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ENVIRONMENTAL ASPECTS OF FUTURE SPACE VEHICLES AND IMPLICATIONS FOR TESTING

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AERODYNAMIC ASPECTS OF FUTURE SPACE VEHICLES AND IMPLICATIONS FOR TESTING

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This paper treats some of the technical characteristics of lifting spacecraft and considers some problems of testing. Some general observations about operating lifting spacecraft in the "atmospheres" of other planets have been included in the hope of stimulating thought and discussion of such future possibilities.

INTRODUCTION

The role of aerodynamic lift in the design of future space vehicles has been discussed and analyzed in many papers and at many conferences. For the most part, such discussions are limited to a particular phase of flight. In this paper we shall try to highlight the role of aerodynamic lift in future space vehicle design during as many phases of the flight regime as possible. The reader is warned that as a result this discussion will be broad in nature; some of the details may be filled in by subsequent presentations.

This paper is generally organized to provide (1) a brief review of some of the technical characteristics and problems associated with lifting spacecraft operating near the Earth, (2) a method of comparing the performance of lifting spacecraft with other methods for achieving similar goals, and (3) an indication of future trends in test facilities and ranges associated with the future use of lifting spacecraft. Later, we will introduce some thoughts about operations in the vicinities of other planets.

TECHNICAL CHARACTERISTICS

The main technical features that characterize lifting spacecraft operations are maneuvering and rapid return from orbit to a limited

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number of landing fields, a reduced acceleration environment, and cooling systems that may be different from ballistic reentry technology under certain conditions.

Operationally, maneuvering the spacecraft may be the most important use of lifting surfaces. While many analysts have intensely studied reentry maneuvering, lift can be used during other phases of orbital flight such as during exit from the atmosphere and during the orbit phase of flight.

One can imagine the use of lift to achieve significant offsets from a launch site. Figure 1 illustrates this concept. Essentially, the upper stage of a rocket might be a powered lifting spacecraft. After injecting the spacecraft into a flat trajectory in the upper portion of the atmosphere at a relatively high speed, the spacecraft would glide and turn so as to achieve a new heading. After the desired heading is achieved, an engine is started to restore the velocity lost during the turn as well as to speed up the vehicle to initiate an ascent trajectory to orbit.

The utility of using such a scheme for doglegging is not obvious at this time, but may hold some promise. Figure 2 shows the velocity loss during the turn for one specific glide initiation condition. The trend appears to favor higher L/D* vehicles for this maneuver. Whether or not this trend will be the same with regard to performance in terms of payload weight remains to be seen. Further analyses of specific vehicle designs are apparently needed to answer this question. Some progress has been made recently but is not conclusive with regard to need[1].

For the orbit phase of flight, maneuvering can be accomplished by use of synergetic plane changes[2-5]. For use of the lifting capabilities of a spacecraft, it must be deorbited. The atmospheric forces needed to make the turn can be generated by flight in the upper part of the atmosphere as shown in Fig. 3. At the end of the turn the velocity losses are restored and an additional velocity increment is imparted to initiate the ascent to orbit.

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*Notation is shown at the end of the paper.

