12
4-12-94 950

UCRL-ID-114862

PulseSoar

Preston Carter
Steve Peglow

July 21, 1992

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

**This report has been reproduced
directly from the best available copy.**

**Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401**

**Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.,
Springfield, VA 22161**

PulseSoar

Preston Carter
&
Steve Peglow

July 21, 1992

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Table of Contents

The Future of Commercial Aviation	3
What is PulseSoar?	3
A Typical Mission Profile	9
Advantages of PulseSoar over Sub Sonic Aircraft.....	13
The PulseSoar Vehicle	15
Aerothermal Advantages of PulseSoar.....	19
Propulsion Advantages of PulseSoar	21
Wave Riders	25
Guidance and Control of the Flight Profile	25
History of Dynamic Soaring	27
Applications	28
Demonstrator Proposal	31

The Future of Commercial Aviation

This paper is an introduction to the PulseSoar concept. PulseSoar is a hypervelocity airplane that uses existing airport facilities and current technologies to fly at the very edge of space. It will be shown that PulseSoar can fly between any two points on the globe in less than two hours with fuel efficiency exceeding current state of the art commercial airliners. In addition, it will be shown that PulseSoar avoids environmental issues concerning the ozone layer and sonic booms because of its unique flight profile. All of this can be achieved with current technology. PulseSoar does not require the development of enabling technology. It is a concept which can be demonstrated today.

The importance of this idea goes beyond the technical significance's of PulseSoar in terms of feasibility and performance. PulseSoar could provide a crucial economic advantage to America's largest export market: commercial aircraft. PulseSoar is a breakthrough concept for addressing the emerging markets of long range and high speed aircraft. Application of PulseSoar to commercial transport could provide the U.S. Aerospace industry a substantial lead in offering high speed / long range aircraft to the world's airlines. The rapid emergence of a U.S. developed high speed aircraft could also be important to our competitiveness in the Pacific Rim and South American economies. Since the U.S. is geographically, and economically positioned to assume a major role in these emerging markets, PulseSoar could be an important advantage to America.

PulseSoar has strategic advantages as a progenitor to other concepts, technologies and applications. These include the commercial use of liquid hydrogen, single stage to orbit launch vehicles, intercontinental transportation of a rapid deployment force and high speed military airlift. Several near-term applications will be identified which can be implemented in order to prove the PulseSoar concept and to provide useful solutions to existing problems. Perhaps the most significant opportunity PulseSoar represents is the independence from petroleum-based fuels. This will be discussed later in more detail.

A quick and inexpensive demonstration vehicle is proposed to bring the concept to reality within two years. This discussion will address all the major technical subjects encompassed by PulseSoar and identifies several near-term, and low risk, applications which may be further explored with the initial demonstration vehicle.

What is PulseSoar?

PulseSoar could enable high speed, high altitude and long range flight without many of the difficulties encountered by traditional hypersonic vehicles. This concept combines old

ideas^{1,2}, and current technology, in a unique fashion to sustain hypersonic speeds without severe aerodynamic heating and without propulsion which requires supersonic combustion. There are a number of "near space" applications for this vehicle which are of considerable interest to U.S. industry³: the Department of Defense, the Department of Energy, the Department of Transportation, the National Aeronautics and Space Administration and the Department of Commerce⁴. This concept is consistent with Lawrence Livermore National Laboratory's missions in materials research, biological research, environmental research, development of defense technology, development of space technology, and the enhancement of U.S. economic competitiveness.

The key to PulseSoar is its use of a sustained dynamic soaring trajectory combined with a multicycle air breathing / rocket engine. A sustained dynasoaring trajectory is a flight path upon the Earth's atmosphere which is similar to a rock skipping across the surface of a lake. A lifting vehicle at high speed will skip in and out of the atmosphere due to unchecked phugoid oscillation. Skipping can be continued indefinitely by thrusting at the low point of the trajectory in order to make up for losses from aerodynamic drag. The following sketch is a comparison of a dynasoaring trajectory, a steady state cruising trajectory and a ballistic trajectory.

Flight Profiles of Various Intercontinental Trajectories

-
- 1 E. Sanger and J. Bredt, Airring, "A Rocket Drive for Long Range Bombers (Über einen Raketenantrieb Für Fernbomber)", Pg 108, August 1944, Deutsche Luftfahrtforschung UM3538, Translated by M. Hamermesh, radio Research laboratory, Reporduced by Technical Information Branch, Buaer Navy Department, C-84296.
 - 2 "History of Rocketry and Astronautics, American Astronautical Society History Series, Volume 8", Pg 283, Chapter 18, Richard P. Hallion, "American Rocket Aircraft: Percursors to Manned Flight Beyond the Atmosphere", 1989.
 - 3 "Questionary Results", Pg 221, "High Speed Commercial Flight - 'The Coming Era'", Battelle Press, 1987.
 - 4 "Keynote Address: Clarence J. Brown, Deputy Secretary U.S. Department of Commerce", Pg 9, "High Speed Commercial Flight - The Coming Era", Battelle Press, 1987.

