurement of ballast weighto dolly for handling empty tanks
2. Anchors	o set of four fixed anchors placed in tarmac at Home Base that will be used for tie-down during integration or certification tests

- o 6-8 tie-down cables with lengths yet to be determined, but variable adjustment within 10% of nominal length
- 3. Dollies o 2-4 dollies for use by ground crew in movement of tools, spare parts, etc.
- 4. Tractor o all purpose, heavy unit, e.g. Mississippi Road Service (MRS) off-road, with articulated wheels
- 5. Boom Truck o 1500 lb capacity with 100 ft reach
- 6. Fork Lift o 20,000 lb capacity
- 7. Pickup o two, personnel transport

Helium Subsystem

- 1. Helium Purifier o mobile, multi-pass unit sized for purifying 300,000 cu ft of on-board gas every six months
- 2. Helium Measuring Unit o Cambridge Analyzer, leak detectors, etc.
- 3. Helium Trailers o maintain 4-6 commercial trailers on-site, re-supply as required
- 4. Hoses o 200-300 ft of 2 to 4 in dia hose for helium transport between purifier and aircraft

Power Subsystem

- 1. Generator o three phase, 400 HZ, 440 V crystal controlled mobile unit
- 2. APUs o small, gasoline driven AC and DC sources
- 3. Batteries o a variety of small to large DC sources
- 4. Battery Charger o two standard units

Checkout Subsystems

- 1. Lap Top Computer o to be utilized during pre-flight checkouts where, with auxiliary power applied, inputs can be provided to the Controls Group, to assess the proper functioning of the Air Computer and Hydraulic Subsystems, as well as for the

setting or changing of gains within various loops. This might also facilitate checkout of the pilot's controls in the crew cab

- 2. Protractors o in conjunction with the above, portable, or built-in protractors would be used to measure throw positions of the wings, blades & stalks
- 3. Balancing Table o a portable table set up for checking dynamic balance of the propellers
- 4. Checkout Tools o a variety of voltmeters, ammeters, gauges, oscilloscopes, wrenches, optical RPM unit, etc. would support the technician checkouts of the Controls Group and the Propulsion Group

Data Subsystem

- 1. Weather o beyond the regular inputs from local stations, there is a need for micro-weather, i.e. temperature and winds, at the H.1 Cyclocraft's location, which could be integrated with the local station inputs into a small computer for record keeping and output

Cargo Handling Subsystem

- 1. Top Frame, Cargo o a metal framework which attaches to the top of the aramid fiber cargo net, approx. 10 x 30 ft rectangle, which has two large eyebolts on its top for attachment to cables, which will be lowered from the load handling area of the cyclocraft and then pulled up to attach to connection links on-board the aircraft
- 2. Cargo Net o aramid fiber, woven cargo net that, when stretched, will approximate a vertical, rectangular tube, which is 10 x 30 ft and 75 ft high
- 3. Bottom Frame, Cargo o a metal framework which attaches to the bottom of the net and interfaces with the ground level attachments of the skid mounted payloads

Fueling Subsystem

- 1. Fuel Truck o two standard units, allow filling of both fuel tanks simultaneously

2. Hose/Couplings	o	extra lengths needed for reaching, bottom, fuel tank inlet for fuel and purging; crew member at fuel tank will lower line to pull up unit
3. Fuel Farm	o	tank storage of fuel supplies

Maintenance Subsystem

1. Work Platforms	o	small platform for attachment in cyclorotor hub areas for work on engines and hydraulics
	o	small platform for attachment in load-handling area of H.1 Cyclocraft, e.g. working on winches
	o	several platforms for attachment in ballonnet areas close to plenums, valves and controls
	o	platform slung from hub area of rotor to allow crew member to get to blade and wing areas
	o	two scissor type, personnel work platforms for general purpose use, elevation of 40+ ft
2. Slings	o	tailored slings for engines, propellers and other items on cyclorotors or in the hub area for removal and replacement activities
3. Mobile Stands	o	mobile units to accept removed engines, propellers or other items which are of large weight and/or size for transit to main facilities
4. Oil Servicing Unit	o	for maintenance functions
5. Hydraulic Bench	o	to provide power for checking hydraulic units
6. Hose	o	for oil and hydraulic servicing units
7. Welding Equipment	o	for structural repairs
8. Aerostat Mending Equipment	o	for repair of tears, rends or holes in aerostat
9. Tools	o	several sets of a variety of maintenance tools packaged in tool boxes or mobile work benches
10. Portable lights	o	provide emergency illumination at night
11. 40 ft van	o	focus key maintenance & spares near operation

Communications Subsystem

1. Com Network	o	a mix of VHF transceivers, HF transceivers, radio telephones, VHF walkie-talkies with power will be needed to tie the ground crew together, provide ties between the ground crew and the flight crew and provide communications between the Home Base, Forward Base, Truck/Barge Landing, Drill Site and the H.1 Cyclocraft

Safety Subsystem

1. Hard Hats	o	for all personnel in vicinity of H.1 Cyclocraft operations
2. CO ₂ Fire Extinguishers	o	several
3. Dry Chemical Fire Extinguishers	o	several
4. First Aid	o	containers & arrangements with local medical units
5. Mobile Fire Trucks	o	arrangements with local fire units at critical operation points
6. Scott Packs	o	personnel breathing apparatus

7.7 Other Base Requirements

7.7.1 Forward Base Ground Requirements

With one exception, all of the items listed for the Home Base would be required at the Forward Base. The exception would be the helium purifier. MRC is of the current opinion that that unit may be too large and expensive to replicate for both sites. Which would then require the H.1 Cyclocraft return to Home Base periodically, for major purification activities. An area of difference would be the anchors. At the Home Base there would be anchors imbedded in the flat, tarmac area and the particular Forward Base may be more primitive. Thus it may be necessary to use truck mounted augers to provide holes in whatever medium is available for the insertion of different, fluted anchors.

Beyond the above, of course, there will be crew living facilities.

7.7.2 Other Site Requirements

MRC, as noted earlier, will have ground support personnel at the Truck/Barge Landing, the liquids barge and areas between it and the drill site, and the drill site, itself. In all cases these

personnel will need living quarters nearby and will require suitable communications gear to provide the necessary coordination with the H.1 Cyclocraft and other operational site locations. Specific other ground support equipment would include (1) "clamshell" attachments for dragging Poly Pipe, (2) Poly Pipe fusing kits and (3) two-man transportation for Poly Pipe attachment/fusing crew.

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8. Prototype Development Plan

8.1 Development Approach

In the preparation of its Cyclocraft Commercialization Plan, Reference 15, MRC provided an overview of the history of the evolution of the cyclocraft, with some preliminary projections of the "thrusters" that might be pursued beyond 1993 (Figure 30). The figure presents both the USAF program, which addresses the small, unmanned U.1 Cyclocraft System, as well as reference to the DOE program, which is the subject of this report. Briefly, the approach offered by MRC to the USAF was "a step at a time" mode for the cyclocraft, where the U.1 Cyclocraft required a modest investment for development of a prototype, and further considerations for possible production would await user evaluations of that prototype. In the same vein, as shown in Figure 30, a somewhat similar approach was inferred for the development of the heavy-lift configuration, now being addressed under the subject DOE contract. These are considered further in Section 8.2.

Figure 30. Past, Current & Potential Cyclocraft Developments

MRC believes that the existing information, data, experience and knowledge provide the datum necessary to allow MRC to embark on the subject development program, with the expectation of achieving the desired objectives for schedule, cost and performance.

DOE's objective is clear, i.e. the agency would like to foster development of a transportation method in support of current and future oil and gas related activities in the Louisiana wetlands, that is least harmful of the environment. MRC believes that the identified H.1 Cyclocraft provides that solution and its development, followed by production of a suitably sized fleet of H.1 Cyclocraft is warranted. Thus, MRC's primary objective is to develop and test a prototype configuration of the H.1 Cyclocraft in a manner that will provide a solid definition of the system, for subsequent replication in a production environment. Of fundamental concern, however, is how to structure the desired program, such that funding for that effort is facilitated. The fact that DOE intends to foster such development does not imply that it, or other Government sources, would necessarily provide the funds for that effort. These funding difficulties were noted in the commercialization plan (Reference 15) discussed under Background and they deserve further comment at this point.

As noted on Figure 30, the previous thoughts were that there were two attractive paths for cyclocraft developments, i.e. the first being the pursuit of a relatively small, unmanned cyclocraft prototype, i.e. U.1 Cyclocraft, that had considerable user potential, and the second being a slightly lagging, but parallel development of a heavy-lift configuration for other users, e.g. DOE. This approach allows for minimal, initial investment for building a prototype that had direct use, in addition to it providing the incentive for stimulation of funds for the lagging development of the heavy-lift cyclocraft. That stimulation of interest could be in the US Government, the commercial sector or both. Beyond the question associated with commitment of funds, the initial small prototype would also provide hardware demonstrations, which may be important to potential, heavy-lift users, with respect to validating the concept's possibilities at that scale, before embarking on its development. For the record, MRC does not believe that the "one-step-at-a-time" approach is a prerequisite for movement into the heavy-lift cyclocraft regime and the successful hardware history provides the datum to proceed. Nonetheless, the corporation is mindful of the concerns for both the sources of funds and the possible desire for hardware substantiations.

Consequently, MRC recognizes the strong potential that a sequential program may evolve which might include (1) preliminary phases that encompass the development and testing of a relatively small scale prototype, and (2) the full scale development phase for a prototype of the identified, 45 ton H.1 Cyclocraft System. The preliminary phases could include added engineering evaluations or studies, the actual building of a relatively small prototype and the formulation of detailed planning for subsequent full-scale development. The relatively small prototype could be any of a number of choices, e.g. the U.1 Unmanned Cyclocraft, that meets a number of government user needs, or a similarly sized vehicle with manned capability. The latter, in fact, was the subject of a recent, cooperative proposal between MRC and LSU's Center for Coastal Energy Research & Environmental Resources, submitted to DOE (Reference 41).

In Reference 41, a three phase project was proposed which consisted of (1) definition of a small, manned cyclocraft, designated P.1 Cyclocraft, for a variety of personnel uses in the wetlands, #2) the building of the prototype P.1 Cyclocraft and demonstration of its utility in the Louisiana wetlands, and (3) subsequent detailed planning for a heavy-lift cyclocraft for wetland operations. This approach is similar to that developed under MRC's commercialization plan for the USAF. Figure 31 presents an overview of the options discussed to date.

Figure 31. Phasing Options for Cyclocraft Developments

Although these type of development options increase the opportunities for continued DOE or other government funding, they push substantive actions on a heavy-lift cyclocraft several years downstream. Such dollar support would provide additional time for MRC and its potential partners, e.g. Unifab, Schellstede and Associates, Petroleum Helicopters and Moncla Well Service to raise capital from the commercial markets for the bulk of the development program. Beyond this, further commitments of funds by the government might even stimulate earlier acquisition of commercial funding, thereby accelerating the start date for full H.1 developmental activities.

Beyond the above options, there are many other options that could be postulated for downstream movement into a development program for the H.1 Cyclocraft. That downstream movement could, as noted, involve several years of activities before real effort on the H.1 Cyclocraft begins or, by selecting a more aggressive approach, proceed with H.1 Cyclocraft development without the preambles discussed above. The point being, however, that the real avenues of movement are not yet defined.

Consequently, MRC is of the current position that a development program for the H.1 Cyclocraft System should be structured without regard to possible preceding phases. Thus, the corporation presents a development program which encompasses all that is necessary to achieve the previously stated objective, i.e. "...develop and test a prototype configuration of the H.1 Cyclocraft in a manner that will provide a solid definition of the system for subsequent replication in a production environment."

Specific groundrules and assumptions that will be employed by MRC to achieve program objectives are presented in the following section.

8.2 Ground Rules and Assumptions

MRC, and its potential partners, have the ultimate goal of providing a fleet of H.1 Cyclocraft for use by an operator in, primarily, transportation support of oil and gas activities in the Louisiana wetland areas. To facilitate early achievement of this goal, the defined development program must result in a prototype H.1 Cyclocraft that is the exact, or very nearly exact, configuration of what will be produced for that fleet. In essence, this means that the prototype that is flight tested at New Iberia (proposed facilities and basing are covered in Reference 5) must be an FAA certified configuration, with all necessary documentation and procedures in-hand such that it can be readily duplicated, at the New Iberia facilities, for the production fleet. That initial certification would likely be an "experimental" type from the FAA and, the possible differences between the prototype and the production units would probably be related to installed instrumentation for the certification testing and, maybe some changes as a result of those tests.

In line with the above, a number of guidelines have been established by MRC which are considered important to the achievement of a cost effective development program, namely:

1. MRC and its involved partners shall interact with the FAA early in the program to work out the basic requirements of that agency with respect to what is needed, e.g. for hardware definition, acceptance testing and FAA participation, during the course of the prototype development, in order to have a "certified" vehicle at the end of that program, along with defined procedures and related documentation for subsequent production units.
2. MRC and its involved partners shall provide a comprehensive documentation trail of the ongoing tasks related to the eventual prototype H.1 Cyclocraft, e.g. general specifications, hardware sketches and drawings, results of fit and function testing, results of subsystem and system testing, technical reporting of program facets and maintenance type manuals. That material will be informal in nature, i.e. per in house standards of participants.
3. MRC and its involved partners shall utilize a judgmental approach to determine the level of testing for hardware, i.e. piece parts, assemblies, subsystems and the system level. If there is adequate justification for eliminating certain test phases, e.g. an assembly or subsystem is a proven off-the-shelf configuration, it is expected that fit and function checks would only be

performed and the item would be fully validated as part of the planned system level tests for the complete prototype. This approach will not exclude specific testing desired by the FAA for the certification processes.

4. MRC and its involved partners, shall be cognizant throughout the design and development phases of the need for adequate maintainability, reliability and availability of the hardware in the intended operational deployment.

5. MRC and its partners, to minimize the development period, shall plan on adequate funds being available to support a meaningful level of personnel for the pursuit of program tasks, e.g. rather than have one engineer handle several subsystems there would be, likely, several engineers involved in many of the more involved subsystems.

8.3 Program Management

As shown on the H.1 Cyclocraft Development Schedule, Figure 32, an initial task will be directed at bringing personnel on-board for implementation of the organization which is to be formulated in the Baseline Package. In parallel, there would be a need to finalize agreements with the funding sources, e.g. a statement-of work, likely a derivative of this development plan, for the period funded, with options for program continuance upon success of the initially, stipulated phases.

Although the teaming arrangements are yet to be defined, MRC expects that a MRC directed management team will evolve and it would include members from all the participating organizations. Those team members would utilize, to the degree required, elements of their own organizations to effect the execution of their assigned activities. For example, Unifab, beyond its individual hardware responsibilities, will have significant roles in the overall process of manufacturing, assembling and testing of the H.1 Cyclocraft System at their facilities in New Iberia.

Thus, through Unifab, many organizational elements needed by the development program would be in place, or readily augmented as required, e.g. shipping and handling, receiving inspection, purchasing, quality control, engineering, manufacturing and policies and procedures. The same would be true for other potential participants, e.g. a selected aircraft operator would have within its organization the capabilities to support, across the board H.1 Cyclocraft testing, with pilots/copilots, maintenance and overhaul skills, engineering pertinent to flying the vehicle and the handling of large payloads. MRC expects that all members of the selected team will be able to supply experience, expertise and associated resources from their existing organizations. The final organizational structure must await the identification of the funding source(s) for the program, i.e. whatever the source, they will have requirements with respect to how the program is run. Despite the organizational unknowns, MRC believes that the planned teaming arrangements will provide the bulk of the evolving personnel needs for the development program, without having to embark on an extensive hiring program to effect its pursuit. A fast

Figure 32. H.1 Cyclocraft Development Schedule

start is expected.

In parallel with the establishment and implementation of the program's organization, the team must also provide early focus with respect to the major make-or-buy issues, since some of the selections for outside procurement may have lead-times which could be the critical elements in the resultant, achievable schedule. As noted in earlier discussions, the team will have identified some of the potential outside sources prior to go-ahead, e.g. powerplants, propellers and parts of the Aerostat subsystem. At this point, the area which looks to be the most critical is the aerostat, itself. Beyond this, the engines, propellers and maybe the Air Computer Subsystem will be procured from outside and they will have significant lead times, after the requirements are provided to the sources. Regardless, management must address the whole issue of make-or-buy with relevant members of the new organization as soon as possible, so that agreements can be made with identified outside sources. Further, there must be management guidance to Engineering at this point to implement whatever priority actions are necessary to scope the whole subject of make-or-buy, such that the in-house and outside procurement pictures are clear. Procurement fundamentally effects program tasks, workloads and schedules.

As noted, there is also an early need to coordinate with the FAA and other potential groups which may have an impact on the development. An objective of the program is to field a prototype configuration of the H.1 Cyclocraft System, with a type certificate from the FAA, which can be utilized to some degree in early support of oil and gas operations in the Louisiana wetland regions. Further, the work accomplished on the prototype H.1 Cyclocraft should also form the basis for the MRC team to build production units, near replicas of the prototype, that would be fully certified by the FAA, for similar operational roles.

To date, MRC and its potential partners have had some limited interchanges with other groups, which have provided insight into areas of need, that would affect the planned development program for the H.1 Cyclocraft, e.g. some of the well work-over organizations and their identification of hardware/equipment utilized in such roles. The team must establish, early on, a continuing dialogue with the user community, any local or state government entities that might have important inputs or requirements and federal organizations which may have pertinent involvement. The Program Management office will establish such a coordination function with assignments to individuals for continued follow-up throughout the course of the development effort.

Beyond the above type of activities within the Program Management, the group is the focal point for all development efforts, e.g. establish system guidelines, program plans, specification of documentation requirements, major program trade-offs relevant to schedule, cost and performance, setting of priorities, interfacing with outside organizations and all of the usual facets of management for a major development program involving a new aircraft system. Elements of those management activities are implicit in the following program areas.

8.4 Engineering

Engineering is applied in all phases of the planned development program and, consequently, elements of it are discussed within the framework of other tasks, as well as under this heading. Early engineering will be aimed at providing further detail to the overall system's definition, i.e. develop a system performance specification, subsystem performance specifications and specific design criteria for the system's hardware. Although, as has been noted previously, much work has been accomplished in this area with respect to anticipated hardware configurations, it is certain that perturbations will occur as a result of coordination with prospective partners, potential end users of the H.1 Cyclocraft and the FAA. These inputs could change the operational requirements that were initially delineated for the desired H.1 Cyclocraft System (References 1 through 5). Any such changes would require a rework of the parametric analyses previously performed (Reference 3) to upgrade the basic configuration, e.g. range, speed, aerostat volume and gross weight, for the planned H.1 Cyclocraft. If those upgrades were materially different from the previous baseline configuration, it would certainly have effects on one or more of the H.1 Cyclocraft's subsystems, as well. The efficiency of MRC's computer models for cyclocraft are such that these reevaluations can be performed in very short timeframes.

The resultant output of these initial system reassessment activities would be a clear, overall Work Breakdown Structure (WBS) for the total system. That WBS would be utilized subsequently for the assignment of work, the accounting of activity and the accumulation of cost and schedule data. It also provides the necessary framework for intelligent discussion of the complete make-or-buy structure for the H.1 Cyclocraft hardware, i.e. what components will be fabricated in-house by the MRC team and what components will be procured from the outside.

Those make-or-buy decisions would require engineering and economic evaluations in many instances to effect the proper choice. For example, up to this point, MRC has assumed that the very large aerostat would be procured through a subcontract to a suitable manufacturer that would design, build and deliver the unit to New Iberia for final installation phases of the H.1 Cyclocraft. This may not be a proper assumption and further detailed engineering, and economic assessment should be accomplished before that make-or-buy choice is made. This particular subject is discussed further in Section 8.5 Design.

Engineering personnel of the MRC team will be involved from the start in both system and subsystem level efforts relative to all facets of the planned development program. That work, as noted above, begins with the analysis necessary to establish the fundamental definition of the system's configuration, i.e. the WBS. From that fundamental hardware identification, the engineering personnel will then address specific designs for the hardware at all levels. At the system level, there is an early need to establish the actual payload characteristics, e.g. stable, average weight or wide variations expected. That information is vital in the fundamental establishment of the targeted buoyancy fraction, discussed in Section 6.6. At the subsystem level, engineering will utilize the wealth of historical engineering and developmental hardware data, discussed previously, as a starting point for individual design areas, e.g. detailed design

approaches, piece part selections or fabrication and assembly guidelines for the involved hardware. Engineering continues through the hardware building phases, associated test activities at various levels, the overall evaluation of results and technical, as well as relevant program status reporting. These are discussed further within the body of the following sections.

8.5 Design

Using the developed WBS, the engineering personnel will develop (1) the top level drawing of the Prototype H.1 Cyclocraft System and, (2) top level drawings for each of the major subsystems of that system. In parallel, other design subtasks will be addressed as required, such as (1) conceptual hardware and software definitions, (2) engineering analyses to develop details of a particular design, (3) development of criteria for procurement actions, (4) recommending make-or-buy choices to management, (5) development of documentation in support of make-or-buy decisions, (6) developing preliminary and detailed design drawings for selected piece parts, assemblies and subsystems, (7) initiating, where required, all actions necessary to promulgate exploratory testing of hardware for evaluation of design options, (8) provide criteria in support of subsystem and system level testing activities of hardware, and (9) develop all engineering documentation required in support of the foregoing efforts. All engineering documentation will be in conformance with in-house standards set by the MRC team.

For each critical hardware area, e.g. subsystem or major assembly, an informal White Paper will be developed, which addresses the thinking employed with respect to the design process, the trade-offs performed and the ultimate decisions reached. The intent of this process, which will ultimately involve a number of team members, is to ensure that cost effective solutions for particular hardware are reached, i.e. there is a good balance among cost, schedule and performance requirements. As shown on the schedule the current opinions are that the Aerostat, Structure, Handling and Cargo Handling Subsystems (Figure 10), as well as the powerplants, i.e. engines and accessories, are the minimum number of areas that need such treatment. In addition, it is expected that critical areas, and hardware regions where interactions are somewhat complex, will also require mock-ups to evaluate optional approaches. Such areas are discussed further in subsequent material.

It should be noted that References 4 and 5 provide the present status of the preliminary design for the H.1 Cyclocraft and its required Ground Support Equipment (GSE), covering system elements shown in Figure 10. MRC expects that further evolution of the current definition of that design will occur downstream, due to future interactions with the FAA, or other entities associated with the planned program. Thus the following discussions presuppose that a certain amount of the preliminary, and the bulk of the detailed design, will be accomplished after the go-ahead for the development program.