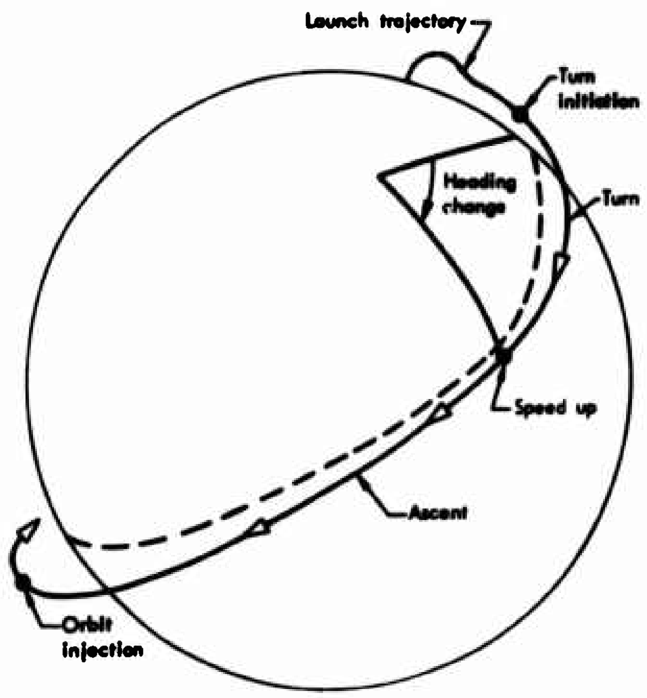

Fig.1—Maneuvering on exit

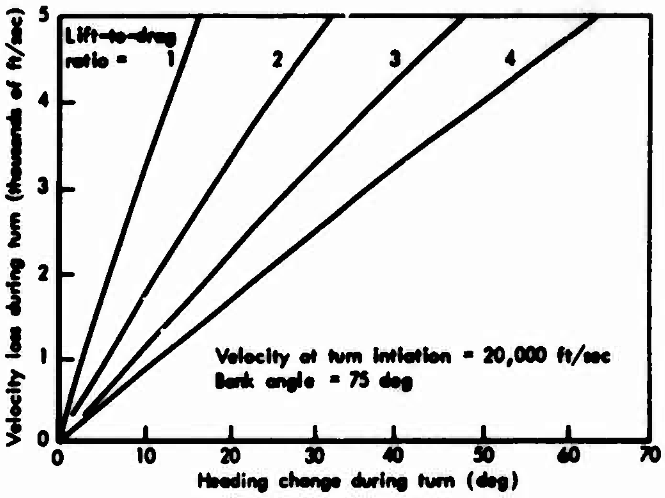

Fig.2—Velocity losses for turning during exit

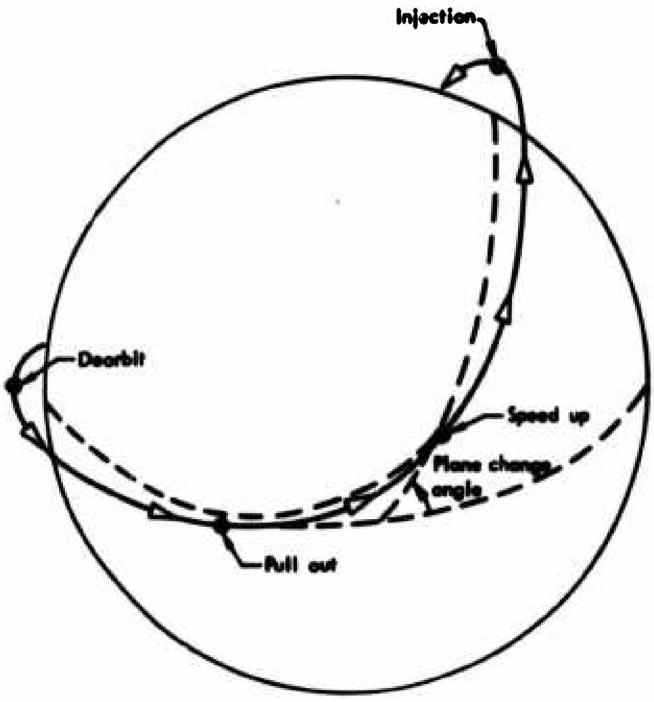

Fig.3—Maneuvering in space

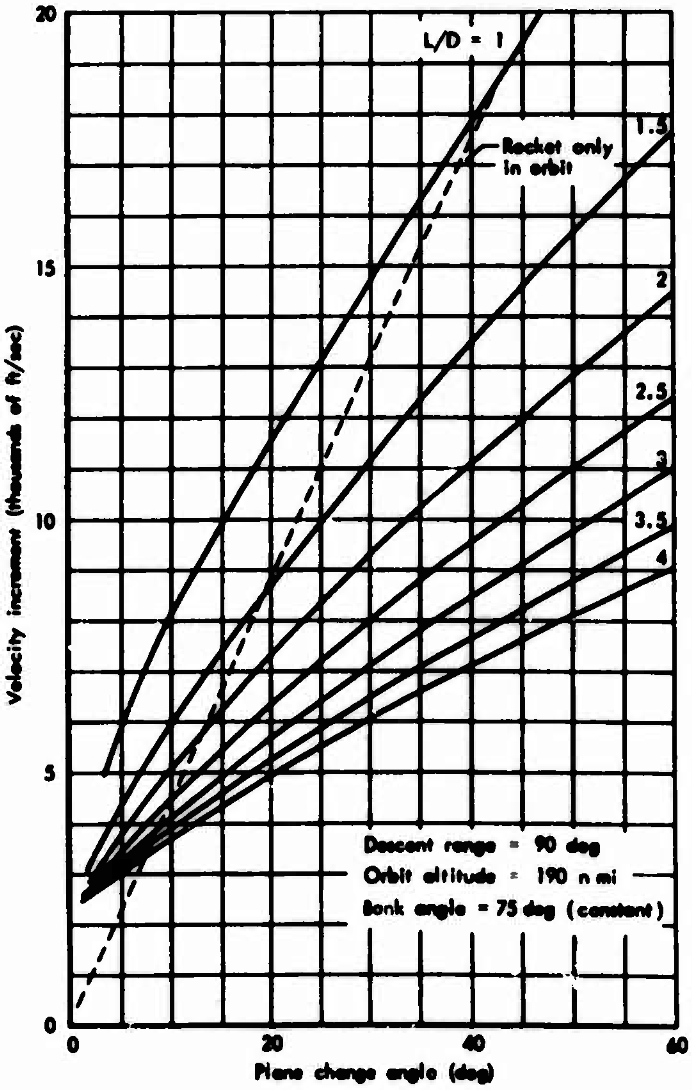

Fig.4—Velocity requirements for synergetic plane changing

The advantages of synergetic plane changing are shown in Fig. 4 in terms of the velocity increment needed to achieve various heading changes. Later we shall discuss weight trends. The example shown here includes provisions for the descent from the initial orbit and ascent to the new orbit to take place in one quarter of an orbit revolution (descent range = ascent range = 90 deg). From these results* it seems that a very high lift-to-drag ratio would be better for keeping the velocity increments smaller. It is also apparent that if the plane changes are small (less than 10 deg or so), synergetic plane changing requires larger velocity increments than use of a purely propulsive system. A lift-to-drag ratio in excess of 1.5 or 2 would appear to be required to perform this maneuver efficiently.

Finally, one can imagine maneuvering during atmospheric entry. Maneuvering during this phase of flight by gliding has been extensively studied in the past[7,8,9]. The concept is illustrated in Fig. 5 where side range or distance maneuvered out of the orbit plane is the measure of performance. The performance estimates of such maneuvers are shown in Fig. 6. Large side ranges can be achieved by using vehicles with high lift-to-drag ratios. Such maneuverability can be used to shorten return time from orbit, if this is required in a particular mission. For example, the access to one landing site for a randomly positioned lifting spacecraft is shown in Fig. 7.

