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Interagency Advanced Power Group

MECHANICAL WORKING GROUP

MEETING MINUTES

May 5-6, 1993

MASTER

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Mechanical Working Group Meeting

DATE: May 5-6, 1993
LOCATION: Greenbelt, Maryland
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WELCOME AND INTRODUCTIONS

Mr. Richard Shaltens, Working Group Chairman, opened the meeting by welcoming the attendees to the spring Mechanical Working Group meeting and he introduced the meeting host, Mr. Ted Swanson. Mr. Swanson welcomed everyone to NASA Goddard Space Flight Center and noted various locations within the facility he thought would be of interest to the group. The attendees introduced themselves and then Mr. Shaltens reviewed the meeting agenda. He offered a few general remarks regarding the IAPG's purpose of programmatic information exchange aimed at helping to avoid duplication of effort and stated that in today's environment, with the Clinton administration, many changes are taking place and the issue of power/energy was being re-stated. He cited the change of DARPA to ARPA, which involves transition money from industry and government, as an example. Mr. Shaltens informed the group that a representative from NASA headquarters could possibly be available as guest speaker for the following day to explain the ARPA program.

Improving the Mechanical Working Group

Mr. Richard Shaltens, NASA Lewis Research Center, addressed the first agenda item "How Can We Improve the Mechanical Working Group." He initiated the discussion by displaying a historical IAPG Organization Chart which graphed the structure of the Group three years ago and highlighted major changes that had taken place. He explained that the Panels had been expanded to more accurately address those specific power areas that the Group represented. Mr. Shaltens suggested that with the Clinton administration that maybe now more re-structuring is necessary.

The next administrative element Mr. Shaltens identified was the manner in which the Mechanical Working Group conducts its meetings. He explained that the group attempts to rotate its meeting locations among the five sponsoring agencies. The purpose of this rotation is to afford the members an opportunity to visit other agency facilities and to help reduce travel requirements.

The last item Mr. Shaltens discussed, "dual-use" and "technology transfer", elicited an extensive discussion from all of the attendees. Mr. Sebestyen commented that he was led to the IAPG to fulfill his own needs and has become somewhat disappointed because he has not acquired enough knowledge of the other agencies' work. Mr. Shaltens discussed the issue of "responsibility" of transitioning members. Dr. Kuck suggested that the Group look at areas that apparently need particular emphasis. Mr. Shaltens responded that the Group relies on the Steering Group for that type of guidance. Mr. Swanson stated that there is a general awareness that the IAPG exists and suggested that they let the Steering Group know of the opportunities that exist for the Mechanical Working Group and maybe recommend to the Steering Group what the Mechanical Working Group should be.

Mr. Colegrove stated that the broad area that the Mechanical Working Group covers presents a problem. He saw this as a negative feature because although interests are broad, the number of individuals interested in each area is small. This is a detriment because it's hard to elicit

participation if individuals have to travel far because their expenses cannot be justified. He pointed out that attendance at this meeting was not from those who were present to just listen, but that the individuals attending this meeting were either IAPG Chairmen or were giving presentations. An example used was that no one was going to fly all the way from California to come to the Mechanical Working Group meeting. Mr. Swanson interjected that joint meetings, whether held in conjunction with industry or government, should be considered and he cited the success of the Electrical Working Group's meeting at EPRI, in Palo Alto, California, as an example. He stated that the Mechanical Working Group could also hold joint meetings to foster more interest and encompass a greater information base.

Mr. Shaltens next addressed the PIC database controversy, questioning whether the PIC gets proper involvement from the members. Discussion regarding the PIC database, lack of PIC briefs for current programs, and duplication of effort on various programs ensued. Some suggestions of implementing a slightly different PIC brief sheet was suggested and this was rebutted with comments to make use of what is already established; the PIC database works, it only needs conscientiousness of individuals to keep their programs current with the PIC. Mr. Shaltens encouraged everyone to go back to their agencies and let their co-workers know about the PIC database and explain what a potential resource they have at their disposal. He also encouraged using the IAPG Membership Roster, stating that all of the key people in the Government are listed in the roster. He emphasized that the members should use the resources available: the Membership Roster and the Compilation of Briefs.

The last topic discussed concerned meeting the changing needs within the Government. Mr. Swanson discussed how the emphasis was going to be on more contact with industry and he relayed some of the information that was discussed in the past Steering Group meeting. Mr. Kurylowich explained that there was a means by which the agencies could get information on this new issue of "dual use", by calling 1-800-DUAL USE. At this time, Mr. Shaltens turned the meeting over to Mr. Sebestyen.

TERRESTRIAL POWER PANEL

Mr. Thomas Sebestyen, Panel Chairman, introduced Mr. H. Scott Coombe as the first of three speakers representing the Terrestrial Power Panel.

Mr. H. Scott Coombe, US Army Belvoir RD&E Center, presented information on the "*Ground Based Radar Power Source Development Program*". Mr. Coombe's presentation began with a program overview in which he discussed the functions of the Electronics Equipment Unit (EEU), the Cooling Equipment Unit (CEU), and the Prime Power Unit (PPU) for the power source of the Ground Based Radar (GBR). He explained that Fort Belvoir is developing an advanced PPU which will meet projected requirements for weight, size, survivability, etc. He stated that the present funding level was \$21M for the next five years and that Fort Belvoir is in the process of manufacturing and assembling both diesel and turbine prototypes. Mr. Coombe explained that the GBR is the mobile portion of the theater missile defense concept.

In the Technical Approach section of his presentation, Mr. Coombe addressed the system requirements and compared the power concepts used by the radar system contractor, Raytheon, to those that Fort Belvoir has implemented. Mr. Coombe summarized the technical status by stating that the program is fully funded for the delivery of prototypes in January 1996.

Next, Mr. Coombe addressed the power generation concepts by showing early line drawings of diesel and turbine engine generator sets. He also displayed laminations from the Belvoir/Bendix high speed, high frequency alternator and discussed the advantages to this technology. He discussed the various differences of the turbine and diesel engines being used and compared the hardware configurations.

The next topic in Mr. Coombe's outline was power processing concepts in which he justified the need to explore higher frequencies in the 700-2,500 Hz range. He compared commercial off the shelf alternators to the Fort Belvoir/Bendix alternator. Mr. Coombe discussed four different power processing options that were being considered. He discussed possible methods of interfacing to a utility grid and explained that utility grids worldwide are different in terms of frequency, voltage, and capacity, which all present problems in terms of using this power.

Mr. Coombe briefly identified the system requirements and he illustrated the diesel power system, which utilizes two trailer mounted diesel generator sets, and the turbine power system which contains trailer and truck mounted generator sets. Mr. Coombe completed this segment by showing concept illustrations of integral auxiliary (60 Hz) power and separate auxiliary power for the GBR.

Mr. Coombe summarized his presentation by stating that the program is on schedule and that no technical problems exist at this stage, but added that they are not far into the program. He reiterated that there is not a lot of hardware available at this point and also said that, the alternator performance tests have gone well, but reliability tests have not been performed yet. He also concluded, as a positive feature, that they are constantly communicating with the user. Mr. Sebestyen announced a break and after everyone returned he introduced Mr. Siegel as the next speaker.

Mr. William Siegel, DOE, presented information on the "*Hybrid Propulsion Systems*". He stated that DOE has a responsibility for increasing fuel efficiency. Attaining this goal would also give the U.S. automotive industry a competitive edge. He stated that the programs started in '92 and that they are still planning and working with the goals and milestones. Mr. Siegel stated that some of the objectives were to increase fuel efficiency by 100% and to meet lowest emission requirements (EPA Tier 2). Another objective discussed was the ability to operate on alternative fuels. Mr. Siegel defined *hybrid* in a diagram by demonstrating that it lies somewhere on the scale between an internal combustion engine (larger engine) and an electric vehicle (larger battery). There is substantial improvement in energy efficiency and load leveling with a hybrid vehicle. Auxiliary power units had some characteristic drawbacks; one being a marketing issue of noise vibrations. Mr. Siegel identified four key elements for implementing this program: 1)

competitive teams--automotive manufacturer, fuel supplier, and small business; 2) 50% cost share; 3) providing teams a release from the Freedom of Information Act (FOIA); and 4) U.S. firm preference. Mr. Siegel showed a chart depicting the program implementation schedule and stated that industry wants Government to be a partner until one of the last phases, the production approval stage. After many questions were answered by Mr. Siegel, the next speaker was introduced.

Mr. Paul Richard, Belvoir RD&E Center, presented the "*3 kW Tactical Quiet Generator Program*". The 3 kW Tactical Quiet Generator (TQG) is part of a larger program to replace the Department of Defense's generators that do not meet new user requirements. He compared previous MIL-STD gasoline fueled generators to that of the new diesel fueled requirements. To initiate the program, a market investigation was done which concluded that no commercial sets met the user requirements. Mr. Richard discussed the hardware design which is made up of an Italian engine, generator, voltage regulator, governor, and an aluminum housing with skidbase. He explained that there are few American companies marketing small diesel engines. Mr. Richard stated that many corrective actions had been taken since the initial preproduction qualification test and that new hardware was scheduled for delivery in July '93 for the fourth test in the series. One of the biggest concerns stated was a 10% deviation in the voltage waveform which exceeds the 7% requirement. Another problem area concerns the life of the generator brushes. New brushes are undergoing proof testing to correct the problem. Reliability is not at an acceptable level and corrective actions are being implemented. The current plan is to do a Fermont proof test consisting of 600 hours at ambient conditions at rated load and 300 hours at 120°F, rated load. Mr. Richard concluded his presentation by showing a schedule in which he indicated that pending a successful preproduction qualification test the first field units would be equipped with the 3 kW TQGs in August '95. At this time, Mr. Sebestyen announced a lunch break and stated that Mr. Swanson would be conducting the meeting at the conclusion of lunch.

THERMAL MANAGEMENT PANEL

Mr. Ted Swanson, Panel Vice Chair, introduced the first of five speakers who presented overviews of current refrigeration technology research.

Mr. Jeffrey Didion, NASA Goddard Space Flight Center, gave a presentation outlining the "*Refrigeration Issues within NASA*". Mr. Didion's presentation included NASA issues regarding the space shuttle refrigerator, space shuttle ground support, space shuttle requirements, and advanced development of thermal transport loops. Mr. Didion stated the size and capacity of the space shuttle refrigerator and compared it in size to that of a small college dormitory refrigerator. Some of the shuttle refrigeration concerns were that the acoustic specifications cannot be met and that the maintenance is high because the compressor is short-lived. Various replacements for ground support equipment was discussed because R114 is banned and the R21 loops, used presently, are a by-product of R114. Future requirements for refrigeration, driven by Space Station Freedom, are food storage, drug & film storage, water chilling, biological sample freezing and storage, and crystal growth experiments. Another requirement is achieving evaporation of

4°C to 196°C and current NASA systems (i.e. vapor compression) cannot meet this requirement. Mr. Didion discussed the NASA refrigerator team and explained that they are chartered to evaluate existing technology for suitability to NASA requirements; recommend direction for a technology development program; and to recommend improvements to existing hardware. The technology survey evaluates individual technologies and does not include a detailed engineering analysis. There were three leading candidates mentioned for vapor compression, stirling based gas cycles, and thermo-electrics. Mr. Didion discussed the vapor compression system and showed a pressure enthalpy diagram, emphasizing that the selection of fluid is paramount. In another graph he showed how the vapor pressure curves based upon the Clausius-Clapyron Equation could be matched against other candidate refrigerants. Mr. Didion discussed stirling based gas systems stating that this technology is mature, reliable, and has been successfully applied over the entire evaporator temperature range. Thermo electric systems need more development to become competitive at refrigerator temperatures. He discussed component research stating that a lot of money and research effort is being spent on high performance heat exchangers and that tremendous improvements can be seen.

Mr. Didion reviewed the local efforts at NASA Goddard, stating that they successfully used stirling coolers for cryogenic heat pipes. There was concern about the thermal transport loops for the vapor compression systems. He stated that raising heat rejection temperature would lower system mass/volume. Also, lunar martian application studies for heat pumps are complete. He discussed further efforts of optimization studies for systems engineering applications. Mr. Didion stated that they were constructing a vapor compression breadboard loop to do system evaluation for micro gravity issues of fluid behavior. The vapor compression breadboard loop would also enable component evaluation and new applications for compressors, heat exchangers, and expansion devices. Mr. Didion concluded his presentation with a conceptual design of the breadboard loop. After all of the questions were answered, Mr. Swanson introduced the next speaker.

Mr. Rick Rentz, TA Engineering, Incorporated, covered the commercial issues in his presentation, *"Private Sector Technology/R&D Activities for Refrigeration/Space Conditioning"*. Mr. Rentz stated that the driving functions in the commercial sector regarding refrigerants, were utility demand (economic incentives from utility companies) and phasing out ozone depleting refrigerants. He stated that there was much concern about the depletion of the ozone and that they were concentrating efforts on replacing refrigerants. Vapor compression is a key element of this issue. He discussed demand side management stating that it is forcing conservation technologies of thermal storage, heat pumps, and heat pipes (mainly generators).

Mr. Rentz proceeded by giving a technology overview in which he stated that decisions have to be made for chiller selection and design for commercial applications. Mr. Rentz showed charts of many different types of water chillers and explained their general characteristics. He also showed many types of large tonnage absorption equipment and products available. He discussed ice storage and showed examples of thermal storage equipment. He also discussed brine coil thermal storage products and used churches and shopping malls as examples for applications.

In the next section of Mr. Rentz's presentation, he gave an R&D overview citing many selected refrigeration techniques. He then identified some large R&D entities that included trade and industry R&D organizations, commercial deployment organizations, and private industry and business. He highlighted EPRI's contributions to technology transfer pointing out the work in heat pumps, thermal energy storage, and dehumidification. Mr. Rentz summarized his presentation with the recent endeavors stating that the relative interest is with COP/cost improvements, waste heat utilization, gas engine heat pumps, and thermal transport.

Dr. George Kurylowich, Air Force Flight Dynamics Directorate, was introduced next to give his presentation on "*ECS Technologies-Yesterday/Today/Tomorrow*". Dr. Kurylowich segmented his presentation to demonstrate the change and growth of the Air Force's efforts. Advanced Air Force technologies were the concentration of 1970-1982. From 1982 to the present, the concentration was to advance the Department of Defense (DOD) technologies. The hope for the future is to continue advancing DOD technologies and to foster defense conversion initiatives.

Dr. Kurylowich began by identifying the advanced Air Force technologies of "yesterday". He discussed a flight test program, Advanced Environmental Control System (AECS) and an AECS with digital computerized steady-state analytical capability. Also, waste heat conversion and an Environmental Analysis System (EASY) with computerized transient capability was discussed. He showed a photo of an aircraft and the location of both a high pressure water separator and a variable geometry air cycle machine. He next discussed the Environmental Analysis System (EASY) stating that it had been developed by Boeing and stated that crew escape was a concern. Dr. Kurylowich discussed a program with Macair to convert waste heat to useful energy.

In identifying the technologies of "today", Dr. Kurylowich discussed system tuning of refrigerant mixtures and also focused on integrated closed environmental control systems, a joint agreement between Garret of Canada and Allied Signal. He stated that they are analyzing, building, and demonstrating an advanced ECS concept for military aircraft.

Next he discussed the Integrated Closed Environmental Control System (ICECS) stating that this is the trend in avionics. The pilot has a large amount of data to digest and assess in a short amount of time so there is a push for artificial intelligence programming. Dr. Kurylowich compared the differences between an open-loop and a closed-loop Environmental Control System (ECS). He demonstrated that the closed-loop is much more effective because the catalytic device needed is one-fifth of that needed with the open-loop system. He discussed the various phases of ICECS stating that there is a problem with the liquid to liquid heat exchanger because it is g sensitive. Dr. Kurylowich showed the enhancements that have occurred over the lifetime of digital equipment. These advancements in the use of electricity have transpired from the five circuit card, which was replaced by the single circuit card, which was replaced by the hybrid package. Next, Dr. Kurylowich showed photos of various ICECS in digital controls, in rack mounted form, and in the Phase IV version of the g simulator. Dr. Kurylowich gave the status of Phase IV stating that the ICECS had achieved the proper flight weight, and was ready to go on the centrifuge, but was not flight worthy. He stated that currently the static/orientation test

is being repeated along with the safety procedures checkout and the test plan review. The final report submittal is expected by the end of October '93.

Dr. Kurylowich next discussed the Chemical and Biological Agent Protection System (CABAPS) Program, describing the three phases. He expressed the threat a Nuclear Biological Chemical (NBC) presents and showed an artist's rendering of a CABAPS test unit which is based on automotive technology. A chart, showing results of the concentration profile of products, revealed that the GD, HD, and AC agents were broken up in the catalytic device. The chart also pointed out that the allowable concentration levels were too high and that an acid gas absorption element is needed along with many filtration systems.

In the final segment, Dr. Kurylowich discussed the issues of "tomorrow", focusing on Integrated Thermal Energy Management (I-TEM), Phase Change Material (PCM) coolants, and efforts to foster defense conversion. Mr. Swanson introduced Mr. McNamara as the next presenter.

Mr. Jim McNamara, Naval Air Warfare Center, presented an *"Overview of Current Navy Refrigeration Technology Research"*. He expressed that the importance of this issue hinges on the fact that refrigeration causes ozone depletion. Mr. McNamara reviewed the Navy research of variable speed vapor cycle compressors on subsonic patrol aircraft and high performance aircraft. He briefly discussed advanced ECS problems on aircraft and showed a chart depicting heat load growth. Mr. McNamara discussed the Navy's need of cooling avionics and improving the reliability. He also stated that the Navy needed to reduce fuel storage because it is so expensive. A chart was shown comparing an open-loop ECS to closed-loop ECS which saves energy because instead of cooling the temperature before it is released overboard (open-loop), it goes through a vapor cycle and is used internally. He discussed a variable speed vapor cycle system for patrol aircraft which is designed to reach 113°F. A large cost savings should be reaped if it is used on advanced patrol aircraft. Other payoffs that will be seen with the use of the EECS for the advanced patrol aircraft are a fuel savings, or an increase in ASW mission radius, or increased hours. Mr. McNamara showed that this technology has been adapted to high performance aircraft and has been transitioned to the centrifuge test described by Dr. Kurylowich in the previous presentation. Mr. McNamara discussed their CFC compliance to support the Clean Air Act by implementing hardware to recover refrigerants. He explained that production of Class 1 refrigerants will expire at year-end, 1995 and stated that two alternatives were available: stockpiling or retrofitting the system to use ozone-safe fluid. Mr. McNamara concluded by stating that both of these alternatives are being assessed. Mr. Swanson introduced the final speaker for the Thermal Management Panel.