Current design approaches, or options, are presented in the following paragraphs.

8.5.1 Airborne Platform

The Airborne Platform, defined in Figure 10, includes the Lift, Controls and Propulsion Groups, which are discussed below.

Lift Group

This group includes the Aerostat, Aerodynamic and Structure Subsystems. Most items within these Subsystems, except for size, are similar in some respects to the hardware utilized in the successfully flown X.2 Cycloplane. Each Subsystem is presented in turn.

o Aerostat Subsystem

Basically this consists of a conventional aerostat/ballonet arrangement which is to be designed to provide a predetermined amount of aerostatic lift from sea level to the maximum operating altitude of 2000 ft. From Reference 4, the targeted volume for the aerostat, itself, is 3,637,230 cu ft and inflated ballonets would be about 444,000 cu ft. There will be two cylindrically shaped ballonets, in the bottom portion of the aerostat, with their associated plenums, fans and vent valves for pressure control of the helium. The aerostat, like that of the successfully flown X.2, has a 2:1 fineness ratio, made up of two semi-ellipsoids with the maximum diameter occurring somewhat forward of the center e.g. 40% of the total length. The H.1 Cycloplane's major diameter is 151.4 ft and the aerostat's length is 302.9 ft.

With respect to design, both the successfully flown X.2 and the planned H.1 Cycloplane have, except for size, similar aerostats. In fact, based only on the above it would also appear that the H.1 aerostat would be very similar to a conventional lighter-than-air (LTA) configuration. Those apparent similarities, however, are not true. Figure 33 presents comparative sketches, somewhat to scale, of the H.1 Cycloplane and the flown X.2, which depict their basic aerostats, with associated, internal structural arrangements. As noted in Section 2, the X.2 had a single cyclorotor, which rotated along with the aerostat, in hover, about the longitudinal axis of the vehicle. That rotation, and slung payload location, resulted in an internal, tension type structure and a ballonnet that was along the central axis. A conventional LTA would generally have no internal structure and its underside gondola would be supported by internal, attached, curtains, i.e. the major loads would be carried by the aerostat itself. Both the single-rotor X.2 Cycloplane and the dual-rotor H.1 Cycloplane are configurations that integrate considerable internal structure with the aerostat, which provides inherent strength that is not present in LTA designs.

With respect to aerostat design, the requirements for material strength, helium permeability and ultraviolet protection pose no special concerns. The state-of-art for using laminated films on a strong textile base is in-hand and, even the size of the H.1 Cycloplane is considered feasible, e.g. the Westinghouse/TCOM program, which addressed a large surveillance LTA, was in the range of two and a half million cubic feet and past LTAs were built in much larger sizes. The real design issues relate to how the aerostat's configuration can be laid-out, to facilitate the integration of the internal needs in such a fashion as to effect, in parallel, a reasonable approach

Figure 33. Comparison, Internal Structure, H.1 Cyclocraft versus X.2

to final assembly. In the case of the 330,000 cu ft X.2, which was built by ILC Dover, the complete aerostat, with pass-throughs for structure, was fabricated at the supplier's facility and then shipped to Aerolift, Inc. at Tillamook, OR. At that location, the final assembly basically involved both support of, and air inflation of, the aerostat, while the internal members were inserted through pass-throughs and the structural erection performed by personnel within the bag itself. However, the X.2's aerostat/structure assembly, as shown, is different from that planned for the H.1 Cyclocraft. Both, however, do have central truss structures, which pass through the fore and aft ends of the aerostat, requiring a flexible intertie between structure and bag. Early on, MRC had assumed that most, if not all, of the Aerostat Subsystem would be procured through a subcontract with a recognized supplier. However, recent evaluations under the present DOE contract, which resulted in the preliminary design for the H.1 Cyclocraft and the

requirements for ground support in the planned oil and gas operational environments, References 4 and 5, have stimulated further thought with respect to potentially viable alternatives. Note that suppliers that could be considered "recognized", e.g. ILC Dover, Raven/Aerostar, Virgin Airways, Westinghouse/TCOM et al, have not built aerostats of this volume with its companion need for fairly strong envelope materials, in fact, some of the well established firms in the US and Europe, are not interested in addressing the manufacturing of such units unless there are guarantees of some level of production.

These cursory reviews by MRC, relative to potential suppliers and the developments in the LTA arena, have determined that the previous choice, i.e. subcontract the total job, does not appear to be a reasonable approach. It is now apparent that the task of integrating the large scale internal structures with the aerostat of the H.1 Cyclocraft dictates that the designs must evolve in parallel, i.e. there must be close coordination and integration of the two, large scale design areas, to effect the desired end results. In-house, this integration will demand a design team approach between those personnel involved in the internal structure and those working on the Aerostat Subsystem. In addition, the design team will need subcontracted support from a recognized firm in the aerostat arena. That subcontracted support must be from a company that has the experience and capabilities in (1) developing engineering specifications for laminated aerostat material, (2) either building or obtaining large supplies of the specified, laminated materials, and (3) manufacturing and assembling aerostats of various sizes. The intent would be to subcontract with such a firm, or combination of firms, for (1) an engineering and design phase, (2) a build phase for the gores, panels and special internal aerostat features, e.g. tunnels, (3) parallel material and other testing required to insure materials meet specs, and (4) support of the total fabrication and assembly phases, with the MRC team at New Iberia. Further discussion of the subject is included in Section 8.6, Fabrication and Assembly.

o Aerodynamic Subsystem

The major elements in this area are the wings and blades with ancillary hardware for their integration into the four stalk assemblies, for each of the two cyclorotors. Although these units are much smaller those utilized on the X.2, their designs will have the same fundamental configurations. Those designs will be premised on standard, light aircraft construction for wings, rudders or elevators, i.e. very simple, proven and cost effective. The major aerodynamic consideration is the choice of aspect ratio for the wings. Smaller chord length permits the earlier establishment of the flow pattern, required for maximum aerodynamic lift, as the wing goes through its pitch angle cycle. The successfully flown X.2 used a wing aspect ratio of 4 and MRC employed an aspect ratio of 10 on the wings of the 42 ft subscale cyclocraft, to bound the regions of interest. Analysis of historical and recent data has resulted in the determination that an aspect ratio of 6 (67.5 ft span with 11.2 ft chord) would be appropriate for the wings of the H.1 Cyclocraft.

The wings will be designed as single units that pivot, with low inertia, about their aerodynamic axes, to reduce servo loads. The design will employ molded outer surfaces, with sandwich construction of carbon fiber epoxy prepreg, with a high density foam core. The wings will have

a unidirectional carbon fiber main spar to provide bending strength. The same approach will be utilized for the four blades, except for the spars, since they rotate on the stalk tubes. The blades have an aspect ratio of 4, i.e. 40 ft span with 10 ft chord. The pivot points for the wings will be built into the center portions of the units for attachment to the main spar. It is expected that the design will be accomplished in-house, while the fabrication of the wings and blades will be subcontracted to a recognized manufacturer, since they will require tools, molds and processes that are not inherent to the Unifab manufacturing skills, i.e. a sound fabrication decision that would be cost effective. The assembly of these units with the basic cyclorotor structure would be accomplished by Unifab in the Final Assembly building, shown in Figure 25.

o Structure Subsystem

This subsystem includes the central structure, i.e. the cyclocraft's longitudinal members and the beams/cables, that provide the necessary ties between them and the Aerostat Subsystem, the two large bearings for the mounting of the cyclorotors, the main structure of those two cyclorotors, the underside cabin or pod for crew and equipment, mounting provisions for the two ballonets, structure for the tricycle landing gear and the load handling framework. Figure 33 depicts the basic approach being contemplated, although it is very preliminary in nature. Considerable design trade-offs are yet to be accomplished before the structural design is fixed. As noted earlier, that design must evolve in concert with the design of the Aerostat Subsystem. One important facet of that interaction is the needs for personnel access within the aerostat for a variety of reasons, e.g. maintenance operations on the ground and the in-flight roles of the on-board load handling personnel. Figure 29 shows the general areas for which such personnel access will be required. Basically personnel must be able to move between the cab and the load handling region and have direct internal access from the lower rectangular opening to either end of the cyclocraft, e.g. for preflight and maintenance functions relative to the engines, hydraulics, bearings and other items within the hubs at both ends of the aircraft.

Although the need for the interaction between the structure and aerostat to assure optimization of the design, as well as facilitation of the assembly process, has been highlighted, it should be noted that to varying degrees, this is also true in most areas of the aircraft. For example, the engines, associated fuel supplies and the power transmission interconnections through the bearings, up the stalks to the propellers, cuts across important interfaces in a number of areas, e.g. between the Aerodynamic, Structure, Hydraulics, Propeller and Fuel Subsystems. The whole question of interaction between, or within, Subsystems is always an area of importance in development programs and the MRC team will give integration activities a high priority, e.g. early on, the team will require, likely through the Engineering Group, that the total design process be founded on solid configuration control mechanisms at the system level, with definite criteria for establishment and control of the interfaces between Subsystems.

Main elements of the Structure Subsystem's design are briefly presented below.

Internal Structure. The central longitudinal structure, Figure 29, would be a combination of a truss from one end of the aerostat to the other, where, at both ends, it would transition to

suitable shapes for mounting of the bearings for the cyclorotors just outside the aerostat's envelope and, on the outer extremes, having structural mounting provisions for the engines, hydraulics, fuel tanks and other accessories. That central truss will be in the range of 330 to 340 ft long, i.e. approximately 300 ft inside the aerostat with 30 to 40 ft extensions at each end, outside of the aerostat, for mounting of the noted items. MRC believes that the final design will likely incorporate a variety of materials, e.g. steel, aluminum and composites, embodying current state-of-art aircraft technologies for lightness and strength. Thus, it is expected that the designs will be accomplished in-house, however, the fabrication of the central longitudinal unit will be purchased from, or subcontracted to a manufacturer with the needed capabilities. Assembly will be accomplished by Unifab during the final build phases of the H.1 Cyclocraft.

From the longitudinal truss there will be a vertical subassembly, Figure 29, that will be provided to interconnect the central member with the load handling area. The latter, at the bottom end of this subassembly, will be flush with the underside surface of the aerostat and interconnected with the bag through flexible panels of aerostat material. The handling frame is expected to be on the order of 25 ft wide by 50 ft long, and it would have a variety of cross members to facilitate different external load configurations. As noted, a 10 ft high space above the handling frame will be open to the atmosphere where, during hover operations, the load handling crew would operate during the pick-up or release of external payloads. It is believed that those payloads would be attached via load links, which would be of fixed lengths that could readily be attached or detached manually by the handlers. Further information on the load handling expected in the operational environment are contained in References 4 and 5. Design trade-offs are still necessary during the early program phases to fix the overall approach and the degree or mix of manual versus automatic load attachment and release mechanisms. This interconnecting structure will be designed by the MRC team and will be acquired from an outside source, since it will be fabricated of materials similar to the central longitudinal member.

In addition to the above, it is expected that a catenary curtain, or curtains, would be utilized to attach the upper portion of the central truss to the top, underside of the aerostat, Figure 29, to provide a means to distribute, more uniformly, the buoyant forces generated by the helium in the aerostat. This would be part of the Aerostat Subsystem and the design, with its interfaces to the central truss, would be a coordinated effort amongst the engineering personnel involved in the Structure and Aerostat Subsystems, as well as with the subcontractor selected for support of the aerostat activities. All tunnel areas, as well as the bottom, load handling opening, will have helium barriers, designed into the interfaces between the aerostat and the structure, such that personnel safety is appropriately considered, along with the obvious concerns for loss of lift through leakage of helium.

The design personnel involved with the structure and aerostat integration must pursue extensive analyses to assess the interactions, e.g. expansion and contraction of the bag and flexing of the structure, between the two subsystems, to ensure that appropriate flexible-type arrangements are incorporated at pass-through points for structure. The major pass-throughs would be associated with the exit of the longitudinal structure through each end of the aerostat. The type of interconnection at these points could be very similar to the approach utilized by the X.2, where

the aerostat was allowed to expand or contract in a fore and aft direction about a fixed attachment between the aerostat and the longitudinal pass-through structure. The major design differences would be the size of the openings and the amount of flexibility needed.

It is noted, however, that in both cases there was, and is, a need to have an opening, which would also allow for passage of personnel, in either direction. The X.2 had a personnel passageway only at the forward end and it was to allow for personnel to enter from the outside housing directly into the centrally located ballonnet for a variety of reasons, e.g. preflight checkouts or maintenance and repair functions. The H.1 Cyclocraft, Figure 29, will have a requirement to enter the aerostat from the bottom area, up a ladder to the central structure and then through a passageway to exits at either end. The H.1 Cyclocraft's pass-throughs will be somewhat more complicated than those of the X.2, since the individuals will have to egress from the aerostat around the cyclorotors' bearings to get access to the engines and other items at the outer ends of the longitudinal structure. The intent is to have these fore and aft pass-through tunnels associated with an air environment, i.e. separated from the helium sections of the aerostat, although it will be standard practice for personnel to use Scott packs, or similar devices, when in these tunnels.

As shown on the schedule, the design teams from the Aerostat and Structure Subsystem areas will be integrated throughout the complete design, build, assemble and test phases of hardware development. Further, the Engineering Group's system engineering personnel will be active in overlaid activities relevant to the interfaces of this work with the other effected areas of the completed H.1 Cyclocraft System, e.g. Hydraulics and Engine Subsystems.

Cyclorotors, Bearings, Housings and Stalks. An individual cyclorotor consists of a basic structure of four stalks, which converge in a hub or housing, basically an "X" frame mounted on a bearing, which rotates around the central shaft. Those large bearings are located within housings, just fore and aft of the aerostat's envelope. The bearings will be in the range of 4-5 ft in diameter and might be available off-the-shelf from commercial sources, e.g. the shipping industry. If not available, engineering will develop the design specifications and have the units procured from outside sources. The configuration will likely be a conventional roller bearing type of approach, with races and a number of large roller bearings. The purpose of the bearings are to allow free rotation of the cyclorotors, as well as to provide the ability to transmit applied control forces and bending moments from the rotors to the main longitudinal structure of the H.1 Cyclocraft.

The bare cyclorotor structure, i.e. without wings/blades/propellers and associated hardware, will probably have a design for the stalks, which is composed of a combination of truss work and tubular sections. The cyclorotors are 132 ft in diameter and the individual stalks, mounted on their bearings, would be a few feet less. The wings and propellers will be mounted at the extreme ends of the stalks and the 40 ft blades would be just below those assemblies, leaving 20+ ft between the end of the blade and the housing that encompasses the bearing. Thus the stalk structure could be composed of a short truss framework, e.g. 2-4 ft for attachment of the wings/propellers, transitioning to a 40 ft tubular section for mounting of the blades, which, in

turn, would transition to a 20+ ft truss section, which is attached to whatever collar structure is employed around the bearing to which it mounts. The internal, 20+ ft portion, could also be further stiffened in the plane of rotation through the use of cables running from stalk to stalk, attached below the blades. To achieve light weight and strength, the stalks would employ the latest material technologies employed in the aircraft industry. Consequently, it is expected that the MRC team would develop the criteria and specifications for the design but would, through subcontract, acquire the basic cyclorotor structure from outside commercial sources.

As in other designs, the system engineering personnel from the MRC team must be involved from the start in criteria and interface definitions for the cyclorotors and their interactions with other hardware areas, e.g. the Hydraulic, Engine and Propeller Subsystems. In the case of the cyclorotors, there will be a design team involved during the early design phases, composed of members from the interfacing subsystems, as well as from the subcontractors involved in key hardware areas.

The present thinking is that each cyclorotor will be driven by a pair of gas turbines or turboshaft type engines (see Engine Subsystem discussion) to provide redundancy for reliability purposes. Consequently, the integrated installation of a cyclorotor, its housing, the engines and their fuel sources, plus the hydraulics and other accessories, will occur along the external portions of the central longitudinal structure for the H.1 Cyclocraft. Conceptually, MRC believes that this can be accomplished in a meaningful manner by mounting some of the noted hardware on the rotating portions and other equipment, e.g. the engines, on a non-rotating portion, which then uses power splitting techniques for transmission from that point, through the rotating section, to the individual propellers on each stalk. Conceptually, the approach has not been defined and that task will be of first priority for the design team selected to work in this overall design area.

Cab, Mounting Structure and Landing Gear. As shown on Figure 29, there will be a crew cabin on the underside, forward portion of the aerostat, which will accommodate a pilot and copilot, as well as two load handling personnel during flight operations. The mounting structure for this cab will be supported by the main longitudinal structure and the truss framework that supports the load handling frame. As such, it and the supporting foundations for the two ballonet assemblies and the tricycle landing struts, will be engineered in concert with the work that will be ongoing by the design team associated with the Aerostat and Structure Subsystems. The cab, itself, will be built of composite materials and will emulate, to a large degree, the interior of a helicopter with respect to instrumentation panel, controls and seating arrangements for the pilot and the copilot. The aft portion of the cabin will house a variety of other hardware or equipment, e.g. portions of the Air Computer Subsystem, and will provide space for the two load handlers and their associated equipment needs, e.g. communications system. MRC expects that the basic requirements for the cab will be developed within the MRC team, but the complete unit will likely be subcontracted to an appropriate supplier.

As is indicated on Figure 26, the H.1 Cyclocraft will have a tricycle landing gear, one steerable unit in front and two, non-steerable units at the rear. The struts for these will be anchored to structure at the underside of the aerostat. Again, as with the cab, the necessary structural points

for attachment will be at the aerostats surface and they will be integrated, appropriately, into the central, longitudinal truss and the vertical, load handling truss frameworks.

Controls Group

The controls for the H.1 Cyclocraft are effected by the Air Computer and Hydraulics Subsystems. Fundamentally, the control concept is predicated on the previous, successful, hardware experience with the X.2, which was tailored to a helicopter-type control approach. In fact, a modified Huey was directly used by the pilot and copilot. Thus the controls are aligned to conventional manual and foot inputs of a helicopter, as follows:

<u>Control</u>	<u>Response</u>
Fwd/Aft Stick	Pitch Rate
Left/Right Stick	Lateral Velocity
Rudder Pedals	Yaw Rate
Collective Stick	Vertical velocity
Twist Grip	Forward Velocity

The engineering personnel will utilize the history from the X.2, as well as the empirical data obtained from the current 42 ft subscale dual-rotor cyclocraft, as direct inputs into the development of the design for the H.1 Cyclocraft's controls. Conceptual work by MRC, to date, has determined that each cyclorotor will have its own computer for input/output functions and the necessary synchronization, or coordinated control of both cyclorotors will be accomplished electronically, i.e. via a master computer, or controller. The block diagram for the contemplated approach is depicted in Figure 19.

It is noted, that the noted control structure was utilized, successfully, in the 42 ft cyclocraft, with one obvious variation, i.e. for low cost purposes, the 42 ft cyclocraft's controls were built around a mechanical link, i.e. a shaft, between the two cyclorotors, to maintain synchronization. This resulted in a number of problems which substantiated the initial thoughts by MRC for an electronic link. In addition, a mechanical linkage in the full scale H.1 Cyclocraft, i.e. 350+ ft in length, would require very difficult design approaches.

At this point, the intent is to have the computer for each cyclorotor generate positional information for the wings, blades and the throttles with respect to the cyclorotor's angular position, via a shaft encoder. The shown Master Controller, which would likely be contained within one of the two computers, operates on the gathered data and, based on commands, provides the necessary synchronization inputs to the individual cyclorotors. That does not necessarily mean that each of the, likely counter-rotating, cyclorotors are a mirror image of each other. The algorithms to be developed for specific control functions may result in a number of differences, between the two cyclorotors, in response to commands at a given point in time. Those commands, as discussed earlier, will result in the H.1 Cyclocraft having flight capabilities of both a helicopter and a conventional aircraft. Further, as was demonstrated in the X.2 and

the 42 ft cyclocraft, both static and dynamic stability characteristics can be achieved through the application of very conventional, control hardware approaches. Each of the Subsystems are discussed in the following subsections.

o Air Computer Subsystem

This subsystem combines, through a fiber-optic or hardwired local area network (LAN), the two flight computers and their remote data collection and control units. The computer portions provide formatted commands for control of wings, blades and stalks, along with the power settings of the propulsion units in response to (1) pilot inputs, and (2) various sensor or data inputs from airborne elements, e.g. positions, rates, accelerations, temperatures, pressures, stalk angles, fuel weight and airspeed over the wings. Basic control modes are the following:

<u>Aircraft Maneuver</u>	<u>Implementation</u>	
	Control	Movement
Forward flight	Blades	Collective
Ascent/Descent	Wings	Cyclic*
Lateral Motion	Wings	Cyclic*
Yaw	Wings	Cyclic**
Pitch	Wings	Cyclic**

*Fore and Aft cyclorotors operate in unison

**Fore and Aft cyclorotors operate differentially

The design philosophy to be employed by the MRC team is to make the subsystem (1) fail-operational for single faults and (2) fail-safe for multiple faults. Reliability is an underlying goal for the complete H.1 Cyclocraft System.

The hardware approach for this subsystem does not require anything new; previous designs in the X.2 and the 42 ft cyclocraft provide a solid foundation for what is needed. The software aspects, e.g. development of control algorithms, will require considerable effort, involving coordination with other interactive subsystems and upgrading, or developing new computer models for the H.1 Cyclocraft. As noted on the schedule, the Aerodynamic, Hydraulic and Propeller Subsystems have clear interactions with this area of activity and, as such, in the early design phases, there should be close coordination to facilitate appropriate design approaches. Beyond this, the existing MRC computer models for the dual-rotor cyclocraft provide some fundamental insights into control issues, but they do not provide the kind of needed information which could be derived from a dynamic tool, e.g. a six degree-of-freedom mathematical model. MRC, however, believes that there are approaches which would preclude the necessity for extensive computer model developments.

One such approach would be very similar to that accomplished in the X.2's flight control development. Fundamental engineering approaches, with very limited model support, were

utilized to determine the ballpark requirement for control of the cyclocraft. This provided for selection of the control system's hardware but not clear identification of the specific "gains" that might be necessary for proper control during flight. This resulted in the incorporation of an ability to vary the gains for optimization during the prototype development process. Initial, tethered flights of the X.2 had gain control inputs available to the test pilot and copilot, so that they could tune the various control loops for, initial, safe operation. Subsequently, off of the tether, these gains were further assessed for appropriateness during free flights. These approaches are very reasonable for a cyclocraft type vehicle since one is not dealing with high speeds or the fast reactions associated with those speeds, e.g. in a fighter aircraft. Although it is noted that there are existing aircraft development programs which use a baseline flight control system with very conventional components and an on-board software package which can accept external inputs for varying the gains within the flight control loops. e.g. hook-up a properly programmed personal computer to assess the on-board software and provide input for change.