One of the often cited advantages of utilizing lifting spacecraft during entry is the reduced acceleration environment (1 or 2 g's) as compared to ballistic reentry (6 to 8 g's). If future space research indicates that man's tolerance to high acceleration levels is degraded by long duration orbital flights, then use of a lifting spacecraft may be required for logistic support of space stations or interplanetary flights. For high lift-to-drag ratios, the normal load factor (the acceleration that tends to break off wings) provides an estimate of total deceleration. For lift-to-drag ratios of about unity, the drag-to-weight ratio would also be important and the total acceleration would be about 41 percent greater than the normal load factor.

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*Computed by the method of Ref. 6.

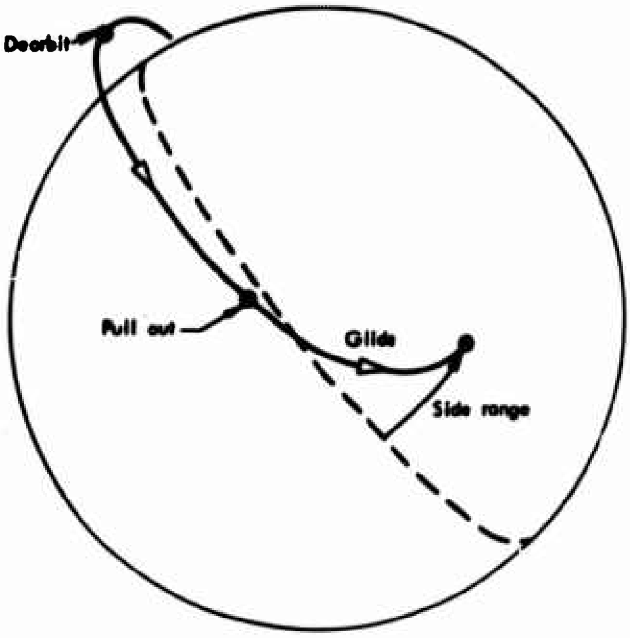

Fig.5—Maneuvering on reentry

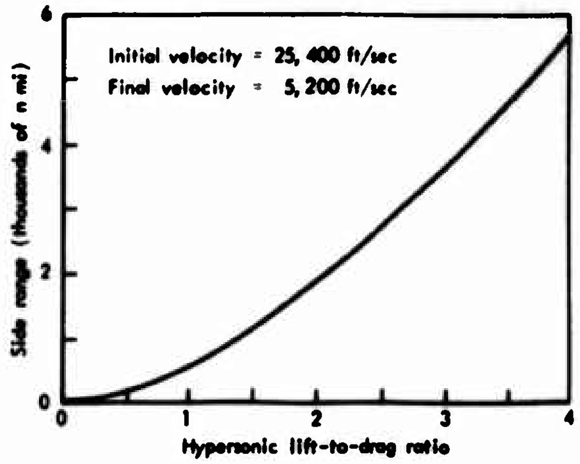

Fig.6—Side range achievable with gliding

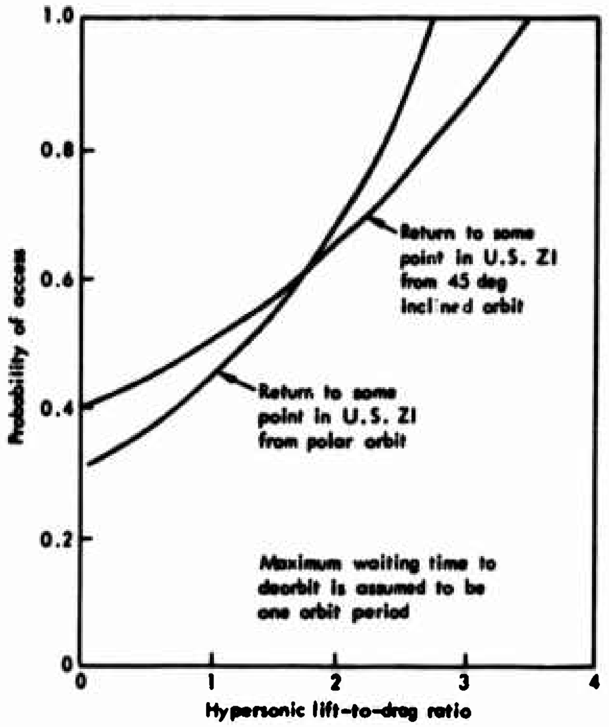

Fig.7—Access to landing in the United States

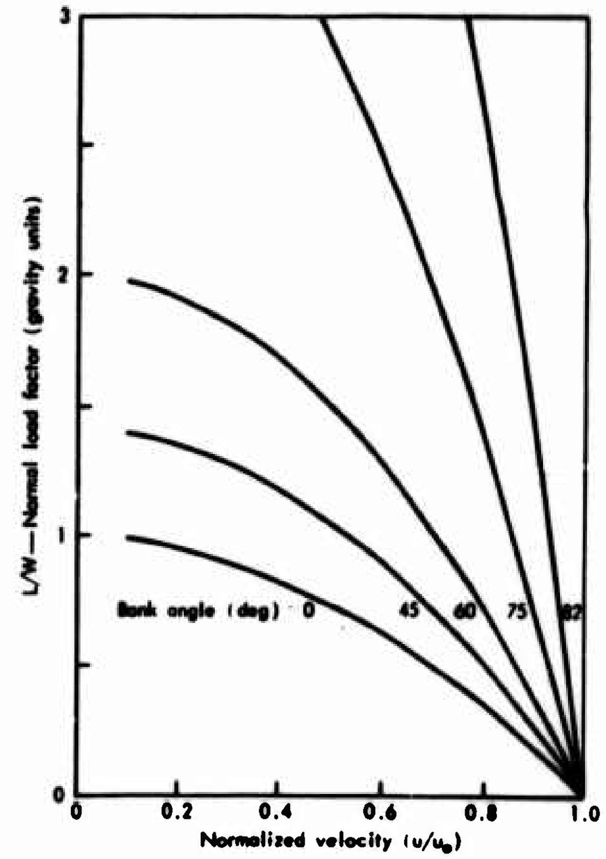

Fig.8—Acceleration environment for lifting entry spacecraft

Figure 8 shows the normal load factor through the velocity range of interest for constant bank angle and angle of attack control. For the "straight-in approach" or zero bank angle trajectory the forces are the least and gradually build up to one g. If one is to consider maneuvering, however, higher accelerations will be experienced. If the bank angle is 45 deg or less (the approximate amount usually required for large side ranges) then only a moderate increase is noted. For plane changing with minimum energy loss, larger bank angles are required (70 to 90 deg)[3]. Under these conditions normal load factors can be large and should be taken into consideration early in the design phase of any vehicle that may be required to perform maneuvers as part of its mission.

The use of lifting spacecraft may introduce design and operational problems. One of these problems is that of cooling the spacecraft structure during atmospheric portions of flight. For many of the proposed low L/D lifting vehicles, cooling problems are apparently solvable. In most cases it may be that low L/D vehicles are popularly proposed simply because they present few cooling problems. If, however, a vehicle is required to perform maneuvers such as we have just described, then heating may become very severe. The trend of heating difficulty is illustrated in Fig. 9 (p. 9) by some simple estimates of stagnation temperatures as a function of vehicle bank angle. The velocity chosen here is 21,000 ft/sec and is near the maximum heating rate condition on an equilibrium glide trajectory. Also, the $W/C_L A$ is assumed to be 200 lb/ft^2. If this parameter is increased in value, more severe heating would result. As the bank angle is increased the temperatures increase markedly because the vehicle sinks farther into the atmosphere. In addition, the heating is further increased by use of a small nose radius. If it is assumed that small nose radii are used on high L/D vehicles, then the heating is indeed severe. Rather than say that such curves merely illustrate the hopelessness of ever building and flying such vehicles, one may view these trends as indicators of areas where research and technology capabilities must be brought to bear more forcefully. Beyond study of different cooling techniques, one might consider the use of propulsive force to maintain a turning vehicle at higher altitudes where heating is less severe. This method would seem particularly applicable for synergetic plane changing where large bank angles are desirable so as to minimize energy losses during turns.