Dr. Mitch Olszewski, Oak Ridge National Laboratory, presented an *"Overview of DOE Funded Refrigeration Technology Development Efforts"* which included two programs; one on thermal energy storage and one concerning industrial heat pumps. The thermal energy storage program is overseen by the Office of Utility Applications which concentrates on complex compound heat pumps/TES for refrigeration applications at -40°F to 40°F. The industrial heat pump program is controlled by the Office of Industrial Technology which implements two technologies:

complex compound heat pump for -20°F and magnetic heat pump for cryogenic applications below -150°F.

Dr. Olszewski gave an introduction to complex compound technology and credited Rocky Research of Bolder City, Nevada for the information. He began by defining a complex compound and stated that desorbing takes heat and that absorbing makes heat and explained how this is useful. He also described the physical properties of complex compounds and gave formulas of the coordination reaction and equilibrium relations. A graph conveyed that CC180-1580, CC480-1110, and CC260-1300 sorption media had a much greater refrigerant holding capacity than activated carbon, Zeolite, or liquid-vapor. He briefly discussed complex compound reactions and heat and mass transfer. He next addressed complex compound thermal energy storage systems explaining the uniqueness of coordinative reactions and the ability to shift peak demand. He showed a schematic diagram of an existing refrigeration system and how the thermal storage addition would add to the capabilities. Dr. Olszewski explained and showed a diagram of the complex compound refrigeration cycle which shows heat supply, heat rejection, the use of ammonia for absorption, and the resulting evaporation. After highlighting the key achievements at Rocky Research, Dr. Olszewski discussed magnetic heat pumps.

Dr. Olszewski explained that magnetic heat pumps for cryogenic applications had been "zero" funded this year after the design phase, but the program is continuing under separate money from CRADA. He expressed that the magnetic heat pump is analogous to the vapor compression cycle because the solids replace liquids and gases as the working media. He showed a few diagrams which illustrated the concept and concluded with DOE information for the development of a prototype unit.

Mr. Swanson thanked all of the speakers of the Thermal Management Panel and then Mr. Shaltens announced that a guest speaker, not shown on the agenda, would be the first speaker at the commencement of the meeting on the following day.

GUEST SPEAKER

Mr. Michael Weingarten, NASA, with the Office of Advanced Concepts and Technology Commercial Development and Technology Transfer Division was introduced to inform the attendees about the "*Technology Reinvestment Project (TRP)*". Before giving the goals of the program, Mr. Weingarten encouraged using the phone number, 1(800)DUAL USE, to acquire step by step booklets on the TRP. The goal is to get the Government needs of the past to the commercial sector in a form that can be adapted for private use. To promote this national industrial capability, a strategy was formulated to invest defense conversion, Title IV funds, into activities which stimulate development of technologies for new products, deploy existing technology into commercial and military uses, and integrate military and commercial research and production activities.

The Defense Technology Conversion Council (DTCC) which is comprised of ARPA (representing DOD), DOE, National Science Foundation, Department of Commerce, and NASA was formed in December '92 to implement the TRP. There are three activity areas concerned with this project. The first one identified was technology development which covers spin-off transitioning, dual-use development, and spin-on promotion. The second activity area is technology deployment which includes outreach, integrating service providers and technical sources, in-reach, and technology access services. The third activity area is Manufacturing Education and Training.

Mr. Weingarten next addressed the common concepts in the program stating that all programs require competitive award, participation and organizational requirements, cost sharing of at least 50% (except SBIR), and emphasis on defense. Cost sharing is another common concept of all of the programs, and Mr. Weingarten explained that the percentage of matching funds can vary. He also explained that matching funds can include cash or in-kind contributions which include compensated services of personnel, equipment, or land. The cost sharing principles were covered in detail and then Mr. Weingarten covered funding vehicles and intellectual property rights. The Government is to avoid acquiring rights if it impedes commercialization, but they can retain the license rights. The firm retains ownership of any inventions, but the Government has "march-in" rights if the invention is not commercialized in a reasonable amount of time.

Mr. Weingarten next covered technology development issues as he showed a matrix chart which identified the funding levels available for the different program emphasis areas. He stated that proposals need to cover creation and exploration of the technology and the ability to take it to the prototype phase. He went over some of the development focus areas, stating that there are nine, but that these areas are not inclusive. He covered four elements that must be included in each proposal which addresses selection criteria. Mr. Weingarten offered two suggestions for prospective applicants. He explained that it is the applicant's job to convince the DTCC what their program is capable of and under what category it falls. Secondly, he encouraged bringing in as many commercial investors as possible to strengthen the proposal. The Council uses this aspect as an evaluator. Mr. Weingarten concluded with one last piece of advice and that was to submit a detailed Executive Summary, stating that the summary was the most important part of the proposal. Mr. Shaltens thanked Mr. Weingarten and turned the meeting over to Mr. Hoffman of the Aerospace Power Panel.

AEROSPACE POWER PANEL

Mr. Gene Hoffman, Panel Chairperson, opened the final panel session of the meeting and introduced the first speaker.

Mr. Albert Juhasz, NASA Lewis Research Center, presented the "Space Power System Radiator Development". He began by giving a general overview of the NASA LeRC Thermal Management program composed of the following Project Elements: Power System Radiator Requirements & Integration; Advanced Radiator Concepts (ARC) Development Contracts; Heat Pipe Development; Composite Materials Technology; and Surface Emissivity Enhancement. The

goal of these synergistic project elements is to demonstrate a space radiator panel with an areal specific mass of 5 kg/m^2 or less at an emissivity of 0.85 or higher with a 0.99 reliability over a 10 year operating life.

Following the overview, Mr. Juhasz focused on the ARC contracts which are presently in the final phase (Phase 4) with the objective of demonstrating engineering performance of a prototype radiator panel.

The final focus of the presentation then shifted to an elemental radiator panel consisting of a light weight carbon-carbon heat pipe with integrally woven fins. The heat pipe design, based on a concept developed by the presenter while working in the Power System Integration Office of the NASA Lewis Research Center, Cleveland, Ohio, features a tubular C-C pressure shell with integrally woven C-C fins and a thin walled metallic liner for containment of the working fluid (potassium).

Fabricated by Rockwell's Rocketdyne Division under Phase 4 of ARC contract NAS 3-25209, the heat pipe weight is less than half that of a conventional metal structure having the same heat rejection area. This weight advantage is largely due to the low specific gravity of C-C (near 1.7) and its high strength-to-weight ratio (up to eight times that of superalloys and refractory metals at the design operating temperature of 850 Kelvin).

During thermal testing at Rocketdyne's Santa Susanna Field Laboratory, Ventura, California, the heat pipe was operated for 11 hours. Starting at ambient temperature with the potassium working fluid in the frozen state, smooth transition to steady state conditions was achieved at various power levels. The final power level, dictated by the facility limit, was 290 watts, representing about 50 percent of design power, at an average condenser fluid temperature of 700 Kelvin. Additional testing at higher power levels and temperatures is planned at NASA Lewis.

For the heat pipe tested, using T-300 graphite woven fabric with 2.5 cm length fins, the specific mass goal of 5 kg/m^2 . An additional 33 percent reduction in specific mass would be achieved if a heat pipe were to be built using a high conductivity P-95 WG carbon-carbon preform with integrally woven fins of 5 cm length which was also fabricated under the contract. Mr. Juhasz showed that for this heat pipe the specific mass could be reduced to 3.2 kg/m^2 , if funding were to be made available to perform the liner fabrication and brazing, end cap welding, working fluid filling and demonstration testing operations. Moreover, this second generation heat pipe would be capable of rejecting 50 percent more heat than the demonstration tested heat pipe.

The presentation was concluded by pointing out that extension of the technology to other operating temperature ranges would only require replacement of the heat pipe working fluid and the thin metal foil containment liner. Application of oxidation resistant coatings or substitution of ceramic matrix composites would make this technology also available for a variety of terrestrial applications, some of which were identified in the concluding remarks.

Dr. Inara Kuck, Phillips Laboratory, presented information about "*Air Force Satellite Power Technologies*", beginning with a discussion of small satellites. She stated that cost is the main driver, but weight and volume, and weight and size are also factors. She discussed specific needs and the various technology programs. Medium satellites were discussed and Dr. Kuck stated that they were looking at user requirements before a lot of life testing is done. The customer has a seven to ten year life requirement that Phillips Lab is trying to meet. Dr. Kuck stated that there is not much involvement at Phillips Laboratory with large satellites, but did mention that they had achieved eight to nine percent efficiencies in thin film cells.

Dr. Kuck discussed the objectives of the Air Force power program emphasizing where they want to be in three to five years. The objective is to reduce spacecraft weight by cutting power and thermal management systems weight. She stated that small improvements are not worth high risks. She stated that their aim is geared toward high payoff. Dr. Kuck discussed Phillips' accomplishments in flight tests, photovoltaics, and batteries.

Dr. Kuck explained that they were combining efforts with NASA on a photovoltaic array solar panel that would be launched into orbit July '93. She discussed a launch to occur in early '94 that is a cooperative effort with the British involving a space technology research vehicle. Dr. Kuck identified the conventional power ten year goals of achieving greater energy efficiencies, lower costs, providing a ten year (at least) service life at close to 100% reliability, increasing satellite autonomy, and assuring survivability to natural and enhanced radiation environments. Dr. Kuck concluded her presentation by summarizing current and planned programs stating that the concentration of efforts needs to be geared toward thinking in terms of "systems" and not in components. At this time, Mr. Hoffman introduced Mr. Mike Doyle as the next speaker.

Mr. Mike Doyle, Naval Air Warfare Center, Lakehurst, offered a presentation on the "*Electromagnetic Aircraft Launch System (EMALS)*". Mr. Doyle gave a brief background about the Naval Air Warfare Center by first stating the mission of the Naval Air Warfare Center (NAWC) and then discussing the Aircraft Division's integration. The efforts of the NAWC are divided into five centers at various locations. The Lakehurst facility is responsible for anything dealing with the aircraft platform interface. Mr. Doyle explained that they have all the basic testing facilities including mechanical testing capability for shock and vibration. He also explained that Lakehurst has five parallel jet test tracks that are 1.5 miles in length and expandable to two miles. He stated that they have the longest runway East of the Mississippi. Mr. Doyle showed an aerial photograph of the Lakehurst facility as he discussed the future plans to consolidate the Aircraft Division and close two facilities. He explained that an overall reorganization would occur before the end of the fiscal year. He next discussed the future technical plans highlighting aircraft launch and recovery, laser communications, imaging, artificial intelligence, and "man out of the loop" for deck handling.

Mr. Doyle presented the history of catapult development. He showed a graph that displayed the progression of catapult capabilities up to the present steam catapult, and the increased capabilities of the EMALS. He pointed out the several advantages of the EMALS over the present system

including life cycle cost savings, smaller and lighter, highly controllable, stand alone, and operationally flexible. The EMALS launches, brakes, and retracts all with the same linear launch motor, thereby eliminating the large number of subsystems on the steam catapult that serve the same functions. EMALS performance requirements were presented and the launch energy of 90 Mft-lbs (122 MJ) was pointed out. Mr. Doyle discussed the development history, from the feasibility model to the recent preliminary Demonstration/Validation Phase design contracts. He also highlighted the three stages of the acquisition strategy and discussed the Congressional directional that has been given.

Mr. Doyle showed a block diagram and photograph of the feasibility demonstrator model previously developed. He explained the major components of this system, including the electromagnetic shuttle, the stator in the catapult trough which consists of 96 coils, and the power system of 30 car batteries. Mr. Doyle then discussed the DEMVAL design, including the pulse alternator assembly, the principles of the cycloconverter, the controls, the launch motor, and the various subsystems. He discussed the present phase of the program, the Critical Component Demonstration Phase, which is a technical risk reduction effort. Technologies being studied are permanent magnets, cycloconverter topologies, and overall control issues. Mr. Doyle concluded that at the end of two years, the DEMVAL design will pick up and an Advanced Demonstrator Model will be manufactured to study overall system and integration performance. At this time, Mr. Shaltens announced a small change in the agenda and began the business meeting.

Mr. Gene Hoffman, Panel Chairman, presented the final presentation entitled "*Magnetic Bearings for Aircraft Electric A.P.U.*" Mr. Hoffman opened his presentation by justifying the usage of magnetic bearings. He explained how removing the lubrication system allowed for an overall reduction in meantime to failure. Mr. Hoffman highlighted five other reasons supporting the use of magnetic bearings. He showed an illustration of a Integrated Power Unit, pointing out the turbine, exhaust, combustor, and air inlet, stating that this direct drive unit has improved reliability since the hydraulics have been removed. He next showed a baseline design layout of an MEA integrated power unit which utilizes both magnetic bearings and auxiliary bearings. This unit has some design issues to be rectified, one of which is negative stiffness. Mr. Hoffman discussed the bearing analysis and radial bearing operation. He stated that Allied Signal is the prime contractor of this program. He demonstrated the P.M. flux path and the E.M. flux path stating that the combined effect gets the bearing size down and the load also decreases. Mr. Hoffman discussed auxiliary bearing concerns stating that the auxiliary bearings must be able to endure the same radial and axial loads that magnetic bearings endure. Bearing temperatures were also a concern that Mr. Hoffman expressed. He stated that the cooling of rear radial bearings requires inductor flow, and that thrust bearing operates at the edge of current magnetic material usage range, which is near capacity. Thrust reversal was discussed along with sensor concerns for axial position and wire insulation.

In summary, Mr. Hoffman stated that the MEA IPU program will demonstrate the magnetic bearings for aircraft electric APUs. He stated that the temperature and controls issues have been identified, but there may be more. An advantage of the magnetic bearing is that fault tolerance

can be an integrated function. He lastly identified that better auxiliary bearing approaches, the use of air bearings, may be needed to compliment the magnetic bearing.

BUSINESS MEETING

Mr. Richard Shaltens, Working Group Chairman, opened the business meeting by asking for a motion to approve the meeting minutes from the previous meeting of October 27-28, 1992. A motion was made and seconded and the minutes were accepted as written.

Mr. Shaltens next addressed the various Panel positions that had nominations pending. He stated that there was a past action item to fill the Vice Chair position of the Terrestrial Power Panel. He stated that Mr. H. Scott Coombe had been nominated for that position by Mr. Belt (Army) which needed Working Group approval so it could be forwarded to the Steering Group for final approval. Motions for Mr. Coombe's approval were made and he was unanimously accepted. Mr. Shaltens next confirmed Mr. Juhasz's resignation as an officer of the Aerospace Power Panel since a replacement had been found. Mr. Shaltens announced that Dr. Inara Kuck had been nominated by Col Herrera (Air Force) as Vice Chair of the Aerospace Power Panel and stated that the nomination needed Working Group approval. A motion for her approval was brought to the floor, seconded, and the vote was unanimous to accept Dr. Kuck as Vice Chair. Mr. Shaltens also announced Dr. Jerry Beam's future retirement stating that Mr. Ted Swanson would move up to chair the Panel, but that a replacement would be needed for the Thermal Management Vice Chair position. Mr. Shaltens declared an action item to fill the upcoming Thermal Management Vice Chair position and suggested an Air Force or Navy representative be identified.¹ Mr. Shaltens will advise the Steering Group of the two approved positions for Steering Group approval.²

The next item on the business meeting agenda was to determine the date and location of the fall Mechanical Working Group meeting. After little discussion, Dr. Kuck graciously offered to host the next meeting at Phillips Laboratory in Albuquerque, New Mexico. The meeting will be held in November with a firm date forthcoming. Mr. Shaltens announced a break for lunch and stated that the business meeting would continue after lunch.

The Steering Group meeting highlights were the next item on the agenda and Mr. Shaltens asked Mr. Swanson to enlighten the members on the proceedings of the April Steering Group meeting. Mr. Swanson stated that the future role of the IAPG had been discussed, in light of the changes from the Clinton administration. He identified the current emphasis on outreach to industry; joint IAPG/industry/technical association meetings; possible overlap with other organizations, and is it desirable; and increased outside interest in the IAPG. After briefly discussing these topics with

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¹ Action Item

² Action Item

the attendees, Mr. Swanson provoked discussion regarding participation with industry. A concerted effort needs to be taken to raise the level of consciousness about the Mechanical Working Group within the IAPG. A short discussion ensued regarding non-participation within and between the agencies. Mr. Shaltens suggested contacting all Working Group Chairs and alerting them of the interest and encouraging them to update the status of the PIC briefs.

Mr. Swanson stated that the other topic of concern at the Steering Group meeting concerned the PIC contract at Horizon Data Corporation (HDC). He stated that the current contract ends September '93, and that additional money was still needed. He stated that a decision had been reached to extend the HDC contract for 16 months, but that cost reduction options would be considered. Mr. Swanson stated that the Navy was to assume the contract management role for the new contract. Lastly, Mr. Swanson discussed the issue of looking at electronic data transfer because packaging and mailing costs are a significant part of the contract costs.

Mr. Rogelio Sullivan, COTR, and Ms. Judy Hanst, PIC Program Manager, interjected that various recommendations were being considered in an effort to reduce contract costs. It was stated that because publications represented a significant portion of the contract's funds that some of the publications would be eliminated and possibly replaced by other support. This information received a mixed response. The members concluded that while decreasing costs were a good idea, that they did not want to trade off any PIC support or lose any publications.

There was a short discussion regarding length of terms for Working Group Chair/Vice Chairs and Panel Chair/Vice Chairs. The conclusion was that the Mechanical Working Group believes it is best for that group to decide the length of terms and that the decision would be made on a year to year basis.