PulseSoar is a rocket plane which skips on the Earth's atmosphere like a rock skips upon water when thrown across a lake.

- Between each skip the vehicle follows a ballistic trajectory
- The range and shape of each skip is adjusted with a rocket burn in the trough of each skip.
- Flight time and range of each flight is a function of the initial fuel load upon takeoff.

PulseSoar is a hypersonic aircraft; however, its skipping trajectory allows it to avoid most of the difficulties associated with hypersonic flight.

- A typical cruising velocity of Mach 10 to Mach 15.
- PulseSoar is not subjected to prolonged aerodynamic heat because its trajectory keeps it out of the atmosphere most of the time.
- Each hot phase of a PulseSoar trajectory is followed by a long period of radiative cooling in space.
- Propulsion is provided by conventional air breathing and rocket engines. Supersonic combustion ram jet propulsion is not required.

PulseSoar provides a platform which is at high altitude and high velocity with long periods of zero gravity, which makes it an excellent platform for:

- micro gravity research
- high altitude research
- hypersonic research

The vehicle takes off and accelerates with rocket propulsion. As soon as possible, the engine transitions to an air breathing mode in order to reduce fuel consumption during acceleration. As the vehicle accelerates to higher velocities, the engine transitions back to a rocket mode until the initial boost velocity is achieved. The rocket is used for subsequent burns to sustain the skipping trajectory. Once the vehicle has been boosted to a dynasoaring velocity, it can sustain this cruising velocity as long as fuel is available.

Applications for this vehicle include all traditional high speed / high altitude applications along with applications which emerge because of its skipping trajectory. Of the numerous traditional applications the most suited markets appear to be express mail, remote sensing, military reconnaissance and long range strike. The unique characteristics of this vehicle also qualify it for applications traditionally left to sounding rockets. During each skip, PulseSoar achieves a high altitude and follows a ballistic flight path; therefore, the same missions

performed by sub-orbital rockets can be performed by PulseSoar. These applications include: high altitude atmospheric science, micro gravity, and astronomy. Advantages of PulseSoar are that it will fly multiple skips per flight and that it will be reusable. Secondary uses of PulseSoar include the use of the vehicle as a reusable first stage for an orbital launch system and a platform for hypersonic research.

This concept is frequently compared to the hypersonic planes. PulseSoar can perform many of the same missions traditionally performed by hypersonic planes; however, PulseSoar utilizes currently available and proven technology. PulseSoar avoids the problems which make hypersonic cruise difficult⁵: supersonic combustion propulsion and a severe aerothermal environment. PulseSoar avoids thermal problems by popping in and out of the atmosphere, thereby reducing the heat load to the airframe and providing periods of radiative cooling each skip. PulseSoar avoids propulsion issues by relying entirely upon more traditional propulsion concepts.

Possible TODAY with PulseSoar:

- Hypersonic travel to any point on Earth in less than 1 1/2 hours,
- Flight 25% to 100% more efficient than airliners,
- NO environmental issues
 - Sonic booms,
 - Ozone layer
- Leap frog in international competition in high speed aircraft
- Possible with current established technology
 - NO enabling technology development required
- Low cost / low risk stepping stone towards a single stage airbreathing launch vehicle.
- Low cost / reusable high speed and high altitude and low gravity platform for science and technology development.

Applications:

- Civilian: Aircargo, Airliner, Business Travel.
- Research and Development: High altitude science, Microgravity science, Hypersonic Studies, Reusable Sounding Rocket, Space Systems Development
- Space: Launch Vehicle, Crew Training.
- Military: Rapid Deployment Force, Airlift, Reconnaissance, Global Strike from American soil.

⁵ Frank D. Boensch, "Design Challenges for the National Aero-Space Plane", IAF Paper 90-266, A91-13915.

PulseSoar

FIGURE 1 - PULSESOAR

Progenitor to Other Technologies

- Because PulseSoar is a blend of many ideas, it will be a progenitor of many other technologies and applications.
- PulseSoar allows applications to be developed as technology is advancing.
- Spin off technology and applications will also be an important contribution of PulseSoar.
 - Commercialization of liquid hydrogen for transportation
 - Micro-Gravity research and development
 - High temperature engineering materials
 - High speed propulsion and aerodynamics

A Typical Mission Profile

Figure 2 on the next page illustrates several aspects of the PulseSoar flight profile which are important and unique to its application. Note that the altitude region for which dynamic soaring takes place are not accessible by other forms of transportation. PulseSoar cruises in the Mesosphere and Thermosphere of the atmosphere. This is just below orbital altitudes and above altitude accessed by unmanned high altitude balloons. Currently the only access to these altitudes are with rockets. PulseSoar will provide, for the first time, extended periods of flight in this region.

A second important aspect of the PulseSoar flight profile is that it flies well above the Ozone. The original Super Sonic Transport (SST) program, and all SST programs proposed since, have been designs to fly at altitudes coinciding with the Ozone Layer. This environmental dilemma was the primary reason for the SST's cancellation and continues to challenge proposed aircraft. PulseSoar avoids the entire issue by flying well above the layer.