Part of the early design process for the flight controls will involve evaluation of the options available and the determination of a cost effective approach. The MRC team expects that the requirements will be developed in-house and that a subcontract will be let for the acquisition of the needed subsystem, since the requirements might be met by existing off-the-shelf hardware, directly or with little modification.

o Hydraulic Subsystem

The approach for this subsystem will involve close interaction with the Aerodynamic and Engine Subsystems, i.e. the hydraulics could be powered by an independent source or through a take-off from the engine pad and the hydraulics drive the servos which control the wings, blades and stalks. Here, as for all areas, reliability is a fundamental goal. Consequently, it is envisaged by MRC that there will be two independent hydraulic subsystems per cyclorotor, operating in parallel, each aligned to two stalks. The make-up of the hydraulics requires considerable evaluation before the final selection. If an engine pad were used to acquire power there would be a requirement to transfer the pressurized fluid through the rotating bearing section of the cyclorotor up each of the four stalks to the individual servo valve areas for the wings, blades and stalks. On the other hand, if the power was provided from another source, e.g. electric motor or small engine for a pair of stalks, on the rotational side of the bearing, it could simplify the mechanization. These tradeoffs will be accomplished early on and the design will be finalized by the MRC team. Most of the hardware is expected to be available off-the-shelf, through direct purchase.

Propulsion Group

This group is comprised of the Engine, Propeller and the Fuel Subsystems and are briefly discussed in the following subsections.

o Engine Subsystem

As discussed in Reference 4, the intent is to provide a pair of engines at each cyclorotor, to provide parallel input of the required SHP, i.e. the combination provides 2500+ SHP. That selection from a number of options was considered to be the one that affords the greatest reliability, i.e. failure of one engine would still allow for rotation of the affected cyclorotor at a lower rate which would automatically correct, through appropriate control sensors, the other cyclorotor's rate to stabilize the vehicle. The cost and weight penalties are considered to be nominal in comparison to the resultant enhanced reliability, and thus increased safety.

The design approach to packaging and integration of the subsystem with the other closely related hardware will require considerable thought. Presently, the Engine, Fuel and, maybe, portions of the Hydraulic Subsystems, are planned to be located at the outer ends of the H.1 Cyclocraft's central, longitudinal structure, on the outboard sides of the two cyclorotors. This presents a number of design problems, e.g. how to provide for the transmission of power through the bearing and up the individual stalks to drive the propellers or how to orient the engines such that the exhausts, with some thrust and temperature, can be properly handled. Conceivably, the two engines could be mounted above and below the central longitudinal structure at some angle off the centerline, with right angle drives from their power take-off points through the center of the central longitudinal structure, to a four-way split right angle gear box, up through the bearing and along each of the stalks. A pair of two-way split gear boxes could be considered, arranged such that each engine's output is aligned to a pair of opposing stalks. The angled positions of the engines would allow for an easier solution to the handling of their exhausts, e.g. through deflectors, or other means, to divert or control the thrust and temperature effects on areas of concern.

Beyond the design issues, the actual selection of suitable engines is another area that will require considerable thought. As noted in Reference 4, an objective would be to select off-the-shelf designs that are currently being used by helicopter operators in the oil and gas regions of interest. This would provide ready availability of knowledge with respect to design issues, as well as downstream benefits with respect to maintenance and operational applications. In addition, MRC expects that a suitable helicopter operator in the region would be a potential addition to the anticipated team for this development program.

MRC expects that the complete design for the Engine Subsystem will be effected by a combination of in-house engineering and the participation of the potential helicopter operator. The resultant hardware will likely be available off-the-shelf from a variety of suppliers, while the assembly and installation will be effected by Unifab at the Home Base.

o Propeller Subsystem

The intent at this point is to have three bladed, fixed pitch propellers, of some 12-15 ft diameter, mounted above the wings, on each of the stalks of the two cyclorotors. As noted above, the power from the engines is routed through the cyclorotor's bearing and up the stalks by shafts

to the individual propellers. Though not yet fixed, the propeller's maximum speed will likely be in the range of 800-1000 RPM, which will impose fairly significant speed reduction, through gearing, between the engine and the units.

For this subsystem MRC believes that the requirements can be realistically projected by in-house engineering and that a subcontract would be structured for outside procurement from a recognized supplier.

o Fuel Subsystem

The fuel tanks which will be located outboard of the engines, from the aerostat, will require a single fuel point at the bottom. These tanks pose no serious design problem and, in fact, there may be suitable units available, off-the-shelf, from outside suppliers. The engineering group in-house will spell out the requirements and procure the hardware, if available, from outside sources. If not available from suppliers, Unifab will design and build the tanks.

6.5.2 Ground Support Equipment (GSE)

Figure 10 shows that there is a wide variety of GSE involved with the H.1 Cyclocraft System. A large number of those items, e.g. anchors, dollies, generators, checkout tools, batteries, start carts, APUs, computer, protractors, hydraulic benches, hoses, Poly pipe fusing kits and Scott packs, are readily available through direct purchase from suppliers. Other items, e.g. tractors, trucks, portable lights, hard hats, and welding equipment, would be available from the inventory at Unifab. A few items would be available through agreements with local municipalities, e.g. fire trucks and ambulances, on a nominal cost basis. There are only a limited amount, noted to this point, which will have to be specially ordered or designed and built, e.g. Ballast Tank, helium purifier, balance table for propellers, weather station, handling structures, work platforms, load links, tailored cargo nets, mobile stands and communications network.

The GSE design team will be responsible for the definition of requirements for all items that will be purchased, or subcontracted, from outside. Units such as the Ballast Tank, Poly pipe clamshell, balance table, mobile stands and handling structures can be fabricated and assembled by Unifab. The helium purifier is a special case item which may only be available, i.e. the design or a unit, through limited sources and it will likely be the subject of a subcontract with the chosen source.

8.6 Fabrication and Assembly

In the early program phases, the detailed plans for upgrading or adding to the existing Unifab facilities must be completed so that they can make the alterations in a timely fashion. The largest of these relates to the "add-on", Figure 25, contemplated for the putting together of the aerostat and the final assembly of the H.1 Cyclocraft. The portion related to the sewing, taping and shaping of envelope panels, gores and whatever else will be formed from those materials, e.g.

tunnel sections, will be approximately 400 x 300 feet with a ceiling height on the order of 15-20 ft. The aerostat can be cut, sewed, taped and sealed in whatever forms required without the need for a clean room or environmentally controlled area, but it must be protected from the elements. The final assembly area must be 400 x 200 feet also, but it needs a ceiling height of 200+ ft. Also, that ceiling will probably require the means for installation of traveling hoists for access to the top of the H.1 Cyclocraft, as well as for other duties.

Overall facility needs will be initially outlined in the Baseline Package, prior to go-ahead, and these will be upgraded as the team is put in place at the start of the program. Unifab will have the responsibility for the implementation of defined requirements.

As noted earlier, Unifab has an infrastructure in-place that will form the major nucleus of the fabrication and assembly organization, e.g. contracts, procurement, quality control and manufacturing. The MRC team will add others to this framework, e.g. electronic technicians, riggers, engine mechanics, computer technicians and envelope fabricators. The MRC team, including Unifab, will develop guidelines for the interactions of various members' organizations at the outset, in conjunction with the formulation of the development program's organization.

As noted on the schedule, the early activities generally focus on long lead time procurement, the modification and additions to facilities, the procurement of piece parts and fabrication and assembly of mock-ups or other hardware items for early engineering evaluations. Beyond these are the fit and function type of units that are planned to be built to assess assemblies or subsystems at various points in their development. Most of these would evolve from the engineering groups. Key phases of the schedule are discussed in the following paragraphs.

o Long Lead Procurement

Many of the requirements for outside acquisition of hardware and services, involve significant lead times to actually get them into the fabrication and assembly processes. As the MRC team develops the make-or-buy determinations, those pieces or groups of hardware, which are of greatest concern timewise, receive the highest priority actions. On the front end, those actions include the time necessary to spell out requirements for outside acquisitions, which can involve considerable in-house assessment before procurement documentation can be prepared. Examples of system hardware, which may fall into these categories, include the aerostat, structure, engines, flight controls and helium purifier. All of these require a fairly significant amount of system, subsystem and design engineering efforts, before such procurement documents can be realistically prepared. That preparation process may be further complicated if it is necessary to acquire technical support from a potential supplier in the development of the hardware specifications, which, may also require an interactive process with ongoing engineering for other subsystems, in-house.

At this time, MRC believes that there are two areas that may involve this sequential approach, i.e. the aerostat and the flight controls, and most other outside procurement can be effected through contact with suppliers, along with the in-house development of procurement specifica-

tions. In the case of the aerostat, it is expected that the MRC team will develop a subcontract with a suitable source for initial engineering aimed at mutual definition of the criteria for the complete Aerostat Subsystem, with agreed to options for subsequent subcontract efforts. The subsequent subcontract, again with some mutual definition of needs, will require the selected firm to, at least, (1) pursue the engineering and test necessary to select suitable materials for the bag, tunnels and ballonets, (2) support the mutual development, with the MRC team, of the detailed design of the Aerostat Subsystem, (3) acquire all of the materials needed to fabricate a complete aerostat and the two ballonets, (4) provide, with all materials and processes necessary, direct support at the Unifab, Add-On facility in the construction of, and assembly of the aerostat, tunnels and ballonets, and, subsequently, (5) support the integration of the aerostat, tunnel and ballonets with the H.1 Cyclocraft's Structure Subsystem in the final assembly area at New Iberia.

For the flight controls, the MRC team's engineering personnel must, at least, complete a performance specification for the subsystem before they can consider talking to potential subcontractors. Then, engineering will be in a position to develop a statement-of-work for the required hardware. The probable subcontract would be fairly comprehensive, requiring (1) detailed design and test phases, with review milestones, (2) specific criteria with respect to the building and delivery of a prototype subsystem, with any critical spares, and (4) providing support to the MRC team during subsequent program phases, through FAA certification.

Items such as the Helium Purifier pose other procurement issues. At this point, MRC is only aware of a few possible sources for working units, which are of limited "through-put" capacity. The possible units are assumed to have patent, or other protection on the designs, and those that really work may have busy schedules. Consequently, the only avenues may be (1) through subcontract, make arrangements with one of the sources for the building of a suitably sized unit for purchase or lease by the MRC team, (2) through subcontract, have one of the sources build a suitably sized unit for which they will provide service as required throughout the development program, or (3) acquire rights from a suitable source for the MRC team to use in the building of their own, suitably sized unit. On the schedule, option three is shown.

Most other procurements will be straightforward, not requiring significant lead times, i.e. well below the periods shown for some of the above.

o Facility Modifications

As discussed, above, and shown on Figure 25, the major modifications required to the Unifab facilities is the Add-On to the major assembly area. Beyond those, for the fabrication of aerostat material and the final assembly of the H.1 Cyclocraft, Unifab will have other requirements which will call for additions or modifications to existing buildings, or possibly totally new installations. During the development of the Baseline Package, most of these needs will likely be able to be spelled out, some may await initial program phases before they can be defined.

Based on current thoughts, MRC would expect that facility modifications would be necessary

to incorporate some mock-ups, allow for fit and function checks for some subsystem areas and facilitate movement of major subassemblies from the building contiguous to the final assembly Add-On. The potential mock-ups, without specifying where they will be located, are discussed under "Mock-Ups", later in this section. They would require significant space, area and height. An example of a fit and function need would be a set-up for receiving inspection of propellers, which would need a power driven source to rotate the units for acceptance and calibration purposes. The cyclorotor subassembly, consisting of a complete cyclorotor with its bearing, blades, wings, propellers and possibly hydraulics installed, would be completed, in a upright position, in the existing building next to the add-on for the aerostat and H.1 Cyclocraft final assembly activities.

Such facility modifications as are necessary for the above, as well as for conditions yet to be defined, will generally have more than adequate time spans for their accomplishment, prior to the actual need date.

o Mock-Ups

A number of mock-ups are desired to support the evolving engineering for particular areas of system design. These, in most cases, would be totally mocked-up hardware units or assemblies, constructed of wood, cardboard, etc, during early program phases, to support engineering evaluations, i.e. the relationship between subassemblies. Later, they could be replaced by actual hardware for operating investigations, and further they might support receiving inspection of hardware from outside sources, i.e. checking fit and function with interacting elements. Possible examples are noted in the following:

(a) Engine installation mock-up. Beginning with wood or other light material, develop an installation set-up which depicts the major elements of hardware that would be involved in the engine, hydraulics, fuel and cyclorotor bearing designs associated with getting power from the engines to the propellers, i.e. sizes, relative positions, gear boxes and shafts involved. As the program evolves, replace mock-ups with actual hardware to evaluate fit and function aspects. This mock-up does not include stalk and propeller.

(b) Cyclorotor installation mock-up. As hardware becomes available, set up two positions which allow for upright assembly of the cyclorotors, i.e. including pseudo shaft, with bearing, stalks, blades, wings, propellers, shafts, servos and other hardware that will be part of the completed rotational elements of a complete cyclorotor. These set ups will be utilized for fit and function testing of the final prototype cyclorotors. Handling methods and devices will be engineered to allow for movement of these units into the main assembly area after the Aerostat and Structure Subsystems are integrated.

(c) Cargo handling installation mock-up. Initially build a wooden replication of what is planned for the Load Handling Frame for use in assessing optional approaches for the design of load links and an aramid cargo net for load handling. The Load Handling Frame should be about 30-40 ft in the air for these evaluations, and it should be strong enough to support pseudo load

handling personnel. When actual hardware is available, use it in place of wooden mock-up to evaluate fit and function, or other design options as warranted.

(d) Tunnel installation mock-up. Build a fabric and frame mock-up of a section of the internal tunnels which will be used inside the aerostat to evaluate (1) routing approaches for fiber optics and electrical wiring, (2) means for attaching fabric to top and side frameworks, as well as to a solid floor panel and (3) assessing options for the introduction of sealed doorways at one end of the tunnel.

(e) Aerostat and structure subscale mock-up. Build a subscale model, using suitable flexible materials and pseudo trusses, to allow for the assessment of options on how to put the aerostat together, such that it can be readily wrapped about the internal structure in the final assembly phase. The mock-up of the aerostat material should also facilitate the evaluation of pattern techniques for marrying received, standard panels from a supplier into shapes that facilitate that assembly process, i.e. ease of integration with the structure and portable methods for closing seams or openings of the aerostat.

o Subassemblies

The schedule indicates the estimated times expected for the major subassemblies contemplated. With one exception, most of the planned subassembly phases would be a normal marrying of hardware into a unit that would be available for final assembly phases of the H.1 Cyclocraft System. That exception, discussed previously under Section 8.5.1, is the Aerostat and Structure Subsystems.

Fundamentally, the plans for the integrated assembly of those two subsystems is the foundation for the final assembly process of the H.1 Cyclocraft System. The key to that process, conceived and discussed in References 4 and 5, is the water Ballast Tank, a piece of GSE to be designed, that will be used throughout the final assembly phases. That tank, shown on Figures 25 and 26, is approximately 7 x 15 x 18 ft in size and can carry up to 113,000 lb of water. Thus, assuming the tank weighs 10,000 lb, the unit can provide a load of 123,000 lb, which would allow filling of the aerostat with helium, after only the Aerostat and Structure Subsystems are completed, i.e. missing all other airborne hardware. In other words, keep the assembly on the ground, even with a full complement of helium, which provides an aerostatic lift of nearly 206,000 lb.

Consequently, the final assembly phases will begin by locating the water filled, Ballast Tank at the center of the final assembly portion of the Add-On facility, depicted in Figure 25. The specific sequence of assembly for the two subsystems must be worked out during the early engineering phases, including the cooperative subcontract phase noted earlier with a qualified aerostat supplier. MRC would expect that the Ballast Tank would be placed directly on the floor, without a skid, dolly or wheels, for the initial phases. At that time, the major portions of the Structure Subsystem, i.e. the central longitudinal truss and its "subtruss" that extends downward to the Load Handling Frame, would be mounted directly to the Ballast Tank. The interface would be the Load Handling Frame, itself. Additional, artificial supports might be needed to

keep the complete structure balanced properly on the Ballast Tank at this point.

The subsequent sequences would have to do with the movement of major portions of the completed aerostat, from the contiguous area where its manufacturing was taking place, to selected positions around the in-place structure for the final wrapping of the aerostat around the Structure Subsystem hardware. The details of this process can only be estimated at this point, since considerable engineering is required, with an array of trade-offs before realistic approaches can be codified. The historical manufacturing and assembly technology for non-rigid LTAs does not provide much guidance. For non-rigid, blimp configurations, the usual mode was to put, basically the complete aerostat together on a large open floor space. Then, to fill it with air, under pressure, to look for leaks or other problems and, then add the gondola or cab, displace the air with He and do the final checking of integrity. For these phases a large bridle of rope (like a big cargo net) was usually placed over the aerostat and anchored to the ground with sandbags or other means to keep the aerostat from floating up when filled. In fact, that bridle was usually left on until all of the airship's hardware was installed such that it was near neutral buoyancy and could be rather easily tied down.

The H.1 Cyclocraft's design will be completely buoyant without the planned payloads and, thus, there is a need for the Ballast Tank during assembly, as well as in subsequent system phases of activity, e.g. moving on the ground or in the air, with the Ballast Tank set, by water level, to a weight that establishes neutral buoyancy for the aircraft, or any other desired buoyancy or non-buoyancy condition. There are a number of approaches for the subject process that have been discussed, but none of them are based on a rigorous engineering evaluation at this time. MRC believes, however, that concerted efforts by in-house engineering in concert with a recognized aerostat builder, should result in meaningful and cost effective solutions. The other subassembly areas, e.g. Engine, Propeller, Hydraulic and Fuel Subsystems, will be facilitated by the mock-up approaches discussed earlier and pose no serious problems with respect to final installation on the central structure or cyclorotors, after the aerostat and structure are completed.

o System Assembly

This has been essentially discussed for the cyclocraft and the schedule depicts the estimated time involved. The final GSE units, assemblies or subsystems, have no perceived schedule problems and the timeframe depicted for GSE easily encompasses the availability dates anticipated for all items shown on Figure 10.

8.7 Test and Evaluation

The component, subassembly and subsystem testing includes exploratory type of early engineering evaluations, including mock-ups as discussed above. It is expected that these would involve a fairly normal level of investigation in each of the subsystem areas for the complete airborne system and they would be accomplished in the time periods shown. Details would await initial phases of planned development efforts in the engineering and design phases.

System tests are more predictable. After the complete cyclocraft has been assembled and checked out for proper functioning, there would be both ground and flight test sequences planned by the MRC team to assess the complete suitability of the hardware. As for significant subsystem testing, the system tests would require that appropriate test plans were developed covering the objectives, test procedures, requisite data needs, associated instrumentation, data acquisition and analysis requirements and the format for reporting results. The ground tests would have key objectives with respect to mobility, stability and interactions with GSE. Flight tests would address airworthiness, envelopes of performance, handling of payloads and all facets of the expected operational scenarios.

8.8 FAA Certification

The intent by the MRC team is to have established a datum of FAA requirements during the development of the Baseline package, which is a forerunner of the go-ahead for this program, and to have a continuing interaction with that organization throughout the conduct of the complete program. Hopefully, the planned ground and flight tests which are considered to be standard type of approaches for aircraft development, would serve most of the FAA's requirements for the attainment of an initial certification for the prototype H.1 Cyclocraft System. In parallel with this, MRC would elicit the needs of the FAA with respect to full certification of the planned production follow-ons for a fleet of H.1 Cyclocraft systems.

8.9 Program Risks

MRC was asked by the DOE to identify program risks and to develop contingency plans for their resolution. In that regard, MRC's interpretation is that the risks of concern are those which would obviate meeting, within some reasonable variances, the planned mix of schedule, cost and desired performance for the prototype H.1 Cyclocraft System.

Assuming that the funds asked for are provided, MRC would take the position that the schedule and targeted performance for the system would, under reasonably projected success, have a low level of risk associated with their achievement. This assumption would probably be valid if the planned, prototype H.1 Cyclocraft System was backed by historical hardware developments that provided significant similitude between them and the H.1 Cyclocraft System. In that respect, the cyclocraft field of reference includes the initial, successfully flown experimental X.2 single-rotor cyclocraft, related engineering evaluations on many derivatives, the current flight testing of a 42 ft subscale dual-rotor cyclocraft and, the paper definition of the H.1 Cyclocraft System. All of which contain significant similitude in many areas, e.g. cyclorotor technology, hardware configurations, mathematical models, fabrication and assembly approaches, test and evaluation techniques and the feasibility of flight. Of key importance is the fact that the flight feasibility, for both single and dual-rotor cyclocraft configurations, has been clearly demonstrated. Despite this background, it is also recognized that the work to date has not included a cyclocraft configuration of the size of the H.1 Cyclocraft prototype. The aerostat of the X.2 was 330,000

cu ft, while that of the H.1 Cyclocraft will be 3,637,230 cu ft. In addition, although there were extensive, successful ground and flight testing of the single-rotor X.2, there has been only been limited testing of the 42 ft subscale dual-rotor cyclocraft planned for the H.1 Cyclocraft.

With respect to the above, MRC would contend that the hardware and engineering data base provides substantial arguments in support of the MRC consideration that the proposed development program should be of low risk. Size, of itself, does not negate the feasibility of the concept for flying as expected. However, we would be remiss if it was not noted that there are potential areas of hardware risk, which are associated with the H.1 Cyclocraft's dual-rotor configuration and size. Those areas of concern would include (1) safety issues associated with the malfunction of a cyclorotor in flight, (2) contending with the large amount of buoyancy associated with the unloaded H.1 Cyclocraft, (3) developing a reasonable approach to the fabrication and assembly of the integrated aerostat and internal structure. No other areas are considered to be of any real risk with respect to schedule, cost and performance.