Mr. Tom Sebestyen, Terrestrial Power Panel Chair, presented his ideas on ways to improve the Mechanical Working Group. He stated that increased communication, modernization, and minimizing duplication of effort was necessary. He presented seven points of ideas to accomplish these improvements: 1) quick PIC briefs-two line summary of project, 2) computer link-agency to agency and agency to PIC, 3) presentation materials on file at PIC and the PIC providing a list to the agencies, 4) database access system-single point of contact (like PRISM), 5) video usage-video conferencing and videotape programs, 6) membership roster-add keywords and/or technical and component interests, and 7) information transfer via floppies vs. "books". Mr. Shaltens stated that recently there has been much discussion regarding the database and the accurateness of information contained in the database. He also mentioned that there were many opposing views among the membership regarding the database. Mr. Sebestyen felt very strongly that the process of information cannot continue in the same manner as it is being dealt with now. It was stated that the Steering Group needs to provide/approve/consider another means to accomplish what the Working Group needs. This is a Steering Group level issue and the Steering Group needs to be convinced of what is needed. A suggestion was made that when the charter is "re-stated" by the Steering Group to include *technology transfer*, that an ideal opportunity would exist to bring up these needs.

Another idea was discussed to enhance the PIC brief status which involves the presenters at every meeting. It was discussed that when a presentation is given, that the presenter should submit a brief sheet. This prompted discussion as to whether or not the PIC staff was capable of filling out a PIC brief sheet after listening to the presentation of the program at each of the meetings. As a test, the PIC staff was assigned an action item to review the presentation materials of this meeting and the previous meeting, create PIC brief sheets, send to the authors for corrections, and then enter the briefs into the database.³

Before adjourning the meeting, Mr. Shaltens stated again, that the next meeting was tentatively planned for November 3 & 4, 1993 at Phillips Laboratory and then the meeting was adjourned so that the tour of Goddard Space Flight Center could commence.

NASA GODDARD SPACE FLIGHT CENTER TOUR

Mr. Swanson scheduled an enlightening tour of the Goddard Space Flight Center in which the members were transported via a facility bus to various locations of the Center. The tour began in the testing facility where the attendees could see a replica of the space shuttle. Then the tour director showed the testing locations for the sound impact of the shuttle take-off and the effect of the g forces. The tour continued to a look-out area where NASA employees and contractors could be seen building the cradle that will be used in a mission to rendezvous with the Hubble Space Telescope (HST) for repairs. Many replacements need to be made to the HST and it has been determined that every three years the HST will need maintenance. A small model of the HST was shown which exhibited the various elements that needed attention.

While in transport, the tour director explained that the facility grounds were virtually divided in half with pre-shuttle activities on one side of the facility and post-shuttle activities on the other side. The tour concluded with a walk through the communications building which housed all of the computers that stay in contact with the astronauts and other NASA facilities during a shuttle mission.

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³ Action Item

ACTION ITEMS

TASK TO COMPLETE	RESPONSIBLE FOR COMPLETION
Find an Air Force or Navy representative to fill the upcoming Thermal Management Vice Chair position.	Ted Swanson
Advise the Steering Group of the two approved positions for Steering Group approval.	Dick Shaltens
Review the presentation materials of this meeting and the previous meeting, create PIC brief sheets, send to the authors for corrections, and then enter the briefs into the database.	PIC

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Ground Based Radar Power Source Deveioption Program

GROUND BASED RADAR POWER SOURCE DEVELOPMENT PROGRAM

INFORMATION BRIEF

for

INTERAGENCY ADVANCED POWER GROUP (IAPG) Mechanical Working Group Terrestrial Power Panel

5 May 1993

US Army Belvoir RD&E Center
Power Generation Division
H. Scott Coombe

BRIEFING OUTLINE

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GROUND BASED RADAR SYSTEM CONCEPT

UOE as Deployed

Note:
Unit separation is $\approx 1.8\text{m}$ (6 ft) except OCU

<u>WHO?</u>	SDIO (\$) PEO GPALS (\$) PM-GBR (Management) BELVOIR RD&E CENTER (Engineering)
<u>WHAT?</u>	GBR Power System - Power Unit - Power Processing/Conditioning/Switching
<u>WHEN?</u>	Jan 96 -- Prototypes Jan 97 -- Production Contract Awd
<u>WHERE?</u>	Prototype Mfg & Assy -- Ft. Belvoir, VA
<u>WHY?</u>	Advanced Technology Demonstration GBR Operational Requirements Document
<u>HOW?</u>	Optimize thru a Systems Viewpoint Concurrent Engineering Design Approach Risk Reduction
<u>HOW MUCH?</u>	\$21M / 5 years

"BIG PICTURE"

GROUND BASED RADAR (GBR) SYSTEM

- PART OF THEATER MISSILE DEFENSE (TMD) CONCEPT
- ANALAGOUS TO PATRIOT
- LARGER SCALE

DEM/VAL CONTRACT AWARDED TO RAYTHEON (1992)FOR

"RADAR SYSTEM":

- RADAR ANTENNAE
- ELECTRONICS EQUIPMENT UNIT
- COOLING EQUIPMENT UNIT
- CONTROL SHELTER
- POWER SYSTEM

USER OPERATIONAL EVALUATION (UOE) --> OCT 95 - MAR 96

ENGINEERING MANUFACTURING & DEVELOPMENT (EMD) CONTRACT
AWARD --> JAN 97

GOAL

CLOSE INTEGRATION OF POWER GENERATION
AND CONDITIONING TO REALIZE SYSTEM
LEVEL BENEFITS

- * INTERFACE OPTIONS TO UOEs IDENTIFIED
- * CONCEPTS FOR OPTIMIZED EMD POWER ESTABLISHED

BACKGROUND

PHASE I -- 1992 ...

MARKET INVESTIGATION

DIESEL BASED *POWER UNIT* CONCEPTS
TURBINE BASED *POWER UNIT* CONCEPTS

POWER CONDITIONING STUDY

SYSTEM CONCEPTS DEVELOPED FOR

DIESEL BASED *SYSTEMS*
TURBINE BASED *SYSTEMS*

UOE & EMD CONCEPTS DEVELOPED

PROGRAM PLANS DEVELOPED

MAXIMIZING PROGRAM FLEXIBILITY FOR RISK REDUCTION
SYSTEM CONCEPTS CONSIDER FUTURE POWER GROWTH

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POWER SYSTEM REQUIREMENT CATEGORIES

GBR PRELIMINARY POWER CONCEPTS

<u>CONTRACTOR (UOE)</u>	<u>BELVOIR (UOE/EMD)</u>
MODIFIED OFF-THE-SHELF ONE PER C130	CUSTOM BUILT TO GBR SPECS TWO PER C130
STANDARD FREQ & VOLTAGE	STANDARD VOLTAGE, HIGHER FREQ
CURRENT FOCUS ON DIESELS	REVIEWING DIESELS AND TURBINES
1,800 RPM, 60 HZ ALTERNATOR	COMPACT, HIGH SPEED ALTERNATOR
30,000 LBS (ESTIMATE)	18,000 LBS (DIESEL SET) 12,000 LBS (TURBINE SET)
"MOBILIZER" PLATFORM	STANDARD ARMY TRAILER
1 MW AT 8,000 FEET	1.2 MW MINIMUM AT 8,000 FEET (HIGHER POWERS WITH TURBINE SET)

FULL PROGRAM

'HSHF' • HIGH SPEED, HIGH FREQUENCY
'LSHF' • LOW SPEED, HIGH FREQUENCY

TECHNICAL STATUS

PROCEEDING WITH FULL PROGRAM

EVALUATING TECHNICAL TRADEOFFS...

DIESEL -- TURBINE

LOW SPEED ALTERNATOR -- HIGH SPEED ALTERNATOR

EXISTING HS ALTERNATOR -- NEW HS ALTERNATOR DESIGN

POWER CONDITIONING (AC -- DC INPUT)

AND ASSESSING TECHNICAL / USER TRADEOFFS...

INTEGRAL -- SEPARATE AUXILIARY POWER

UTILITY ADAPTER -- TACTICAL POWER

PRIME POWER OUTPUT (60 Hz -- 1000 Hz)

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1.5MW ENGINE GENERATOR

TOP VIEW

SIDE VIEW

1 MW ENGINE GENERATOR

TOP VIEW

SIDE VIEW

PRIMARY ENGINES

TURBINES...

T55/TF40

MFG: Textron-Lycoming, Stratford, CN
USES: T55 -- Army CH-47 Chinook
TF40 -- Navy Lighter Air Cushion Vehicles
WEIGHT: 850 lbs.
TYPE: Dual Spool

T64

MFG: General Electric,
USES: Navy CH-53 Super Sea Stallion Helicopter
WEIGHT: 850 lbs.
TYPE: Dual Spool

DIESEL...

CONDOR V12

MFG: Perkins Engines Limited, Shrewsbury, England
USES: Challenger Tank, Hard Mobile Launcher, etc.
WEIGHT: 4145 lbs.
TYPE: Turbocharged, intercooled
DISP: 1593 in³ (26.1 litres)

FUEL CONSUMPTION AT 850 KW OUTPUT GBR CANDIDATE ENGINES

HARDWARE CONFIGURATIONS

HSHF = HIGH SPEED, HIGH FREQUENCY ALTERNATOR
 LSHF = LOW SPEED, HIGH FREQUENCY ALTERNATOR

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WHY EXPLORE HIGHER FREQUENCIES

(700 - 2,500 HZ)

- * HIGHER SPEEDS = SMALLER ALTERNATORS
- * HIGHER SPEEDS = HIGHER FREQUENCIES
(FOR A GIVEN NUMBER OF POLES)
- * HIGH SPEED ALTERNATOR DEVELOPED
BELVOIR/BENDIX 850 LB, MULTI-MEGAWATT ALTERNATOR
- * HIGHER FREQUENCIES = SMALLER TRANSFORMERS
- * SMALL ALTERNATORS ALLOW DIESEL OPTION TO
MEET ALL TRANSPORT/DEPLOY REQUIREMENTS

ALTERNATOR COMPARISON

<u>COMMERCIAL OFF-THE-SHELF</u>	<u>BELVOIR/BENDIX</u>
1,500 KW	UP TO 3,000 KW
8,000 LBS	1,250 LBS TOTAL (850 LBS + 400 LBS COOLING)
75" LONG	30" LONG
55" DIAMETER	15" DIAMETER
60 HZ	870 HZ
1,800 RPM	13,000 RPM
DIESEL DIRECT DRIVE	TURBINE DIRECT DRIVE
ESTABLISHED TECHNOLOGY	ADVANCED TECHNOLOGY

POWER CONVERSION OPTIONS

MED-FREQ = 0.7 - 2.5 KHZ. HI-FREQ = 25 - 300 KHZ.
LVDC = LO-VOLTAGE DC = 10 - 25 VDC

UTILITY INTERFACE

MOTOR-GEARBOX-ALTERNATOR

- * POSSIBLE VOLTAGE FLEXIBILITY
- * NO FREQUENCY FLEXIBILITY
- * LOW RISK SOLUTION
- * PRE-EMPLACED FOR SPECIFIC SITE

SOLID STATE UTILITY INTERFACE

- * POSSIBLE VOLTAGE AND FREQUENCY FLEXIBILITY
- * POSSIBLE INTERFACE FOR A WIDE RANGE OF SITES
- * HIGHER RISK, HIGHER PAYOFF
- * SOLID STATE TECHNOLOGY RAPIDLY ADVANCING
- * ISSUES BEING STUDIED

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C130 TRANSPORTABILITY

DIESEL POWER SYSTEM
(WEIGHT: 42,400 lbs.)

TURBINE POWER SYSTEM
(WEIGHT: 39,950 lbs.)

CONCEPT ILLUSTRATION

INTEGRATED AUXILIARY POWER

(LTE = LOAD TRANSFER EQUIPMENT)

CONCEPT ILLUSTRATION

SEPARATE AUXILIARY POWER

(LTE - LOAD TRANSFER EQUIPMENT)

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PROGRAM ON SCHEDULE

NO TECHNICAL "SHOW-STOPPERS"

MULTIPLE PROGRAM PATHS PROVIDE RISK REDUCTION

TECHNICAL / USER DIALOGUE CRITICAL

Mr. William Siegel
Hybrid Propulsion Systems

HYBRID PROPULSION SYSTEMS

PROGRAM OVERVIEW

William L. Siegel
Program Manager

May 5, 1993

Goal

To assist U.S. industry in the development of Hybrid Vehicles that:

- Reduce U.S. dependence on foreign oil
- Reduce the environmental impact of the Nation's transportation sector
- Increase the competitiveness of the U.S. automotive industry

Potential Technologies for Significant Improvements in Fuel Economy and Emission Reductions

U.S. Petroleum Use and Production

Scenario 2 2/9/93

Ambient Emissions Reduction Estimates For Light Duty Vehicles

Scenario 2 2/9/93

Objectives

- Increase fuel efficiency by 100%
example: CAFE = 27.5 mpg, Hybrid = 55 mpg
- Meet lowest emission requirements (EPA Tier 2)

Non-Methane Organic Gas	0.075 g/mi
Non-Methane Hydrocarbons	0.125 g/mi
Carbon Monoxide	1.700 g/mi
Nitrogen Oxides	0.200 g/mi
Particulates	0.080 g/mi
Formaldehyde	0.015 g/mi
- Compete with conventional vehicle on performance, range, safety, and cost.
- Operate on alternative fuels.

Note: CAFE = Corporate Average Fuel Economy
EPA = Environmental Protection Agency

What is a Hybrid ?

SERIES HYBRID

Rationale - Energy Efficiency

Conventional Vehicle

Hybrid Vehicle

AUXILIARY POWER UNITS POSSIBLE CHARACTERISTICS

- 20 - 40 kW
  - > 35% Thermal Efficiency
  - Small, Lightweight
  - NVH Sensitive
  - Constant or Narrowband Power Operation
  - Multifuel Capable
-

APU ENGINE TECHNOLOGY

CANDIDATES

- Gas Turbine (metallic, ceramic)
- High Speed Rotary (wankel)
- Diesel
- Spark Ignited Piston
- Sterling

Implementation - Key Elements

- Competitive teams
  - Automobile manufacturer
  - Fuel supplier
  - Small business
- 50% cost share
- Release from FOIA
- U.S. firm preference

DOE HV Program Implementation Schedule

Electric and Hybrid Propulsion Development

FY 1993 Appropriation
\$59.79 Million

FY 1994 Request
\$82.64 Million

Significant FY 1994 Objectives

- Field test first advanced batteries developed by the USABC
- Initiate testing and evaluation of hybrid propulsion system components
- Initiate EV demonstration and infrastructure development program

**Mr. Paul Richard
3 kW Tactical Quiet Generator Program**

***US ARMY
BELVOIR RESEARCH DEVELOPMENT
&
ENGINEERING CENTER***

***3 KW TACTICAL QUIET
GENERATOR PROGRAM
(3 KW TQG)***

***LOGISTICS EQUIPMENT DIRECTORATE
POWER GENERATION DIVISION***

PAUL M. RICHARD

MAY 5, 1992

3 KW TQG

INTRODUCTION

- * PART OF TOTAL FLEET REPLACEMENT**
  - 3 KW THRU 60 KW
  - FOUR ALTERNATIVES (MS, IMS, COM, ECOM)

- * EXISTING MIL-STD FAMILY OF GENERATORS**
  - 80% GASOLINE
  - 70% GREATER THAN 10 YEARS OLD
  - DO NOT MEET NEW USER REQUIREMENTS

- * PRIMARY GOALS**
  - REDUCED WEIGHT
  - INCREASED RELIABILITY
  - REDUCED NOISE
  - STANDARDIZATION ON DIESEL FUELS

- * NDI PROGRAM WITH PERFORMANCE PD**
  - MANAGED BY PM-MEP
  - BRDEC PROVIDING TECHNICAL SUPPORT

- * PRODUCTION CONTRACTS AWARDED**
  - 5-60 KW / AUGUST 1988
  - 3 KW / APRIL 1989
  - ATCOM PROCUREMENT

3 KW TQG REQUIREMENTS

PAST vs NEW

<u>PAST REQUIREMENTS (Gasoline):</u>		<u>NEW REQUIREMENTS (Diesel):</u>
*	Provide 3 kW at 0.8 pf, single phase & 3 phase power	* Provide 3.0 kW at 1.0 pf, single phase only
*	Manual rope start, non-electric	* 24-volt DC starting system
*	Lightweight (325 lbs wet)	* Lightweight (325 lbs wet)
*	Unsuppressed noise signature (90 dBA)	* Suppressed noise signature (75 dBA)
*	Gasoline fueled	* Diesel fueled

3 KW TQG

MARKET INVESTIGATION

- * ANNOUNCEMENT IN CBD 3QFY87 FOR BASIC REQUIREMENTS**
- * SELECTED HARDWARE BASED ON WEIGHT, COST & SCHEDULE**
- * STARTED JAN 88' - COMPLETED OCT 88'**
- * 20 UNITS USED FOR TESTING**
  - 6 for Hi (120°F) & Low (-25°F) testing**
  - 12 for 500-hour Endurance test**
  - All units subjected to various electrical tests**
- * RESULTS:**
  - Weights ranged from 177-270 lbs**
  - All units provided 3 kW at 1000 ft/107°F**
  - Only 1 unit met 75 dBA at 7 meters**
  - Most of the units met voltage & frequency regulation requirements (4% & 3%)**
  - No units met the 7% waveform deviation requirement**
- * CONCLUSIONS:**

NO COMMERCIAL SETS MEET USER REQUIREMENTS!