Sonic booms will not reach the Earth's surface. PulseSoar's extreme altitude is too distant from the surface for sonic booms to be of any concern. In addition, PulseSoar flies in the Mesosphere, above the temperature inversion of the Stratosphere. Its sonic booms will be reflected upwards. This will protect the Ozone Layer from the mechanical energy of sonic booms. The Ozone Layer is also protected by the vertical distances between PulseSoar's cruise altitudes and the layer's altitudes and by the low density of the upper atmosphere. PulseSoar is environmentally superior to traditional SST and HST concepts.

Another important advantage of PulseSoar's flight profile is the reduced level of aerothermal heating the vehicle will experience. The highest heat loads occur at the low point of each skip. PulseSoar's advantage is that this hot region will take place at a high altitude where the air density is low. A second advantage is that this hot phase of flight will have a short duration. Heating will only occur during the skip portions of the trajectory. Between skips, PulseSoar's third advantage is that the vehicle cools from thermal radiation. Short durations of heating followed by long coasting periods of cooling prevent temperatures from building up. PulseSoar will not require an active cooling system to protect its airframe and payload like most proposed hypersonic aircraft.

PulseSoar's flight profile is divided into four major phases: 1) boost, 2) cruise, 3) reentry / glide and 4) landing. During boost the vehicle is accelerated to the altitude and velocity for dynamic soaring. From the point of view of maximizing range for a given amount of fuel the

initial dynamic soaring velocity should be as high as possible. In reality the initial velocity is dictated by the quality of propulsion technology available. The feasibility and specific impulse of airbreathing propulsion technology decreases as velocity increases. At some point airbreathing propulsion must transition to rocket propulsion because of operating limitations and decreasing efficiency of airbreathing propulsion technology. The velocity at the end of the boost phase will reflect the optimal tradeoff between vehicle performance and available propulsion technology.

Figure 2 - Flight Profile

- PulseSoar cruises in an altitude region which has not been accessible by any other mode of transportation.
- PulseSoar flies well above the ozone Layer.
- PulseSoar's extreme altitude prevents sonic booms from reaching the Earth's surface and prevents most of their energy from reaching the ozone Layer.
- Aerothermal heat is much less than hypersonic aircraft and much less than orbital reentry.

There are a number of ways the vehicle can be launched into the boost phase. The three major classifications of launch, (horizontal takeoff, vertical takeoff and air drop) are all available for consideration. The selection of launch technique is dependent upon tradeoffs in cost, operations and performance required by potential applications.

During the cruise phase the vehicle is engaged in steady state dynamic soaring. The bulk of the range achieved during flight occurs during this phase. In order to sustain the skipping motion, sustaining burns are performed after each skip to make up for lost energy. Cruise can continue until all the fuel is expended.

The reentry / glide phase begins when the sustaining burns are discontinued. After several skips, the motion of dynamic soaring is damped. Altitude and velocity decreases until a steady glide path is achieved. This entire phase is unpowered. A significant portion of the overall range achieved during flight is accumulated during this phase. At the terminal end of this phase is the landing. The landing is also unpowered. Energy management techniques developed and demonstrated by the X-15, Lifting Bodies and the Space Shuttle are compatible with the vehicle's design.

Parameters of a typical flight profile are presented in Figure 3 (a-c). The trajectory presented is a preliminary example of a PulseSoar flight. The example given is not an optimal example of a trajectory. The guidance and control algorithms which are required to smooth and improve the efficiency of the trajectory are not implemented in this example. Looking at the plot of altitude versus time, there is poor repeatability in the shape of the skips during the cruise phase. When more optimal guidance and control algorithms are implemented the shape of the trajectory should be smoother and increases in range can be expected.

Figures 3 a-d - PulseSoar Flight Parameters

Altitude (M)

Velocity (M/Sec)

Range (M)

Nose Temp (°C)

Advantages of PulseSoar over Sub Sonic Aircraft

PulseSoar is superior to, or competitive with, today's sub-sonic airliners in terms of performance and cost. When it is considered that PulseSoar will reduce trip times by a factor of 10 and that PulseSoar can fly distances beyond today's airliners, PulseSoar has important advantages over today's aircraft.

PulseSoar has better payload carrying capability than today's sub-sonic airliners; that is, PulseSoar will carry more payload per kilogram of vehicle takeoff weight. Figure 4 clearly shows that PulseSoar has superior efficiency to current state of the art airliners. This chart shows the ratio of payload mass over gross takeoff mass versus flight range. Sense this chart emphasizes the amount of fuel required to carry payload, this chart shows that PulseSoar is more fuel efficient, in terms of mass, than current aircraft. The corner of the "Sub-Sonic Aircraft" region represents the best long range aircraft currently available, the Boeing 747-400. The PulseSoar region is bounded by two extremes. The lowest boundary line represents a PulseSoar design assuming conservative numbers for structural, propulsive and aerodynamic efficiencies. The upper boundary line represents the best assumptions which can be made assuming current technology. As you can see, PulseSoar is between 25% to 100% more efficient than current aircraft.