MRC has addressed the above areas of concern and have introduced approaches for their resolution within the context of previously discussed material, amplified in the following paragraphs:

(a) Malfunction of a cyclorotor in flight. In a helicopter this would be similar to an engine out situation where, on single engine rotorcraft, such a condition results in lack of power to the rotor and a crash. The helicopter solution has been to employ twin-engine configurations. MRC is proposing a similar solution for the H.1 Cyclocraft by providing twin-engines for the powering of the propellers, which drive the cyclorotor. As discussed in the design section, the detailed design is yet to be worked out, but MRC believes the solution will provide the elimination of the associated risk.

(b) The large unloaded buoyancy condition of the H.1 Cyclocraft could lead to difficult situations when the vehicle is unpowered on the ground. MRC has already identified the use of a Ballast Tank for unloaded conditions on the ground and for ferry applications of the aircraft, between landing locations, without a normal payload. This solution eliminates the inferred risk of too much buoyancy and provides an additional realm of stability for mooring the vehicle in a fixed position on the ground, rather than a nose mooring solution, which is a weak point for operational deployment of conventional LTAs.

(c) Fabrication and assembly of the large aerostat with its integral, internal structure. The integrated aerostat/structure, of course, provides the strength that is inherent to a cyclocraft configuration versus conventional LTAs. However, as noted in the previous discussions, it poses difficult issues with respect to the methods for cost effective fabrication and assembly of the unit. In fact, there are no comparable methods for reference, i.e. associated with a large aerostat made of, usually, a multiple lamination of material backed with a strong textile base, but still very light weight. MRC presented the approach to a solution in previous material, which was (1) to utilize a design team approach with members gathered from the interacting subsystems, aerostat and structure, in-house, and (2) a close participation in the evolution of that design,

construction, and assembly phases by a recognized, aerostat supplier. Further, as noted in the mock-up discussions, there is planned to be a subscale, ongoing assessment of options to facilitate the achievement of desired results, prior to the start times for full size integration activities. MRC believes this approach will eliminate the identified, potential risk.

9. Operating Cost Study

9.1 Study Ground Rules

The basic scenario for supporting oil and gas drilling and production operations, as previously used in the parametric study discussed in Section 5, also provided the basis for the cyclocraft operating cost study reported in this section. The latter study also addressed significant departures from the basic scenario for several of the operational parameters, in order to determine the sensitivity of the H.1 Cyclocraft operating cost to those parameters. The scope of the sensitivity studies is addressed in Section 9.2. Table 53 shows sample utilization and productivity that could be accomplished by the H.1 Cyclocraft.

Table 53. Utilization and Productivity of the H.1 Cyclocraft

Endurance	5 Hours
Maximum Airspeed at Max Weight	67 MPH
Number of Work Days per Annum	180
Average Refuels per Work Day	1.25
Average Operating Hours per Work Day	9.58
Unproductive Operations per Work Day	2 Hours
Annual Utilization	1,725 Hours
Productive Utilization	1,365 Hours
Number of Pilots per Cyclocraft	3.5
Average Time per Delivery Round Trip	1.25 Hours
Number of Delivery Round Trips per Annum	1,092
Maximum Payload with Full Fuel	45 Tons
Average Payload	40.5 Tons
Equipment and Materials Delivered per Annum	44,226 Tons

To support the most realistic evaluation of the economics associated with operating H.1 Cyclocraft to support oil and gas drilling and production in wetland areas, care was taken in structuring the bases for each component that makes up the total operating cost of the H.1 Cyclocraft. The basis for computing the Ownership Costs of the H.1 Cyclocraft operations is given in Table 28. The bases for computing the Annual Operating Costs and the Hourly Operating Costs for the H.1 Cyclocraft operations are presented in Tables 29 and 30 respectively.

In the cyclocraft parametric model, described in Section 5.2, the acquisition cost of cyclocraft components and phases in the development program, are expressed in the following manner:

$$\text{Cost of each component/function} = \$(1,000.x + y.\text{vol} + z.\text{SHP})$$

The values of the coefficients x, y and z for a prototype heavy lift cyclocraft have been developed and are shown in Table 31. The coefficients are based on data obtained from the X.2 Cyclocrane and related programs, e.g. LTA and light aircraft. Note that the cost coefficients given in Table 31 are for a large heavy-lift commercial cyclocraft, with very restricted FAA certification. A cyclocraft designed to meet military standards would cost substantially more. The values shown in Table 31 were used in the H.1 Cyclocraft operating cost study, using appropriate values for the aerostat volume and installed power. The component costs derived for the prototype H.1 Cyclocraft are given in Table 54.

Table 54. Prototype H.1 Cyclocraft System Component Costs

Component/Function	Cost (\$ millions)
Project Management	1.757
Engineering/Design	2.704
Aerostat	5.874
Structure	3.374
Cyclorotors	5.074
Propulsion	2.124
Controls	2.029
Crew Cabin	0.231
Landing Gear	0.374
Assembly	4.733
Helium	0.327
Payload Handling	0.237
Flight Test	2.573
Total Aircraft	31.411
G.S.E.	0.486
Spares	0.636
Total System	32.533

Table 55 shows how the unit H.1 Cyclocraft system, i.e. including spares and ground support equipment, costs change during a production run of up to twelve aircraft. The total fleet costs

and the average H.1 Cyclocraft system costs, for fleet sizes of up to twelve cyclocraft, are also given in Table 55. The table shows, for example, that for a fleet of six H.1 Cyclocraft, the total fleet cost is \$152,153,000 and average unit system cost would be \$25,359,000.

Table 55. Acquisition Costs of H.1 Cyclocraft Fleets

Number of Cyclocraft	Total Fleet Cost (\$ millions)	Unit System Cost (\$ millions)	Average Unit Cost (\$ millions)
1	32.533	32.533	32.533
2	57.708	25.175	28.854
3	82.127	24.418	27.376
4	105.801	23.675	26.450
5	129.113	23.312	25.823
6	152.153	23.039	25.359
7	174.966	22.814	24.995
8	197.592	22.625	24.699
9	220.047	22.455	24.450
10	242.359	22.313	24.236
11	264.545	22.186	24.050
12	286.616	22.071	23.885

The subject cost analysis was based on a very simple mission profile, i.e. repetitive cruise segments at a constant low altitude. Accordingly a simplified version of the MRC Cyclocraft Parametric Design Model, which is described in Section 5.2, was utilized in the cost study.

9.2 Scope of Operating Cost Study

As indicated above, the scope of the H.1 Cyclocraft operating cost study was based on perturbations about a basic scenario. The latter is defined in Section 5.1. The six operating parameters that were perturbed to determine their individual impact on the H.1 Cyclocraft operating cost were as follows:

- (a) Number of cyclocraft
- (b) Number of operational days per annum

- (c) Number of operational hours per day
- (d) Average payload carried
- (e) Cargo handling time per round trip
- (f) Average distance payload is carried

Values assigned to the parameters that were perturbed in the sensitivity studies, together with the baseline scenario values, are given in Table 56. The resulting operating cost sensitivity data obtained from these perturbations are given in Sections 9.3 through 9.7. The resulting total round trip times in terms of cargo handling time and distance payload is carried, are shown in Table 57.

Table 56. Values of Operating Parameters Studied

Variable	Baseline Value	Other Values Studied
Number of Cyclocraft	6	2, 4, 8, 10, 12
Number of Days per Annum	180	120, 150, 210, 240
Number of Hours per Day	10	6, 8, 12
Average Payload, tons	40.5	32, 35, 38, 42, 44
Cargo Handling Time, min/rt	15	10, 12.5, 17.5, 20
Distance Payload Carried, mil	15	5, 10, 20, 25, 30

Table 57. Total Round Trip Times

Distance Payload Carried (Statute Miles)	Round Trip Cargo Handling Time (minutes)				
	10	12.5	15	17.5	20
5	42.6	45.1	47.6	50.1	52.6
10	57.6	60.1	62.6	65.1	67.6
15	70.0	72.5	75.0	77.5	80.0
20	82.0	84.5	87.0	89.5	92.0
25	94.0	96.5	99.0	101.5	104.0
30	106.0	108.5	111.0	113.5	116.0

Note that the Round Trip Times given in Table 57, are in minutes.

The component operating costs for the H.1 Cyclocraft in the baseline scenario, which is defined

in Section 5.1, are tabulated in Table 58.

Table 58. Operating Costs in the Baseline Scenario

Depreciation	\$1,319.64	
Insurance	362.87	
Licenses and Taxes	109.31	
Operating Base	18.69	
Total Ownership Costs		\$1,810.51
Salaries - Pilots	\$92.75	
Mechanics	78.36	
Others	53.62	
Helium and Purification	42.10	
Total Annual Operating Costs		266.83
Fuel	\$599.09	
Oil	8.99	
Engine Maintenance	283.71	
Other Maintenance	197.34	
Total Hourly Operating Costs		1,089.13
Total Cost per Operating Hour		\$3,166.47
Total Cost per Ton Delivered		\$123.51

9.3 Cost Sensitivity to Fleet Size

A change in the number of H.1 Cyclocraft that comprise the operating fleet impacts the acquisition cost of the acquisition cost of the system, as shown in Table 55. Change in the H.1 Cyclocraft system acquisition cost impacts a number of the components that make up the ownership cost. Table 59 summarizes the changes in the ownership cost with variation in fleet size. In addition the fleet size has some impact on the annual cost; this impact is shown in Table 60. Note that fleet size has no impact on the hourly cost. The overall impact of a change in the H.1 Cyclocraft fleet size on the total operating cost is shown in Table 61.

Table 61 shows that reducing the fleet size from six to two adds 8.3 % to the total operating cost per hour; increasing fleet size from six to twelve gives a 3.4 % reduction in cost. The total cost per ton delivered varies proportionally to the cost per hour, reducing from \$133.82/ton for a fleet of two aircraft to \$119.30/ton for a fleet of twelve. It should be noted that smaller fleet

Table 59. Effect of Fleet Size on Ownership Cost

Cost Component	Number of H.1 Cyclocraft in Fleet					
	2	4	6	8	10	12
Depreciation	1,497.88	1,375.28	1,319.64	1,285.98	1,262.37	1,244.47
Insurance	413.72	378.74	362.87	353.27	346.53	341.42
Licenses & Taxes	124.38	114.01	109.31	106.47	104.47	102.96
Operating Base	18.69	18.69	18.69	18.69	18.69	18.69
Total Ownership	2,054.67	1,886.72	1,810.51	1,764.41	1,732.06	1,707.54

Table 60. Effect of Fleet Size on Annual Operating Cost

Cost Component	Number of H.1 Cyclocraft in Fleet					
	2	4	6	8	10	12
Salaries - Pilots	95.65	93.47	92.75	92.39	92.17	92.03
Salaries - Mechanics	81.01	79.02	78.36	78.03	77.83	77.70
Salaries - Others	68.11	57.24	53.62	51.81	50.72	50.00
Helium & Purifn	42.10	42.10	42.10	42.10	42.10	42.10
Total Annual Cost	286.87	271.83	266.83	264.33	262.82	261.83

Table 61. Effect of Fleet Size on Total Operating Cost

Cost Component	Number of H.1 Cyclocraft in Fleet					
	2	4	6	8	10	12
Total Ownership	2,054.67	1,886.72	1,810.51	1,764.41	1,732.06	1,707.54
Total Annual	286.87	271.83	266.83	264.33	262.82	261.83
Total Hourly	1,089.13	1,089.13	1,089.13	1,089.13	1,089.13	1,089.13
Total Operating/Hour	3,430.67	3,247.68	3,166.47	3,117.87	3,084.01	3,058.50
Cost/Ton Delivered	133.82	126.68	123.51	121.61	120.29	119.30

sizes reduce the cyclocraft availability to accomplish a particular task in a timely manner, whereas a larger fleet size might introduce more severe utilization problems.

9.4 Cost Sensitivities to Hours and Days Operated

Changes in the number of hours available per day and the number of days operated per annum have similar impacts on the total operating cost of the H.1 Cyclocraft, i.e. through the annual utilization of the system. Utilization and productive operating time are independent of the other four parameters varied in the study, i.e. number of cyclocraft in the fleet, average payload carried, distance payload is carried and the payload handling time per round trip.

The relationship between the number of available hours per day and the number of productive operating hours per day is shown in Table 62. Note that the difference between number of operating hours per day, i.e. daily utilization, and productive hours per day, is the assumed one hour of non-productive operation at both the beginning and end of each day in flying from forward base to the loading barge. This assumption may prove to be too conservative however.

Table 62. Daily Utilization and Productive Hours

Number of Hours Available per Day	Average Number of Refuels	Utilization in Hours per Day	Productive Hours per Day
6	0.80	5.86	3.86
8	1.00	7.33	5.33
10	1.25	9.58	7.58
12	1.90	11.37	9.37

Both ownership cost per hour and annual operating cost per hour are dependent on annual utilization. Hourly cost is directly proportional to utilization and hence hourly cost per hour is independent of the number of hours operated. The effect of the number of operating days per annum on the total operating cost per hour is given in Tables 63, 64, 65 and 66, for 6, 8, 10 and 12 available hours per day, respectively.

Tables 63 through 66 show that both the number of days operated per annum and the number of hours available per day, have significant impact on the operating cost per hour, e.g. operating for 120 days of 6 hours per day availability, results in hourly operating cost of about two and a half that for 240 days of 12 hours availability. The impact on cost per ton of payload delivered is even greater, providing a factor of over three for the same two cases. The latter impact is due to the higher ratio of productive hours to operating hours in the longer days.

Table 63. Effect of Days per Year on Total Operating Cost, for 6 Available Hours per Day

Cost Component	Number of Operational Days per Annum				
	120	150	180	210	240
Total Ownership	4,439.76	3,551.81	2,959.84	2,537.01	2,219.88
Total Annual	519.63	434.26	377.34	336.68	306.19
Total Hourly	1,089.13	1,089.13	1,089.13	1,089.13	1,089.13
Total Operating/Hour	6,048.52	5,075.20	4,426.31	3,962.82	3,615.20
Cost/Ton Delivered	283.39	236.95	207.39	185.67	169.38

Table 64. Effect of Days per Year on Total Operating Cost, for 8 Available Hours per Day

Cost Component	Number of Operational Days per Annum				
	120	150	180	210	240
Total Ownership	3,549.39	2,839.51	2,366.26	2,028.22	1,774.69
Total Annual	434.02	365.77	320.27	287.76	263.39
Total Hourly	1,089.13	1,089.13	1,089.13	1,089.13	1,089.13
Total Operating/Hour	5,072.54	4,294.41	3,775.66	3,405.11	3,127.21
Cost/Ton Delivered	215.29	182.27	160.25	144.52	132.73

Table 65. Effect of Days per Year on Total Operating Cost, for 10 Available Hours per Day

Cost Component	Number of Operational Days per Annum				
	120	150	180	210	240
Total Ownership	2,715.77	2,172.61	1,810.51	1,551.87	1,357.88
Total Annual	353.87	301.65	266.83	241.96	223.31
Total Hourly	1,089.13	1,089.13	1,089.13	1,089.13	1,089.13
Total Operating/Hour	4,158.77	3,563.39	3,166.47	2,882.96	2,670.32
Cost/Ton Delivered	162.22	138.99	123.51	112.45	104.16

Table 66. Effect of Days per Year on Total Operating Cost, for 12 Available Hours per Day

Cost Component	Number of Operational Days per Annum				
	120	150	180	210	240
Total Ownership	2,288.22	1,830.57	1,525.47	1,307.55	1,144.11
Total Annual	312.76	268.76	239.42	218.47	202.76
Total Hourly	1,089.13	1,089.13	1,089.13	1,089.13	1,089.13
Total Operating/Hour	3,690.11	3,188.46	2,854.02	2,615.15	2,436.00
Cost/Ton Delivered	138.19	119.41	106.88	97.94	91.23

9.5 Cost Sensitivities to Average Payload and Cargo Handling Time

The costs incurred in operating a particular cyclocraft are generally independent of the average payload carried and the payload handling time, as the cyclocraft's annual utilization is independent of both of these operating parameters. The cyclocraft's productivity and its total cost per ton delivered are impacted by both the average payload carried and cargo handling time however. In the basic scenario it was assumed that the average payload carried is 90 % of payload capacity, i.e. 40.5 tons and that there was 15 minutes cargo handling time for each round trip. Using the baseline scenario values for the other operating parameters, the effects of changes in average payload carried and cargo handling time on the annual productivity, i.e. tons of payload carried per annum by a single H.1 Cyclocraft, are given in Table 67.

Table 67. Effects of Average Payload and Cargo Handling Time on Tons Delivered per Annum

Average Payload Carried, Tons	Cargo Handling Time, Mins/Round Trip				
	10	12.5	15	17.5	20
32	37,440	36,149	34,944	33,816	32,760
35	40,950	39,538	38,220	36,987	35,831
38	44,460	42,927	41,496	40,157	38,903
40.5	47,385	45,751	44,226	42,799	41,462
42	49,140	47,445	45,864	44,384	42,998
44	51,480	49,705	48,048	46,498	45,045

Table 68 shows the variations of total cost per ton of payload delivered by the H.1 Cyclocraft with the average payload carried and the cargo handling time per round trip. The table shows that, for a cargo handling time of 15 minutes per round trip, increasing the average payload carried from 32 tons to 44 tons, results in a reduction in the cost per ton delivered from \$156.32 to \$113.69. Table 68 shows further that the average cost of cargo delivered over the standard distance of 15 miles, could vary from \$104.39/ton to \$164.04/ton with the changes in average payload and cargo handling time studied. The cost per ton mile may be obtained by dividing the values of \$/ton delivered, given in Table 68, by 15.

Table 68. Effects of Average Payload and Cargo Handling Time on Cost per Ton Delivered

Average Payload Carried, Tons	Cargo Handling Time, Mins/Round Trip				
	10	12.5	15	17.5	20
32	143.53	148.66	153.79	158.92	164.04
35	131.23	135.92	140.60	145.29	149.98
38	120.87	125.19	129.50	133.82	138.14
40.5	113.41	117.46	121.51	125.56	129.61
42	109.36	113.27	117.17	121.08	124.98
44	104.39	108.12	111.84	115.57	119.30

9.6 Cost Sensitivity to Flight Distance

As for the cases of average payload and cargo handling time addressed in Section 5.4, changes in the average distance the payload is carried do not impact on the cyclocraft's annual utilization or its total cost per operating hour. Table 62 shows the effect of distance flown per delivery on the time for one round trip. The number of round trips per annum is inversely proportional to the round trip time for a given annual utilization.

The effects of distance travelled on the number of round trips per annum, the annual cargo delivery, the cost per ton of cargo delivered and the cost per ton mile, are presented in Table 69. The table shows that if the distance the payload is carried is reduced from 15 miles to 5 miles, the H.1 Cyclocraft would carry about 58% more payload in a given period of time, i.e. 69,701 versus 44,226 tons per annum; increasing the distance flown to 30 miles reduces the tonnage delivered by 32% however. The total cost per ton of cargo delivered varies from \$78.37 for 5 miles, to \$123.51 for 15 miles to \$182.75 for 30 miles. On the basis of total cost per ton mile, the longer distances are more attractive as would be expected, reducing from \$15.67/ton mile for 5 miles to \$6.09/ton mile for 30 miles distance flown. Although the costs per ton mile are lower than those of helicopters by a wide margin, cyclocraft operations should be planned

for minimum flight distances.

Table 69. Effects of Flight Distance on Productivity and Cost

Distance Payload Carried, Statute Miles	Round Trips per Annum	Cargo Carried, Tons/Annum	Cost per Ton Delivered, \$	Cost per Ton Mile, \$
5	1,721	69,701	78.37	15.67
10	1,308	52,974	103.11	10.31
15	1,092	44,226	123.51	8.23
20	941	38,111	143.33	7.17
25	827	33,494	163.08	6.52
30	738	29,889	182.75	6.09

9.7 Comparative Cost Sensitivities

A quantitative comparison of the impacts of changes in the six operating parameters considered in Sections 9.3 through 9.6 may be obtained by assigning a given change in operating cost and determining the change needed in each of the variables to realize that cost change. Table 70 presents the change required in each of the operating parameters studied to obtain a 10 % reduction in the total cost per ton delivered.

Table 70. Parametric Changes Required for 10 % Reduction in \$/Ton Delivered

Operating Parameter	Basic Scenario	Change Required
Number of H.1 Cyclocraft in Fleet	6	Add 4 cyclocraft
Number of Operational Days per Annum	180	Add 30 days/annum
Number of Operational Hours per Day	10	Add 1.9 hours/day
Average Payload Carried	40.5	Add 4.5 tons
Cargo Handling Time per Round Trip	15 mins	Subtract 7.5 mins
Average Distance Payload is Carried	15 miles	Subtract 3 miles

Table 70 reveals some very interesting results. The cyclocraft designer and operator has a measure of control over some of the operating parameters and in some cases a 10% cost reduction might well be realized. For example, it could be realistic, through design and other preparation, to reduce the cargo handling time per round trip from 15 minutes to 7.5 minutes. Restricting the distance travelled to 12 miles, rather than the baseline 15 miles could also be

achieved by selection and preparation. Other parameters, such as number of cyclocraft in the fleet, are more dependent on the size of the market place, rather than under the control of the cyclocraft designer and operator. The number of hours the H.1 Cyclocraft will operate per year, the product of the hours per day and the days per year, are dependent on the reliability and maintainability of the cyclocraft's systems, in addition to the market place and the weather. In view of the simplicity of the cyclocraft's systems, the cyclocraft should have high availability, but the market place is less predictable. Clearly achieving an average payload of 45 tons, which is the capacity of the H.1 Cyclocraft, is unrealistic within the operating constraints imposed. It should be noted that favorable changes in two or three of the operating parameters could be compounded into a significant overall reduction in the cost per ton delivered.

9.8 Comparison of Cyclocraft and Helicopter Costs

No helicopters exist that have a comparative payload to that of the H.1 Cyclocraft. The closest available helicopter is the Russian MI-26, which has been leased by U.S. oil companies in recent years. The MI-26 has a payload capacity of 44,100 lb. Although its speed capability is higher than the cyclocraft, the helicopter will have little opportunity for utilizing it in the type of operation studied, because of payload restrictions and limited stage lengths. The speed advantage would be more than offset by the additional time lost for refueling. It is considered that the H.1 Cyclocraft will have at least twice the work capacity of the MI-26 Helicopter.