TRADE-OFFS NEEDED TO MEET REQUIREMENTS

3 KW TQG

TRADE-OFFS

- * RATED LOAD**
  - From 3 kW at 4000 ft/95°F to 1000 ft/107°F

- * ELECTRICAL PERFORMANCE**
  - From 0.8 pf to 1.0 pf
  - Allow brush type alternators

- * AURAL SIGNATURE**
  - From 70 dBA to 75 dBA at 7 meters

- * SET INSTRUMENTATION**
  - Limited to voltage, frequency & hour meters
  - Limited to low oil pressure, low fuel & high temp faults

- * NO DIAGNOSTIC CONNECTOR ASSEMBLY**
  - Limited to diagnostic test points

- * AUTOMATIC SHUTDOWNS**
  - Limited to low oil pressure, low fuel & high temp with manual override

3 KW TQG HARDWARE DESIGN

- * ENGINE**
  - Lombardini 6LD400 (Modified)
  - Weight with accessories - 105 lbs
  - Horsepower rating - 7.3 continuous

- * GENERATOR**
  - Mecc Alte Model B14/B9 (60/400 Hz)
  - 3600 rpm (60 Hz)/3428 rpm (400 Hz)
  - Unity power factor (pf = 1.0)
  - Weight - 57.7 lbs (60 Hz)
  - Incorporated battery charger

- * VOLTAGE REGULATOR**
  - Mecc Alte - solid state (4% regulation)

- * GOVERNOR**
  - Lombardini - mechanical (3% regulation)

- * HOUSING & SKIDBASE**
  - Aluminum construction
  - Structural housing integrated with skidbase

3 KW TQG PROGRAM STATUS

- * MANY CORRECTIVE ACTIONS INCORPORATED SINCE THE INITIAL PREPRODUCTION QUALIFICATION TEST (PPQT)
- * NEW HARDWARE SCHEDULED FOR DELIVERY IN JUL 93 FOR PPQT IV

TEST RESULTS: PPQT III (FEB-SEP 92')

TEST	PASS/ FAIL	RESULT/REQUIREMENT	SOLUTION
WEIGHT	FAIL	325.6-328.6 lbs/325 lbs	None.
TM 608.1	PASS	IAW MS-1332	N/A.
NOISE	FAIL	85 dBA at op station	None.
NOISE	PASS	Sets meet 75 dBA at 7m	N/A.
HIGH TEMP	PASS	Set operates at 120°F	N/A.
ALTITUDE	PASS	@ 1000/4000/8000 ft	N/A.
LOW TEMP	PASS	Set operates at -25°F	N/A.
RR IMPACT	PASS	No damage found.	N/A.
COLD STORAGE	FAIL	AC Volt regulator resin	New resin.
ROAD (PP)	PASS	No damage found.	N/A.
ROAD (5-ton)	TBD	Testing complete.	To be retested.
RELIABILITY	FAIL	Numerous failures.	Numerous fixes.

3 KW TQG

PROBLEM AREAS

*** VOLTAGE WAVEFORM**

- **10% waveform deviation discovered during Fermont PPQT (7% required)**
- **Government assessment of the impact of the 10% waveform deviation on-going**

*** GENERATOR BRUSHES**

- **Brush wearouts occurred between 750-900 hrs vs 1500 hr requirement**
- **Fermont proposing 2 new brushes - 99% graphite**

*** RELIABILITY**

- **500 hr MTBF with 90% confidence level required**
- **385/171 hr MTBF demonstrated (60/400 Hz respectively)**
- **519/366 hr MTBF projected (60/400 Hz respectively)**
- **Keys: Battery chargers, vibrational failures**

*** WEIGHT**

- **325 lbs wet weight requirement**
- **Currently 328 - 330 lbs.**

3 KW TQG RETEST PLAN

*** FERMONT PROOF TEST**

- Test out new brushes, new battery chargers & other fixes
- 4 sets (2 each 60 & 400 Hz)
- 600 hrs at ambient conditions, rated load
- 300 hrs at 120°F, rated load
- Referee grade diesel fuel

*** PPQT IV RETEST**

- 18 new sets for Government testing/4 rebuilt sets for Fermont testing
- Complete Government retest with the exception of power plant testing
- Partial repeat of Fermont tests

Name	88	1989		1990		1991		1992		1993		1994		1995	
		Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr	Qtr
3 KW TQG PD APPROVAL	◆														
MILESTONE-III A IPR	◆														
SOLICITATION	■														
AWARD	◆														
PROTOTYPE PRODUCTION	■														
PROTOTYPE EXAM	■														
PROTOTYPE EXAM REPORT	■														
PRODUCTION OF PPQT SETS	■														
PPQT EXAM	■														
PPQT DELIVERY	■														
DT&E I	■														
DT&E II	■														
IOT&E CANCELLED	■														
DT&E III															
DT&E IV															
IOT&E															
IAR & AOR															
MILESTONE-III B IPR PACKAGE REVIEW															
MILESTONE-III B IPR DECISION															
PRODUCTION															
DELIVERY TO FUE SITE															
FUE															

Critical

Noncritical

Progress

Milestone

Summary

Rolled Up

**3 KW TACTICAL QUIET GENERATOR SET
FACT SHEET**

HARDWARE: 3 kW (60 Hz & 400 Hz)

Engine: Lombardini Model 6LD400 (Fermont Spec)

- Single cylinder, 7.3 Hp (Continuous)
- 3600/3428 rpm (60/400 Hz)
- 105 lbs w/ accessories

Generator: Mecc Alte Model B14/B9 (60/400 Hz)

- Unity power factor (pf=1.0)
- 57.7 lbs (60 Hz), incorporates battery charging system

Voltage Regulator: Mecc Alte

- Solid state, 4% regulation

Governor: Lombardini

- Mechanical w/ flyweights, 3% regulation

Structure: All aluminum

- Structural housing

Dimensions & Weight:

- 37"x28"x30" (LxWxH)
- 325 lbs. (operational)

TESTING: PPQT IV / JUL 93 - DEC 93 at Aberdeen Proving Grounds

Test Hardware & Sites: 22 PPQT units

- 10 APG (8 - 60 Hz; 4 - 400 Hz)
- 6 Fermont (4 - 60 Hz; 2 - 400 Hz)
- 6 Ft. Hood (60 Hz)

STATUS: Contractor completing proof testing of corrective actions.

- Rejected PPQT hardware for 3rd time SEP 92
- Corrective actions being incorporated
- Restart of PPQT planned for JUL 93
- MS III IPR - JUL 94
- FUE - AUG 95

PRODUCTION:

Sets Ordered: 4,132 total / Unit cost of \$ 3,100.[∞]

- 4,035 60 Hz
- 97 400 Hz

NOMENCLATURE:

60 Hz	NSN # 6115012853012	MEP-831
400 Hz	NSN # 6115012872431	MEP-832

POC: Mr. Paul M. Richard (703) 704-2648, DSN 654, or Mr. Michael T. Payne X-2647

Mr. Jeffrey Didion
Refrigeration Issues within NASA

Refrigeration Issues within NASA

**Jeffrey Didion
NASA GSFC**

NASA Refrigeration Issues

- Space Shuttle Refrigerator/Freezer
- Space Shuttle Ground Support
- Space Station Requirements
- Advanced Development of Thermal Transport Loops

Space Shuttle Refrigeration

- Space Shuttle Refrigerator
  - 293 W @ 4C and 117 W @ -22 C
  - R502 working fluid
- Shuttle Flight Systems
  - Orbiter R21 Loop
  - Spacelab R114 Loop

Shuttle Refrigeration Issues

- Refrigerator & orbiter loop employ CFCs
- Refrigerator compressor has short lifetime
  - oil free diaphragm type compressor
  - JSC pursuing scroll compressor & linear compressor replacements
  - JSC investigating stirling machines
- Refrigerator can not meet acoustic spec

Ground Support Equipment

- R113 Loop for to cool oxidizer for OMS/RCS while on pad
  - KSC testing perfluorocarbon 5060 to replace
- R114 Loop serving as thermal sink for Orbiter R21 Loop
  - KSC testing HFC-134a as replacement
- R21 Loops to be replaced - R114 banned

Future Refrigeration Requirements

- Space Station Freedom Science and Crew Requirements
  - Food Storage
  - drug & film storage
  - water chilling
  - biological sample freezing and storage
  - crystal growth experiments
- Evaporator Temperatures 4 C to -196 C

NASA Refrigerator Technology Team

- Evaluate existing technology for suitability to NASA requirements
- Recommend direction for technology development program
- Recommend improvements to existing hardware

Technology Survey

- Top level survey - no detailed engineering analysis
- Individual Technologies evaluated
  - thermodynamic efficiency
  - technology readiness/maturity
  - NASA engineering constraints
- Vapor Compression, Stirling Based Gas Cycles, and Thermo-Electrics

Vapor Compression System

- Two Phase Systems are inherently most efficient systems
  - low mass flow rates
  - high heat transfer coefficients
  - low heat exchanger irreversibilities
- Thermodynamic performance of system dependent upon working fluid selection
  - CFCs/HFCs exhibit most desirable properties
  - efficiency decreases w/ evaporator temperature

Vapor Compression System Pressure Enthalpy Diagram

Vapor Compression System Working Fluid Selection

Pressure - Temperature Diagram of Selected Refrigerants

Vapor Compression System Evaluation

- Workhorse of industry
  - Extremely Reliable
  - Extensive R&D, and applications
- Loss in performance is great enough to allow gas systems to become competitive at low temperatures
- Can Not be applied to cryogenic regimes

Thermo Electric Systems

- Development still needed to become competitive at refrigerator temperatures
  - possible niche: low capacity refrigerators
  - efficiency improvements to approx. 25% of V/C
- Long History - Well Developed Technology
- Accurate Temperature Control w/ no moving parts

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2 of 4

Stirling Based Gas Systems

- Mature and Reliable Technology
- Successfully applied over entire evaporator temperature range
  - single stage compression even at cryogenic temperatures
  - existing hardware at normal refrigeration temperatures - lower COP than V/C system
- Space Flight experience

Component Research

- Improve performance of any Generic Refrigeration System
- Insulation Technology
  - soft vacuum
  - hard vacuum
- High Performance Heat Exchangers
  - heat exchangers represent largest irreversibility
  - active pursuit by refrigeration industry

GSFC Efforts

- Stirling Coolers for Cryogenic Heat Pipes
- Vapor Compression Systems
  - thermal transport loops
  - raise heat rejection temperature
  - lower system mass/volume
  - lunar martian application (studies completed)
  - thermal bus
- refrigeration
- Phase II SBIR: Modular Chemical/Mechanical Heat Pump for S/C Thermal Bus Applications

GSFC Efforts (2)

- Optimization Studies
- Vapor Compression Breadboard Loop
  - system evaluation:
    - micro gravity issues - fluid behavior
    - NASA specific engineering requirements
  - component evaluation
    - compressors
    - heat exchangers
    - expansion devices

GSFC Breadboard Loop Conceptual Design

Mr. Rick Rentz
Private Sector Technology/R&D Activities for
Refrigeration/Space Conditioning

**PRIVATE SECTOR TECHNOLOGY/R&D ACTIVITIES
FOR
REFRIGERATION/SPACE CONDITIONING**

PRESENTED TO:

**INTERAGENCY
ADVANCED
POWER GROUP**

MAY 5, 1993

**TA ENGINEERING, INC.
5509 YORK ROAD
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(410)-323-0126 (voice)
(410)-323-0128 (fax)**

DRIVING FUNCTIONS

o UTILITY DEMAND--SIDE MANAGEMENT

- ECONOMIC INCENTIVES**

o PHASE-OUT OF "OZONE-DEPLETING" REFRIGERANTS

- INSTITUTIONAL INCENTIVES**

ONE VIEW OF TECHNOLOGY R&D THRUSTS & INTERESTS

- o OZONE ISSUE IS FORCING MUCH WORK WITH REPLACEMENT REFRIGERANTS
  - o Product Redesign Issues
    - o compressors/heat exchangers
    - o materials
  - o Non-Ozone Depleting Refrigerants
    - o absorption
    - o NH₃ (ammonia)
- o DSM Issue Is Forcing
  - o Load Shifting & Conservation Technologies
    - o thermal storage
    - o heat pumps
    - o heat pipes
  - o Fuel Shifting
    - o gas cooling

TECHNOLOGY OVERVIEW

**REFRIGERANT RELATED ISSUES AFFECTING CHILLER SELECTION AND
DESIGN FOR COMMERCIAL APPLICATIONS**

ISSUE	COMMENTS
Conventional Versus Alternative Refrigerants	- o HCFC-123 as a low pressure alternative, for centrifugal machines - o HFC-134A as a medium (to high) pressure alternative for various applications - o HCFC-22 as a near term alternative for various applications (also a traditional high pressure refrigerant) - o R-717 (Ammonia) as a possible alternative (also a conventional industrial refrigerant)
Low Versus High Pressure Refrigerants	- o Low pressure refrigerants require purging and/or containment systems - o High pressure avoids purging, but highlights monitoring needs
Refrigerant Monitoring and Alarm/Ventilation	- o Group 1 refrigerants require O₂ monitoring, alarm and ventilation system (1) - o All other refrigerant groups require refrigerant concentration monitor, alarm and ventilation system (1)
Toxicity/Flammability	o Toxic and/or flammable refrigerants require special design precautions for their application (e.g., NH₃ requires special mechanical room design)
Open Drive Versus Hermetic Compressor Applications	o Open Drive avoids concerns over refrigerant/system clean-up in event of electric motor failure; much lower insurance rates

(1) Group 1 refrigerants include CFC-11, CFC-12, HCFC-22, CFC-113, HFC-134a, R-500, and R-502. HCFC-123, HFC-152a and R-717 (NH₃) are not Group 1 refrigerants.

**SUMMARY: FUNDAMENTAL TYPES AND GENERAL CHARACTERISTICS OF
PACKAGED COMMERCIAL WATER CHILLERS**

BASIC TYPES	CAPACITY RANGE (TONS)	REFRIGERANT	CAPACITY CONTROL TECHNIQUES	COMMENTS
Centrifugal Compressor	150 to 10,000	CFC-11, HCFC-123, HCFC-22, HFC-134a, R-500	- Typically variable geometry inlet guide vanes and/or diffuser - Dual compressor arrangements are available	- Open drive or hermetic systems available - Low or high pressure refrigerants available - Usually water-cooled
Rotary Screw Compressor	125 to 1,100	HCFC-22	- Typically sliding valve guide for refrigerant exhaust - Multiple compressors and/or refrigerant circuits	- Open drive or hermetic systems available - Water or air-cooled
Reciprocating Compressor	5 to 300	HCFC-22	- Multiple compressors and/or refrigerant circuits - Cylinder unloading	- Usually hermetic or semi-hermetic - Water or air cooled

SUMMARY: FUNDAMENTAL TECHNOLOGY CHARACTERISTICS AND AVAILABLE CAPACITY MACHINES FOR PACKAGED COMMERCIAL CENTRIFUGAL WATER CHILLERS

FUNDAMENTAL CHILLER TYPE	SINGLE STAGE COMPRESSOR	SINGLE STAGE AND DUAL COMPRESSORS	TWO STAGE COMPRESSORS WITH FLASH GAS RECIRCULATION	THREE STAGE COMPRESSORS WITH FLASH GAS RECIRCULATION	MODULAR THREE STAGE COMPRESSORS WITH FLASH GAS RECIRCULATION	COMMENTS
Open Drive Compressor Systems	150 to 13,500	500 to 2,100	1,300 to 7,000	N/A	N/A	o In many cases, alternate driver sets may be used. For example, gas or steam turbine, or variable speed electric motor
Hermetic Compressor Systems	150 to 13,500	500 to 1,000	900 to 1,400	160 to 1,400	1,500 to 3,000	

SUMMARY: TECHNOLOGY OPTIONS FOR PACKAGED COMMERCIAL CENTRIFUGAL WATER CHILLERS

TECHNOLOGY OPTIONS	COMMENTS
Free Cooling	Compressor inactive. Internal valving/controls allows evaporator/condenser to operate as refrigerant boiler/condenser. An alternative to water-side economizer as it avoids plate and frame heat exchanger system in building.
Auxiliary Condenser	A second, parallel refrigerant circuit, condenser is used for low temperature fluid heating. Either condenser typically carries chiller heat rejection load. Can improve kW/t of chiller when fluid heating temperatures are lower than tower water temperatures.
Heat Recovery Condenser	A second, parallel refrigerant circuit, condenser is used for higher temperature fluid heating. Can worsen kW/t of chiller when temperatures exceed tower water temperatures. Multiple stage compressors can better handle the resulting high refrigerant side pressure ratios.
Multi-tube Passes for Evaporator and/or Condenser	Increased heat transfer surface improves approach temperatures and thus machine kW/t. Usually increases water side pumping energy requirements.
Brine Chilling/Ice Making	More amenable to multi-stage compressors due to resulting higher refrigerant side pressure ratios, as offset by lower nighttime condenser water temperatures. Generally derates capacity of machine and/or worsens kW/t rating when operating in lower water/brine supply temperature mode.

SUMMARY: AVAILABLE SCREW COMPRESSOR PACKAGED WATER CHILLERS FROM SELECTED VENDORS

VENDOR	NOTABLE CHARACTERISTICS	CAPACITY RANGE (tons)	COMMENTS
Carrier	Hermetic	160 to 250	
Dunham-Bush	Open Drive	500 to 1,100	
Trane	Hermetic, water cooled	130 to 450	
	Hermetic, air cooled	130 to 400	o Applies multiple compressors and dual refrigeration circuit
York	Open Drive	125 to 1,250	

SUMMARY: TECHNOLOGY OPTIONS FOR PACKAGED COMMERCIAL SCREW COMPRESSOR WATER CHILLERS

TECHNOLOGY OPTIONS	COMMENTS
Heat Recovery Condenser	o Can worsen kW/t of chiller when temperatures exceed tower water temperatures.
Multi-tube Passes for Evaporator and/or Condenser	o Increased heat transfer surface improves approach temperatures and thus machine kW/t. Usually increases water side pumping energy requirements.
Brine Chilling/Ice Making	o Generally derates capacity of machine and/or worsens kW/t rating when operating in lower water/brine supply temperature mode.