Another problem appears to be that of structural efficiency of various aerodynamic vehicles. As we shall see later, lightweight structures will be required to make the use of lifting spacecraft competitive with the use of pure rocket methods of maneuvering, if the measure of performance is in terms of payload weight.

An often cited problem associated with lifting spacecraft is the incompatibility of such shapes with rocket boosters. Large lifting surfaces can lead to large bending moments in the booster structure during parts of the launch phase of flight. Much of the strain on the launch vehicle can be alleviated by use of a load relief autopilot and by proper trajectory selection.

There are probably other problems that I have not mentioned above. It seems that while problems exist at the present time, many solutions may also exist. Further work is obviously required to find as many solutions as possible so that the system analyses of lifting spacecraft missions can proceed and meaningful guidelines to future space operations can be established.

COMPARISON OF BALLISTIC AND LIFTING SPACECRAFT PERFORMANCE

Before it is possible to state whether or not there is a promising future for lifting spacecraft, one must compare the performance of lifting vehicles with that of ballistic spacecraft equipped with rocket propulsion. Some of these comparisons have not yet been made and should be made. Planners and engineers will be remiss if such comparisons are not presented.

During the entry phase of flight, one might consider use of a ballistic spacecraft equipped with a rocket to deorbit and change the plane of the descent trajectory. This concept is shown in Fig. 10 (p. 9). The maximum side range is achieved with a given velocity increment when the distance from the deorbit point to impact point is about 5400 n mi. The total weight of either a lifting or ballistic vehicle to implement this concept is shown in Fig. 11 for various types of propulsion[10,11]. From these trends, it appears that one might very well consider using purely rocket techniques to achieve moderate side ranges up to 500 n mi or so. Thus it appears from this data that there would be no requirement for lifting spacecraft whose lift-to-drag ratio is 1.25 or less for I_{sp} = 300 sec or so. The crossover point as to whether lifting or ballistic spacecraft should be used would be very sensitive to the structural weight assumed for the lifting vehicle. Fairly firm data on vehicle design would be needed to actually establish the crossover point, and the example given here is only illustrative of the type of analysis needed to make a decision. The main point is that there is some minimum L/D combined with some structural weight fraction that satisfies the condition for better performance with regard to returned payload and side range. If the mission requirement for side range is on the order of a few hundred miles at most, use of existing ballistic spacecraft with larger retro-rockets would appear to be preferred to use of a new and comparatively expensive lifting reentry vehicle. The choice of ballistic capsules may be more attractive if a simple "landing on land" capability can be devised.