The cost of operating the MI-26, reported by the oil companies, is \$17,500 per hour, excluding some of the costs included in the cyclocraft study, e.g. dispatcher, ground operations directors. As shown in Table 61, the H.1 Cyclocraft has a projected total system operating cost of \$3,166.47 per operating hour. Allowing for dividends of profit for investors, in terms of payload delivered, the H.1 Cyclocraft costs would be less than 15 % of those of the heavy-lift helicopter. In addition, Sections 9.3 through 9.7 address opportunities for reducing the cyclocraft costs further.

10. Subscale Unmanned Cyclocraft Test Program

10.1 Subscale Cyclocraft Description

10.1.1 Configuration

The existing platform is a dual-rotor cyclocraft that combines the lift capability of a helium filled aerostat with the aerodynamic lift from two cyclorotors. The shape of the helium filled aerostat is of two semi-ellipses, having 19 ft diameter and 34 ft overall length. At each end of the aerostat is located a cyclorotor. Each cyclorotor rotates about a horizontal axis and has four wings, which provide forces within the plane of rotation, including aerodynamic lift. Each cyclorotor has four blades that provide forces along the longitudinal axis of the cyclocraft. Figure 34 is a general arrangement drawing of the aircraft. In this platform, the cyclorotors are mechanically joined together, so that they rotate at the same speed. The angle of attack of each wing on each cyclorotor is independently controlled by a ground based computer, which sequences the pitch movement of each wing in proper order, to provide a force vector in any direction in the plane of rotation. This arrangement gives the cyclocraft the capability to maneuver in pitch and yaw and to move up, down and sideways. Fore and aft movement of the aircraft is controlled with eight blades, four on each cyclorotor, which act as propellers, moving the aircraft forward or backward, depending on the angle of incidence of the blades.

10.1.2 Cyclorotors

Each cyclorotor consists of four arms or stalks, each stalk has a wing attached at its end and a blade attached below the wing and in the plane of rotation of the cyclorotor.

Figure 34. General Arrangement of Subscale Cyclocraft

The diameter of the cyclorotor at the wing pivot is 27 ft; each wing has an area of 10 sq ft. The blades, which rotate in the plane of the cyclorotor, have an area of 4 sq ft each. The four stalks are made from aluminum tube. Located at the outer end of each tube is a machined fitting, which acts as the wing pivot and servo mounting bracket. The wing is attached to the fitting with an aluminum tube, located on the aerodynamic axis of the wing. The wing incidence angle is controlled by a servo motor. Figure 35 shows this fitting, with the wing and servo attached.

Figure 35. Wing Pivot and Servo Motor

The stalk tube passes through the blade along its aerodynamic axis. The blade rotates about the stalk tube and uses a servo to control its angle of attack. The blade is supported on two teflon bearings at each end. Figure 36 shows one end of the blade, with its operating servo and one of its teflon bearings.

Two of the stalks accommodate electric motors, gearboxes and propellers, which power the cyclorotor. These are located just below the blade, 8 feet from the hub center. Figure 37 shows the motor and gearbox, with its front housing removed. Figure 38 shows the power plant mounted to the stalk tube. Each power plant consists of a 1.3 HP electric motor, a 11:1 planetary gearbox and a 24 in diameter propeller. The motor rpm is regulated by a speed controller.

All of the stalks are mounted to the hub structure, which is a built up framework made from sheet and extruded aluminum. The hub itself is mounted on bearings to the central shaft, which runs the full length of the aerostat. Each stalk tube slides into a bearing, which allows the stalk to rotate on its own axis. At present the stalk is fixed against rotation; however consideration

Figure 36. Blade Bearing and Servo Motor

Figure 37. Motor and Planetary Gearbox

is being given to allow the stalks to rotate, in future operations. When all of the stalks are in place, they are braced together in the plane of rotation by tension wires, to add stiffness to the cyclorotor and transfer the thrust of the propellers to the unpowered stalks. The batteries, which

supply power to the electric motors, together with their speed controllers, are mounted to the hub and are held in place with velcro straps. The latter allow for quick change of the batteries. The uplink receiver and its battery are also mounted to hub structure. Figure 39 shows a view of the cyclorotor hub, with batteries and other components attached.

Figure 38. Power Plant Installation

Figure 39. Cyclorotor Hub

A shaft encoder is mounted on one of the cyclorotors; the purpose of the encoder is to determine the position of the cyclorotor relative to a fixed reference. This positional information is sent, via a down link transmitter, to the ground based computer. The encoder consists of a reader head and an optical encoder disk. The reader head is fastened to the center tube and is stationary with respect to the cyclorotor; the optical disc is attached to the cyclorotor and rotates with it. The pin, which holds the optical disk, is also connected to a synchronizer tube, which runs down the center of the main structural tube, joining the two cyclorotors. The synchronizer tube connects the two cyclorotors together, to ensure that they rotate in unison. Figure 40 shows the encoder head, optical disk and synchronizer pin.

10.1.3 Internal Structure

The internal structure is located inside the aerostat and its primary component is a main shaft

Figure 40. Encoder Disk and Reader Head

of 2 inch diameter aluminum tube. The shaft is braced internally with a simple truss, consisting of a vertical king post in the center, with wire bracing from the post to the cyclorotor hubs. The aerostat curtains are laced to the main shaft to stabilize it and prevent it from buckling under compression loads. The aerostat curtains also transfer the aerostat lift loads to the cyclorotor hubs. The landing gear support tubes are also attached to the main center tube, at the same location as the king post. The support tubes penetrate through the side of the aerostat, to connect to the landing gear legs. Figure 41 shows the inside of the aerostat, with the main tube laced to the curtains and the landing gear support structure.

10.1.4 Landing Gear

The landing gear comprises four tubes attached to the internal structure and wire braced to the cyclorotor hubs, both fore and aft. Figure 42 shows the landing gear in place on the bottom of the aerostat.

10.1.5 Aerostat

The aerostat is constructed from a material that consists of two layers of mylar, with a kevlar scrim sandwiched between them. The envelope is made up of 16 separate gores, joined together with 3M double sided tape. At each joint a clear mylar tape is laid over the seam both inside and out, to seal the joint against leakage. Inside the envelope are four equally spaced curtains, which

Figure 41. Interior of Aerostat, Showing Internal Structure

are attached to the envelope and laced to the center tube, as shown in Figure 41. The purpose of the curtains is to transfer the helium lift loads from the aerostat to the center tube and to stabilize the center tube. There is additional reinforcing of the aerostat, where the landing gear support tubes exit the envelope and where the main center shaft exits the envelope at the ends. This reinforcing consists of extra material and lacing, which spread the local loads into the envelope. At each point where a tube exits the aerostat, there is a fiberglass fitting, which seals the opening, but allows for expansion of the aerostat relative to the tube. A metal plate on the bottom of the envelope has the inlet for the helium and the outlet for the air. The metal plate also has a pressure tap for a gauge that measures the internal pressure in inches of water. To allow access to the inside of the envelope, there is an opening on the lower surface. This opening is sealed, after all the assembly work inside the aerostat is completed.

10.1.6 Control System

The control system is a modified Airtronics model aircraft radio control unit. A block diagram of the system components is shown in Figure 43. The ground unit consists of the pilot controls, a computer and the RF transmitter, contained in one housing and a down link receiver in a separate box. The receiver is connected to the computer by cable. The airborne system has two receivers, one for each cyclorotor. Each receiver has 12 channels, with separate channels for each wing. The motor speed controllers, blade servos and stalk rotation servos each use common channel. The airborne unit also has a shaft encoder on one of the cyclorotors, the positional information from this encoder is sent to the ground computer via an airborne transmitter and the ground receiver. There is also another airborne receiver, which, in conjunction with the 12th

Figure 42. Cyclocraft Landing Gear

Figure 43. Control System Block Diagram

channel, can be used to switch on a tape recorder, to obtain flight data. This switch is controlled by the pilot.

The control system has an RF uplink sending information to the cyclorotors and a downlink sending cyclorotor positional information to the ground based computer. For every degree of angular rotation, the computer determines the incidence angle in the form of a servo pulse width, for each of the 8 Wings. The angle depends on either the pilots inputs or the wing incidence algorithm. The pilots inputs are continuously variable; the wing incidence algorithm can be changed at the transmitter to accommodate lead or lag, maximum angle, sine or square wave etc, but the algorithm is not changed during a flight. A second algorithm controls the relationship between the motor speed and the lift; as the lift control is advanced, the power to the motor is increased, both for positive and negative lift. This algorithm can also be changed at the transmitter to provide for a wide range of relationships between power and lift. The blade incidence angle and stalk rotation are controlled directly by the pilot moving the control sticks. Since there is only one encoder on the aircraft, both cyclorotors must rotate together and maintain their position relative to each other. This is accomplished with a synchronizer tube, which ties the two cyclorotors together, thus the ground computer has data on the position of all 8 wings, which is essential for control.

Motions in pitch, yaw, up, down and sideways, are accomplished by the application of power, which causes the cyclorotors to turn and generate wing lift. The sum of the lift from each cyclorotor provides a force vector in the plane of each cyclorotor, over a 360° circle. By varying the magnitude and direction of this force vector, all of the foregoing motions can be obtained. Motion along the axis of the aircraft is obtained by deflecting the blades to an angle of incidence, which produces a force normal to the plane of rotation, thus moving the cyclocraft fore and aft. For vertical movement, up or down, the lift control stick is moved in the appropriate direction, as shown in Figure 43. As the stick is moved, the propellers start to turn, which rotates the cyclorotors. The wing incidence increases from zero, thus generating aerodynamic lift. The control is proportional, i.e. increasing the stick movement increases both power and wing incidence. To obtain a yaw motion, the control stick is moved left or right, as shown in Figure 43. This generates a pulse, which the computer mixes into the wing lift algorithms in both time and width. The effect of this is to swing the force vector round to the side. For a yaw motion, this direction is opposite at each cyclorotor, which places a resultant torque about a vertical axis through the craft and thus rotates it. For sideslip, the force vectors on both cyclorotors are turned in the same direction, which causes the craft to experience a pure sideforce and to move sideways. For pitch control, the force vector is increased at one end and decreased at the other, which causes the cyclocraft to rotate about its pitch axis.

All of the controls can be operated simultaneously; the computer sorts out the data from each control stick and mixes them together in the appropriate order, so that the aircraft responds correctly. The ratio of the amount of each control that is mixed in with the wing incidence algorithm has been chosen in a purely arbitrary fashion; however, these ratios can be varied at the transmitter and will be determined during flight test, after the response of the cyclocraft to control inputs is better understood.

10.1.7 Subscale Cyclocraft Specification

The specification for the 42 foot test cyclocraft was based on the following guidelines:

- (a) The basic dimensions of the subscale cyclocraft would be in the same proportion as the U.1 Cyclocraft.
- (b) The cyclocraft would be targeted for both positive and negative buoyancy test assessments.
- (c) The cyclocraft's design would use a propulsive thrust, estimated by the MRC parametric design model, to provide aerodynamic lift in the range of 10% of the cyclocraft's gross weight.
- (d) Per the USAF, MRC could simplify the subscale design to stay within available funding.
- (e) To conform to a USAF directive, all flight testing of the subscale cyclocraft would be performed on a slack tether.

The major design characteristics are summarized below:

Aerostat	Length	38 ft
	Diameter	19 ft
	Volume	7180 cu ft
Electric motors	Installed Power	4 x 1.28 HP
Transmission	Gear Ratio	11:1
Propellers	Diameter	24 ins
	Pitch	18 ins
Wings (8)	Span	10.25 ft
	Chord	1.0 ft
	Area	10.25 sq ft
Blades (8)	Span	3.5 ft
	Chord	1.25 ft
	Area	4.375 sq ft
Aerostatic Lift	at Sea Level	430 lbs
Aerodynamic Lift	at $C_L = .8$	56 lbs
Cyclorotor	Max Speed	30 rpm
Performance	Max Speed	22 mph
	Duration at 1.28 HP	5 mins
	at 1.0 HP	15 mins

10.2 Ground Handling and Transportation

10.2.1 Approach to Ground Operations

The cyclocraft platform is designed for assembly and disassembly in the field. It can be broken down completely for transport to other flying sites. For normal flight operations, the cyclocraft is attached to its mooring mast/workstand and stored in a hangar. When required for a flight, the cyclocraft is towed to the flying site and attached to its mast. Two photographs of flight preparation are shown in Figures 44 and 45. The mooring mast is designed to tether the aircraft in winds up to 20 mph. The wings and blades are rotated 90 degrees to face into the wind, when in this mode. The mast also has a work platform which enables work on the hubs and allows access to the batteries, for changing between flights. The mooring mast/work platform, shown in Figure 46, can be disassembled for transport. Note that a mooring mast would not be required for normal cyclocraft operations of a dual-rotor cyclocraft.

Figure 44. Cyclocraft Platform Exiting Hangar

In Sections 10.2.3 through 10.2.6, the ground handling procedures developed to support flight operations of the cyclocraft at Brown Field Airport, San Diego, California, are documented. Some of the tasks enumerated may be considered trivial, but they are included for completeness, so that, should another support team be used in the future, it would have a better starting point. The total ground handling procedure is broken down into four phases:

- (a) Preparation
- (b) Preflight Assembly
- (c) Flight Support
- (d) Recovery

Figure 45. Ground Handling Without Mooring Mast

The ground handling procedures presented in Sections 10.2.3 through 10.2.6 are unique to the facilities available to MRC at Brown Field Airport, which were extremely limited by the only available hangar. The ideal hangar would have a 30 ft doorway height and a 40 ft ceiling height. A hangar of these dimensions would simplify the ground handling operations. Much of the simplicity is due to the elimination of preflight assemblies. These are no longer necessary because the cyclocraft could be removed from the hangar "flight ready". This would also allow the crew to have full utilization of the mooring mast. The latter consideration alone would eliminate the need for 3 of the 6 aircraft handlers. The list of ground handling tasks to be accomplished, should an ideal hangar become available, would be considerably less than those used at Brown Field Airport.

10.2.2 Need for Special Handling Procedures

To accomplish the intended flight tests on the cyclocraft described below in an expeditious

Figure 46. Work Stand/Mooring Mast

manner, it is essential to plan the sequencing of tasks to be performed in the preparation, preflight, flight and recovery phases of each test. Because of the restricted accommodations available at Brown Field Airport, San Diego, MRC developed a special set of ground handling procedures to permit cyclocraft flight testing to proceed at that location. These procedures, which are listed in Sections 10.2.3 through 10.2.6 below, are of necessity, both cumbersome and time consuming in nature. For example the cyclocraft could not exit nor enter the hangar in the fully assembled condition. The procedures were tailored specifically for the design of the cyclocraft and the Brown Field facility, and they were developed during the assembly and test cyclocraft work accomplished between February and June, 1993. In a facility that provides for better cyclocraft accommodations, a more simple and efficient set of ground handling procedures can be implemented.

10.2.3 Preparation

Preparation takes place inside the hangar. The purpose of this operation is to ready the cyclocraft for flight and to safely exit the hangar. The following steps are used for preparation:

1. Verify that all scheduled repairs have been completed and that the cyclorotors are functional.
2. Purge the aerostat of impurities. At a helium purity level of 90%, this provides from 10 to 40 lb of positive lift, without the landing gear in place. At 95 % helium purity positive buoyancy can be achieved for the complete aircraft.
3. Check cyclorotors as follows:
 - A. Ensure that upper starboard and lower port blades are tied back, so that they are parallel to the wings.
 - B. Ensure that the vertical bracing wires on the stalks are connected; the horizontal wires should not be connected.
 - C. Tape upper starboard and lower port wings, so that the leading edge is pointing inward, i.e. towards the hub.

4. Check electronics as follows:

- A. Ensure that the receiver has 7 wires connected.
- B. Ensure that the encoder cable is connected.
- C. Power packs are strapped in place and disconnected.
- D. Speed controller slave wire is connected.
- E. Switch harness and blade harness are connected.

Note: Receiver batteries and encoder battery are not installed until the preflight phase.

5. Organize preflight equipment as follows:

- A. Check that each of the two green buckets contain the following:

Tools:

- 1 small screwdriver
- 4 x 4-40 screws and nuts
- 1 set of small hex wrenches
- 1 .25" spanner wrench
- 1 roll of tape

Equipment:

- 4 counter balance weights with pins
- 4 outer wing braces(numbered 1-8)
- 2 1/4-20 bolts and washers(one set)

- B. Place the following landing gear equipment in the staging area:

- 4 legs
- 4 extensions
- 2 1/4-20 bolts 6" length
- 4 washer/wirer assemblies
- 3 bracing ropes

- C. Place both work-stands outside at either end of the staging area.

6. Cyclocraft exits the hangar. Six people are required to safely remove the cyclocraft from the hangar. One crewman is assigned to each of the four downward stalks. Their task is to move and control the cyclocraft. With the stalk handlers in place, the two observers remove the cyclorotor support stands. The aircraft is then moved out of the hangar, while the observers make sure that the upper wings do not interfere with the doorway.

10.2.4 Preflight Assembly

1. Check cyclorotors as follows:

- A. Remove tape from wings.
- B. Remove tie back ropes from blades.
- C. Position limit pin into blade stop.
- D. Connect stalk bracing wire.
- E. Install counterbalance weight.
- F. Attach upper wing brace.
- G. Repeat for all 8 stalks.

2. Adjust nose hub equipment as follows:
 - A. Secure receiver battery to box shaft and connect to switch harness (off position).
 - B. Install encoder battery (do not connect).
3. Adjust tail hub equipment as follows:
 - A. Secure receiver battery to box shaft and connect to switch harness (off position).
 - B. Align cyclorotors (stalks 1 and 5) and bolt hub to synchronizing tube.
4. Assemble landing gear as follows:
 - A. Attach legs to vehicle by removing rubber stop and sliding the strap joint over the tube. Each leg has its position indicated on its strap. Secure the legs by reattaching the rubber stop to the end of the tube.
 - B. Cross the legs according to the labels near the bolt holes. Using the 6" bolt and the washer/wire assemblies, fasten the legs together.
 - C. Attach one rope between the fore and aft gear and tighten. The legs should form a 90° angle at the strap joints.
 - D. Tie fore and aft lines between gear and hubs. Adjust them so that the center tube is horizontal.

10.2.5 Flight Support

1. Prepare nose hub equipment as follows:
 - A. Turn on transmitter.
 - B. Turn on receiver.
 - C. Connect encoder to battery, and check the position of the cyclorotor
 - D. Check that the propellers are clear. The master power pack is connected, then the slave power pack is connected. If the motors run, disconnect power packs and inform the flight director.
 - E. Check that the blades, wings, and throttle are receiving clean signals.
2. Prepare tail hub equipment as follows:
 - A. Instruct pilot to turn on transmitter.
 - B. Turn on receiver
 - C. Check that the propellers are clear. The master power pack is connected, then the slave power pack is connected. If the motors run, disconnect power packs and inform the flight director.
 - D. Check that the blades, wings, and throttle are receiving clean signals.
3. Handle cyclocraft during ground test as follows:
 - A. A crewman is positioned on either side of the aircraft, they use the tie down ropes to restrict the amount of cyclocraft roll. The aircraft should only be restricted if it becomes necessary to stabilize the aircraft externally.
 - B. A crewman is positioned fore and aft between the landing gear. They use the legs to restrict the pitch and yaw of the cyclocraft. Again, this should only be done if external

stability is required. The crewmen also relay the movements that they perceive.

10.2.6 Recovery

1. Shut down cyclorotors

2. Hub, Tail

- A. Remove receiver battery from box shaft and disconnect the switch harness
- B. Unbolt the hub from the synchronizing tube

3. Hub, Nose

- A. Remove receiver battery from box shaft and disconnect the switch harness
- B. Remove encoder battery

4. Cyclorotors

- A. Press limit pin out of blade stop
- B. Remove counterbalance weight
- C. Remove upper wing brace
- D. Upper starboard and lower port blades should be tied back so that they are parallel to the wings
- E. The vertical bracing wires on the stalks should be connected; the horizontal wires should not be connected
- F. Tape upper starboard and lower port wings so that the leading edge is pointing inward, i.e. towards the hub

5. Landing gear

- A. Untie fore and aft lines between gear and hubs
- B. Remove ropes from between the fore and aft gear
- C. Remove the 6" bolt and the washer/wire assemblies
- D. Remove legs from vehicle; reattach the rubber stop to the end of the tube

6. Return cyclocraft to hangar

10.3 Scope of Tests

The test program was divided into three phases as follows:

1. Component testing of mechanical and electronic subsystems.
2. Testing of a complete cyclorotor to measure lift and HP requirements.
3. Flight testing of the complete cyclocraft.

The objectives of each test phase were as follows:

1. Component testing was to ensure that each subsystem would perform its assigned function before integrating it into the cyclocraft.
2. The cyclorotor tests were to prove its functionality and to measure lift and power requirements.
3. The flight testing was to prove that the cyclocraft was stable about all axes and that it could fly in a controlled manner, in the hover mode; further the flight tests would provide information applicable to future designs.

10.4 Component Tests

10.4.1 Wing Structural Test

A half wing was cantilevered from its center tube; the aluminum yoke which holds the center tube was clamped to a bench. Figure 47 shows a complete wing with the yoke between the wing halves. The wing was then loaded along its aerodynamic center line with a uniform load of 22 lb, i.e. 1.25 times the maximum lift load of 17.5 lb. The deflection at the tip was measured at 6.5 inches. Although there was no sign of structural failure, the deflection was considered excessive and bracing wires were added to the wing to reduce the deflection to .5 inches. Figure 47 shows the complete wing with bracing wires in place.

10.4.2 Stalk Structural Test

The "worst case" load on a stalk is at the start of forward flight, when the full thrust of the engine is applied, prior to experiencing aerodynamic drag. The load on the engine centerline is 20 lb. The stalk was tested by clamping the cyclorotor hub to a bench, with a stalk in place and by suspending a 27.5 lb load at the engine mount. The stalk was unsupported, except at the hub. The deflection at the tip of the stalk was measured at 3.25 ins. This gives a stress of 22 kips at the point where the stalk enters the hub. The allowable stress for 2024-T3 tubing is 58 kips.