The primary reason PulseSoar is competitive with sub-sonic aircraft is illustrated in Figure 5 on the next page. The propulsive impulse required of PulseSoar is less than sub-sonic aircraft because it skips upon the atmosphere. Sub-sonic aircraft must plow through the atmosphere, where PulseSoar skips over it. Sub-sonic aircraft have an advantage in the efficiency of the propulsion they can use. PulseSoar has an advantage in the efficiency of its flight profile.

Figure 4 - Advantages of PulseSoar over Sub Sonic Aircraft

PulseSoaring hypersonic aircraft are more fuel efficient than all other forms of long range aircraft, including present day airliners.

PulseSoaring aircraft have less environmental impact upon the upper atmosphere than all other forms of long range aircraft because it flies out of the atmosphere most of the time.

Figure 5 - Skip Trajectory Provides Advantages in Fuel Efficiency

PulseSoar has an advantage over sub-sonic aircraft because:

- Skip upon the atmosphere requires less impulse than flying through it.
- PulseSoar is structurally more efficient because it does not have wings.

The PulseSoar Vehicle

The conceptual vehicle in Figure 6 illustrates the major features of a PulseSoar vehicle. The proportions of the vehicle have been estimated in order to approximate the vehicle being proposed.

The aerodynamic configuration of the vehicle is Wave Rider. The particular configuration depicted in the figure approximates a wave rider optimized to maximize lift to drag at a dynasoaring Mach number of 10, and to maximize internal volume⁶. This configuration is derived assuming a conic shock wave and viscous flow. Minor consideration in the derivation of configuration is given to the propulsion inlet blended into the underside of the vehicle (not shown). The shape is not optimized for propulsive efficiency because the vehicles does not

⁶ McDonnell Douglas paper

utilize air breathing propulsion during its cruising phase. There are several reasons why propulsion considerations are not stressed in the optimization of the wave rider shape: 1) PulseSoaring lift to drag is extremely important to the overall performance of the vehicle. Preliminary analysis indicates that compromises in vehicle lift to drag for improvements in propulsive efficiency are not necessary. 2) Computer Fluid Dynamic (CDF) analysis tools for the optimization of wave rider configurations with integrated air breathing propulsion is still in a state of development. Since propulsion considerations are secondary to lift / drag performance, and since a clear approach for blending propulsion into the wave rider shape is still evolving, the wave rider shape depicted in the figure does not assume optimization which considers propulsion integration.

Figure 7 illustrates the vehicle architecture. The vehicle is laid out with a payload module located along the back bone of the vehicle. This location affords the most flexibility to the vehicle and payload in terms of in volume, center of gravity and thermal protection.

The PulseSoar Vehicle

FIGURE 1 - THE PULSESOAR VEHICLE

Aerothermal Advantages of PulseSoar

For traditional hypersonic vehicles aerothermal issues are major concerns in the vehicle's design. PulseSoar has a natural advantage in that its flight profile minimizes aerothermal heating. This advantage translates into a simplified, and lighter, airframe design because a passive thermal protection system is all that is required to withstand flight temperatures. This means that aerodynamic concerns about the transition of laminar flow to turbulent flow are minor and that complexity of an active thermal control system are unnecessary. A PulseSoar vehicle will be lighter than a more traditional hypersonic vehicle because the operating temperature of the airframe will be lower. This means the relative strength of the airframe construction material will be higher; therefore, less structural material will be required. In addition, the mass of the active thermal control system will not be carried by a PulseSoar vehicle.

There are several reasons why PulseSoar's flight profile gives it an aerothermal advantage. First of all, the vehicle only spends about 10% of the time in cruise actually in the atmosphere. The remainder of the time it is on a ballistic path coasting through space. This is an advantage because the cumulative heat load upon the vehicle is reduced because on its short duty cycle in the atmosphere. It also provides an advantage because the vehicle is able to radiate more than 95% of the heat accumulated during the previous skip into space. This cools the vehicle before it enters the atmosphere again. Another advantage is that dynamic soaring takes place at a higher altitude than traditional hypersonic cruise. Traditional cruising aircraft operate at altitudes between 30 and 50 Km because of airbreathing propulsion requirements. PulseSoar skips off of the atmosphere at altitudes of between 60 and 80 Km. Aerothermal heating is proportional to atmospheric density. Since atmospheric density decreases at exponential rates with altitude, the heating upon a PulseSoar vehicle is naturally lower for the same velocity. PulseSoar also has an advantage over orbital reentry vehicles. Aerothermal heating rates are proportional to V^3 . PulseSoar's velocity is about Mach 10 where reentry vehicles fly in the atmosphere at velocities greater than Mach 20. Again, PulseSoar has a natural aerothermal advantage.

The plot on the opposite page shows the nose cone temperature of a PulseSoar vehicle over the duration of a typical flight. Note that the temperature remains below 750°C. Current reusable thermal protection systems for high speed vehicles are capable of temperatures greater than 2000°C. It is clear that technology for PulseSoar's thermal protection system is available.