There has been practically no analysis of lifting vehicles used as upper stages of a booster. One exception has been noted[1]. Because of this void, we will only consider the potential outcome of such an analysis. If it is assumed that the launch location of a booster is Cape Kennedy, the performance of a rocket is generally similar to the "pure rocket" curve shown in Fig. 12. The highest payload placed into orbit would be for a due east launch, or an orbit inclination of 28 deg. The payload in orbit falls off rapidly for orbit inclinations less than 28 deg because a dogleg maneuver is required to meet range safety as well as maneuvering to change inclination, and less payload can be carried on the rocket booster. If, however, the upper stage were a lifting vehicle, a long gliding turn could be used to achieve

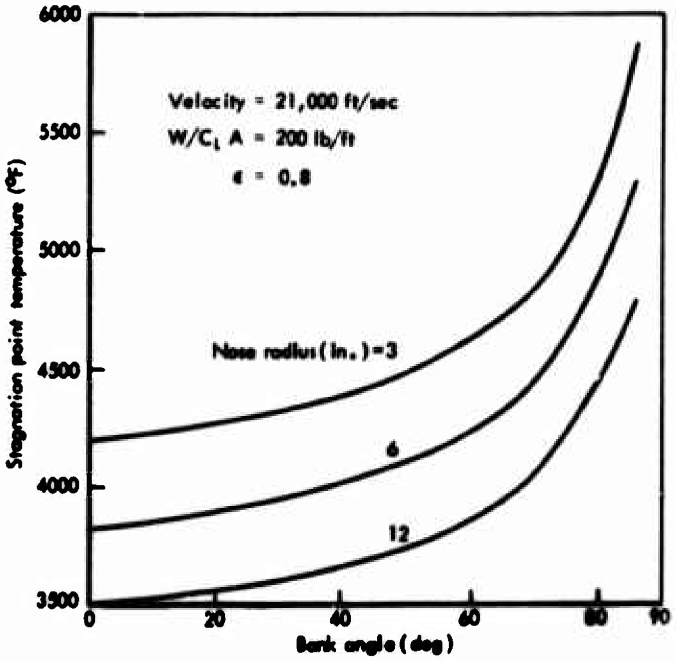

Fig. 9—Estimated stagnation point temperatures

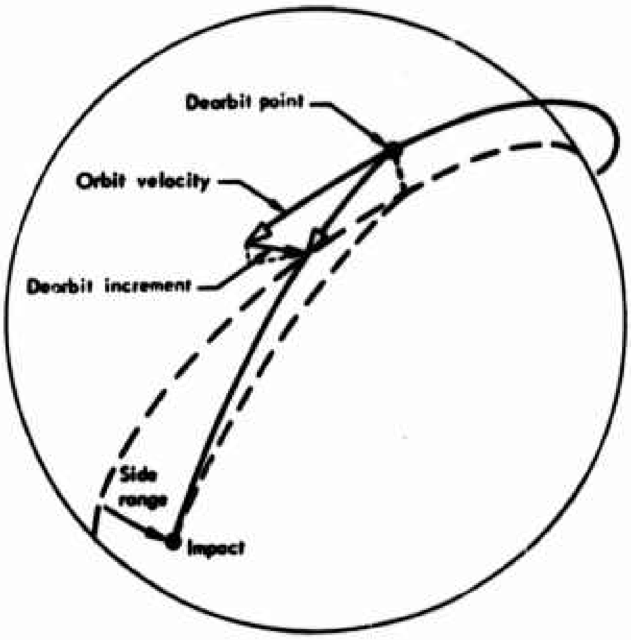

Fig. 10—Obtaining side range propulsively

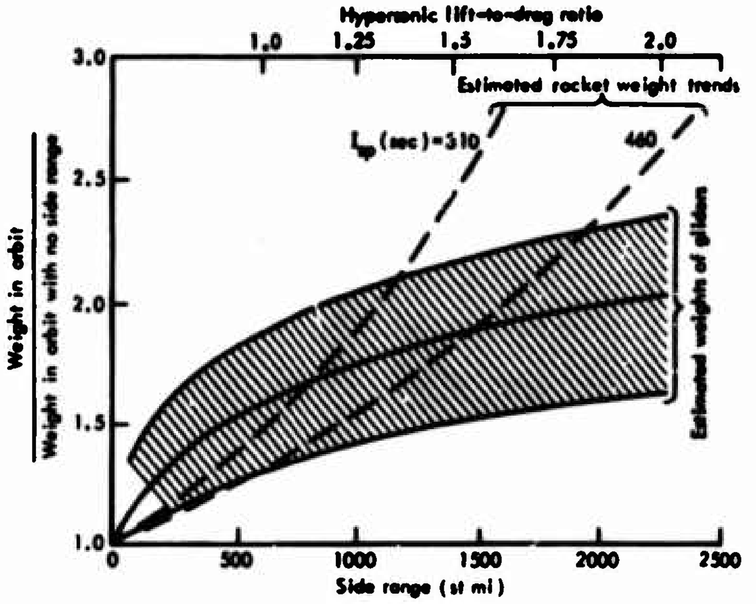

Fig. 11—Comparison of weight trends for achieving side range

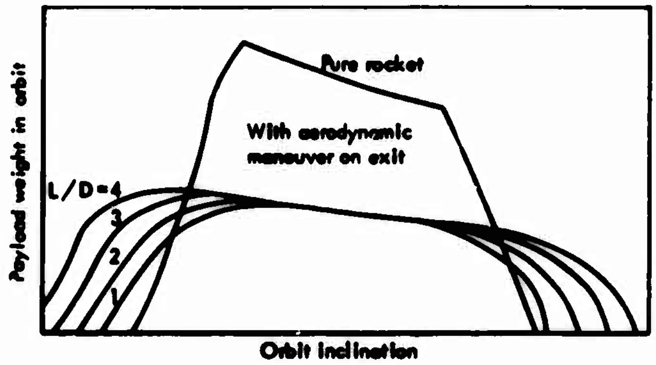

Fig. 12—Potential results of a comparison between rocket and aerodynamic maneuvers on exit

a heading change. Because it is doubtful that the structure of a lifting vehicle would ever be as light as a rocket stage, the payload delivered into orbit would probably be less than that delivered by the pure rocket within range safety limitations. It seems probable that at low and extremely high inclinations, however, the use of a lifting upper stage might provide enough maneuverability to achieve orbit with significantly useful payload weights. Because high L/D designs would not lose as much velocity during the turn, they should be more useful than low L/D designs in this role. The curves presented here are only meant to indicate what is felt to be the trend. Detailed analysis is needed to determine the actual tradeoffs. Again, the reader is cautioned that the outcome of such comparisons will be sensitive to the structural weight of the lifting vehicle.