10.4.3 Control System Tests

A bench test was conducted by assembling the cyclorotor in a horizontal position, with the stalks supported on stands. All of the electronic system was operational, including the encoder and its down link. The motors were disabled by disconnecting the batteries. The encoder has an LCD, which displays the cyclorotor shaft position in one degree increments. By rotating the shaft by hand any position of the cyclorotor can be selected and thus the wing incidence angles can be observed. For the software program to function correctly the cyclorotor must rotate in a clockwise direction, looking forward, with the no.1 stalk at top dead center (TDC). With the

Figure 47. Complete Wing with Bracing Wires

by cyclorotor in this position, the lift command was given. The wings at TDC and BDC both moved to an incidence angle of 0° . The wing incidence algorithm was set to a sine wave, i.e. by rotating the cyclorotor to various angles between 0° and 90° , the wing incidence angle should follow a sine wave distribution. This was confirmed by test, within a tolerance band of $\pm 1^\circ$. Note the wing incidence algorithm can be set to any cyclic motion, e.g. a square wave. The side force and pitch commands were also tested in a similar manner and tested in combination. The side force command, in combination with the lift command, rotates the lift vector in the direction of the side force. All of the tests indicated that the control system was functioning normally. The control arm on the wing incidence servo was increased to give a wing angle of 16° at maximum throw.

10.5 Cyclorotor Tests

10.5.1 Functional Tests

The cyclorotor was attached to the test stand for a powered rotation test in a vertical plane, without the wings attached, but with all systems functioning. The cyclorotor was turned by hand to ensure that all servos followed the pilots commands; the servos cycled correctly as the cyclorotor was rotated. Figure 48 shows the cyclorotor test in progress.

Figure 48. Cyclorotor Test in Progress

The cyclorotor was held against rotation and the motors run up to full power. Using the motors and propellers to drive it, the cyclorotor was run up to 30 RPM, i.e. its design speed, which was attained at low throttle. The wings could not be cycled, since they are coupled to the throttle and the cyclorotor would overspeed if the throttle was opened to the point at which the wings cycled. The side force command was activated and it functioned correctly. A problem with stalk rotation was encountered with this test, in that the stalk rotation servos could not prevent the stalks from turning about the stalk axis. To correct this problem the mechanism for stalk rotation was changed to provide an increase in mechanical advantage.

The second cyclorotor test performed was similar to the first, except that the wings were attached and tufting was added to the wings, to confirm if the flow over the wings was attached. Figure 49 shows testing with the wing tufts in position.

The throttle was progressively opened, up to a cyclorotor rotational speed of 15 rpm. At this speed the tufts showed attached air flow over the wings. The pitch command was then given; this increases the wing incidence angle, independent of the throttle. The air flow over the wings remained attached. The throttle was then advanced to increase cyclorotor speed. When the stalk servo was over powered and one of the wings rotated out of position, the test was stopped. As a result of this test, the method of rotating the stalk about its own axis was changed. Instead of a servo rotating the stalk directly, a tab attached to the blade was used to turn both the blade and

Figure 49. Cyclorotor Testing with Wing Tufts

the stalk together. The tab can provide at least 5 times the torque of the servo motor. Figure 50 shows the tab in place on the blade. Note that the blade tab was a convenient means of blade actuation for the subscale craft only and would not be used on an operational cyclocraft.

10.5.2 Cyclorotor Lift Testing

A series of cyclorotor tests were made to measure total lift and power required for the cyclorotor. To accomplish this the tube carrying the complete cyclorotor was made into a simple balance beam with the pivot 10 inches behind the lift plane and a mass balance 60 inches on the opposite side of the pivot. A level was attached to the tube to ensure that the tube was horizontal at its balanced position. A pointer aligned with a mark on the test stand indicated the position of equilibrium. Any positive lift developed by the cyclorotor would deflect the pointer down. To measure the lift, a line was placed over a pulley, to a weight pan suspended below the balance beam. The weight pan consisted of a graduated water container. With the cyclorotor running and developing lift, water was poured into the container until the pointer indicated that the balance beam was in equilibrium. By multiplying the weight of the water by 6, the total lift of the cyclorotor was determined.

These tests indicated that the performance of the cyclorotor conforms to the data utilized in the MRC Cyclocraft Parametric Design Model described in Reference 10, both in lift capability and power required. At 24 rpm the total lift from the cyclorotor was 29 lb and the shaft HP was 0.83. This compares favorably with the lift and shaft HP of 28.06 lb and 0.89 HP respectively,

Figure 50. Blade and Tab Arrangement

calculated at the same rpm, using the algorithms in the design model. This excellent confirmation of the design model is considered to be very significant and reassuring of the data on which the H.1 Cyclocraft and other designs are being based. The tests were performed at a maximum wing incidence of 16° , i.e. very close to the stall. In fact, when the wing incidence was increased, the upper wing stalled; the lower wing never stalled, most probably because of the downwash from the upper wing reducing its effective angle of attack.

The shaft HP was calculated using the motor current and voltage to determine the input wattage and from this the input HP. The latter was reduced by multiplying it by the motor and gearbox efficiencies. The maximum speed reached by the cyclorotor during steady state lift tests was 24 rpm. This was less than the design speed of 30 rpm. The cause of this is associated with the propeller design. The propeller design was based on NASA charts, which are applicable to full scale aircraft propellers and are not

accurate for propellers of the size used because of Reynolds number effects. The normal procedure for designing propellers for electric motors is to determine the pitch and adjust the diameter until the motor is drawing the full design amperage and voltage. The propeller pitch and diameter are then adjusted to give maximum thrust. This trial and error method is used in the design of electric model aircraft. As reported in Section 10.5.1, a cyclorotor speed of 30 rpm was achieved when the wings were not generating aerodynamic lift, i.e. no induced drag was incurred. With substantial aerodynamic lift, this speed was not achieved however, for the reason discussed above.

10.6 Flight Tests

10.6.1 Scope of Tests Made

Flight tests of the subscale cyclocraft were attempted at Brown Field Airport, San Diego, on several days. Because this was the first aircraft of this configuration to fly, it is understood that much of the flying was devoted to providing the pilot with familiarization of the dual-rotor

cyclocraft controls. Tests were performed with a slack tether for safety reasons only. On many occasions, and not unexpected in new aircraft programs of this type, system failures resulted in abandonment of the tests; on other occasions wind gusts prevented the pilot from proceeding with his controls familiarization program. Four days of tests made, which are representative of the results obtained, are described in Sections 10.6.2 through 10.6.5. Later, after the cyclocraft had sustained damage in the hangar at Brown Field, it was transported to the US Navy In-Service Engineering (NISE) Facility, San Diego, where repairs were made and additional flight tests attempted indoors. The latter sequence of events is described in Section 10.6.6. In addition larger diameter propellers were designed, manufactured and tested, as described in Section 10.7.

10.6.2 Tests Made on March 10, 1993

The cyclocraft assembly was completed, the aerostat filled with helium and the aircraft was rolled out of the hangar. Figures 51 and 52 show the cyclocraft outside the hangar. The control system was tested and then power was applied to the cyclorotors. The two cyclorotors remained in synchronized rotation for about five revolutions before they began to slip out of synchronization. The cyclorotors were stopped and were realigned. The bolt that holds the cyclorotors in synchronization was found to have slipped; consequently the bolt was torqued to maximum tightness. The motors were restarted, but again the cyclorotor synchronization slipped after a few revolutions. The test was abandoned, pending a fix to be worked out for resolution of this problem, before attempting further tests. Otherwise all systems functioned satisfactorily.

Figure 51. Cyclocraft Outside the Hangar at Brown Field

10.6.3 Tests Made on March 22, 1993

After the problem with the synchronizer tube was fixed, the testing of the cyclocraft was resumed. The aircraft was rolled out of the hangar early in the morning and prepared for flight. The first test was carried out with the cyclocraft tied down. The cyclorotors were run up to full speed and maximum lift and the tie downs were pulled tight, indicating positive aerodynamic lift was attained from the cyclorotors. The latter were then stopped and the tie downs removed. Three personnel were stationed under the aerostat to restrain the landing gear, as a precaution should the cyclocraft malfunction and go out of control. The lift command was slowly increased until the aircraft lifted off the ground to a height of about 3 ins. The command for forward flight was then given and the vehicle moved about 1 ft and was stopped. The yaw command was given, but there was no apparent response. In retrospect the pilot was uncertain whether the yaw command or the side slip command was given. The pitch command was then given and the aircraft pitched until the landing gear touched the ground. At this point the cyclocraft started to go unstable, so the cyclorotors were stopped and the vehicle landed. After the cyclorotors had stopped, it was noticed that they were out of phase, but were slowly moving into phase. This was caused by unwinding of the synchronizer tube.

Figure 52. Preparation of the Cyclocraft for Flight Tests

Another attempt was made at flight, however the motors on one cyclorotor started to open up well before the motors at the other end of the aircraft. In addition, when the motors finally

started, they were at full speed, which caused the cyclorotors to go out of phase and the aircraft started to oscillate. The tests were stopped and the cyclocraft was returned to the hangar.

The motor speed controllers were returned to the manufacturer for testing and adjustment. During the testing it was discovered that the speed controllers had been designed for the standard 2 millisecond pulse width, but the computer in the radio was designed for a 1 millisecond pulse width. The problem was subsequently corrected and the motors were functioning normally.

10.6.4 Tests Made on April 15, 1993

Several attempts were made to fly the cyclocraft, but they were thwarted in turn by excessive gusting, mechanical problems arose and the lack of the full number of personnel available, in all but one of the attempts. In the latter instance the aircraft was flown for about 30 minutes. Control was marginal however, for the cyclocraft tended to roll. This was averted, only by applying full movement of the trims and the control sticks, to counteract the rolling moment and to make flight possible. Even in this situation the ground crew were required to stabilize the cyclocraft. The flight attempts were stopped when the main batteries for the power plant ran down. During the debriefing it was discovered, after viewing the videos of the flight, that the cyclocraft force vector, instead of acting vertically for positive lift, was acting sideways, i.e. 90° out of phase. After carefully reviewing the preflight preparation, it was determined that the encoder wheel on the cyclorotor shaft had not been oriented correctly or tightened onto the cyclorotor shaft. Because of this, the computer had been receiving incorrect information on the cyclorotor position and hence had been sending incorrect data to the flight control servos. Because of the encoder problem the flight was not successful. The side force was determined to be considerable however, as it took two men on the landing gear to prevent the aircraft from rolling over.

At the end of the flight the encoder wheel was found to be broken. A new encoder was ordered, but further testing in the near term was delayed by a three week delivery schedule.

10.6.5 Tests Made on June 8, 1993

The weather was clear, the temperature was 75° F and the wind variable, out of the south-west at 0-5 mph. The cyclocraft was at 40 lbs negative buoyancy; the maximum wing incidence was 9°, with a trapezoidal wing algorithm selected for the tests. Six flights were attempted, as identified below.

Flight No 1. The cyclorotors run up to speed 25 rpm; the cyclocraft lifted off to about 2 to 3 feet; the aircraft yawed to port, with no apparent control, as opposite yaw had little effect. The motors were shut down and the cyclocraft landed on its gear.

Flight No 2. The aircraft lifted off, yawed to starboard and started oscillating. The motors were shut down and the aircraft landed. The cyclorotors were determined to be out of synchronization, the safety rivet having sheared. The rivet was replaced.

Flight No 3. The cyclocraft lifted off and started to pitch nose down; the pitch control had been pushed the wrong way, causing the aircraft to pitch down violently. The motors were stopped; the aircraft landed, but one of the wings hit the ground, damaging it slightly. This was the first time that the model had responded to a definite control input.

Flight No 4. Prior to starting up, the aircraft was moved around, so that its nose pointed into the wind. The latter, although very light, was variable in direction. The cyclocraft lifted off, but was never fully under the pilots control. This could have been caused by several factors, e.g. the wind, the ground crew holding on to the landing gear legs, or the pilot over control.

Flight No 5. The fifth flight was similar to the fourth flight attempt. It was noticed however that although the aircraft was again not fully under the pilots control, the forces acting on the aircraft were primarily from the wings. In addition the pilot gave the wrong control command on several occasions, which exacerbated the out of control syndrome.

Flight No 6. For this flight the pilot moved from his position in front of the cyclocraft and to the side of it, to a position directly behind the aircraft, so that stick movement was coordinated with flight movement, as in flying a full size aircraft. The wind had diminished to a dead calm. The cyclocraft was lifted off; the batteries were running down, which slowed the cyclo rotor RPM. The ground crew released their hold on the landing gear and the aircraft remained stationary for about 10 seconds, at which time a very small yaw command to the left was initiated by the pilot; the cyclocraft yawed left. The pilot then gave a small yaw command to the right and the aircraft yawed right. The yaw command was removed and the aircraft continued to hover. The motors were shut off and the aircraft landed. Flight duration was about 30 seconds; all flight trims were in neutral, except for 75% nose up pitch.

From observations made, it is considered that the five unsuccessful flight attempts can be attributed to several causes: (a) the light, but variable wind direction put significant forces on the aerostat, the pilot was late in compensating for this and then either over corrected, or in some cases corrected in the wrong direction, which exacerbated the maneuver, (b) the pilot was unaware of, and could not compensate for, the forces that ground crew put on the landing gear, (c) the controls were not set up correctly and harmonized to make stick movements approximately the same for equivalent control authority, (d) pilot skill level was low, due to the control system set up, dictated by the unusual type of aircraft.

For the sixth flight attempt, the wind had died down and the pilot had moved to a better position relative to the aircraft, to avoid confusion. In addition the ground handlers had released their hold on the aircraft. These factors combined to give the pilot better control of the cyclocraft.

10.6.6 Indoor Testing and Repairs

10.6.6.1 Decision to Test Indoors

The arrangements made at Brown Field had three disadvantages:

- (a) Its location was some 150 miles from the residences of the members of the test personnel.
- (b) Because of the restricted hangar door space, it was necessary to disassemble the cyclocraft to take it out of the hangar, reassemble it for test, disassemble it for returning it to the hangar and finally reassemble it in the hangar, each time a flight test was attempted.
- (c) At Brown Field the gusts and winds encountered were substantial, particularly later in the morning when the cumbersome preparation procedure had been completed.

The above three disadvantages combined to make it extremely difficult for the pilot to develop the skills to operate the complex control system successfully. Consequently, when the NISE Facility at San Diego became available it was determined that problems (b) and (c) above would be completely eliminated and (a) would be relieved about 25%. After the pilot had learned to fly the cyclocraft successfully indoors, using the remote controls, moving on to outdoor gusty conditions would be a reasonable progression.

Consequently the decision was made to transfer the cyclocraft to NISE Facility for testing indoors.

10.6.6.2 Damage Sustained at Brown Field

Two additional problems had been encountered with the only available facility at Brown Field:

- (a) The landing gear could not be installed on the cyclocraft in the hangar because of a height restriction. Consequently MRC had two wooden stands constructed to support the aircraft at its nose and tail hubs.
- (b) The owner of the hangar stored some equipment in the hangar and consequently opened the hangar doors from time to time to retrieve the equipment.

During the week of July 5, 1993, prior to moving the cyclocraft to the NISE Facility, the doors of the hangar at Brown Field were left open and a particularly heavy gust, acting upon the relatively large aerostat area, put a sufficiently high aerodynamic load on the cyclocraft to topple one of the stands. The aircraft fell on to its cyclorotors and suffered the following damage:

- (a) One of the half-wings, which are of wood and foam construction, was completely broken.
- (b) Four half-wings were damaged.
- (c) One blade, which is of the same construction as the wing, was broken.
- (d) Two of the aluminum stalks were broken.

The above damage to the cyclocraft was repaired after the cyclocraft had been disassembled and

transferred to the NISE Facility. In addition substantial work was done on stopping leaks in the aerostat.

10.6.6.3 Indoor Testing

Subsequent to the transfer and repairs, the cyclocraft was reassembled at NISE and the aerostat was filled with helium. Although some helium leaks were still encountered, the cyclocraft had a positive buoyancy of approximately 50 lb when fully assembled.

A further attempt to fly the cyclocraft was made, but after a few simple maneuvers, malfunctions of the flight controls were experienced. The latter was traced to improper electrical connections. Subsequently the cyclocraft was damaged further when unauthorized personnel attempted to move it.

10.7 Propellers of Increased Diameter

As discussed in Section 10.5, the aerodynamic lift was measured at 29 lb per cyclorotor, at a cyclorotor speed of 24 rpm. The cyclorotors were designed for 30 rpm operation, but because of a mismatch between the propeller design and the electric motors, inadequate propeller thrust was obtained to provide the necessary torque for the design cyclorotor speed of 30 rpm.

Consequently it was decided to replace the existing 24 inch diameter propellers, two of which are mounted on each cyclorotor, with 55 inch diameter propellers. Analysis projected that this modification would result in achieving the cyclorotor speed of 30 rpm, which in turn would provide for a total aerodynamic lift from 58 lb to 92 lb, for the two cyclorotors. Fixed pitch propellers were retained, because of the limited range of airspeed at the propeller locations during flight.

The larger diameter propeller was designed and four units were manufactured. The new propeller was tested on the cyclocraft successfully. The new propeller was run at 980 rpm, i.e. close to the design speed of 1,000 rpm, and absorbed 880 watts of power. The latter represents almost the maximum power available, demonstrating a good match between motor and propeller.

10.8 Conclusions from Subscale Tests

The subscale test program proved unsatisfactory in one respect. To stay within the program budget, some short cuts were taken in the design of the 42 ft cyclocraft that will not be taken in the design of operational cyclocraft. One such short cut was to tie the two cyclorotors together with a single shaft, to simplify control. As a result, the opportunities to develop control techniques were limited more than intended. Based on the testing that was accomplished on the 42 ft cyclocraft, the following tentative conclusions have been drawn:

(a) The measured aerodynamic lift of 29 lb per cyclorotor, confirmed the prediction of the MRC computer-based parametric cyclocraft design model.

(b) In its hover mode, the dual-rotor cyclocraft is both stable and controllable.

(c) The mechanical synchronization tube, which was used as a cost reducing means, proved to be unsatisfactory and the electronic synchronization, which has been selected for the full scale H.1 Cyclocraft, should be employed in the future.

(d) No information is available at this time on the stability and controllability of the dual-rotor cyclocraft operating at forward speed, because all tests were done on a safety tether.

(e) The existing cyclocraft's design, with some upgrading, would provide a suitable platform for obtaining significant data on a dual-rotor configuration for a range of potential mission scenarios. Modifications would include larger propellers for greater aerodynamic lift, conversion to synchronization through electronics, to attain more reliable cyclorotor performance, and replacing aerostat with a unit that has little helium leakage, to increase test availability.

11. Environmental Impact Evaluation

11.1 Basis of the Evaluation

As addressed in Section 4, Louisiana is a leading oil and gas producing state in the United States. Significant portions of this production are located under the eight million acres of swamps, marshes, open bays, other water bodies, and forested wetland areas in Louisiana's coastal zone. Louisiana wetlands include salt, brackish, intermediate, and freshwater marshes, bottomland hardwood forests, and cypress-tupelo swamps. For this evaluation the wetlands will be divided into two very broad categories consisting of marsh and forested wetland environments.

This section of the report addresses the environmental impacts of using the H.1 Cyclocraft air transportable system to access oil and gas exploration and production activities in wetland areas. Because the prototype U.1. Cyclocraft has yet to be successfully flight tested, we were unable to actually observe it in operation over wetlands. This fact limits the ability to evaluate conclusively all the possible environmental impacts of the proposed system. Attempts are made to examine all potential environmental impacts of the H.1. Cyclocraft system as it is presently designed. Future design changes in the system may enhance or negate some of the benefits described that presently apply to the planned H.1. Cyclocraft system.

Exploration and production of oil and gas resources present unique problems in wetland areas. Traditional access methods by land (roads) or water (boats) were modified to allow access into wetland areas. These methods were developed early in Louisiana's production history and included dredging access canals and building board roads. These practices are covered in detail in Section 4. The environmental impacts of these two types of access practices are significant. Canals and the associated spoil banks affect wetlands directly and indirectly. Conversion of marsh or forested habitat to open water is the most obvious direct impact. Besides conversion to open water, the adjacent banks are converted to upland habitat by deposited dredged material which forms spoil banks. These direct physical changes can also have long-term indirect effects on the ecosystem.

Board road construction directly impacts wetland ecosystems by converting marsh to either open water or upland habitat. The elevation of these roads permits the invasion of upland species of plants. Road dumps or board roads also indirectly cause wetland loss by altering hydrology and sediment distribution patterns. Board roads alter surface flow and hydrology. Borrow pits, if continuous, are as damaging as canals. Total wetland impacts of board roads are not as severe as canals.

Presently no air-transportable systems for drilling site access are in use in wetland areas. Limited use of helicopters to transport small rigs has occurred in remote mountain regions of the world. The high cost of helicopters has limited the areas of use to extreme situations. Hovercraft are another access method that have been researched because of the limited impact

they have on marsh habitat. Cost and lack of available vehicles along with the large capital expenditures necessary to begin operations has prevented this technology from being effectively tested or used in wetland environments.

The need for a minimum impact access method for drilling and production operations in wetland areas of Louisiana and the world can be met by the H.1. Cyclocraft. This prototype with an optimum 45-ton load capacity would be capable of transporting all equipment and supplies necessary for drilling operations at a wetland drillsite, as discussed in Section 7. The home base is located in New Iberia with the outlying forward base and truck/barge staging area. The truck/barge landing site will be at an existing open site suitable for use by the cyclocraft. The system assumes that no additional preparation will be needed at this site because it will be in upland areas or open water so no additional wetland damage should occur. The main areas of concern for environmental evaluation will focus on the final transport leg and at the drilling location itself.

The H.1. Cyclocraft system will move equipment to the desired well location by air where a pile driven platform (figure 21) will be constructed. The pile driven platform was chosen to minimize environmental impacts of cyclocraft operations. This platform will be constructed by moving a 50-ton crane into the location and driving 365 piles to form the base of the platform. The crane used to drive the piles will be on marsh mats each weighing 2000 lbs. or placed on flexi-float barges in open water areas, as addressed in Section 3. Once the piles are driven and the decking is attached, operations on the marsh surface will cease and all operations will take place on the deck. The rig components, closed loop mud system, personnel quarters, and other necessary equipment including drill pipe and casing, logging equipment, and cementing equipment will be transported to the location as needed. Extra or one time use equipment will be stored on the supply barge.

One of the limiting factors of alternative access systems is how to transport large volumes of liquids for drilling operations and to solve the problems associated with transporting these liquids. The H.1. Cyclocraft system provides a unique solution by using an inland barge which will be located within three miles of the drill site, used as a supply base, and loaded with the fluids needed for drilling operations. From this barge a three-inch diameter poly pipe (figure 28) would be towed to the drill site across the marsh. This pipe will transport liquids to the drill site and drill cuttings and excess drilling mud from the drill site to the barge for treatment, storage, and disposal. The poly pipe line is also used to transport fuel to the rig location. Use of the poly pipe line eliminates the need for the H.1. Cyclocraft to transport the mud, drill cuttings and other liquids needed for operations, reducing the total transport requirements by over 23 million lb of material, thereby reducing the cost of the H.1. Cyclocraft system and allowing it to compete with present access methods.