The vehicle's nose cone and leading edges are constructed of coated carbon / carbon material to withstand high temperatures during flight phases within the atmosphere. The bottom of the vehicle is covered with fused silica thermal protection tiles similar to those used on the

Space Shuttle. The upper surface is covered with a mixture of thermal protection tiles and flexible thermal protection blankets.

A skipping trajectory provides PulseSoar an aerothermal advantage over traditional hypersonic vehicles:

Technology for the thermal protection system is available.

Heating experienced by PulseSoar is less than that of traditional hypersonic vehicles and re-entry vehicles.

- PulseSoar is able to radiate >95% of the heat absorbed during each skip into space between bounces.
- Aerothermal heating is proportional to V^3 and proportional to the atmospheric density.
 - PulseSoar flies much slower than a reentry vehicle: Mach 10 to 15 versus Mach 25.
 - PulseSoar flies higher than a traditional hypersonic vehicle and for shorter periods in the atmosphere.
 - * PulseSoar skips at altitudes of 60 to 80 Km. Hypersonic vehicles fly at altitudes of 30 to 50 Km.
 - * PulseSoar spends less than 10% of its cruise time in the atmosphere. Hypersonic vehicles never leave the atmosphere.

Typical worst case nose cone skin temperatures are well within current thermal protection system capabilities.

- Space Shuttle nose cone skin temperatures are 3 to 4 times higher
- NASP nose cone skin temperatures are 4 to 5 times higher

Propulsion Advantages of PulseSoar

PulseSoar has the flight characteristics of both a launch vehicle and a hypersonic aircraft. The largest component of propulsion is required to boost the vehicle to its dynamic soaring velocity and altitude. After this initial boost is achieved, propulsion is required after each skip in order to makeup whatever energy it loss along the way.

During the boost phase rocket propulsion can be used just like a launch vehicle. Rocket propulsion is very inefficient but since a launch vehicle spends the majority of its time in flight regimes too fast and too high for airbreathing propulsion, rocket propulsion provides acceptable performance. PulseSoar differs from a launch vehicle is one important way, its ascent is always in a flight regime for which airbreathing propulsion is feasible. Since airbreathing propulsion has significant performance advantages over rocket propulsion, PulseSoar can, and should, use airbreathing propulsion for the majority of its ascent trajectory.

Near the final boost velocity, airbreathing propulsion could begin to show marginal performance advantages over rockets. This is partly due to limitations is current technology and may be partly due to the selection of the propulsion design. Whether or not airbreathing propulsion is practical all the way to the final boost velocity is not critical. If rocket propulsion must supplement airbreathing modes during the final portions of ascent this is compatible with the PulseSoar concept. Rocket propulsion will be required during the dynamic soaring phases anyway; therefore, the vehicle already possesses the rockets if they are required.

Research and development are constantly improve our understanding of supersonic combustion ramjets (SCRAM). As advancement in airbreathing propulsion ais made, they can be implemented into a PulseSoar vehicle to upgrade its performance. Advance propulsion concepts are likely to be implemented on a PulseSoar vehicle before a traditional hypersonic airplane because PulseSoar does not require a significant degree of aerodynamic / propulsion integration in order to achieve its desired performance. Traditional hypersonic planes require the airframe and the propulsion system to be integrated together in order achieve desired performance. PulseSoar is not constrained by these requirements. PulseSoar does not boost to orbital velocities and PulseSoar does not cruise within the atmosphere. For these reasons the selection, operation and integration of a propulsion system into PulseSoar is simplified compared to a hypersonic vehicle.

PulseSoar's skipping trajectory allows flexibility in the selection of a propulsion system.

Propulsion is used to boost the vehicle to its initial dynasoaring velocity and it is used in intermittent bursts to sustain flight. Since propulsion is not used in a steady state mode:

- The integration of the propulsion system with the airframe is not critical to overall vehicle performance.
- The vehicle aerodynamic configuration is not as complex.
- There is flexibility in the way the propulsion system can be integrated with the vehicle.

PulseSoar can use evolutionary propulsion systems rather than requiring revolutionary systems.

- Technology readiness can determine how advance PulseSoar's propulsion system will be initially.
- As propulsion system technology advances, these advances can be incorporated into the PulseSoar vehicle.

PulseSoar's Advantage is in its flexibility to the type of propulsion system employed.

The two most important characteristics are the specific impulse of the propulsion and the thrust to weight of the propulsion system. Of these two, specific impulsion has the most significant impact upon overall vehicle performance.

PulseSoar's minimal requirements for concept feasibility are extremely modest. However, if PulseSoar's performance must match, or exceed, competing approaches, minimal propulsion requirements are important. For example, if PulseSoar is to compete with existing sounding rocket vehicles, minimal propulsion requirements are comparable to the same propulsion technology used on existing sounding rockets ($I_{sp} \geq 250 \text{sec}$, $T/W \geq 40$). If PulseSoar's performance must be competitive with a 747-400 airliner traveling over inter-continental distances, then propulsion requirements are: $I_{sp} \geq 1500$, $T/W \geq 15$. Regardless of likely performance requirements expected of PulseSoar, there appears to be a broad enough range of propulsion technologies which are compatible with PulseSoar to meet the challenge.