Finally, to compare ballistic and lifting vehicle performance for synergetic plane changing, we will consider use of powered flight for the lifting spacecraft. Some sort of propulsion will be needed to restore velocity loss in achieving the heading change as well as to achieve the new orbit altitude. Thus, the specific impulse of the propulsion system is also an important parameter for this comparison. In this comparison, we assume that the structural factor of a rocket stage is 0.9 (90 percent of the stage weight is propellant), and that the specific impulse of the rocket is either 310 sec or 460 sec corresponding to the performance estimates of liquid storables and high-energy cryogenic liquid propellants respectively. We also assume the same values of specific impulse for the powered flight of the lifting spacecraft. With regard to the lifting spacecraft structure, we assume that its weight is 30 percent of the entire vehicle weight. Later we shall discuss variations in this parameter, since subsonic aircraft seem to have this same characteristic structural fraction, and one might doubt that a hypersonic vehicle could be designed so efficiently.

For the case where storable propellants are used for the lifting vehicle and the ballistic vehicle with a rocket (I_{sp} = 310 sec), the comparison of payload package weight after the maneuver is shown in

Fig. 13. Payload package weight is defined as everything left except structure and propellant. The velocity increment data presented earlier translate into payload weight in such a way that high L/D and large plane changes would be required if the lifting spacecraft is to be better in performance. A lift-to-drag ratio of 2.5 appears to be the minimum one would probably consider. Almost the same situation prevails when both methods utilize higher energy cryogenic propellants. There is, however, another possible propulsion device that might be used on a lifting spacecraft but not in conjunction with orbital maneuvers taking place at orbital altitudes. This alternative is to use air breathing propulsion while performing a synergetic plane change. Assuming a specific impulse of 800 sec for a supersonic ramjet, and comparing the results of high energy rocket propulsion in orbit (I_{sp} = 460 sec), the performance of the powered lifting spacecraft is increased considerably as shown in Fig. 14. The high lift-to-drag

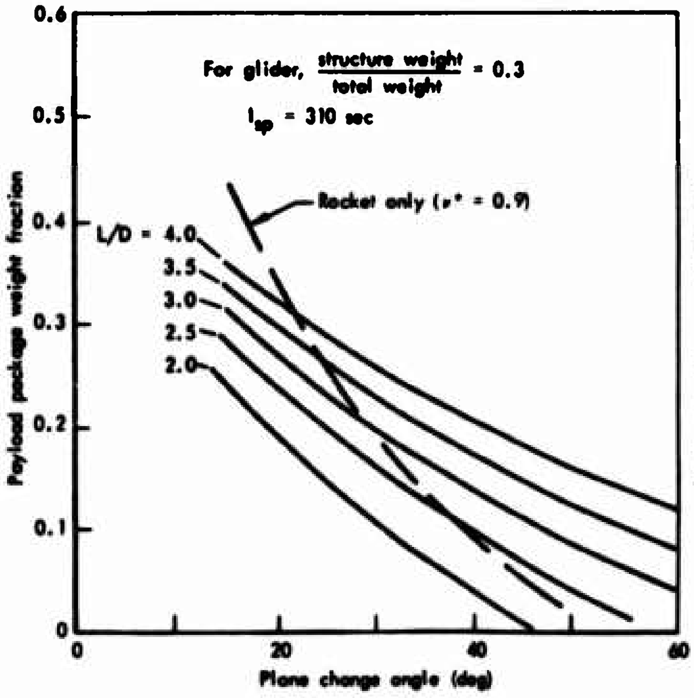

Fig. 13—Influence of L/D on payload for plane changing with conventional propulsion

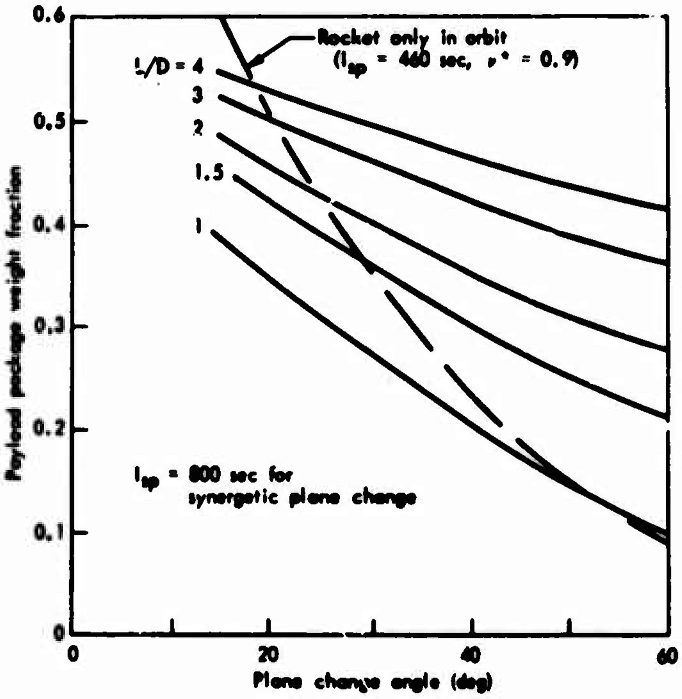

Fig. 14—Influence of L/D on payload for plane changing with advanced propulsion

ratio vehicles appear to have the best performance under the assumptions of this analysis. If, however, the scramjet engine weight is large (20 percent of the spacecraft weight, for example), then it would seem that no significant performance gains have been achieved by use of such an advanced propulsion system.