SUMMARY: LARGE TONNAGE ENGINE DRIVEN CHILLERS

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGE (tons)	COMMENTS
Nova Group	- o industrial engine drive - o centrifugal or screw compr.	250 to 800	- o Products may not be UL listed - o Amenable to waste heat recovery
Tecogen	- o automotive derivative engine - o centrifugal compressors	150, 250 and 500 tons	- o Only 150 ton product is commercially available - o Amenable to waste heat recovery
Interex (Econochill)	- o industrial engine drive - o reciprocating	40 to 300 tons	
Alturdyne	- o industrial engine drive - o reciprocating compressor	to 285	

**TYPICAL TECHNICAL CHARACTERISTICS FOR A 665 TON
ENGINE DRIVEN CHILLER**

ROTARY SCREW

PARAMETER	VALUE
Specific Power (hp/ton)	.75
Gaseous Fuel Input (therm/hr)	45
COP (chiller only)	1.8
COP (with heat recovery)	2.3
Total Available Waste Heat (Btu/hr)	2,300,000
Unit Condenser Flow (gpm/ton) 10° F. delta-T	3.0
Unit Operating Weight (lb/ton)	50
Dimensions, L x W x H (ft)	engine/compressor skid 17.8 x 8.25 x 9.33 condenser/controls skid 18.8 x 7.2 x 5.7
Weight Pressure, max (lbs/ft ²)	120

SUMMARY: FUNDAMENTAL CHARACTERISTICS OF AVAILABLE LARGE TONNAGE ABSORPTION EQUIPMENT

CHILLER TYPES	CAPACITY RANGE, COOLING (TONS)	COP/STEAM FIRING RATE (HEATING EFF.)	COMMENTS
Direct Gas Fired (double effect)	100 to 1,500	1.0 (80-83%)	Chiller/heaters
Steam Fired (low pressure, single effect)	100 to 1,660	0.67 18 lb/ton-hr	Chillers
Steam Fired (high pressure, double effect)	100 to 1,500	1.0 to 1.2 10 lb/ton-hr	Chillers

SUMMARY: LARGE TONNAGE ABSORPTION PRODUCTS

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGES (TONS)	COMMENTS
Trane/Kawasaki	direct gas-fired, double effect chiller/heater	100 to 1,100	- o dual fuel burner - o low NO_x burner - o 2-pipe system
	low pressure steam or hot water, single effect chiller	101 to 1,660	- o steam or hot water - o many sizes
	high pressure steam, double effect chiller	385 to 1,060	
York/Hitachi	direct gas-fired, double effect, chiller/heater ¹	120 to 1,500	- o dual fuel burner - o low NO_x burner - o 4-pipe system
	low pressure steam or hot water, single effect	120 to 1,377	
	high pressure steam, double effect	250 to 1,500	
Carrier	direct gas-fired	135 to 500	- o dual-fuel burner - o low NO_x w/FGR - o 2-pipe system
	low pressure steam or hot water, single effect	100 to 650	o steam or hot water
	high pressure steam, double effect	90 to 1,500	

(1) Heat recovery (hot gases) models are also available

SUMMARY: LARGE TONNAGE ABSORPTION PRODUCTS (CONTINUED)

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGES (TONS)	COMMENTS
McQuay/Sanyo	direct gas-fired, double effect chiller/heater	100 to 1,500	- o dual fuel burner - o 4-pipe system
	high pressure steam, double effect	100 to 1,500	
Mitsubishi	direct gas-fired, double effect chiller/heater	75 to 1,190	- o dual fuel burner - o 4-pipe system
	high pressure steam, double effect	100 to 1,500	

SUMMARY: SMALL TONNAGE ABSORPTION PRODUCTS BY MANUFACTURER/SUPPLIER

SUPPLIER	GENERAL CHARACTERISTICS	GENERAL CAPACITY RANGE COOLING (TONS)	COMMENTS
Robur Corp. (Serval)	- o NH₃/H₂O cycle - o air-cooled - o direct gas-fired	3 to 25	Discrete units up to 5 tons, then modular assemblies. Integrally packaged heating available thru a separate gas burner
American Yazaki	- o LiBr/H₂O cycle - o water cooled - o energy input types - o direct gas-fired - o hot water fired - o steam fired - o steam/hot water fired	5 to 100	Generally discrete units up to about 20 tons, then modular assemblies. Availability of steam units is uncertain.
McQuay/Sanyo	- o LiBr/H₂O cycle - o water cooled - o energy input types - o direct gas-fired - o hot water fired - o steam/hot water fired	20 to 100	Generally discrete units to 40 tons, then modular assemblies.

SUMMARY: SELECTED EXAMPLES OF THERMAL STORAGE EQUIPMENT

VENDOR	ICE MAKING EQUIPMENT			STORAGE EQUIPMENT	
	Harvester	Ice-on-Coil	Brine Coil	Encapsulated	Chilled Water
Baltimore Air Coil		X			
Calmac/Trane			X		
CBI Strata Therm					X
Chester Jensen		X			
FAFCO (IceStor)			X		
Morris & Assoc.	X				
Mueller	X				
Reaction/Carrier				X	
Sullair		X			
Transphase				X	
Turbo	X				
Vilter Mfg.	X				
Vogt	X				
York IceBall				X	
York Icepak		X			

SUMMARY: ICE-ON-COIL THERMAL STORAGE PRODUCTS

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGE (ton-hrs)	COMMENTS
Baltimore Air Coil	- o Offer Packaged storage system - o Also offer custom coils for field erected systems - o Compatible with direct refrigerant system or glycol chiller	120 to 950	Typically available for mating with direct refrigeration or glycol chiller equipment. Variety of air or water cooled condensers available. Air blower used in ice tank to maintain even temperature distribution, represents parasitic load.
Chester Jenson	o Offer complete refrigerant based system	12 to 1,200	
York	- o Small size range is complete with direct refrigerant system - o Large size range available with recommended York glycol chiller	75 to 480 (pkg'd w/ refrig sys) 230 to 1,400 (storage sys)	

SUMMARY: BRINE COIL THERMAL STORAGE PRODUCTS

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGE (ton-hrs)	COMMENTS
Calmac	o cylindrical tanks	90 to 120	Both systems are designed for glycol chillers
FAFCO	o rectangular tanks	125 to 270	

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGE (ton-hrs)	COMMENTS
Morris & Assoc.	- Utilizes screw type distribution device - Ice is formed on evaporator tubes	370 to 6200	Can operate as water chiller
Mueller	Ice is formed on evaporator plates	700 to 5,600	Can operate as water chiller
Turbo	Ice is formed on evaporator plates	770 to 4,130	Can operate as water chiller
Vogt	Ice is formed on evaporator tubes	350 to 3,000	Very tall ice making unit. Must be mated with storage tank system

SUMMARY: DYNAMIC ICE HARVESTER THERMAL STORAGE PRODUCTS

SUPPLIER	GENERAL CHARACTERISTICS	CAPACITY RANGE (ton-hrs)	COMMENTS
Carrier/Reaction	Utilizes plastic containers filled with de-ionized water	500 to 3000	Available as packaged system in modular tanks
York	Utilizes plastic spheres filled with de-ionized water	Any	Intended to be installed in tanks, can be pressurized to 300 psig
Transphase	Utilizes eutectic salt in plastic containers	3000+	Typically in-field erected in vaults

SUMMARY: ENCAPSULATED THERMAL STORAGE PRODUCTS

R&D OVERVIEW

SELECTED REFRIGERATION TECHNIQUES

o ABSORPTION

o HEAT PIPE

o ADSORPTION

o AIR STANDARD CYCLES

o CHEMISORPTION

o IMMERSION

o THROTTLING/EXPANSION

o INJECTION

o THERMOELECTRIC

o VORTEX TUBE

o JET EJECTOR

SELECTED MAJOR PRIVATE SECTOR R&D ENTITIES

o TRADE/INDUSTRY R&D ORGANIZATIONS

- o ASHRAE**
- o ARI/ARTI**
- o EPRI**
- o GRI**

o TRADE/INDUSTRY R&D/COMMERCIAL DEPLOYMENT ORGANIZATIONS

- o AGCC**
- o ITSAC**
- o Thermal Storage Applications Research Center**
- o Wisconsin Center For Demand-Side Research**

o PRIVATE INDUSTRY/BUSINESS

- o Utilities (e.g., BUG, Columbia Gas, PG&E)**
- o Equipment Manufacturers/Suppliers**

EPRI ACTIVITIES

o HEAT PUMPS

- o Industrial/Heat Recovery**
- o Ground/Ground Water/Water Source**
- o Air Source**

o THERMAL ENERGY STORAGE

- o Ice**
- o Water**
- o Eutectics**

o DEHUMIDIFICATION

- o Heat Pipes**

o MISCELLANEOUS APPLICATIONS TOPICS

- o Cold Air Distribution**

GRI ACTIVITIES

o RESIDENTIAL SPACE CONDITIONING

- o Desiccants**
- o Absorption Air Conditioning**
- o Absorption Heat Pumps**

o COMMERCIAL SPACE CONDITIONING

- o Desiccants   o GAX**
- o Engine Chillers/DX   o Heat Actuated**
- o Absorption**

o RESIDENTIAL HEAT PUMPS

- o Engine Driven**
- o Absorption**
- o Chemisorption**

o COMMERCIAL HEAT PUMPS

- o Engine GHP**
- o Stirling GHP**
- o Rotary GHP**
- o Chemisorption**

RECENT "ENDEAVORS"

o COP/COST IMPROVEMENTS

- o Absorption
- o Adsorption
- o Chemisorption
- o Jet Ejector

o WASTE HEAT UTILIZATION

- o Heat Pumps

o GAS ENGINE HEAT PUMPS

- o Heating Mode Enhancements
- o Alternative Drives

o THERMAL TRANSPORT

Dr. George Kurylowich
ECS Technologies-Yesterday/Today/Tomorrow

**AIR FORCE
FLIGHT DYNAMICS DIRECTORATE**

ECS

TECHNOLOGIES

YESTERDAY/TODAY/TOMORROW

AGENDA

YESTERDAY

(1970-1982)

- ADVANCE AIRFORCE TECHNOLOGIES

TODAY

(1983-1993)

- ADVANCE DEPARTMENT OF DEFENSE (DOD) TECH.

TOMORROW

(1994-?)

- ADVANCE DEPARTMENT OF DEFENSE (DOD) TECH.
- FOSTER DEFENSE CONVERSION INITIATIVES

YESTERDAY (1970-1982)

- ADVANCE AIR FORCE TECHNOLOGIES

- ADVANCED ENVIRONMENTAL CONTROL SYSTEM (AECS) - FLIGHT TEST
- ADVANCED ENVIRONMENTAL CONTROL SYSTEMS (AECS) - COMPUTERIZED STEADY - STATE ANALYTICAL CAPABILITY (AIR/VAPOR)
- ENVIRONMENTAL ANALYSIS SYSTEM (EASY) - COMPUTERIZED TRANSIENT CAPABILITY
- WASTE HEAT CONVERSION

ICECS / OPEN AIR ECS TEMPERATURE CONTROL COMPARISONS

- 80°F DEW POINT TEMP.
AT SEA LEVEL STD.

ADVANCED ENVIRONMENTAL CONTROL SYSTEM

HIGH PRESSURE
WATER SEPARATOR

VARIABLE GEOMETRY
AIR CYCLE MACHINE

ADVANCED ENVIRONMENTAL CONTROL SYSTEMS (AECS)

ENVIRONMENTAL ANALYSIS SYSTEM (EASY)

TODAY (1983 - 1993)

- ADVANCE DOD TECHNOLOGIES

- REFRIGERANT MIXTURES
  - SYSTEM TUNING
- INTEGRATED CLOSED ENVIRONMENTAL CONTROL SYSTEM (ICECS)
  - JOINT CANADA/USA AGREEMENT
  - NAVY/AIR FORCE DEVELOPMENT
- CHEMICAL & BIOLOGICAL AGENT PROTECTION SYSTEM (CABAPS)
  - FDL/ASD EFFORT
  - CRDEC/ERDEC TRANSITION

**IMPROVED HEAT
TRANSFER COEFF.**

IMPROVED COP.

CHEMICALLY HARDENED ENVIRONMENTAL CONTROL SYSTEM (CHECS)

ANALYZE, BUILD AND DEMONSTRATE
AN ADVANCED ECS CONCEPT
FOR MILITARY AIRCRAFT

INTEGRATED CLOSED ENVIRONMENTAL

CONTROL SYSTEM

(ICECS)

GROWTH OF THE AVIONIC SUITE

- THE PROBLEM:
- MORE DATA
  - INCREASED WORKLOAD
  - REDUCED RESPONSE TIME
  - IMPROVED THREATS
  - SYSTEM FAILURE
- THE SOLUTION: USE AI FOR
- INFORMATION MANAGEMENT
  - PLANNING
  - DECISION AIDING
  - STATUS MONITORING
  - SYSTEM CONTROL
  - FAILURE RECOVERY

GROWTH OF THE AVIONIC SUITE

OPEN/CLOSED ENVIRONMENTAL CONTROL SYSTEM (ECS)

OPEN-LOOP

CLOSED-LOOP

PHASES OF ICECS

PHASES I - III LABORATORY TEST

- PH.I - (MARCH 85 - NOV 86) - ANALYSIS
- PH.II & III - (DEC 86 - JAN 90) - FAB. & TEST
- PAYOFF: 5% TOGW REDUCTION/10% RANGE IMPROVEMENT
20% REDUCTION IN ECS/AVIONICS LCC
- PROBLEM AREA - McAIR/SUNDSTRAND IR & D 1987-88
- LIQ. TO LIG. H/X G SENSITIVE
- PH. IV - (APR 91 - 30 OCT 93) - ARMSTRONG LAB.
(AL) SIMULATOR)

LIFE CYCLE COST ESTIMATES

Three-Phase ICECS Mission

MISSION SEGMENT	MACH NUMBER	ALTITUDE (ft)	DURATION (hr)	SPEED (ft/sec)
A - Cruise	90	50,000	.583	846.7
B - Ascent/Descent	85	25,000	.847	890.1
C - Dash	88	0	.385	967.9

Ground Rules and Assumptions

PARAMETER	VALUE
Quantity of Aircraft Development Production	12 200
Operation and Support Years of operation Annual flying hours/aircraft Aircraft/squadron Operational aircraft/wing Average No. of operating aircraft Total program flying hours	15 300 24 72 150 675,000
Economic Factors Year of economics Pol Cost (\$/Gal) (AFR 173-13, March 1988)	1988 0.61

Life Cycle Cost Estimates (Millions of \$1988)

	F-15 ECS	ICECS
ECS RDT & E Hardware Spares O & S (15 years) (Subtotal)	14.6 38.1 9.5 15.6 77.8	44.5 106.0 6.7 11.7 168.9
Fuel (Subtotal)	50.7 128.5	23.8 192.7
Avionics Spares O & S (15 years)	183.6 1793.4	146.3 1424.0
Total LCC	2105.5	1763.0

LCC SAVINGS = 16.3%
LCC SAVINGS = \$22.8M/YR

INTEGRATED CLOSED ENVIRONMENTAL CONTROL SYSTEM(ICECS/PHASE IV)

BROAD OBJECTIVES

- DEMONSTRATE VAPOR CYCLE ICECS
- PERFORMANCE IN A/C HIGH g ENVIRONMENTS

VCS DEMONSTRATION

- AT WPAFB ARMSTRONG LAB CENTRIFUGE FACILITY

ICECS VARIABLE FREQ. FOIL BEARING COMPRESSOR

- ENVIRONMENTALLY SAFE REFRIGERANT (R134a)
- 13-TON COOLING CAPACITY
- TWO-STAGE CENTRIFUGAL
- HIGH SPEED (75,000 RPM)
- FOIL BEARINGS
- TWO-POLE-TOOTHLESS PM MOTOR
- LIGHT WEIGHT (24.5 LB)
- HIGH EFFICIENCY (30 KW)

DIGITAL CONTROL TECHNOLOGY

5 CIRCUIT CARD

- HIGH ANALOG
- LOW DIGITAL

1985-1987

SINGLE CIRCUIT CARD

- LOW ANALOG
- HIGH DIGITAL

1988-1990

HYBRID PACKAGE

- ALL DIGITAL
- HERMETIC

1991 +

INTEGRATED CLOSED ENVIRONMENTAL CONTROL SYSTEM (ICECS)

INTEGRATED CLOSED ENVIRONMENTAL CONTROL SYSTEM (ICECS/PHASE IV)

PHASE IV STATUS

- APR 91 - FEB 93
ELECTRICALLY DRIVEN
FLIGHT ICECS DEV.
- FEB 93 - APR 93
PER./ORIENTATION TEST (ASE)
- 5 APR 93 - 30 APR
ICECS ASSEMBLED/CHARGED/
INSTALLED ON AL SIMULATOR
- MAY 93 - 8 JUN 93
STATIC/ORIENTATION TEST,
SAFETY PROCEDURES CHECKOUT,
TEST PLAN REVIEW
- 9 JUN 93 - 19 JUL 93
VARIABLE HIGH G SIMULATION
- 19 JUL 93 - 30 OCT 93
FINAL REPORT SUBMITTAL

FA SOFI EOS D C IIA CONIRO
C-47

FA SOFT D G IIA CON HRO M22

CHEMICAL AND BIOLOGICAL AGENT PROTECTION SYSTEM(CABAPS) PROGRAM

- **AWARDED MARCH 1987 BY AIR FORCE SYSTEMS COMMAND
(WPAFB)**
- **3-PHASE PROGRAM (FOR 20 LB/MIN CABAPS UNIT):**
  - PHASE I   DESIGN   -   MARCH 1987 - AUGUST 1988**
  - PHASE II   DEVELOP   -   JULY 1988 - JUNE 1990**
  - PHASE III   TEST   -   OCTOBER 1989 - SEPTEMBER 1991**

NBC THREAT IS COMPLEX

N

NUCLEAR

STRONTIUM 90
RADIUM 226
PLUTONIUM 238
IODINE 131

B

BIOLOGICAL

BACTERIAL
VIRAL
RICKETTSIAL
TOXINS

C

CHEMICAL

- NERVE: GD
- BLOOD: AC
- BLISTER: HD

SIMPLIFIED CATALYTIC REACTOR SCHEMATIC

CABAPS TEST UNIT

88731-2

CONCENTRATION PROFILE OF PRODUCTS

AMBIENT INLET = 142 MG/M ³					
AGENT	PRODUCT	REACTOR OUTLET*		WATER SEPARATOR OUTLET	ALLOWABLE*** CONCENTRA- TION
		STOICHI- METRIC	ESTIMATED		
GD	HF	15.6	3.2	0.6	2.5
HD	HCl	65.0	24.4	4.6	7.0
AC	SO ₂	57.2	51.5	51.2	5.0
	NO ₂	240.3**	12.0	12.0	6.0
	NO	OR 156.7**	11.0	11.0	30.0

* ESTIMATED FROM LABORATORY DATA

** ASSUMES COMPLETE NITROGEN CONVERSION TO EITHER OXIDE

*** THRESHOLD LIMIT VALUE

ACID GAS ABSORPTION

AGENT	PRODUCT	WATER SEPARATOR OUTLET, MG/M ³	TOTAL PRODUCT, LB*	ABSORBENT REQUIRED, LB	
				LiOH	MgO**
HD	SO ₂	51.2	0.0679	0.101	0.088
AC	NO ₂	12.0	0.0158	0.0164	0.0143

* TOTAL PRODUCT BASED ON 20 LB/MIN AIR, FOR 36 ATTACKS (3 PER DAY/12 DAYS)
WITH 1-HR MISSION/ATTACK

** BASED ON TOTAL PRODUCT ABSORPTION AT 50 PERCENT DYNAMIC ABSORPTION
EFFICIENCY

TOMORROW (1994-?)