An actual propulsion system for PulseSoar has to have capability. In the previous paragraph specific impulsion and thrust to weight ratio requirements are stated as lumped characteristics. Obviously, the performance characteristics for any propulsion technology will vary with vehicle mach number and altitude. For the sack of discussion, these characteristics are stated as lumped values which represent the average performance characteristics over the entire mission profile.

The simplest multicycle propulsion system which will work over PulseSoar's entire flight profile is a rocket ram jet. The charts presented on the next page show the performance characteristic of rocket ram jets over PulseSoar's expected flight mach numbers.

A number of other multicycle propulsion approaches are viable candidates for PulseSoar's requirements. In addition a number of inlet and nozzle approaches are possible which can significantly influence performance. The point is that an extensive array of existing and proven propulsion technologies are available for fulfillment of PulseSoar's requirements.

Minimum propulsion requirements depend upon the performance of completing approaches for a given type of applications:

- Sounding Rocket: $I_{sp} \geq 250 \text{ sec}$, $T/W \geq 40$
- Long Range Transportation: $I_{sp} \geq 1500 \text{ sec}$, $T/W \geq 15$

The figures on the next page illustrate potential candidates for hypersonic propulsion systems and relative impulse and thrust/weight ratios.

Propulsion Technology

Indicates the Fuel Specific Impulse vs Flight Mach Number for various Technologies

Indicates the Thrust/Engine Weight Ratio vs Flight Mach Number for various Technologies

Wave Riders

Wave Riders are super sonic vehicles which interact with their shockwave to produce lift.

The North American XB-70 Valkyrie is an early example of a successful Mach 3+ wave rider design

Modern wave rider designs use CFD codes to optimize vehicle shapes

- Maximize lift to drag.
- Maximize volume

PulseSoar utilizes a wave rider configuration in order to maximize its lift to drag performance.

Guidance and Control of the Flight Profile

The guidance and control of PulseSoar is different than any previously designed aircraft or rocket. The components and phases of the guidance and control scheme are not unique, but the manner in which they will be used is unique to PulseSoar. Looking at each phase of flight, each can be classified as the trajectory of an airplane, a rocket or a reentry vehicle. The guidance functions will control when to transition between each phase of control and will provide the targeting to direct them. Descriptions of the purpose of the guidance and control schemes during each phase are given below:

Launch: PulseSoar can be launched vertically or horizontally. The guidance and control early portions of the ascent will be dominated by constraints. Normally the type of constraints imposed during this portion of flight are concerned with range safety, sonic booms, airframe loading and abort planning.

Ascent: PulseSoar will use airbreathing propulsion for the majority of the ascent. This means that the ascent will be guided to the maximum design dynamic early and ascent profile with this constant dynamic pressure will be followed. Propulsion efficiency and thrust is maximized with dynamic pressure; therefore, airbreathing ascents usually follow this form of profile. At some point propulsion will be transitioned from airbreathing to rocket modes. When this occurs, the guidance and control will be shifted to a power guidance optimized to minimize burn time and achieve the target conditions at Main Engine Cut Off (MECO). The MECO target will be defined by the shape of the ballistic path desired to begin the dynamic soaring phase of flight.

Dynamic Soaring Cruise: Guidance and control during cruise has several objectives. Dynamic soaring must be continued until the vehicle must transition in the reentry and glide phase to land at its designation. Each skip maneuver must be aerodynamically controlled to minimize the drag loss of each skip and a rocket burn must be guided to maintain the shape of each ballistic arch between skips. Aerothermal heating, dynamic pressure and g-loads during the skip maneuver can be constrained if required.

Reentry / Glide: Guidance and control of the reentry and glide phase of flight will involve the management of flight energy in order to arrive at the landing destination with energy levels which can be handled by the landing strategy. Control will involve modulation of angle of attack, speed brake and bank angle to achieve these objectives. Constraints on aerothermal heating, dynamic pressure and g-load may be required.

Landing: The vehicle will arrive in the landing area within a desired energy level. This flight energy will be managed by the selection of ground track and the control of angle of attack and speed brake to bring to vehicle to the runway and to a safe landing. The technology from this type of unpowered landing has been extensively developed and demonstrated by the X-rocket planes, the early lifting body aircraft and the Space Shuttle.

PulseSoar uses a broad range of flight dynamic techniques. Several flight techniques which PulseSoar uses have been extensively studied, but never demonstrated such as Airbreathing/Rocket Ascent and Optimal Transatmospheric Maneuvers

History of Dynamic Soaring

The concept of dynamic soaring was first suggested by Eugen Sanger in the late 1930's. Although dynamic soaring has been proposed several times in the past, several enabling technologies were not available.