In all combinations of propulsion systems, it is fairly clear that if lifting spacecraft are chosen because of higher performance in maneuvering, the maneuvers must be substantial and the lift-to-drag ratios would have to be fairly large. If potential future missions do not require large maneuvers, then there is no clear reason for designing and developing any lifting spacecraft for orbital maneuvering. There are uncertainties in analyses of this kind, and the largest one here is felt to be the assumed structural weight fraction for the lifting spacecraft. If the value assumed here is too low, then even more maneuvering and even higher L/D would be required to favor the use of lifting spacecraft. If the structural weight increases rapidly with increasing L/D, then the highest L/D may not result in the best performance. If, on the other hand, the structural weight increases only slowly with L/D as shown by data of Refs. 10 and 11, then one might desire to use a very high L/D design to maximize performance.

In comparing maneuvering using rockets or employing lift, it appears that substantial maneuvers will probably be required before lifting spacecraft present a substantial performance advantage.

FUTURE TEST FACILITIES

In trying to organize a discussion of future test facilities, one must consider a number of the different stages in the development of hypersonic flight vehicles. In this discussion we will limit comments to three general areas: ground test facilities, range instrumentation and its deployment, and flight test instrumentation on board the vehicle.

Today's ground facilities are certainly most extensive, but they do have certain shortcomings with regard to hypersonic flight. Such facilities are generally wind tunnels for verifying aerodynamic predictions, testing the performance of new propulsion systems, or investigating the thermodynamic properties of structures often manufactured from new and untried materials.

Present facilities such as those at Arnold Engineering Development Center can be used to investigate many aerodynamic or thermodynamic problems, individually or for very short periods of time in the hypersonic flight regime. The facilities needed to test a new propulsion system under flight conditions at speeds of Mach 10 or 20 simply do not exist and, beyond involving development risk, are likely to be very expensive if designed for full-scale testing. In many instances, such high facility costs may deter the decisionmaker unless it can be shown that a new engine or configuration has an exceptional potential for large performance increases or can lead to a new and needed operational mission. Certain aspects of such development problems have been discussed by Pinkel in a recent paper on procurement of advanced propulsion systems[12].

If missions of interest are found for aerodynamic systems and these systems proceed through ground test successfully, then flight tests may be conducted. Such flight tests may require a large and well instrumented range. Because aerodynamic systems such as we are considering in this discussion travel at high speeds while still in or near the atmosphere, test ranges deployed for testing of ballistic missiles or tracking of satellites may not provide sufficient tracking and telemetry coverage for research or development purposes. It would appear that more precision tracking radars and telemetry readout stations might be needed to gather the large amounts of trajectory data and test information generated by a hypersonic aircraft or reentry vehicle. Even if tracking and telemetry coverage can be provided in a geometric sense, it is not clear that tracking will be accurate or that one can gather telemetered data during certain portions of the flight, because of the ion sheath surrounding the vehicle. Two courses of action appear possible in designing test instrumentation for such an environment. One alternative is to employ higher frequency radars than is currently the practice, so that the tracking and telemetry equipment operate in a "frequency window" that minimizes blackout effects. The other alternative is to carry recording equipment on board that can be commanded to play back the desired test and trajectory information at a more convenient time. If this latter course of action is carried to extremes, the range manager takes the risk of losing all or a large amount of test data if the vehicle should encounter an unforeseen difficulty and have a serious malfunction. Thus, it seems that judicious consideration should be devoted to the extent to which the flight test planner is willing to rely solely on onboard recording instruments. It does seem that if one is testing a new variety of vehicle and it malfunctions during test, enough information should be available after the flight to permit a diagnosis of the problem.

If powered vehicles are tested, then the test range may be very large. For example, tests of a hypersonic cruise vehicle to determine its maximum range could involve an extensive network of monitoring stations. Although it is not absolutely necessary to deploy trackers and instrumentation in a long single line for such flight tests, such a range would still have to be very long even if the vehicle changes direction in flight. This situation arises because of the large turning radii required to keep accelerations within structural limitations of the vehicle. For example, the minimum turning radius needed to keep the normal force-to-weight ratio less than twice the force of gravity is about 470 n mi for a vehicle cruising at Mach 13. Similarly, tests of satellites using aerodynamic plane changing techniques would have to be carefully planned so that the atmospheric portion of the flight profile occurred over an area with good instrumentation and radar coverage.

OPERATIONS NEAR OTHER PLANETS

The preceding discussion has considered operations near the Earth. One might wish also to consider the role of lifting entry or maneuvering in the vicinities of other planets for various reasons, such as sampling their atmospheres, landing expeditions, or performing extensive observations from a variety of orbits. Most readers are aware that other planets do have atmospheres, but very few researchers have thought much about the implications of using lifting vehicles in such environments. Von Braun considered the use of a lifting vehicle for entry into the atmosphere of Mars[13]. This study was performed in the early 1950s, and one major impact recognized even then was that the wing loading would be very different than for Earth entry (Von Braun's glider had a wing loading of about 5 lb/ft^2 for Mars entry, and the Earth entry values most commonly mentioned in the literature range from 30 to 60 lb/ft^2). The reason for this difference is that the atmosphere of Mars is much more tenuous than that of the Earth.