- ADVANCE DOD TECHNOLOGIES
  - INITIATE & CONDUCT DEFENSE CONVERSION EFFORTS
-
- INTEGRATED THERMAL ENERGY MANAGEMENT (I-TEM)
-
- PHASE CHANGE MATERIAL (PCM) COOLANTS
-
- FOSTER DEFENSE CONVERSION EFFORTS

THERMAL MANAGEMENT CONCERNS

NEED DEFINITION:

- AVIONIC HEAT LOADS INCREASE YEARLY

- F-16/F-15E EFF. HEAT SINK
- USED UP/ALMOST USED UP

- INTEGRATED HIGH PERFORMANCE
TURBINE ENG. TECH. (IHPTET)
- USE OF HOT FUELS

INTEGRATED THERMAL ENERGY MANAGEMENT (I-TEM)

I-TEM MAJOR FEATURES

PHASE CHANGE MATERIAL (PCM) COOLANTS

MICRO PCM

OBJECTIVE:

DEVELOP AND DEMONSTRATE MICRO PCM TECHNOLOGIES WHICH WILL RESULT IN WEIGHT REDUCTIONS, AVIONICS GROWTH CAPABILITIES, RELIABILITY INCREASES, AND IMPROVED AFFORDABILITY

APPROACH:

MULTIPLE EFFORTS ARE PURSUED TO INVESTIGATE A WIDE RANGE OF MICRO PCM APPLICABILITY

PAYOFF:

IMPROVED AFFORDABILITY THROUGH REDUCTION OF THERMAL MANAGEMENT SYSTEM WEIGHT, IMPROVED AVIONICS RELIABILITY, AND REDUCTION IN SYSTEM COMPLEXITY

FUNDING:

CONTRACT I — (27 MONTHS, CONTRACT AWARD JUNE 93)
DEMONSTRATE LIQUID COOLED MICRO PCM TECHNOLOGY

CONTRACT II — (15 MONTHS, CONTRACT AWARD JUNE 93)
RESEARCH MICRO PCM TECHNOLOGIES AND DETERMINE HIGH PAY-OFF APPLICATIONS

IN-HOUSE WORK — (18 MONTHS, ONGOING)

DEFENSE CONVERSION INITIATIVES (CONSORTIUMS)

- UNIVERSITY OF MARYLAND
  - COOLING OF AVIONICS
  - REDUCE A/C H/X'S 50%
- PURDUE UNIVERSITY
  - AVIONIC COOLING
  - REMOVE 1.0KW FROM 6"x6" LRU

Mr. Jim McNamara
Overview of Current Navy Refrigeration Technology
Research

OVERVIEW OF CURRENT NAVY REFRIGERATION TECHNOLOGY RESEARCH

IAPG THERMAL POWER PANEL
5 MAY 1993

JIM MCNAMARA
NAVAL AIR WARFARE CENTER
WARMINSTER, PA

IAPG1

NAVY REFRIGERATION TECHNOLOGY RESEARCH

- VARIABLE SPEED VAPOR CYCLE COMPRESSORS
  - SUBSONIC PATROL AIRCRAFT
  - HIGH PERFORMANCE AIRCRAFT
- CFC COMPLIANCE

ADVANCED ECS ECS PROBLEMS

AVIONICS HEAT LOAD GROWTH

ADVANCED ECS NAVY NEED

- REDUCE CURRENT ECS PENALTIES
  - IMPROVE AVIONICS RELIABILITY
  - MINIMIZE BLEED AIR EXTRACTION
FOR ADVANCED ENGINES
  - SIMPLIFY CBR DEFENSE
  - REDUCE GSE REQUIREMENT
  - REDUCE FUEL STORAGE
- NAVY
UNIQUE

ADVANCED ECS TECHNOLOGY SOLUTIONS

CURRENT ENVIRONMENTAL CONTROL SYSTEM (ECS)

ENERGY EFFICIENT ENVIRONMENTAL CONTROL SYSTEM (ECS)
ENGINE BLEED (LEAKAGE AND MAKE-UP)

BLKMY928

DEVELOPMENT OF ADVANCED VAPOR CYCLE SYSTEMS

- **PATROL TYPE AIRCRAFT
FUNDED BY ENERGY PROGRAM**

- **HIGH PERFORMANCE AIRCRAFT
FUNDED BY 6.2 AIRCRAFT BLOCK**

EEEECS HIGHLIGHTS

TECHNOLOGIES - 270 VOLT DC

- VARIABLE SPEED COMPRESSOR
- FLUID FILM BEARINGS
- NONAZEOTROPIC REFRIGERANT MIXTURE

CONTRACTORS - LOCKHEED (AIRCRAFT INTERFACE)

- AIRESEARCH (COMPRESSOR)
- SUNDSTRAND (SYSTEM HARDWARE & TEST)

TEST COMPLETED - 500 HOURS LAB TESTING

- 9 HOURS ACFT FLIGHT & GROUND TEST

HAD BEEN SELECTED FOR P-7

VARIABLE SPEED VAPOR CYCLE SYSTEM FOR A PATROL AIRCRAFT

N1808-GA-88-01301

PAYOFF - ADV PATROL ACFT (\$M)

COST
178.2

SAVINGS
1,311.1

- ASSUMPTIONS :
- 200 ACFT
  - 780 FLT HR/YR/ACFT
  - 1200 APU HR/YR/ACFT
  - 20 YR LIFE

EEEECS PAYOFF FOR ADV PATROL ACFT

11,053
GAL FUEL
/YEAR/ACFT
SAVED

OR

83
NMI
INCREASE
ASW
MISSION
RADIUS

OR

0.61
HR
INCREASED
TIME ON
STATION

ASSUMPTIONS: 28.6 KW AVIONICS LOAD & MIL-STD-210B AMBIENT

EEECs FLIGHT #2

POWER CONSUMPTION COMPARISON

AIRCRAFT SYSTEM	AMBIENT TEMP (°C)	POWER IN (kW)
EEEECS AS TESTED	39 (103°F)	73.2
EEEECS AS PREDICTED	39	65.0
CONVENTIONAL VCS	39	109.9
P-3 AIR CYCLE	39	119.7
EEEECS AS TESTED	22 (72°F)	37.3
CONVENTIONAL VCS	22	109.9

EEEECS FOR TACAIR HIGHLIGHTS

-
- OBJECTIVE: ADAPT EEECS TECHNOLOGY TO THE
HIGH G'S OF A TACTICAL AIRCRAFT
  - TECHNOLOGY: SAME AS EEECS EXCEPT USES
R-134a (NON-OZONE DEPLETING)
  - TRANSITIONED TO AIR FORCE & CANADA ICECS PGM
TO DEMONSTRATE TECHNOLOGY ON A CENTRIFUGE
  - SELECTED FOR:
F-22 (ATF)

EEEECS FOR TACAIR PAYOFF

	FUTURE ATTACK	FUTURE FIGHTER

INCREASED RANGE	-	7%	15%

OR

DECREASED TOGW	-	2%	10%

AND

REDUCED LCC	-	> 20%	> 20%

CFC COMPLIANCE

-
- o NAWCADWAR TASKED BY NAVAL AIR SYS COMMAND TO SUPPORT COMPLIANCE WITH OPNAVINST 5090.2, CLEAN AIR ACT 1990, MONTREAL PROTOCOL
  - o NINE NAVY PLATFORMS USE CLASS 1 REFRIGERANTS AS WORKING FLUID IN THEIR VAPOR-CYCLE SYSTEMS USED FOR COOLING AVIONICS/CREW
  - o SOME AIRCRAFT ALSO HAVE REFRIGERATORS THAT USE CLASS 1 REFRIGERATORS

RECOVERY

-
- o BY LAW, AS OF 1 JUL 92, CLASS 1 SUBSTANCES ARE TO BE RECOVERED FROM SYSTEMS PRIOR TO ANY MAINTENANCE ACTION
  - o NAWCADWAR IDENTIFIED USERS OF CLASS 1 REFRIGERANTS, WORKED WITH NAWC LAKEHURST & NAVAIR GET APPROPRIATE RECOVERY HARDWARE TO FLEET BY 1 JUL 92

STOCKPILE/RETROFIT

-
- o PRODUCTION OF CLASS 1 REFRIGERANTS ENDS
AT END OF CY-95
  - o TWO ALTERNATIVES FOR SUPPORT OF THESE
SYSTEMS:
    - (1) STOCKPILE SUFFICIENT QUANTITY OF
REFRIGERANT TO SUPPORT SYSTEM UNTIL
END OF PLATFORM SERVICE LIFE
    - (2) RETROFIT SYSTEM TO USE OZONE-SAFE FLUID

RETROFITTING

- o NAWCADWAR HAS BEEN ASSESSING PERFORMANCE, COST IMPLICATIONS OF RETROFITTING TO ACCOMMODATE REPLACEMENT FLUIDS
- o SIKORSKY FUNDED BY NAWCADWAR TO TEST VH-60N (PRESIDENTIAL HELO) SYSTEM WITH HFC-134a TO ASSESS PERFORMANCE EFFECTS - FLAGSHIP TEST PGM
  - COOPERATION WITH SIKORSKY, AERO AIRE (MFR), CLASS DESK

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

3 of 4

**OVERVIEW OF DOE FUNDED REFRIGERATION
TECHNOLOGY DEVELOPMENT EFFORTS**

**M. OLSZEWSKI
OAK RIDGE NATIONAL LABORATORY
P. O. BOX 2009
OAK RIDGE, TN 37831-8045
(615) 574-0770**

**PRESENTED TO
IAPG MECHANICAL WORKING GROUP
MAY 5, 1993**

DOE HAS SEVERAL PROGRAMS THAT HAVE REFRIGERATION TECHNOLOGY
DEVELOPMENT EFFORTS

- OFFICE OF UTILITY APPLICATIONS - THERMAL ENERGY STORAGE PROGRAM
  - Complex compound heat pump/TES for refrigeration applications at -40 F to 40 F
- OFFICE OF INDUSTRIAL TECHNOLOGY - INDUSTRIAL HEAT PUMP PROGRAM
  - Complex compound heat pump for -20 F
  - Magnetic heat pump for cryogenic applications [below -150 F (170 K)]

INTRODUCTION TO COMPLEX COMPOUND TECHNOLOGY

**Rocky Research
Boulder City, Nevada**

WHAT IS A COMPLEX COMPOUND?

- A material that is formed by the sorption of polar refrigerant molecules into a salt. This material has a coordinative bond that is capable of hosting a large amount of refrigerant molecules.

HOW IS IT USEFUL?

- Because of their vapor pressure suppression capability with respect to the refrigerant, they can be used in a number of thermodynamic cycles for refrigeration, air conditioning, heat pumps, etc.
- Because of their large refrigerant holding capacity at full vapor pressure suppression, they are ideally suited to direct contact thermal storage at a variety of temperature levels.

**COMPLEX COMPOUND
CHEMISTRY**

DEFINITION OF COMPLEX COMPOUNDS

- Solid-gas chemisorption pair
- Solid adsorbent and gaseous refrigerant
- Refrigerant must be polar (dipole moment, lone pair availability) examples: NH_3 , H_2O , Methanol, Ethanol, Amines
- Solid is a metal salt capable of hosting guest molecules
- Bond is achieved via electron displacement; not surface forces and not through actual bond breaking

PHYSICAL PROPERTIES OF COMPLEX COMPOUNDS

- Refrigerant (ligand) is coordinated in "ligand spheres"
- Large amounts of refrigerant are coordinated on single energy plateaus
- Coordination stoichiometry allows for much higher gaseous reactant content than expected from oxidation number which is only valid for bond-breaking reactions
- Coordinative reaction is highly reversible

COORDINATION REACTION AND EQUILIBRIUM RELATIONS

$$\log P = \frac{Q_0}{2.303 R_m T} + 1.75 \log T - aT + C$$

$$\ln P = \frac{S}{R_m} - \frac{H}{R_m T}$$

REFRIGERANT HOLDING CAPACITIES FOR VARIOUS SORPTION MEDIA

COMPLEX COMPOUND REACTIONS
HEAT AND MASS TRANSFER

INFLUENCE ON REACTION RATES

- Adsorbent
- Adsorbate
- Physical Condition of Complex Compound
- Absolute Temperature
- Differential Temperature and Differential Pressure
- Thermal Conductivity
- Diffusion Properties with Reaction

RELATIVE POWER DENSITIES OF SOLID-VAPOR SORPTION

COMPLEX COMPOUND
THERMAL ENERGY STORAGE SYSTEM

UNIQUENESS OF COORDINATIVE REACTIONS

1. Phenomenon: Reactivities of Approximately 1.5 moles/mole hr Can Be Sustained for 4 Hour Cycles in Thermal Storage Applications

Effect: Little Reactant Inventory

2. Phenomenon: Energy Densities of 2.5 kW/kg Reactant Can Be Achieved for Dynamic Refrigeration/Heat Pump Systems

Effect: Low Heat Exchange Surface Requirements, High Discharge Rates for Peak Demand

COMPRESSOR DRIVEN TES FOR -28°C REFRIGERATION

COMPRESSOR DRIVEN TES FOR -28°C REFRIGERATION

THERMAL ENERGY STORAGE OPTIONS WITH VARIOUS COMPLEX COMPOUND MEDIA

CONTINUOUS COMPLEX COMPOUND CYCLES

CYCLE CHARACTERISTICS

- "Batch" Process Made Continuous with Alternating Sorbers
- Multiple Stage Cycles for High Efficiency
- Cycles are Heat Activated
- Some Single Stage Cycles Waste Heat Driven
- Extremely High Lifts Possible
(Up to 270°F in one stage)
- Refrigeration Temperatures to -85°F
- High Temperature Stability Proven up to 550°F
- No Moving Parts
- Fully Hermetic System
- Not Orientation Sensitive

COMPLEX -COMPOUND REFRIGERATION CYCLE

KEY ACHIEVEMENTS AT ROCKY RESEARCH

- Identified Approximately One Dozen Useful Ammoniated Complex Compounds out of a Database of Approximately 1,000 Compounds
- Proved Cycle Stability Over 16,000 Cycles
- Achieved Power Densities Leading to Mass Requirements of 20 lb Solid per RT (compared to 150 lb of zeolite and 170 lb of activated carbon)
- Developed Efficient Cycles for HVAC and Refrigeration
- Developed First Cost Competitive Sorber Hardware for Thermal Storage and Continuous Cycles
- Developing Prototype Hardware for Consumer Products

MAGNETIC HEAT PUMPS FOR CRYOGENIC APPLICATIONS

MAGNETIC HEAT PUMP IS ANALOGOUS TO VAPOR COMPRESSION CYCLE

- SOLIDS REPLACE LIQUIDS AND GASES AND MAGNETIC FIELDS REPLACE THE WORK DONE BY A COMPRESSOR
- MAGNETOCALORIC WORKING MATERIALS (SUCH AS GADOLINIUM)
  - Heat up when in a high magnetic field
  - cool down when removed from the field
- THE CYCLE OPERATES BY
  - Supplying cooling when the magnetocaloric heat exchanger bed is removed from the magnetic field and absorbs heat
  - Rejects heat from the cycle when the bed is in the magnetic field

THE HEAT PUMP OPERATES BY MOVING A HEAT EXCHANGER BED IN AND OUT OF A STATIONARY HIGH-MAGNETIC FIELD

AN EARLY EMBODIMENT OF THE CONCEPT USED A SCREEN WIRE BED

DOE-OIT FUNDED DEVELOPMENT OF PROTOTYPE UNIT FOR HYDROGEN LIQUEFACTION

- EXISTING TECHNOLOGIES EXPENSIVE AND ENERGY INTENSIVE
  - Liquid vaporization
  - Joule-Thompson effect
  - Expansion of gas in engine
- DOE GOALS INCLUDED
  - Halve energy intensity (250 Btu per Btu of cooling)
  - Cost effective for small-scale (\$2.5 million per ton-day at 1 ton/day)
- Demonstration unit was goal
  - Funded Astronautics Corporation of America
  - Design and build 0.1 ton/day hydrogen liquefier MHP
  - Project now on hold

CONCEPT USED SEVERAL HEAT EXCHANGER BEDS

Mr. Michael Weingarten
Technology Reinvestment Project (TRP)

Technology Reinvestment Project

Program Information Package

Overview

Technology Reinvestment Project

Mission

To stimulate the transition to a growing, integrated, national industrial capability which provides the most advanced, affordable military systems and the most competitive commercial products.

Strategy

Invest Defense Conversion, Title IV funds in activities which stimulate the

- 1) Development of technologies which enable new products and processes**
- 2) Deployment of existing technology into commercial and military products and processes**
- 3) Integration of military and commercial research and production activities**

Technology Reinvestment Activities

- Defense Technology Conversion Council (DTCC) established December 16, 1992
  - Department of Defense (Advanced Research Projects Agency and Military Departments)
  - Department of Energy (Defense Programs)
  - National Science Foundation
  - Department of Commerce (National Institute of Standards and Technology)
  - National Aeronautics and Space Administration
- A single joint competition is planned for the issuance of a formal solicitation
- Evaluation, ranking, and selection of proposals will be conducted jointly
- Distributed execution

Activity Areas

- **Technology Development**
  - **Spin-Off Transitioning (activities that demonstrate commercial viability and have already been developed for defense purposes)**
  - **Dual-Use Development (activities that are applicable to commercial and defense)**
  - **Spin-On Promotion (activities that demonstrate defense applicability and have already been developed for commercial purposes)**
- **Technology Deployment**
  - **Manufacturing Extension Service Providers (outreach)**
  - **Extension Enabling Services (services to integrate service providers and technical sources)**
  - **Alternative Deployment Pilot Projects (in-reach)**
  - **Technology Access Services (brokering, “yellow pages”, etc.)**

Activity Areas (continued)

- **Manufacturing Education and Training**
  - **Engineering education in manufacturing across the curriculum**
  - **Practice-oriented master's degree programs**
  - **Retraining the manufacturing work force**
  - **Educational traineeships for defense industry engineers**
  - **Manufacturing engineering education coalition**
  - **Supplementary education awards to ongoing centers and coalitions devoted to manufacturing**
  - **Individual/group innovations in manufacturing engineering education**

Joint Agency Program

**Concepts Common Across
All Programs**

Common Requirements

Statutory requirements common to all programs

- (1) All programs require competitive award
- (2) All contain participation and organizational requirements
- (3) All (except SBIR) require cost sharing of at least fifty percent (50%)
- (4) Defense emphasis—10 U.S.C. § 2501

Cost Sharing

- **All programs have cost sharing (match) requirements of either 50% or 50%, 60%, 70%**
- **Match can include:**
  - **Cash**
    - **Can come from participants or third parties**
    - **May include IR&D under some circumstances**
    - **Includes license fees, royalties, fees for services**
  - **In-kind contributions**
    - **Compensated services of personnel**
    - **Value of equipment, land, buildings**
    - **Technology transfer activities**
- **Advance agreements on cost-treatment of in-kind contributions are encouraged**
- **Cost records must be kept in accordance with generally accepted accounting practices**
- **Government share is cash provided, not technical assistance**

Funding/Cost Sharing Principles

- Cash must not be included as contributions if included for other federally assisted programs
- In-kind contributions may include matching funds from non-DoD sources, if statutes permit
- IR&D may be included
  - if using a cooperative agreement or other transaction, and
  - if proposal would have been allowed as contractor IR&D had there been no cooperative agreement or other transaction
- The cost of technology transfer may be included subject to mutually agreed evaluation during contract negotiation
- In-kind value of equipment and software may either be the purchase cost or the depreciation during the period of contribution. Depreciation method shall be the method used internally by the contributing organization. The value shall be prorated according to the share of its total use on the proposed project.