- Reusable thermal protection systems,
- Guidance, Navigation and Control hardware and capabilities,
- Computer Fluid Dynamic codes

PulseSoar's sustaining rocket burns are a unique approach which gives a dynamic soaring vehicle the ability to cruise at hypersonic speeds.

PulseSoar is a practical concept because:

- Sustaining rocket burns gives it cruise performance,
- Reusable thermal protection tiles,
- The capability of modern flight computers and GN&C sensors.
- The development of CFD codes.

Applications

PulseSoar applications in four broad categories

- Transportation
- Military
- High Altitude, High Speed & Low Gravity R&D
- Space

Potential Applications:

Transportation: Intercontinental Express Mail
 Business Aircraft
 Passenger Travel

Military: Reconnaissance
 Global Cruise Missile
 Global Strike
 Rapid Deployment
 Air Lift

High Altitude, High
Speed & Low
Gravity R&D: Atmospheric Science
 Remote Sensing
 Hypersonic R&D
 High Altitude Science
 Micro Gravity Science

Space: Launch Vehicle
 Space Systems R&D
 Crew Training

Research & Development Applications of PulseSoar

PulseSoar flies multiple skips each flight. The ballistic portion of each skip is the same as a single sounding rocket sub-orbital trajectory; therefore, PulseSoar provides more opportunities, per flight, for experiments than a sounding rocket.

- Deployable payloads can be checked out in captured flight during preceding skips before committing to the planned deployment.
- Several payloads can be flown on one flight. If operational conflicts between payloads prevent simultaneous activation, they can still fly on the same flight by alternating their operations between skips,
- Mission objectives lost during early skips can be recovered during later skips.
- Experiments can be repeated during follow on skips if results call for verification.

PulseSoar does not expend all of its fuel during its initial boost. It can control its trajectory aerodynamically and propulsively throughout its flight.

- The duration of a flight can be extended with the addition of skips if fuel reserves are available.
- The characteristics of each skip can be adjusted as required.
- Several mission abort options are possible.

PulseSoar is completely reusable. Range safety issues are minimized because hardware is not jettisoned during flight.

The need for using instrumented ranges is reduced since payloads flown upon PulseSoar will not need extensive telemetry support because payloads can be returned intact to the user.

PulseSoar allows payloads to be reusable.

- Program costs are reduced because experiments can be repeated with the same hardware.
- Program risk is reduced because failed hardware can be examined and tested after the flight. Program risk is also reduced because hardware is not lost during an unsuccessful flight.

Long Range Passenger and Air Cargo Markets are Growing Rapidly

Growth of Air Cargo Market

Growth in Airline Passenger Market

Demonstrator Proposal

The proposal is to build a pathfinder vehicle, Figure 8, to immediately establish the viability of the PulseSoar concept. A “quick” and “cheap” approach is proposed. This pathfinder will be large enough to demonstrate applications like air cargo and sounding rocket applications, but will be small enough to allow the vehicle to be designed and built in less than two years.

The target cost of the proposed pathfinder is less than \$5 million. The objectives of this project are:

- 1) Validation of the range performance of the PulseSoar concept.
- 2) Flight demonstration of a hypersonic waverider aircraft configuration.
- 3) Flight demonstration of a RAM / Rocket Hydrogen propulsion system.
- 4) Demonstration of a ascent trajectory using both airbreathing and rocket propulsion.
- 5) Establish a design point for a light weight airframe for this type of vehicle.

Although these objectives are key to the PulseSoar concept, they are also important to a large number of other aerospace technologies. This proposed pathfinder project is not only “Faster”, “Better”, and “Cheaper” than traditional experimental projects, it also will provide an opportunity to flight test several important technologies which could be critical to a broad range of potential applications.

Build a “Quick and Cheap” Pathfinder to prove the concept.

- Fly the pathfinder vehicle in less than two years
- Project costs < \$5 M
- Objectives:
 - 1) Validate the range performance of the PulseSoar concept.
 - 2) Flight demonstration of a hydrogen powered RAM / Rocket propulsion.
 - 3) Demonstration of an ascent trajectory using both airbreathing and rocket propulsion.
 - 4) Flight demonstration of a hypersonic waverider vehicle configuration
 - 5) Establish a design point for a light weight airframe for this type of vehicle.

The PulseSoar Pathfinder will demonstrate technology which have broad applications beyond the PulseSoar concept.

FIGURE 1-1: AIRCRAFT PERFORMANCE

Demonstrator Schedules and Costs

The key technologies required for PulseSoar are fully developed, but the concept of combining these technologies in the manner proposed by PulseSoar has never been demonstrated. There is very little risk in demonstrating the PulseSoar concept but there is, no doubt a great deal to learn on how to combine these technologies in an efficient and cost effective manner. A pathfinder project to explore and demonstrate the PulseSoar concept is recommended. This pathfinder project will design, build and flight test a small scale remotely piloted vehicle in less than two years and for less than \$10M. This demonstration vehicle will be capable demonstrating all the unique flight capabilities of PulseSoar including: hypersonic cruise across intercontinental distances, long periods of low gravity during each flight, full reusability and the exclusive use of existing technology.