Present plans call for the liquids supply barge to hold excess equipment if necessary. When drilling is complete, the H.1. Cyclocraft would either remove the pilings and platform in the case of a dry hole or bring in production equipment along with flowlines for production to begin.

11.2 Direct Environmental Impacts

11.2.1 Overview

Oil and gas development activities in wetlands can cause different types of environmental impacts. These impacts can be either direct or indirect. Direct impacts are usually immediate and are generally a physical change such as an alteration in landscape or habitat. Indirect impacts, which are addressed in Section 11.3, are less obvious and generally over the long term. Indirect impacts can include changes in salinity, hydrology, and sedimentation processes and patterns and composition, quality, and quantity of plant communities. It is difficult to definitely determine the cause of indirect impacts as they are often the result of a direct impact where after a physical change occurs, thus permanently altering the natural processes in the area.

Oil and gas operations cause direct impacts on wetland habitat by either access to a well location and/or at the drilling site. For access, construction of canals and board roads converts wetland habitat into open water (canal and borrow pits) and upland habitat (road dumps and spoil banks). The H.1. Cyclocraft eliminates the need for canals and board roads thereby minimizing wetland loss associated with reaching oil and gas locations. Direct habitat impacts of canals and board road locations are discussed in Section 4. Direct effects of board roads, canals, and cyclocraft are compared in Table 71 with the canal and board road data prepared by Cahoon and Holmes in 1989. All affect wetland habitat in one way or another, but the H.1. Cyclocraft system eliminates many potential impacts.

11.2.2 Physical Impacts

The use of a cyclocraft for transporting of oil and gas exploration and production equipment will have minimal direct physical impact on the environment during the transportation phase of the operation. Because the cyclocraft is airborne, no new roads or canals will be built for access. Direct impacts will occur mainly at the actual drill site and are expected to be minimal. At present, standard plans require a 200 ft x 250 ft area (50,000 ft² or 1.15 acres) to adequately perform drilling operations. The average canal location presently uses approximately 2.90 acres including the canal and drill site. Depending on the depth of the well drilled, ring levee locations themselves can convert from 2.06 to 3.21 acres of wetland into biologically nonproductive sites. Under existing regulations a typical well meeting NOD-13 criteria with a road length of 1500 ft, a road width of 20 ft, and additional clearing of 50 ft for borrow pits along one side of the road and a 300 ft x 300 ft drill site will convert 5.2 acres of wetland habitat to open water or spoil bank. For a 1500 ft canal the environmental cost to reach the site would be 10.3 acres of wetlands. Since 1982, when changes in wetland regulations were made, the average wetland area disturbed per operation has steadily decreased, as shown in Figure 53. Much of the decrease can be attributed to more careful planning of transportation strategies, the use of existing network of canals and the directional drilling program. H.1 Cyclocraft operations would significantly reduce the direct loss of wetlands because new roads and canals will not be necessary.

H.1 Cyclocraft operations are planned to occur on a pile driven structure, to reduce the impacts

Table 71. Comparison of Direct Environmental Impacts of Various Access Methods

Direct Impacts	Board Road	Canal	Cyclocraft
Loss of marsh habitat	X	X	X
Loss of shallow water habitat	X	X	
Loss of forested wetland habitat	X	X	X
Direct conversion to open water	X	X	
Direct gain of upland habitat	X	X	
Direct conversion of marsh/swamp to "nonproductive" sites	X	X	
Increased ponding	X		X
Compacted marsh surface	X	X	X
Changes in plant growth	X	X	
Changes in habitat diversity	X		
Gain of 8 ft deep open water		X	
Resuspension of nutrients and toxins	X	X	
Increase in turbidity	X	X	
Changes in soil/ water chemistry	X	X	
Disruption of natural drainage pattern	X	X	
Changes in surface and subsurface hydrology	X	X	
Noise, Commotion during construction operations	X	X	X
Destruction or burial of biota	X	X	X
Potential for interrupting fish spawning and feeding	X	X	
Interferes with movements of estuarine organisms	X	X	
Potential for disturbing bird nesting by noise.	X	X	X

resulting from the dredging of wetlands. The only direct impacts on the marsh surface will be caused by the 50-ton crane/pile driver and the marsh mats used to support the crane, while driving the piles to support the decking and rig structure. The pile driving operation will cause some compaction of the soil and subsoil directly under the platform and the crane's location. The impacts should be limited, as construction is expected to only take two to three weeks to drive all the piles, as discussed in Section 3. The pile driver will be on each 20 ft x 16 ft plot for only one or two days. In unconsolidated soils, the damage caused by this operation alone could be severe with shallow ponding occurring. Compaction of highly porous and unconsolidated wetland soils can cause a decrease in the soil's ability to hold water and oxygen. This change

in availability of oxygen to the plant could alter the quality and quantity of existing plants and/or alter plant composition. The limited time that the soil will be compacted should limit the damage. However, the soil will not completely rebound until after the pile structure is removed. Use of this pile structure will raise the rig and its equipment off the ground preventing long-term compaction of the soil at the rig-site. This effect will be much less than the damage caused by dredging sediment for a board road or canal location.

Figure 53. Average Distribution Area per Canal

11.2.3 Habitat Impacts

The primary alteration of habitat during drilling operations is the conversion of marsh into open water, upland sites, or nonproductive sites. Cyclocraft operations minimize these habitat alterations since roads and canals are not required. Because a H.1. Cyclocraft has four propeller driven engines and is a large aircraft, a certain amount of background noise will be associated with its operation. Test data presented by the engine manufacturers to Mission Research Corporation place the noise level in the 90 db range. Helicopter noise depending upon power plant and cyclo rotor size and speed can range from 90 db for small helicopters to 125 db for military turbojet heavy lift helicopters such as the Chinook. Since Cyclocraft reach such noise levels they can disturb nesting bird colonies as do similar operations in wetland areas. Noise and commotion can upset the colony and alter the breeding patterns of various bird species found in wetland areas. The commotion caused could also disturb feeding and possibly spawning of estuarine organisms as well.

Other direct effects on habitat from operations include downwash when picking up and unloading cargo. Calculated downwash for a H.1. Cyclocraft is 35 ft/sec or 24 mph in two rectangular

areas 132 ft x 67.5 ft at the front and back of the aircraft. These downwashes will only be noticeable when payloads exceed 23 tons. The downwash created by the aircraft does not exceed normal wind gusts that occur naturally any time in all areas of south Louisiana and will not create any long-term impact. The Cyclocraft downwash is 1/3 the downwash created by most large helicopters where downwash can exceed 105 ft/sec or 75 mph. At these wind speeds damage to plants can occur. This may include stalk breakage, leaf loss, and impacts from foreign objects that could cause mild to severe damage to the plant.

As envisioned, H.1. Cyclocraft system, would use a poly pipe line system to bring all fluid material including fuel and water to the location up to three miles away and to remove drill cuttings and waste water. Accidental discharge of drill cuttings and storm water runoff can affect the water quality and the surrounding wetland habitat. The poly pipe line will also directly affect the marsh habitat that it crosses because a corridor at least 10 ft wide and up to three miles long will be required to bring the pipe from the barge to the drill site. The total possible area affected will be 1.25 acres, which is more than the entire drilling location. Depending on line placement, the poly pipe line could alter sheet flow in the surrounding wetland.

Habitat impacts by a catastrophic event such as a crash caused by high winds or some unforeseen event are possible. These impacts would be limited to the crash debris and any fuel spilled which would be limited to 1000 gallons, the capacity of the fuel reserves on board. Most of these impacts would be temporary. The debris could be removed and the kerosene fuel would evaporate over a short period of time depending on weather conditions at the time of the spill. However, since kerosene is toxic to vegetation, the area vegetation in direct contact with the kerosene would most likely be killed. Recovery will depend upon whether the roots have been affected or not.

Other possible accidental impacts include a breach or leak in the poly pipe line. Depending on the length of pipeline out, the severity of the break, and type of material in the pipe, these impacts could vary from minimal to moderate. If the pipe is transporting water or drill cuttings, a leak or break in the line would not cause significant damage to the marsh area. However, a major break in the pipe when it is transporting diesel fuel could lead to a fire and/or a serious and difficult spill to control and cleanup. In this case the fuel could spread over a large area depending on conditions killing the vegetation that it contacts. The risk of this happening is slight but, it is possible.

11.3 Indirect Environmental Impacts

11.3.1 General

Indirect impacts are long term changes in the ecosystem that cannot be necessarily directly linked to the specific activity involved. The primary indirect impact caused by present canal and board road activity is the alteration of local and regional hydrology. Changes of salinity regimes and plant communities and to some extent introduction of pollutants are changes in the ecosystem

in response to hydrological changes. Cyclocraft will have fewer types of indirect effects on the wetland environment than board roads and canals, as shown in Table 72, because there are fewer direct effects. The Cyclocraft system will not impact the surface in the significant ways that canals and board roads presently do, which includes the direct conversion of marsh habitat to open water or blockage of the natural drainage pattern for site access.

Table 72. Comparison of the Indirect Environmental Impacts of Various Access Methods

Indirect impacts			
Altered Process	Board Road	Canal	Cyclocraft
Wave action		X	
Sediment distribution	X	X	
Water circulation and turnover; stagnant water	X	X	
Deeper channels with increased hydrologic efficiency		X	
Intercepted fresh water flow	X	X	
Hydrologic isolation of surrounding wetlands.	X	X	
Saltwater intrusion	X	X	
Surface hydrology and drainage changes	X	X	X
Subsurface hydrology and drainage changes	X	X	X
Physical/Biological Impact			
Marsh compaction.	X	X	X
Reduced vertical accretion in surrounding wetlands	X	X	
Changes in vegetation dynamics: species: composition, organic matter production and accumulation	X	X	
Changes in mineral accretion and soil nutrition	X	X	
Possible negative influence on aquatic/ benthic organisms		X	
Forest succession	X		
Changes in soil/ water chemistry	X		
Changes in frequency/duration of inundation	X	X	

11.3.2 Alterations in Hydrology

Alteration of the sheet or surface flow is the most significant indirect impact caused by canals and board roads. Alterations in surface hydrology occur through construction of channels and spoil banks for access. The constructed channels which are typically eight feet deep are more

efficient in collecting natural runoff. This causes runoff to bypass the shallow natural channels that slows it down allowing sediment, nutrients, and pollutants to settle out, thus improving water quality, while nourishing the marsh habitat. Additionally, these created canals provide an avenue for saltwater to move inland into fresh water areas, thereby causing changes in wetland communities. In response to salinity changes, vegetation and species composition in freshwater communities will change to more saline types.

Borrow ditches associated with board roads can also connect differing salinity regimes and in limited cases allow movement of salt water into freshwater areas. Borrow pits form shallow depressions that hold water that would normally flow across the surface of the marsh.

Board roads and spoil banks form barriers that prevent sheet flow, the movement of water across the surface of the marsh. They prevent natural flood events from inundating the marsh with sediment and nutrient laden water and also block natural drainage patterns. With less sediment regularly deposited on the marsh, vertical accretion slows or stops, leading to additional wetland loss. When the marsh is inundated, these barriers to flow can cause prolonged inundation of the marsh surface, which affects soil/water chemistry, oxygen levels, and plant growth. This alteration in sheet flow can be mitigated by installing culverts along board roads. As planned for access, the Cyclocraft will not cause these types of changes.

All of the access methods will cause compaction of some parts of the location area. For canals, the area under the barge and the spoil banks will cause compaction affecting subsurface flow. The weight of spoil compresses the surface of the marsh up to 60 percent of its original thickness, thereby reducing the cross-sectional area available for flow. Board roads also compact marsh sediments in the area over which dredged spoil and boards are laid. Compaction can also occur along the borrow ditch where the dredge is located during construction. The same type of marsh compaction occurs during the initial construction phase of the cyclocraft system, when transferring the crane to and from the site and when the piles are being driven. This reduction in subsurface flow for spoil banks, road dumps, and boarded locations have a long-term effect, while the cyclocraft with its limited construction time should have a short-term effect on the marsh substrate. However, it is unlikely that the marsh surface will return to its original elevation. This implies that ponding can occur in areas where little new sediment is deposited. The H.1.Cyclocraft system as planned, would reduce the indirect impacts by reducing the direct impacts on wetland environments.

Sheet flow and surface hydrology would not significantly be affected by the proposed pile drive platforms used in the H.1.Cyclocraft system. If the platform piles were driven very close together, they could simulate a dam preventing surface and subsurface flow over a small area. In the present design, only the piles directly under the rig mast may be close enough together to restrict fluid flow. They would not stop this flow. Localized and temporary impacts may occur to surface hydrology when the piles are being driven, but if care is taken by the operator impact should be minimal. In long-term cases, rainfall penetration and flow will be impeded by the compaction of the soils and the placement of boards over the soil. The platform will also prevent direct rainfall penetration but the pile design will allow runoff to flow freely under the

location thus mitigating the loss of direct penetration. If flow is restricted, the area impacted would be 30 ft x 30 ft, or about 1/43 of an acre. Most areas under the structure should have sufficient space between individual piles to allow water to flow around them freely and subsurface flow should be minimally affected. Some indirect impacts will occur but will be significantly less than canal or board road locations.

All the access methods will change the surface and subsurface hydrology of the impacted area to some degree. The magnitude of this change will vary with the method. Canals will change the existing surface hydrology by either blocking natural drainage patterns with spoil banks or with straight deep channels by creating a hydrologically more efficient system. These new channels will provide an avenue for salt water and pollutants to move over a greater area within the system. The weight of the spoil banks will compress the underlying soil affecting subsurface flow. Spoil banks also form barriers which disrupt natural flooding and drainage patterns. These impacts will be minimized if the cyclocraft system is used. However, evaluation of these effects through a monitoring program can only take place after completion of a well using the system.

11.4 Minimization Strategies

Minimization strategies are strategies for eliminating or minimizing environmental impacts in the work area. These strategies include avoidance techniques such as directional drilling or alternative access methods. Some of these alternative methods are air-transportable rigs, site size reduction, and waste generation control. Reducing the site size may be accomplished by using a bulk mud system, smaller rig, and/or coiled tubing rig to drill the well. Waste can be reduced by using a closed loop mud system.

Present wetland access in Louisiana requires a permit depending on location from either or both the U.S. Army Corps of Engineers and Coastal Management Division of the Louisiana Department of Natural Resources. Each of these permits require that access plans for an individual well is reviewed in the jointly run geologic review process. To minimize impacts, this process could force the well to be drilled directionally or moved to a geologically equivalent site, if it is technically and economically feasible. The geologic review process allows various environmental agencies to review and comment on the proposed permit and to provide options to avoid impacts and incorporate minimization strategies into the project.

The best way to minimize impacts of any operation in wetland areas is to first minimize the length of the route by carefully planning the location of the access route and final site. While H.1. Cyclocraft system eliminates the access route, careful planning to determine the least damaging route for the poly pipe line will be necessary. Final site selection is crucial to minimize impacts of a H.1. Cyclocraft system.

In forested wetlands, the drillsite should be located in already open clearings to minimize tree cutting. If no open clearings exist at the planned drill site, trees should be cut and stacked on the edges of the clearing to provide wildlife habitat as requested by the appropriate wildlife

agencies. The natural contours of the land should not be altered. To eliminate the need for the poly pipe line, bladders could be used to transport fuel and an on-site water well for make-up water along with a closed loop mud system and filtration system could be installed. The 10 ft right-of-way required for this pipeline could do more direct habitat damage than the drilling location depending on the distance to the supply base and the affected habitat.

Discharge of filtered storm and fresh water from drill cutting de-watering should be possible under existing regulations. Drill cuttings from a 16,000 ft well if properly de-watered should not exceed 3000 bbl. of solids and 1000 bbl. of liquid. These cuttings would have to be transported from the location by the cyclocraft, but elimination of the pipeline in forested wetlands may be warranted, depending on the cost of transporting this additional material.

On the basis of the environment alone, no pipeline is best; however economic considerations may require that a poly pipe line configuration be used. If the poly pipe line must be used, clearing to bring it into the location should be limited to a 10 ft wide right-of-way out to the upland or barge transfer site. A 10 ft right-of-way is needed to allow for periodic inspection and movement of the poly pipe line inside the corridor to prevent trenching. This right-of-way should not require tree removal if possible to minimize impacts on the surrounding habitat.

In marsh environments another method to minimize impacts is to use open water areas for site location. There is less damage to the surrounding environment in water than in marsh areas. If no open water areas are available, then the piled structures will minimize impacts. Again careful selection of the poly pipe line route can limit impacts. The shorter the distance to the transfer site, the fewer impacts of the operation. In most cases the poly pipe line will not be running for three miles across the marsh. Participation of existing regulatory oversight personnel during the planning stages of the pipeline routes should also minimize impacts.

All access methods cause disruption to the surrounding wildlife by noise and commotion during operations. The effects on bird colonies and the noise caused by construction can be minimized by avoidance techniques presently used by the wildlife agencies. Cyclocraft noise can be lower than helicopter noise depending on the size of the helicopter. Careful planning to avoid bird colonies and establishing minimum height rules will limit the disruption due to noise on the surrounding habitat and limited access to the site can be allowed for times outside the mating and nesting seasons of the colonies. This impact can be minimized, but due to the nature of oil and gas exploration, some noise disruption will be necessary, if oil and gas are to be produced from wetland areas.

11.5 Site Restoration Strategies

Site restoration and minimization of the impacts of operations are important considerations in planning oil and gas operations in wetland areas. Restoration of the project to pre-project conditions is required in both the Corps of Engineers and Coastal Management Division permits. Mitigation costs for unavoidable activities that cannot be restored can exceed \$100,000,

depending upon the project.

For the H.1 Cyclocraft system, site restoration in most cases should be able to follow routine restoration techniques used for board road locations. These restoration techniques include returning the site to pre-project elevations and replanting the site with appropriate marsh or bottomland hardwood vegetation. Board road locations have been successfully restored, but total restoration because of the surface contour changes is difficult. Resuming natural drainage patterns is very difficult to achieve.

Site restoration of canal locations and spoil banks by backfilling has been attempted an estimated 35 times in Louisiana and have been largely unsuccessful. Success varies by marsh type. Restoration of spoil banks is most successful in intermediate and brackish marshes and restoration of canals is more successful in freshwater marshes. The expense and limited success have prevented backfilling from becoming a more widespread practice.

Cyclocraft site restoration should be more successful than restoration at board road and canal sites because there are fewer direct impacts on the habitat. Man-made structures will be completely removed or, if allowed by the appropriate environmental and regulatory agencies, piles will be cut off below ground level and left in place. Any holes that might be made can be filled with clean soil and the drill site can be replanted with appropriate vegetation. Because the natural contours of the land are not disturbed by cyclocraft operations, natural restoration will probably be highly successful.

11.6 Environmental Impact Summary and Conclusions

Complete evaluation of the H.1. Cyclocraft system effects on the environment can only occur when the system becomes operational. From the data available for evaluation, the following conclusions can be made:

1. Cyclocraft will cause fewer direct impacts than either a board road or a canal.
2. Less habitat is lost, i.e. only 1.15 acres for the H.1. Cyclocraft, compared to over 2 acres for any canal or board road.
3. The cyclocraft system does not eliminate direct impacts caused by the noise and commotion of operations. Noise produced by H.1. Cyclocraft will be less than that of large helicopters however.
4. Velocity effects of the down-wash from the cyclorotors of H.1. Cyclocraft are one-ninth those of helicopters, as downwash velocities are one third, i.e. 35 ft/sec for the H.1. Cyclocraft, compared to 105 ft/sec for helicopters.
5. The poly pipe line used to transport liquids can cause direct environmental damage

of up to 1.25 acres, depending upon the distance to the supply barge. Elimination of the poly pipe line from the system would be environmentally beneficial and is recommended.

6. The indirect or long-term impacts of the H.1. Cyclocraft on wetlands are fewer than present access methods.

7. Careful planning of routes and site selection can further minimize impacts of the cyclocraft system.

8. Site restoration of H.1. Cyclocraft sites should be successful, as long as the natural drainage pattern is not disturbed.

9. Overall the use of the cyclocraft system could reduce wetland loss due to oil and gas operations by up to 66%, as compared to currently used access methods.

12. Technology Transfer

12.1 Scope of Activities

The tasks performed to maximize the transfer of technology to key personnel in government, industry and universities, can be classified into three groups, as follows:

- (a) Personal contact
- (b) Promulgation of documentation
- (c) Presentation of technical papers

In addition to the above, it was intended to hold a seminar, to which all interested personnel would be invited, and at which results of the study would be presented and discussed. This was dropped however, due to funding limitations, logistics problems and the realization that all relevant information could be transferred more expeditiously by the other means employed.

The technology transfer tasks performed are briefly described in Sections 12.2 through 12.4 below.

12.2 Personal Contact

Personal contact was employed to obtain information, to ensure that the study was performed on a realistic basis, and to communicate results obtained from the study. Approximately fifty meetings were held with personnel working in the following organizations:

- (a) U.S. Federal Government, including Department of Energy, Forest Service, Army Corps of Engineers, Fish and Wildlife Service, and various services in the Department of Defense
- (b) Louisiana State Government
- (c) Oil companies, both major and independent
- (d) Potential operating companies, including drilling companies, aircraft operators and geological surveyors
- (e) Candidate designers and manufacturers of cyclocraft, with emphasis on companies based in wetland areas
- (f) Wetland authorities, with the Center for Coastal, Energy and Environmental

Resources, Louisiana State University, being the prime contact

At meetings held with the above personnel, care was taken to ensure that the nature, development status, operational and economic potential, program risks and problem areas, were presented both clearly and fairly. To aid in the communication of the nature of the cyclocraft and its modes of operation, a table top model was made and taken to each of the meetings. The 24 inch model used, which is shown in Figure 54, is a 1 in: 10 ft scale model of a 20 ton payload cyclocraft, sized to support work overs of existing oil and gas wells in wetland areas. The model, although unpowered, incorporates freedom of movement of all of the cyclocraft's control surfaces, which facilitates an understanding of how the aircraft operates.

Figure 54. Table-Top Model of 20 Ton Payload Cyclocraft

A partial listing of personnel, with whom operation of cyclocraft in wetland areas was discussed, is given in Appendix A. Several of the meetings held were semi-formal, in that a presentation was made on the cyclocraft programs. A copy of typical presentation material used, is provided in Appendix B.