Summary of Funding Instruments

- (Procurement) Contracts
  - Acquire supplies and services
  - Not to advance state of the art, improve technology base, or demonstrate feasibility of a new technology
- Grants
  - Transfer something of value to support and stimulate R&D
  - When the degree of involvement of the Government agency is not substantial
- Cooperative Agreements
  - Transfer something of value to support and stimulate R&D
  - Degree of involvement of the Government agency is substantial
  - These are not CRADAs
- "Other Transactions"
  - Any transaction that is not a contract, grant, or cooperative agreement
  - Includes, but not limited to, coordinated research, consortia, joint funding arrangements, bailment agreements, reimbursable arrangements, etc.

PIP Page E-1

Intellectual Property Rights

- **General Policy**
  - Government should avoid acquiring rights if that will impede commercialization
  - Restrict foreign access to technology
  - Encourage broad exposure to technology among consortium partners
- **Patent rights**
  - Contracts, grants, and cooperative agreements
  - “Other transactions”
- **Rights in other intellectual property**

Patent Rights Contracts, Grants, and Cooperative Agreements

- Firm or organization can elect to retain ownership of inventions properly disclosed to the Government unless:
  - Not located in the U.S. or under control of a foreign government
  - Government retention of title necessary to national security
- Government has “march-in” rights if invention not commercialized in a reasonable time (e.g., five years)
- Government retains license for Government purposes

Technology Development

4/7/93 9:40

Mfg	Eng	Ed:	Grant	Prgm	\$44M

Technology Development

Technology Development activities deal with the creation of new product and process technologies and exploration of their potential for commercial and/or defense applications. Proposals that involve either basic research OR final product development beyond the stage of product prototype/feasibility demonstration will be regarded as out of scope.

Proposals will fall into one of three activities:

- (1) Spin-Off Transitioning activities are those that demonstrate non-defense commercial viability of technologies already developed for defense purposes
- (2) Dual-Use Development activities are those that develop commercially viable technologies that have both defense and non-defense uses
- (3) Spin-On Promotion activities are those that demonstrate the defense utility of existing non-defense commercially viable technologies

Technology Development Focus Areas

- **Information Infrastructure**
- **Electronics Design and Manufacturing**
- **Mechanical Design and Manufacturing**
- **Materials/Structures Manufacturing**
- **Health Care Technology**
- **Training/Instruction Technology**
- **Environment Technology**
- **Aeronautical Technologies**
- **Vehicle Technology**
- **Shipbuilding Industrial Infrastructure**
- **Advanced Battery Technology**

These topics are not to be considered exclusive; the Government will entertain ideas in other areas.

Technology Development Planned Selection Criteria

Each proposal must address these selection criteria which are grouped into four equally weighted categories:

- (1) Scientific and Technical Merit**
- (2) Technical Approach and Management Planning**
- (3) Pervasive Impact**
  - Benefits to defense capabilities and enhancement of U.S. industrial base**
- (4) Commitment to Productization**
  - Commercial sustainability**
  - Evidence of previous related effectiveness**
  - Appropriateness of skills and partners/ participants**

Development Activities Statutory Restrictions

- **Defense Dual-Use Critical Technology Partnerships**
  - Requires two or more “eligible firms” or a nonprofit research corporation established by two or more eligible firms
  - Funding: \$81.9M, 50% match required
  - DoD can provide technical assistance
- **Defense Advanced Manufacturing Technology Partnerships**
  - Requires two or more “eligible firms” or a nonprofit research corporation established by two or more eligible firms
  - Funding: \$23.5M, 50% match required
  - DoD can provide technical assistance

Development Activities Statutory Restrictions (continued)

- **Commercial-Military Integration Partnerships**
  - Requires one or more “eligible firms” or a nonprofit research corporation established by two or more eligible firms
  - Funding: \$42.1M, 50%, 60%, 70%, 70% match required
  - DoD can provide technical assistance (included in the 50%, 40%, 30% maximum Federal contribution)
- **Regional Technology Alliances Assistance Program**
  - Requires one or more eligible firms located in the region and sponsorship by State or local government
  - Funding: \$90.5M, 50% match required
  - DoD can provide technical assistance

DEVELOPMENT ACTIVITIES STATUTORY RESTRICTIONS

	FUNDING	REQUIRED PARTICIPANTS	MATCHING FUNDS	DoD TECHNICAL ASSISTANCE
Critical Technology Partnerships Defense Dual-Use	\$81.9M	2 or more eligible firms <u>or</u> non-profit corp setup by eligible firms	50%	Yes
Defense Advanced Manufacturing Technology Partnerships	\$23.5M	2 or more eligible firms <u>or</u> non-profit corp setup by eligible firms	50%	Yes
Commercial-Military Integration Partnerships	\$42.1M	1 or more eligible firms <u>or</u> non-profit corp setup by eligible firms	50% / 60% 70% / 70%	Yes (incl. in Fed. Contribution)
Regional Technology Alliances Assistance Program	\$90.5M	1 or more eligible firms in a region <u>and</u> state or local gov't sponsorship	50%	Yes

---

Mr. Albert Juhasz
Space Power System Radiator Development

is Research Center

**POWER
TECHNOLOGY
DIVISION**

IAPG MECHANICAL WORKING GROUP MEETING

MAY 5-6, 1993

**NASA GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND**

AEROSPACE POWER PANEL

SPACE POWER SYSTEM RADIATOR DEVELOPMENT

**ALBERT J. JUHASZ
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135**

AJJ93-002.1

IAPG MECHANICAL WORKING GROUP MEETING

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**NASA GODDARD SPACE FLIGHT CENTER
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AEROSPACE POWER PANEL SPACE POWER SYSTEM RADIATOR DEVELOPMENT

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CLEVELAND, OHIO 44135**

CSTI HIGH CAPACITY POWER - THERMAL MANAGEMENT

PROJECT ELEMENTS

HIGH CAPACITY POWER

ADVANCED RADIATOR CONCEPTS **PROJECT OBJECTIVES**

- IDENTIFY ADVANCED SPACE RADIATOR CONCEPTS TO MEET THE FOLLOWING REQUIREMENTS
  - TECHNICAL GOALS
    - SPECIFIC MASS OF 5 kg/m²; EMISSIVITY ≥0.85
    - 0.99 RELIABILITY
    - 10 YEAR LIFE
  - APPLICATIONS
    - RADIATORS SIZED FOR POWER SYSTEMS WITH A 2.5 MWt HEAT SOURCE
      - THERMOELECTRIC POWER SYSTEM AT 875 K (Area = 106 m²; Qr = 2.4 MW_t; P = 100 kWe)
      - STIRLING ENGINE POWER SYSTEM AT 600 K (Area = 335 m²; Qr = 1.7 MW_t; P = 800 kWe)
- DEVELOP THE TECHNOLOGY NEEDED FOR THE IDENTIFIED CONCEPTS BY:
JANUARY 1992 (ORIGINAL PLAN)
JUNE 1993 (NEW PLAN)

HIGH CAPACITY POWER

ADVANCED RADIATOR CONCEPTS PROJECT FLOW CHART

NASA

HIGH CAPACITY POWER

GROSS FUNDING HISTORY/PROJECTIONS **NASA SP-100 ATP - HIGH CAPACITY POWER**

HIGH CAPACITY POWER

NASA

ROCKWELL INTEGRAL WOVEN FIN HEAT PIPE

CONCEPT DESCRIPTION

HIGH CAPACITY POWER

NASA

SP-100 Advanced Radiator Concept

ADVANCED RADIATOR CONCEPTS **CARBON-CARBON RADIATOR FOR SPACE POWER SYSTEMS** **NASA =LeRC OAST =**

Figure 1.: Carbon-Carbon Space Power Radiator Heat Pipe Tube

Figure 2.: Thermoelectric Petal Radiator Concept

CSTI HIGH CAPACITY POWER FY92

HIGH CAPACITY POWER

NASA

RADIATOR WITHOUT BUMPER ARMOR

**Minimum Mass Design Point
3" Manifold Width, 2.09 psid
Corrugated Duct Design, 1.0" O.D. HP, 1.5" Pitch, 1.0" Fin Ht.**

<u>Thermal Hydraulic</u>	
Lithium loop temperature drop (K)	95.3
Duct to heat pipe temperature drop (K)	18.8
Average heat pipe evaporator flux (W/cm ²)	15.8
Average fin root temperature (K)	808.
Lithium flow rate per petal (kg/s)	0.55
Loop pressure drop (KPa)	14.4

<u>Physical</u>	
Petal area (m ²)	9.72
Number of petals	12
Number of redundant petals	1
Number of heat pipes per petal	226
Number of redundant heat pipes per petal	11
Heat pipe span across manifold (cm)	3.81
Lithium manifold width (cm)	7.62
Lithium manifold height (cm)	5.08
Petal mass (kg)	59.9
Heat pipe mass per petal (kg)	29.8
Manifold mass per petal (kg)	24.9
Manifold armor mass per petal (kg)	1.7
Structural mass per petal (kg)	3.5
Heat transport subsystem mass (kg)	134
Total HRSS mass (kg)	853

<u>Geometry</u>	
Net view factor to space	1.31
Effective area for 11 petals (m ²)	140

HIGH CAPACITY POWER

NASA

ARC - ROCKWELL CONCEPT

HIGH CAPACITY POWER

KEY ACTIVITIES

- LINER FABRICATION
  - ROLLING METHOD
  - DEEP DRAW
- BRAZE COMPATIBILITY
  - Ti
  - Nb-1Zr
- END CAP WELD DEVELOPMENT
- WICK DEVELOPMENT
- ASSEMBLY
- POTASSIUM FILLING
- TESTING

NASA

HIGH CAPACITY POWER

HEAT PIPE DESIGN

Material Creep Strength

[1% strain in 1000 hours at 850 K]

Comparison of Material Creep Rate

[Temperature = 850 K]

CARBON-CARBON HEAT PIPE

Rockwell International
Rockodyne Division

Carbon-Carbon Heat Pipe

600°C Vacuum Furnace • Glovebox Atmosphere < 1 ppm Impurities

The carbon-carbon heat pipe is a fundamental building block for high-performance, space-based radiators. With a liquid metal working fluid, these heat pipes provide a high-temperature, high-flux capability, with applications in thermoelectric, thermionic and Rankine power conversion systems. Primary structural rigidity and strength is provided by a 1.0-mm thick carbon-carbon tube with integrally woven fins. This carbon-carbon material exhibits a high strength-to-weight ratio at elevated temperatures and good survivability to both natural and man-made threats. The integrally woven fins give a continuous fiber path from the tube interior to the opposite edge of the fin, allowing for low thermal resistance and simplification of assembly.

Type	Carbon-Carbon Nb-1Zr liner
Working fluid	Potassium
Nominal operating temperature (K)	875
Nominal axial flux (W/cm ²)	350
Evaporator flux (W/cm ²)	30
Dimensions*	
Condenser length (cm)	91
Evaporator length (cm)	7.6
Diameter tube (cm)	2.5
Fin width (cm)	2.5
Mass (g)	330
Specific mass (kg/m ²)	4.8

*Scaled from test article

6487-1

C-C HEAT PIPE MASS BREAKDOWN (Grams)

CONDENSER - FIN DIMENSIONS

L = 91.4 cm; D = 2.5 cm
W = 5 cm; T = 0.1 cm

ELEMENT

C-C SHELL	208.8	253.3
LINER W, EVAPORATOR	41.2	41.2
END CAPS	13.1	13.1
FILL TUBES	7.2	7.2
BRAZE	22.5	22.5
WICK	24.0	24.0
WORKING FLUID	13.5	13.5
TOTAL MASS (G)	330.3	374.8
RADIATING AREA - m ²	0.06965	0.11675
SPECIFIC MASS - kg/m ²	4.74	3.20

HIGH CAPACITY POWER

THERMAL CONDUCTIVITY EFFECT ON FINNED HP PERFORMANCE

CROSS-SECTION OF LINER ASSEMBLIES

** NOT TO SCALE **

HEAT PIPE FILLING

- Approach based on ORNL method (DeVan, 1986)
- Uses direct liquid metal contact to remove adsorbed oxygen
  - Fill heat pipe with potassium
  - Soak at elevated temperature
  - Replace with fresh potassium
  - Repeat four times

POTASSIUM HEAT PIPE TEST EQUIPMENT

POTASSIUM HEAT PIPE TEST APPARATUS SCHEMATIC

RD23 2

NEP POWER SYSTEM RADIATOR TECHNOLOGIES THRUSTS

POWER SYSTEMS (10 MWe)			RADIATOR TECHNOLOGIES			
		HEAT REJECTED MWt	TEMP K	NEAR TERM	MID TERM	FAR TERM
THERMIONIC	$\eta_t = .15$	57.0	1000	SS/Na HP	CC/Na HP *	LSR, Fiber HP
	$\eta_t = .20$	40.0	1050	10 kg/m ²	5 kg/m ²	2 kg/m ²
LIQUID METAL RANKINE	$\eta_t = .18$	45.5	950	10 kg/m ²	5.0 kg/m ²	2 kg/m ²
				SS/Na HP	C-C/Na HP	LSR, Electrostatic 3 kg/m ²
THERMOELECTRIC	$\eta_t = .05$	190.0	850	9 kg/m ² Nb Zr/K HP	5.0kg/m ² Ti-SiC/K HP	C-C HP 3 kg/m ²
CLOSED BRAYTON	$\eta_t = .30$	23.3	800 - 400	10 - 15 kg/m ² MP Loop Mixed HP	Mixed HP Ti, C-C 5 kg/m ²	Fiber Fabric/H ₂ O 1-2 kg/m ²
STIRLING - FPSE	$\eta_t = .33$	20.0	500 - 450	10 kg/m ² MP Loop Hg HP	Li-NaK Loop 5 kg/m ²	Fiber Fabric/H ₂ O 1-2 kg/m ²

* ALL C-C HEAT PIPES HAVE INTERNAL COATING COMPATIBLE WITH WORKING FLUID

POWER TECHNOLOGY DIVISION

SUMMARY

- FABRICATED AND TESTED PROTOTYPE C-C HEAT PIPE WITH NIOBIUM-ZIRCONIUM LINER AND POTASSIUM WORKING FLUID AT 700 K CONDENSER TEMPERATURE
- DEMONSTRATED SPECIFIC MASS WITH T-300 C-C FABRIC = $4.7 \text{ kg/m}^2 \text{ AT } \varepsilon \geq 0.85$
- POTENTIAL SPECIFIC MASS WITH HIGH CONDUCTIVITY FABRICS $\rightarrow 3.0 \text{ kg/m}^2 \text{ AT } \varepsilon \geq 0.85$
- TECHNOLOGY CAN BE EXTENDED TO OTHER TEMPERATURE RANGES BY PROPER SELECTION OF WORKING FLUID COMPATIBLE LINER MATERIALS
- ORIGINAL SPACE APPLICATIONS WILL NEED TO BE PRECEDED BY DUAL USE TERRESTRIAL APPLICATIONS AT THE HEAT PIPE AND RADIATOR PANEL LEVEL
- POTENTIAL NON-SPACE USES ARE:
  - AIRCRAFT ELECTRONIC COOLING
  - AUTOMOTIVE ELECTRONIC COOLING
  - FURNACE WALL TEMPERATURE EQUALIZATION
  - REMOTE SITE POWER SYSTEMS

Dr. Inara Kuck
Air Force Satellite Power Technologies

AIR FORCE SATELLITE POWER TECHNOLOGIES

IAPG MEETING

6 MAY 1993

**DR INARA KUCK
POWER AND THERMAL MANAGEMENT DIVISION
PHILLIPS LABORATORY**

SMALL SATELLITES

POWER < 1 KW - BP, TAC SATS, TECH SATS, MSTI, CLEMENTINE

POWER DRIVERS

WEIGHT AND VOLUME (BATTERY)

COST (SOLAR CELLS/BATTERY)

WEIGHT AND SIZE (ARRAY)

SPECIFIC NEEDS

BRILLIANT PEBBLES - CPV NiH_2 , 24% SOLAR CELLS, a-Si CELLS

TECH SAT - CPV NiH_2 , Si OR GaAs CELLS

MSTI OR CLEMENTINE - POSSIBLE USERS OF THIN FILM

TECHNOLOGY (a-Si, CdTe)