The proposed pathfinder project will cost \$10M over an 18 month period. The project will produce a small scale flight vehicle which is air launched from a high performance jet fighter like a F-15 (see figure 1). The design of the vehicle will include extensive testing to minimize risk to the actual flight vehicle. Testing will include wind tunnel testing, super sonic rocket sled tests and captured flight tests while attached to a manned aircraft. The specific goals of the project will be to: 1) demonstrate long range and high efficiency, 2) use of current technology to achieve hypersonic flight, 3) full reusability and 4) demonstration of suitability to various hypersonic missions. Since the vehicle will be able to carry a useful payload of about 100 kg, after the flight test program is completed this vehicle can be used for microgravity research and for the performance of other sounding rocket missions.

Figures 9, 10 and 11 describe the details of the project plan in terms of tasks, cost and schedule. These projections are in terms of raw costs and manpower requirements. Assuming typical procurement burdens and manpower rates, the total project cost is estimated to be \$10M. The 18 month schedule would normally be considered very short; however, because this vehicle is small in size and uses only existing technology, this schedule is reasonable and cost effective.

This project is designed to quickly and cheaply demonstrate a hypersonic transportation concept which could dramatically leap frog existing approaches to high speed transportation. Technology, performance and environmental problems of all existing supersonic and hypersonic aircraft are avoided, or solved by the PulseSoar concept. This proposed project will enable us to demonstrate with a "Faster, Cheaper, Better" approach the PulseSoar concept.

Figure 9 - Pathfinder Project Work Breakdown Structure

Figure 10 - Pathfinder Project Schedule

Figure 11 - Project Costs

PulseSoar Pathfinder Project

		Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6
1.1 Pathfinder Propulsion Design							
1.1.1 Engine Selection and Sizing	Manpower	2					
	Costs	25					
1.1.2 Boiler Engine Design Manf. and Test	Manpower	1	2				
	Costs	25	75				
1.1.3 Flight Engine Design Manf. and Test	Manpower		1	2	2		
	Costs		50	100	50		
Quarterly Manpower Subtotal (man/years)		3	3	2	2	0	0
Cumulative Manpower Subtotal (man/years)		3	6	8	10	10	10
Quarterly Costs Subtotal		\$50K	\$125K	\$100K	\$50K	\$0K	\$0K
Cumulative Costs Subtotal		\$50K	\$175K	\$275K	\$325K	\$325K	\$325K
1.2 Pathfinder Airframe Design							
1.2.1 Aerodynamic Design	Manpower		2				
	Costs		150				
1.2.2 Systems Design and Sizing	Manpower		2	2	1		
	Costs		50	50			
1.2.3 Airframe Design	Manpower		2	1			
	Costs		25	25			
1.2.4 Engineering Mockup and Testing	Manpower		1	1			
	Costs		25	25			
1.2.5 Airframe Manf. and Assembly	Manpower			5	5		
	Costs			600	400		
1.2.6 Checkout and Testing	Manpower				1		
	Costs				100		
Quarterly Manpower Subtotal (man/years)		0	7	9	7	0	0
Cumulative Manpower Subtotal (man/years)		0	7	16	23	23	23
Quarterly Costs Subtotal		\$0K	\$250K	\$700K	\$500K	\$0K	\$0K
Cumulative Costs Subtotal		\$0K	\$250K	\$950K	\$1,450K	\$1,450K	\$1,450K
1.3 Pathfinder Demonstration							
1.3.1 Planning and Coordination	Manpower			0.25	0.25	0.25	0.25
	Costs			10	10	10	10
1.3.2 Captured Rocket Sled Tests	Manpower			2			
	Costs			100			
1.3.3 Captured Aircraft Flight Tests	Manpower			2	2	1	
	Costs			300	200	100	
1.3.4 Crew Training	Manpower			1	0.5	0.25	0.25
	Costs			100	50	25	25
1.3.4 Free Flight Demonstrations	Manpower			1	2	2	1
	Costs			100	200	200	100
1.3.5 Refurbishment and Ground Support	Manpower					1	1
	Costs					50	50
Quarterly Manpower Subtotal (man/years)		0	0	6.25	4.75	4.5	2.5
Cumulative Manpower Subtotal (man/years)		0	0	6.25	11	15.5	18
Quarterly Costs Subtotal		\$0K	\$0K	\$610K	\$460K	\$385K	\$185K
Cumulative Costs Subtotal		\$0K	\$0K	\$610K	\$1,070K	\$1,455K	\$1,640K
Quarterly Manpower (man/years)		3	10	17.25	13.75	4.5	2.5
Cumulative Manpower (man/years)		3	13	30.25	44	48.5	51
Quarterly Costs Total		\$50K	\$375K	\$1,410K	\$1,010K	\$385K	\$185K
Cumulative Costs Total		\$50K	\$425K	\$1,835K	\$2,845K	\$3,230K	\$3,415K

**DATE
FILMED**

5/12/94

END