As a result of the meetings held, a significant amount of interest and enthusiasm was engendered. It was recognized by all participants, that a need exists for a heavy-lift transportation system, that has little or no adverse impact on the environment in wetland areas. The fact that the cyclocraft offers a potential solution, that could be acceptable both economically and environmentally, was readily apparent to the personnel attending the meetings.

Not all personnel, particularly those belonging to one or two of the major oil companies, admitted to having a wetlands transportation problem however, as those companies are tending to work more and more off-shore. A very large percentage of personnel attending the meetings were very encouraging in their support of the cyclocraft programs.

12.3 Promulgation of Documentation

In addition to the personal contact discussed above, a significant amount of documentation was provided to interested personnel. Specific documentation distributed included the reports prepared under this program, including References 1 through 8, and material generated under the USAF-sponsored program, i.e. References 10 through 17, and 42. In several cases, presentation material, e.g. that contained in Appendix B, was also provided to interested personnel.

12.4 Presentations

The Principal Investigator presented a paper "The Cyclocraft and Its Applications in Wetlands" to the WEDA Dredging Seminar, held in New Orleans, LA on April 26/27, 1993. The paper was well received and resulted in subsequent discussions on the subject with several personnel of the Army Corps of Engineers. A copy of the presentation material used is provided in Appendix B.

In June, 1993 an abstract of a paper entitled "Use of Cyclocraft in Support of Drilling Operations in Wetlands" was submitted to the Society of Petroleum Engineers for presentation at the 1994 IADC/SPE Drilling Conference, but in August, 1993, the author was informed that the paper had not been selected for presentation at the conference.

In July, 1993 the Principal Investigator made a status report to the DOE Contractor's Review Meeting, held at the Fountainhead Resort and Conference Center, OK.

On October 21, 1993, results of the environmental impact assessment work were presented as part of a poster session on environmental constraints in wetlands at the Gulf Coast Geological Societies Meeting at Shreveport, Louisiana by LSU personnel. Industry expressed interest in the H.1 Cyclocraft system.

13. Conclusions and Recommendations

13.1 Conclusions

Based upon the results obtained from the study reported herein, the following general conclusions have been reached by the authors:

- (a) There is a very real need for a system that can transport heavy loads in wetland areas, economically and with no permanent adverse environmental impact.
- (b) Cyclocraft operations in wetland areas appear to be very practical and should result in a high level of reliability. Required payloads of 45 tons are well within the cyclocraft's capability.
- (c) The cyclocraft has the potential of supporting oil and gas drilling and production operations in wetland areas, far more economically than any other airborne system, including helicopters.
- (d) The environmental impact of operating heavy-lift cyclocraft is projected to be both low and temporary, and far less than that caused by other options available to support oil and gas drilling and production operations in wetland areas.

13.2 Recommendations

As discussed above, there is a high potential value of utilizing cyclocraft to support oil and gas drilling and production operations in wetland areas. Further, based on work done in this and previous programs, MRC considers that cyclocraft technology is well established and that the risks associated with the development of cyclocraft, either large or small, manned or unmanned, are clearly understood and that those risks are both low and acceptable. This contention is not fully understood by some of the potential end-users however. Further, a significant investment would be required to realize the potential of large payload cyclocraft, such as the H.1 Cyclocraft, defined herein. Consequently it would be prudent to plan for the provision of a demonstration of the cyclocraft's capabilities in the wetlands environment before such a large investment is made.

Accordingly MRC and LSU personnel have formulated a three phase program to develop a smaller cyclocraft, designated P.1 Cyclocraft, which would be a "pilot" version of the 45 ton payload H.1 Cyclocraft. In addition a near term plan of action for obtaining funds for that development has been formulated.

The less than full scale approach resulted from (1) a need to demonstrate the actual ability of the cyclocraft to operate, as stated by MRC, in a non-intrusive manner in the wetlands

environment and, (2) the real world recognition of the fact that it would be easier to raise the four to five million dollars for the "pilot" program than the need for approximately \$ 37 million for either the 45 ton payload cyclocraft.

The proposed three phases of the program have the following content:

- o Phase I: System Design and Program Planning
- o Phase II: System Detailed Design and Manufacture
- o Phase III: Wetlands Operation and Evaluation

Essentially, the program is aimed at designing and building a P.1 Cyclocraft which is capable of carrying 4 to 6 personnel and demonstrating its utility to operate properly in the wetlands environment. Specific applications of the P.1 Cyclocraft would include aerial monitoring of environmental changes and personnel transportation. With demonstrated success, the program also includes the plans for development of a fleet of the P.1 Cyclocraft, as well as the implementation of a full scale 45 ton payload cyclocraft. This proposed program, as well as any permutations thereof, would certainly offer an opportunity for other interests to participate.

To exploit the considerable potential that cyclocraft offer in wetland areas, it is recommended that development of the P.1 Cyclocraft be initiated with minimum delay.

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APPENDIX A

Partial List of Personnel Contacted

<u>Contact</u>	<u>Affiliation</u>
Mr Rich Adams	NAWC Aircraft Division
Mr Vernon E. Albert	Petroleum Helicopters, Inc
Mr Robert Armstrong	The Louisiana Land & Exploration Co
Dr Len Bahr	Office of the Governor, LA
Mr Kenneth Barnum	Western Geophysical
Mr Moss Bannerman	Chevron U.S.A.
Mr Will Beacher	Exxon Company, U.S.A.
Dr Stanley O. Bean, Jr	USDA Forest Service
Mr Dailey Berard	Universal Fabricaters, Inc
Mr Harry Berman	Advanced Research Projects Agency
Mr John R. Bocek	Chevron U.S.A.
Mr Donald Cameron	Dowell-Schlumberger
Mr R. A. Carter	Amoco Production Company
Mr James Case	Porta-Kamp
Mr M. Key Clarke	Great River Oil and Gas
Mr Donald J. Clement	U.S. Army Corps of Engineers
Mr Charles Coates	Pyburn & Odum, Inc
Mr Herman Colligan	Chevron U.S.A.
Mr Pierre Connor	Exxon Company, U.S.A.

Partial List of Personnel Contacted (continued)

<u>Contact</u>	<u>Affiliation</u>
Mr Ed deRitter	Pearson, deRitter and Johnson, Inc
Mr Charles Dick	Western Geophysical
Mr Tom Dowie	Canal Barge Company
Mr Earl Fields	Chevron
Mr Sheldon Fortenberry	Chevron
Mr D. Hugh Fraser, Jr	Grant Tensor Geophysical Corporation
Mr James Furlette	Diamond Services
Mr David Fuller	Haverfield Corp
Mr Ronald Gardner	Hunt Oil Company
Mr Gil Gayout	Pool Company
Dr Victor George	Lawrence Livermore Laboratories
Mr Anthony Gibson	U.S. Army Corps of Engineers
Mr Donald Gish	WHC Pipeline Contractors
Mr John Dale Givens	Office of Water Resources, LA
Mr S. J. Granger	Cajun Exploration
Dr Charles G. Groat	Center for Coastal, Energy & Environmental Resources
Mr Roland J. Guidry	Office of the Governor, LA
Mr Carl Hackenjos	Consultant
Mr John Hanratty	Haverfield Corp
Mr Brian J. Harder	Center for Coastal, Energy & Environmental Resources

Partial List of Personnel Contacted (continued)

<u>Contact</u>	<u>Affiliation</u>
Mr Van Harry	Schellestede & Associates
Mr Charles Heber	Advanced Research Projects Agency
Mr Rodolph Hebert	Louisiana Natural Resources Office of Conservation
Mr Kenneth Helmer	M.I. Drilling Fluids
Mr Robert Herrin	Chevron U.S.A.
Mr Alan T. Herring	EDCON, Inc
Mr Rocky Hinds	Louisiana Natural Resources Office of Conservation
Mr Doc Howe	Highline Construction Co
Mr Russell Janise	Safeguard Disposal Systems
Dr Chacko J. John	Center for Coastal, Energy & Environmental Resources
Ms Nancy Johnson	U.S. Department of Energy
Mr David Jolly	U.S. Forest Service
Dr Donald J. Juckett	U.S. Department of Energy
Mr David L. Kelley	Kelley Oil Corporation
Mr Robert Kennedy	Greenhill Petroleum
Mr Ed Kyle	Consultant, Dredging
Mr Michael Lambert	U.S. Department of Energy
Dr Mary Landin	U.S. Army Corps of Engineers
Mr Eldridge LeBlanc	Vermillion Shell
Mr Greg Leriger	Geco Geophysical Company, Inc

Partial List of Personnel Contacted (continued)

<u>Contact</u>	<u>Affiliation</u>
Ms Dianne M. Lindstedt	Center for Coastal, Energy & Environmental Resources
Mr Jerry Logan	Halliburton Energy Services
Mr Jim Macadam	Halliburton Energy Services
Mr John R. Maddux	The Stone Petroleum Corporation
Mr Terry Mann	Shell International
Mr Robert A. Martt	The Louisiana Land & Exploration Co
Mr Kai Midboe	Office of the Governor, LA
Mr George Miller	Louisiana Office of Conservation
Mr Nicholas Mirza	Frank's Casing Crews
Mr Charles Moncla	Moncla Well Service
Mr Don Nearhood	U.S. Forest Service
Mr Allan Orr	Helmerich & Payne International Drilling
Mr Robert E. Osborne	Taft, Edwards, McNab & Austin, Inc
Dr Michael Palermo	U.S. Army Corps of Engineers
Mr Gene Pauley	U.S. Department of Energy
Dr William Pearson	Pearson, deRitter and Johnson, Inc
Mr John Pennella	Advanced Research Projects Agency
Mr Norman Porterfield	Texaco U.S.A
Mr James Randolph	U.S. Department of Energy
Mr Garry Rauber	U.S. Army Corps of Engineers

Partial List of Personnel Contacted (continued)

<u>Contact</u>	<u>Affiliation</u>
Mr Mortimer Richardson	World Dredging
Mr Allyn W. Rosley	Phillips Petroleum Co
Mr Oscar Rowe	U.S. Army Corps of Engineers
Mr James St Germain	U.S. Army Corps of Engineers
Mr Herman Schellestede	Schellestede & Associates
Mr Don Schultz	Kerr McGee
Mr John Seibert	EDCON, Inc
Dr Brent Smith	U.S. Department of Energy
Mr J. R. Smith	Shell Western E & P
Mr Rick Smith	T. L. James & Co
Dr Robert Stewart	U.S. Fish & Wildlife Service
Dr Jim Stone	Office of the Governor, LA
Mr Carl Struberg	Schlumberger
Dr Joe Suhayda	Consultant
Mr Ancil Taylor	Bean Dredging
Mr Carl Taylor	Exxon
Mr John Taylor	Veda Inc
Mr Ronald Teague	Louisiana Power & Light Company
Mr M.E. Vaughan	GDE Systems
Dr Clive Whittenbury	Consultant

Partial List of Personnel Contacted (continued)

<u>Contact</u>	<u>Affiliation</u>
Mr Robert G. Williams	Exxon Company, U.S.A
Mr Jewel Willis	Willis and Taylor
Mr Thomas Wingerter	Parker Drilling Co
Mr Roger Wood	Aerostar International
Mr Don Wooley	Highline Construction Co
Mr James Young	Production Equipment Service Inc

APPENDIX B

Presentation Made to the WEDA Dredging Seminar, New Orleans, April, 1993Mr

Mission Research Corporation

THE CYCLOCRAFT AND ITS APPLICATIONS IN WETLANDS

**Western Dredging Association Seminar
New Orleans, LA
April 26-27, 1993**

**Wilfred J. Eggington
Mission Research Corporation
7907 Ostrow Street, Suite D
San Diego, CA 92111
(619) 560 5351 Xtn 103**

Mission Research Corporation

THE CYCLOCRAFT

AN AIRCRAFT OF UNIQUE CAPABILITIES

Mission Research Corporation

EVOLUTION OF THE CYCLOCRAFT

Mission Research Corporation

CYCLOCRAFT MANEUVERABILITY

**Collective Pitch of Blades
Provides Propulsive Thrust**

**Stalks Rotate for
Transition from Hover
to Forward Flight**

**Cyclic Pitch of Wings and Blades
Provides Control Forces & Moments**

**Control Forces along each Axis
and Moments about each Axis
are First Order**

FORWARD FLIGHT MODE

HOVER MODE

Mission Research Corporation

CYCLOCRAFT LIFTING CAPABILITY

LOADED

UNLOADED

A Cyclocraft Design can be Tailored to
Provide any Required Level of Buoyancy

Mission Research Corporation

OPERATIONAL DOMAIN OF CYCLOCRAFT

Cyclocraft are VTOL Aircraft &
can Operate Manned or Unmanned

ALTITUDE

High Endurance up to 25,000 ft
Excursions up to 50,000 ft

ENDURANCE

Existing Designs up to 10 Days
Potential up to 21 Days

SPEED

High Endurance up to 50 Knots
Dash up to 110 Knots

PAYLOAD

Existing Designs up to 35 Tons
Potential up to 100 Tons

WETLANDS CYCLOCRAFT ATTRIBUTES

- **Ability to Pickup & Release Large Payloads**
- **No Landing Area Preparation Required**
- **No Refueling Required During Work Day**
- **High Measure of Safety**
- **Precise Controllability**
- **Day and Night Operational Capability**
- **Ability to Handle High Winds & Gusts**
- **Very Low Downwash in Work Areas**
- **Excellent Operational Reliability**
- **Low Acquisition and Operating Costs**

Mission Research Corporation

SPONSORS OF CYCLOCRAFT DEVELOPMENT

- **DARPA**
- **US Air Force**
- **US Army**
- **US Navy**
- **Strategic Defense Initiative Office**
- **US Department of Energy**
- **US Forest Service**
- **US and Canadian Aerial Logging Companies**
- **Forest Engineering Research Institute of Canada**

Mission Research Corporation

X.2 DEMONSTRATION CYCLOCRANE

235

Configuration	Single Rotor
Aerostat Volume	330,000 cub ft
Aircraft Length	184 ft
Cyclorotor Diameter	136 ft
Empty Weight	16,062 lb
Payload	4,000 lb
Gross Weight	21,400 lb
Installed Power	186 SHP
Aerostatic Lift	19,400 lb
Max Aerodynamic Lift	2,000 lb

**The X.2. Cyclocrane Operated in both
Two-Engine & Four-Engine Configurations**

Mission Research Corporation

USAF UNMANNED CYCLOCRAFT PROGRAM

SPONSOR: Aeronautical Systems Division, United States Air Force

TITLE: Initial Development of a Small Remotely Piloted Cyclocraft

CONTRACTOR: Mission Research Corporation

PERFORMANCE PERIOD: August 1991 to June 1993

CONTRACT PRICE: \$657,000

SCOPE:

- (a) Determine USAF and Other Mission Requirements
- (b) Prepare a Preliminary Design of the Cyclocraft System
- (c) Perform Remotely Piloted Subscale Cyclocraft Flight Tests
- (d) Prepare Prototype Unmanned Cyclocraft Development Plan
- (e) Evaluate Mission Effectiveness of the Unmanned Cyclocraft System
- (f) Prepare Design Data for the Dual-Rotor Cyclocraft Configuration
- (g) Prepare Plan for Cyclocraft Commercialization

APPLICATIONS FOR UNMANNED CYCLOCRAFT

Multi-Agency Drug Interdiction

USAF Launch Area Security

US Army Force-on-Force Training

UAV JPO Endurance UAV

Multi-Agency Theater Missile Defense

Border Patrol Interdiction

Special Operations Delivery & Recovery

Geophysical Oil Exploration

Fish and Wildlife Service Utility

Commercial Gravity Survey

Police Surveillance and Enforcement

UAV JPO/USN Maritime UAV

Fish and Wildlife Service Surveillance

USMC MEU Surveillance

Navy/USMC/Army Communications Relay

Mission Research Corporation

DOE HEAVY LIFT CYCLOCRAFT PROGRAM

SPONSOR: Fossil Energy Division, Department of Energy

TITLE: Evaluation of using Cyclocraft to Support Drilling and Production
of Oil and Gas in Wetland Areas

CONTRACTOR: Mission Research Corporation

PERFORMANCE PERIOD: May 1992 to November 1993

CONTRACT PRICE: \$197,400

SCOPE:

- (a) Define Transport System Requirements
- (b) Develop Preliminary Design of Cyclocraft System
- (c) Validate Cyclocraft Operational Characteristics
- (d) Determine Ground Support Requirements
- (e) Determine Environmental Impacts of Cyclocraft Operations
- (f) Evaluate Costs, Risks and Benefits of Cyclocraft Use
- (g) Prepare Development Plan for Prototype Cyclocraft
- (h) Transfer Results to Relevant Agencies

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CYCLOCRAFT OPERATIONS IN WETLANDS

WETLANDS CYCLOCRAFT CANDIDATE APPLICATIONS

- **Support of Oil and Gas Drilling and Production Operations**
- **Support of Work Over and Plug & Abandonment of Existing Wells**
- **Harvesting of Timber**
- **Support of Construction and Maintenance of Electric Powerlines**
- **Support of Sediment Distribution for Wetlands Restoration**
- **Transport of Dredging Equipment**
- **Emergency Transport of Oil Spill Containment Systems**
- **Airlift Support of Offshore Rig Activities**

Mission Research Corporation

WETLANDS CYCLOCRAFT

TENTATIVE SELECTION OF PAYLOADS

Application

Payload

**Support of Oil and Gas Drilling and
Production Operations**

45 Tons

**Support of Work Over and Plug &
Abandonment of Existing Wells**

20 Tons

Mission Research Corporation

45 TON PAYLOAD WETLANDS CYCLOCRAFT

DESIGN CHARACTERISTICS

Geometry	Overall Length	345.0 ft
	Height	170.0 ft
	Width	151.4 ft
	Aerostat Volume	3,637,000 cu ft
	Cyclorotor Diameter	132.0 ft
Weights	Empty	155,230 lb
	Payload	90,000 lb
	Fuel, Oil	10,400 lb
	Personnel	800 lb
	Gross	256,430 lb
Power	Total Installed	5,400 SHP

Mission Research Corporation

45 TON PAYLOAD WETLANDS CYCLOCRAFT

OPERATIONAL CHARACTERISTICS

Payload, lb	90,000
Maximum Airspeed, mph	67
Maximum Altitude, feet	2,000
Endurance, hours	5
Personnel, crew	2
passenger	2
Projected Total Hourly Lease Rate	\$5,000

Mission Research Corporation

45 TON PAYLOAD CYCLOCRAFT

TOWING CAPABILITY

**Vertical Tension,
with full fuel
= 39,800 lb**

Tow Speed (mph)	5	10	15	20	25	30
Horizontal Tension (lb)	84,720	72,960	63,770	56,135	49,755	44,400
Tow Angle (degrees)	25.2	28.6	32.0	35.3	38.7	41.9

45 TON PAYLOAD CYCLOCRAFT

TASKS IN SUPPORT OF DRILLING & PRODUCTION

<u>Tasks</u>	<u>Tons</u>	<u>No. Flights</u>
Transport Pile Driving Equipment, Crane, Mats, Decking	263	7
Remove Pile Driving Equipment, Crane, Mats	95	3
Bring in Drill Rig, Drill String, Mud, Casing Eqpt	2,092	49
Tow Liquids Pipeline into Position	79	2
Bring in Casing, Cement, Pits, Tubing & Logging Eqpt	1,165	27
Remove Casing, Cementing & Logging Equipment	306	7
Remove Drill Rig, Drill String, Unused Mud	1,460	34
Tow Away Liquids Pipeline	79	2
Bring in Production Equipment and Tow in Pipeline	645	16

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20 TON PAYLOAD WETLANDS CYCLOCRAFT

DESIGN CHARACTERISTICS

Geometry	Overall Length, feet	270
	Height, feet	133
	Width, feet	120
	Aerostat Volume, cubic feet	1,817,000
	Cyclorotor Diameter, feet	100
Weights	Empty, lb	78,300
	Payload, lb	40,000
	Fuel, Oil, lb	7,900
	Personnel, lb	800
	Fully Loaded, lb	127,000
Power	Total Installed, SHP	2,600

Mission Research Corporation

20 TON PAYLOAD WETLANDS CYCLOCRAFT

OPERATIONAL CHARACTERISTICS

Payload, lb	40,000
Maximum Airspeed, mph	58
Maximum Altitude, feet	2,000
Endurance, hours	8
Personnel, crew	2
passenger	2
Projected Total Hourly Lease Rate	\$2,500

20 TON PAYLOAD CYCLOCRAFT

TOWING CAPABILITY

**Vertical Tension,
with full fuel
= 16,000 lb**

Tow Speed (mph)	5	10	15	20	25	30
Horizontal Tension (lb)	43,835	37,555	32,375	28,050	24,385	21,250
Tow Angle (degrees)	20.0	23.1	26.3	29.7	33.3	37.0

WETLANDS CYCLOCRAFT

PROVISIONS FOR INCLEMENT WEATHER

- 1. Hurricanes Avoided by Transit to Any Safe Open Field**
- 2. Severe Thunderstorms Avoided by Onboard Radar Detection**
- 3. Designed to Withstand Tropical Rain Downpours and Hail Storms**
- 4. Designed for Safe Mooring in 80 MPH Winds**
- 5. Designed for Rapid Response to 30 MPH Side Gusts**

Mission Research Corporation

CYCLOCRAFT OPERATIONS IN WETLANDS

ADVANTAGES OVER HOVERCRAFT

- **Adverse Effects of Surface Pressure and Surface Erosion on Environment Eliminated**
- **Unrestricted Operations In Swamps**
- **Payloads can be Handled in Minimum Time and Cost**
- **Lower Operating Costs**
- **Reduced Basing Requirements for Maintenance**

Mission Research Corporation

20 TON PAYLOAD WETLANDS CYCLOCRAFT COMPARISON WITH MI-26 HELICOPTER

Characteristic	Cyclocraft	MI-26 Helicopter
Loaded Weight, lb	127,000	123,200
Payload, lb	40,000	44,100
Installed Power, SHP	2,600	22,000
Downwash at Payload, mph	0	75
Lease Charge, \$/hr	2,500	17,500

Mission Research Corporation

PROJECTED AVAILABILITY OF WETLANDS CYCLOCRAFT

20 TON PAYLOAD CYCLOCRAFT 1996

45 TON PAYLOAD CYCLOCRAFT 1997