TECHNOLOGY PROGRAMS

SDIO - MBG SOLAR CELLS, STRV FLIGHT, PASP+

NRL - CPV FLIGHT TEST

AF - MBG SOLAR CELLS, THIN FILM CELLS, IPV NiH_2 TESTING,
NaS BATTERY

NASA - THIN FILM CELLS, InP, NaS BATTERY

TECHNOLOGY GAPS - CPV NiH_2 TESTING/CHARACTERIZATIONS
a-Si CELLS, InP FUNDING

MEDIUM SATELLITES

POWER - 1KW TO 5 KW - BE, FEWS, POSITIONING SAT,
COMMUNICATION SATS, WEATHER SATS

POWER DRIVERS

WEIGHT (BATTERY, ARRAYS)
COST (SOLAR CELLS, BATTERIES)
LIFE/RELIABILITY (CYCLE LIFE, RAD RESISTANCE)
ARRAY STOWED VOLUME

SPECIFIC NEEDS

MOST USERS CURRENTLY LOOKING AT GaAs CELLS/ARRAYS

IPV NiH_2 BATTERY

FEWS - CPV NiH_2 BATTERIES, GaAs CELLS, THIN FILMS/MBG
CELL FOLLOW-ON

BE - CPV NiH_2 BATTERIES, GaAs CELLS, MBG CELL FOLLOW-ON

TECHNOLOGY PROGRAMS

SDIO - MBG SOLAR CELLS, STRV FLIGHT, PASP+

NRL - CPV NiH_2 FLIGHT

AF - MBG SOLAR CELLS, THIN FILM CELLS, IPV NiH_2 TESTING

NASA - THIN FILM CELLS

TECHNOLOGY GAPS

CPV NiH_2 TESTING/CHARACTERIZATION
LIGHTWEIGHT, LOW COST ARRAYS (THIN-FILM, FLEXIBLE BLANKET,
COMPOSITE)
A-Si CELLS
PMAD

LARGE SATELLITES

POWER > 5KW - EOTV MISSIONS, SPECIALIZED COMM, SPACE
BASED RADAR, SPACE STATION

POWER DRIVERS

WEIGHT (BATTERIES)
ARRAY AREA & LAUNCH VOLUME
COST
ARRAY CONTROLLABILITY

GENERAL NEEDS

HIGH ENERGY DENSITY RECHARGEABLE BATTERIES
CONCENTRATOR ARRAY OR ADV ROLL-UP, FLEXIBLE DESIGN,
THIN FILM OR MBG SOLAR CELLS

TECHNOLOGY PROGRAMS

SDIO - MBG SOLAR CELLS, SOLID STATE BATTERIES
AF - MBG SOLAR CELLS, THIN FILM CELLS, NaS BATTERY,
SOLID STATE BATTERIES
NASA - MINI DOME CONCENTRATOR, APSA ARRAY

TECHNOLOGY GAPS

DOD CONCENTRATOR/ARRAY EFFORT
HIGH ENERGY DENSITY PMAD

AF POWER PROGRAM

OBJECTIVES

REDUCE SPACECRAFT WEIGHT 10% BY CUTTING POWER AND THERMAL
MANAGEMENT SYSTEMS WEIGHT BY 50%

GOALS

INCREASE POWER/THERMAL EFFICIENCY TO 15 W/KG VS 4 KG TODAY
PROVIDE TECHNOLOGIES FOR POWER SYSTEMS FROM 50W TO 50KW
REDUCE SYSTEM COST TO \$50000/W

ACCOMPLISHMENTS

FLIGHT TESTS - PASP+, SMALL SAT CONTROLLER
LAUNCHED, STRV FLIGHT QUALIFICATION

PHOTOVOLTAICS - 17% EFF TOP CELLS ON MBG, 10% EFF THIN FILM
CELLS DEVELOPED

BATTERIES - 30,000 LEO CYCLES ON NiH_2 , NaS GROUND TEST
PROGRAM STARTED, SOLID-STATE PROTOTYPES DELIVERED

SPACE FLIGHT EXPERIMENTS

PHOTOVOLTAIC ARRAY SOLAR PANEL (PASP+)

DETERMINE EFFECTS OF SPACE ENVIRONMENT ON NUMBER OF
EXPERIMENTAL CELLS AND ARRAYS

TWELVE EXPERIMENTAL PANELS INCLUDE TWO CONCENTRATORS, TWO
FLEXIBLE BLANKET AND MANTECH CELL ARRAYS
LAUNCH THIS YEAR (COOPERATIVE EXPERIMENT WITH NASA AND NAVY)

SPACE TECHNOLOGY RESEARCH VEHICLE (STRV-1)

RADIATION AND PERFORMANCE ANALYSIS OF 20 EXPERIMENTAL SOLAR
CELL PACKAGES

PROVIDE PRIMARY POWER PANELS OF GaAs MANTECH CELLS (BE,
FEWS BASELINED)

LAUNCH IN EARLY 94 (COOPERATIVE EFFORT WITH SDIO, NASA,
MANTECH, BRITISH)

SMALL SATELLITE CONTROLLER

NEW PEAK POWER TRACKER FOR SMALL SATELLITE SYSTEMS
LAUNCH ON STP RADCAL SATELLITE IN APRIL

TEN YEAR GOALS - CONVENTIONAL POWER

OBTAIN GREATER ENERGY EFFICIENCIES

150 - 200 W/kg (ARRAY LEVEL) VS 30-40 W/kg SOTA
30% BOL CELLS VS 18-19% SOTA
150 - 200 Whr/kg BATTERIES (LEO) VS 21 Whr/kg SOTA

LOWER COSTS (DECREASE COST OF DELIVERED WATT TO \$500 FROM
\$1000 - \$1500 AT PANEL LEVEL)

PROVIDE AT LEAST 10 YEAR SERVICE LIFE AT 0.995 RELIABILITY

INCREASE SATELLITE AUTONOMY

ASSURE SURVIVABILITY TO NATURAL AND ENHANCED RADIATION
ENVIRONMENTS

CURRENT/PLANNED PROGRAMS

NICKEL-HYDROGEN BATTERY LIFE TEST

NICKEL METAL HYDRIDE LEO LIFE TEST

ADVANCED ARRAY FLIGHT TEST

NaS BATTERY DEVELOPMENT AND FLIGHT DEMONSTRATION

MULTI-BAND GAP CELLS

SOLID STATE BATTERIES

SOLAR CELL ASSESSMENT

THIN FILM SOLAR CELLS

INTEGRATED POWER PANEL

SUMMARY

POWER REQUIREMENTS FOR SATELLITES IDENTIFIED
COORDINATED PROGRAMS WITH OTHER AGENCIES AND USERS ONGOING
TECHNOLOGY GAPS NOTED

BUT

INVESTMENT IN KEY, PERVASIVE TECHNOLOGIES IS DECLINING

Mr. Mike Doyle
Electromagnetic Aircraft Launch System (EMALS)

EMALS

Electromagnetic Aircraft Launch System

Naval Air Warfare Center

Mission

To be the Navy's full-spectrum research, development, test and evaluation, engineering and fleet support center for air platforms, autonomous air vehicles, missiles and missile subsystems, weapons systems associated with air warfare, and sensor systems used to conduct antisubmarine warfare from air platforms.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

4 of 4

NAWC AD Integration

Naval Air Development
Center - Warminster

Naval Air Engineering
Center - Lakehurst

Naval Air Propulsion
Center - Trenton

Naval Air Test Center
Patuxent River

Naval Avionics Center
Indianapolis

NAWC AD Leadership Areas

- Aircraft Testing*
- Aircraft T&E Ranges*
- Aircraft Modeling*
- Air Vehicles, Manned and Unmanned*
- Aircrew Equipment & Life Support*
- Airborne Surveillance Systems*
- Air ASW Systems*
- Aircraft Electronic Warfare T&E*
- Air Platform Systems Integration*
- Aircraft Signatures*
- Air Vehicle Propulsion*
- Electronics Manufacturing and Support*
- Electronic Systems Transition to Production*
- Pilot/Emergency Production*
- Aircraft Launch and Recovery Systems*
- Aviation Support Equipment*
- Propulsion Systems Testing*

NAWC-Lakehurst Facilities

■ Testing Facilities

— Mechanical Testing Capability

- Shock, Vibration

— Environmental Testing

- Salt Spray, Humidity, High Temperature, etc.

— Electromagnetic Interference Testing

- Full EMI Testing Facilities
- Can qualify equipment to MIL-STD-461

NAWC-Lakehurst Facilities

■ Test Tracks

- Five Parallel Test Tracks, 1.5 Miles in Length
- Expandable to 2 Miles
- Projectile Arrestment Capability

■ Two Active Runways

- Test Runway is 12,000 Feet in Length
- Complete Launch and Recovery Test Facility

■ Available Hangar Space

- Facilities for Sheltered Testing of Full Size Equipment

Future Plans

Organizational

- Aircraft Division Consolidation
  - Closure of two facilities (by 1996)
    - Naval Air Development Center, Warminster, PA
    - Naval Air Propulsion Center, Trenton, NJ
- Overall Division Reorganization
  - Seamless Organization
    - Little distinction between activities
    - Effective 1 October 1993

Future Plans Technical

Pulse Power Control & Switching
Energy Storage

Infrared Imaging

Artificial Intelligence

Process Automation
Position Control & Guidance
Data Networks

Catapult Development

■ Compressed Air
Catapult

— 3.2 MFt-Lbs

■ Hydraulic Catapult

— 10 MFt-Lbs

■ Steam Catapult

— 70 MFt-Lbs

■ EMALS

— 90 MFt-Lbs

Progression of the Catapult

Energy (Mft-lbs)

WHY DEVELOP EMALS?

- Precise, Closed Loop Launch Control
  - ▬ Extend A/C Life
- Smaller/Lighter
- Stand-Alone Power
  - ▬ Electrically Launch, Brake, & Retract
- High Efficiency
- Scalable
  - ▬ Amphibs/Surface Combatants
  - ▬ Shore Based
- Reduced Manpower
  - ▬ Operation
  - ▬ Maintenance
- Environmentally Sound
- Technology Spin-Offs

EMALS Performance Requirements

EMALS Performance Requirements

Electromagnetic Launcher Desired Performance

DEVELOPMENT HISTORY

Exploratory Development
(FY82-89)

Feasibility Demonstration Model
119,000 # Thrust (Static)

Advanced Development
(FY88-Present)

Requirements Definition
Preliminary Design Contracts

ACQUISITION STRATEGY

- Stage 1 - Advanced Development (Full & Open Competition)
  - Phase I - Preliminary Design (Up to 5)
    - 3 Fixed-Price/Equal Value Contracts
  - Phase IA - Preliminary Design Updates
  - Phase IIA - Critical Component Demonstration Program (CCD)
    - 1 Cost Plus Fixed Fee Contract
  - Phase IIB - ADM Detailed Design (Up to 2)
    - Option - ADM Hardware

Acquisition Strategy

(Continued)

- Stage 2 - Engineering & Manufacturing Development (Limited Competition)
  - Phase 1 - EDM Detailed Design & Hardware
- Stage 3 - Production (Full & Open Competition)

CONGRESSIONAL DIRECTION

FY92 - \$6 Million to begin competitive advanced development of EMALS

Develop program to install in CVN-76

Proceed as long as:
Technology Works
Meets Cost Objectives
Contractors Perform

FY93 - Designated Special Interest Program

Feasibility Demonstrator System Block Diagram

EMALS Block Diagram

PULSE ALTERNATOR ASSEMBLY

EMALS PULSE ALTERNATOR

CROSS SECTION

THE CYCLOCONVERTER PRINCIPLE

Electromagnetic Aircraft Launch System (EMALS)

Critical Component Demonstration (CCD)

- Technical risk reduction effort resulting from Phase I and IA efforts
  - Prove Technology
  - Reduction of risk while minimizing cost
  - Maximize use of existing equipment

CCD Areas of Investigation

Permanent Magnets

Concern: Survivability

Approach: Run environmental tests on magnet pole assemblies (i.e. high temperature, shock, etc.)

Launcher

Concern: Performance and effects of air gap variations and position sense accuracy

Approach: Construct a complete, short section of the launch motor and verify design parameters

Cycloconverter

Concern: Power density - Controllability and Response

Approach: Construct a breadboard cyclo and verify design

CCD Areas of Investigation

Integrated System

Mr. Gene Hoffman
Magnetic Bearings for Aircraft Electric A.P.U.

MAGNETIC BEARINGS FOR AIRCRAFT ELECTRIC A.P.U.

PRESENTED TO : IAPG

DATE : 5-6 May 93

**By : Earl Gregory (513) 255-6241
WL/POOS-1
WRIGHT-PATTERSON AFB, OH**

Presented by E.P. Hoffman

SRM & MAGNETIC BEARINGS, WHY?

- Magnetic bearings allow for removal of lubrication system
- Magnetic bearings allow possibility of active clearance control
- Magnetic bearings have very low steady state power consumption
- Possibility of higher operation temperature, especially if new magnetic materials prove out
- Internal switched reluctance machine allows for removal of gearbox
- Internal machine increases power density of IPU/generator design

MEA INTEGRATED POWER UNIT (IPU) BASELINE DESIGN LAYOUT (1998 TAD)

SWITCHED-RELUCTANCE
STARTER-GENERATOR

MAGNETIC BEARING

MAGNETIC BEARINGS

DESIGN ISSUES

- Negative stiffness for both magnetic bearing and switched reluctance machine (Increased force in direction of displacement)
- Interaction of rotor with these negatively stiff components
  - SRM tends to increase bending mode
  - Sensor placement critical to alleviate deflection
- Stability in subcritical vs. supercritical design
  - Two radial bearing approach not considered capable of operating into supercritical region
  - Auxiliary bearing operation through critical speed

BEARING ANALYSIS

Bearing force :

$$F = \frac{B^2 A}{2 \mu_o}$$

Where magnetic flux density is :

$$B = \frac{NI}{(\sum l / \mu_r \mu_o A)} A_w$$

$$F = f(i_b + \Delta i, x)$$

$$\Delta i = f(\tau, \Delta x)$$

$$F_1 - F_2 - mg = ma$$

RADIAL BEARING OPERATION

P. M. FLUX
PATH

E. M. FLUX
PATH

COMBINED
EFFECT

THRUST BEARING OPERATION

BASIC CONTROL DIAGRAM FOR MAG BEARING

-K_b : negative stiffness for magnetic bearing

G_p : rotating system dynamics (includes SRM negative stiffness)

DESIGN OF MAGNETIC BEARINGS PROVIDES POSSIBILITY OF GRACEFUL DEGRADATION

NORMAL
OPERATION

1/2 E. M.
FAILURE

AUXILIARY BEARING CONCERNS

- Auxiliary bearings must be able to take radial and axial loads at least equal to that of the magnetic bearings
  - Aux bearings must be capable of removing catastrophic failure by allowing time for rotating machinery to spin down
  - Must be capable of lasting through a battery out start w/o greatly deteriorating system operation (operates in this mode until power can be pulled from SRM)
-

SRM IMPACT

- SRM is capable of operating through a variety of failure modes
  - Advantageous from power electronics standpoint to design each phase as two 1/2 phase windings
  - This approach makes it possible for a 2 1/2 Phase operating condition
- Magnetic bearing interactions with SRM failure modes
  - High side loads generated by 2 1/2 Phase operation likely more than magnetic bearings can handle
  - System can go catastrophically unstable before magnetic bearings can react
  - Control scheme must be able to recognize this fault condition and remove the working 1/2 phase

BEARING TEMPERATURE CONCERNS

- High temperature bearing operation
  - Cooling of rear radial bearing requires eductor flow
  - Thrust bearing operates at the edge of current magnetic material usage range
  - Cooling passages add complexity to system (similar to oil lubrication system)
  - New magnetic material being developed shows possible 200 °F higher usage range

THRUST BEARING CONCERNS

- Axial bearing concerns for ground operation
  - Aerodynamic thrust is equal bearing maximum load
  - Heat generation at maximum load is very high (could drive bearing temperature above useful usage range)
  - Axial rotor position could be shifted to offset increased load with magnetic bias field (requires closer position control)
  - Switch from emergency to air breathing mode causes very high axial load opposite to previous load (overall effect: possibly exceeding capability of thrust bearing)

SENSOR CONCERNS

- Sensor operation in bearing is critical
  - failure in one axis of one bearing may produce a situation the magnetic bearings cannot control (forces auxiliary bearing coast down)
  - Adding additional sensors increases controls complexity and interpretation logic
  - Operational temperatures may severely limit sensor life
  - Possibility of sensorless operation removes some failure modes, but increases control logic

WIRE INSULATION

- Harsh environment for both SRM and bearing windings
  - Temperature cycling
  - Vibration
  - Particle Ingestion
  - Shaft Impact (high maneuver, impact loads especially important when IPU is not operating)
- Current wire coatings
  - Subject to flaking
  - Coatings on bearing windings stick to potting compound
- Coating failures cause highly undesirable short in windings

SUMMARY

- Magnetic bearings for aircraft electric APU's will be demonstrated in the MEA IPU program
- Temperature & controls issues have been identified
- Fault tolerance can be integrated into the magnetic bearing function
- Better auxiliary bearing approaches may be needed to complement the magnetic bearing

Advantages Of AVCON Homopolar Magnetic Bearings

- Lubrication systems eliminated
- Parasitic power reduced by an order of magnitude
- Virtually unlimited life
- High reliability through redundant systems
- High rotating speeds
- Vibration and audio noise eliminated
- Continuous monitoring of machine condition
- Insensitive to contamination

Rotor System Is Subcritical: Operates Below Its First Bend Mode

Front Radial Bearing Design Meets IPU

Operating Requirements

Configuration:	Permanent magnet bias
Maximum static load:	242 lbs.
Bearing weight:	5.4 lbs.
Design operating temperature:	200F (93C)
Power required at steady-state:	Less than 10 watts
Power required at maximum load (200F):	48 Watts
Rotor laminate thickness	0.006 inch
Meets IPU interface requirements:	4.200 inches Minimum
– OD	1.75 inches
– Length	
– Rotor OD	
Control coil temperature rise: (Maximum load)	119F (66C)
Control coil temperature rise: (Steady-state)	18F (10C)

Frequency Response Of Bearing Control Defined

- Sufficient stability margin is achieved
- Bearing loads minimized through critical speeds
- Very low steady-state unbalance loads

OPEN-LOOP BODE PLOT OF BEARING CONTROL

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Magnetic Bearing Stability Analogous To Inverted Pendulum

MAGNETIC BEARING CROSS-SECTION

**CONVENTIONAL BEARING ANALOGY
(GRAVITY IS POSITIVE SPRING)**

**MAGNETIC BEARING OPEN-LOOP
(GRAVITY IS NEGATIVE SPRING)**

MAGNETIC BEARING CLOSED-LOOP

Touch-Down Bearing Design Based On Industry Experience And MEA-IPU Program Requirements

- Internal mounted rolling element bearings:
  - Minimize bearing DN
  - Minimize bearing impact on system size
  - Maximize bearing reliability

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END