Another major design problem for entering other planets' atmospheres is the matter of entry velocity. If one assumes that the entry into a planet's atmosphere is initially at a velocity near that of surface parabolic speed (escape velocity), then other problems arise. The following table shows the surface escape velocity and surface skimming satellite velocity for some planets with atmospheres, e.g., Venus, Earth, Mars, Jupiter, and Saturn. This table thus indicates the speed regimes for operations such as entry plane changing, etc.

Table

APPROXIMATE PLANETARY ENTRY VELOCITIES[14]

Planet	Escape Velocity (ft/sec)	Satellite Velocity (ft/sec)
Venus	33,800	23,900
Earth	36,600	25,900
Mars	16,900	11,900
Jupiter	200,000	141,000
Saturn	121,000	95,500

Although the entry regimes of Venus and Mars are less than, and do not differ so much from, those of the Earth, thermodynamicists should find heating problems in entering the atmospheres of Jupiter and Saturn rather challenging. In the case of Jupiter one would want to take into account the surface rotation of the planet, because it also is quite large (about 40,000 ft/sec) and there would be significant differences in entries made with and against the planetary rotation.

If there is interest in exploring the larger planets by sending propelled vehicles through the upper reaches of their atmospheres, there is a unique opportunity for propulsion engineers to consider new "air breathing" or atmosphere breathing designs. The compositions of Saturn and Jupiter appear to be hydrogen, methane, and ammonia. Thus the fuel would be present in the atmosphere, and the oxidizer would be the only propellant needed on board the exploration device. Because of this unique situation, an atmosphere breathing vehicle for Saturn or Jupiter might be much more compact than present-day projected designs of hydrogen-oxygen vehicles for use in an Earth atmosphere, where the tankage is bulky because of the low density of the fuel.

One of the major problems in testing vehicles designed to fly in other planetary atmospheres will be providing a test range. The flight test may have to be accomplished on the first operational flight. The only verification of aerodynamic, thermodynamic, and propulsion performance predictions available before use would be wind tunnel experiments. Thus, it appears that there would be major risks in embarking on such a program. Another alternative, however, may be an extraterrestrial flight test range.

These comments are made to stimulate thought about test planning, and are meant to indicate only a few of the changes one might anticipate in present procedures for testing aerodynamically shaped spacecraft. There are many problems that have not been discussed, and the reader may uncover even more problem areas should he care to consider atmospheric flight in the vicinities of other planets.

CONCLUDING REMARKS

In this paper we have attempted to show some of the maneuvers that are possible with lifting spacecraft. In some there are problems that are not yet solved. Further, we have tried to indicate that atmospheric flight is not necessarily limited to our own planet, and might provide a useful method of exploring other planets in the solar system. The test implications of atmospheric flight vehicles are different from those of instrumentation of ballistic missile and satellite programs of the past. We have only alluded to such differences, and hope that this brief mention of some of the problems will stimulate thoughtful consideration of future opportunities.

With regard to flight in the vicinity of the Earth, there are a few general observations to be made even on the basis of a general discussion such as this. It appears that the major use of lifting spacecraft would be to maneuver in all phases of orbital flight. Whether the lifting spacecraft is the best choice for providing a maneuvering capability depends on the amount of plane or heading change and side range needed for a given objective. For moderate maneuvers, a ballistic spacecraft equipped with a large rocket may be more attractive on the basis of availability and cost.

If maneuvering is important, then it seems wise to pursue a concept of powered aerodynamic flight. Propulsion will be required to perform maneuvers during exit and while in orbit, and could be very useful during reentry in effectively increasing the lift-to-drag ratio or providing for power-on landings.

It appears that a lifting spacecraft might provide substantially more efficient performance than would a powered ballistic vehicle if the lift-to-drag ratio is high. However, cooling problems may be severe for high L/D spacecraft when they are banked steeply. Thus, if lifting spacecraft are to be useful in performing maneuvers, there is a need for research and test of new materials and different cooling systems. During orbital plane changes, there is the possibility of using propulsion in atmospheric turning to maintain the spacecraft altitude and velocity in a regime that avoids extreme heating conditions. Such options should be considered in performing preliminary design and system engineering. An example of such an option has been published recently, and shows great promise in reducing heating rates and heat input, with no apparent degradation in performance efficiency[15].

The range and test facility designers will have some problems if a lifting reentry vehicle is developed. Keeping the cost of testing low is always an important goal. In the testing of a new hypersonic vehicle, however, this goal will become even more important if large performance increases or the possibility of performing new missions remain uncertain.

NOTATION

A = aerodynamic reference area

C_L = lift coefficient

D = drag force

I_{sp} = propulsion system specific impulse

L = lift force

u = vehicle velocity

u_o = earth skimming orbit velocity

ϵ = emissivity

ν^* = structural efficiency for rockets

W = weight

REFERENCES

1. Fey, W., Use of a Lifting Upper Stage To Achieve Large Offsets During Ascent to Orbit, AIAA Paper No. 66-60, January 24, 1966.
2. Nyland, F. S., The Synergetic Plane Change for Orbiting Spacecraft, The RAND Corporation, RM-3231-PR, August 1962.
3. Shaver, R. D., Minimum Energy Loss Heading Changes for Hypersonic Flight from Orbit, The RAND Corporation, RM-4391-PR, December 1964.
4. Koshkov, Y., "Space Maneuver," Aviatsiya i Kosmonavtika, December 1963.
5. London, H. S., "Change of Satellite Orbit Plane by Aerodynamic Maneuvering," J. Aero. Sci., March 1962.
6. Nyland, F. S., Hypersonic Turning with Constant Bank Angle Control, The RAND Corporation, RM-4483-PR, March 1965.
7. Bryson, A. E., K. Mikami, and C. T. Battle, "Optimum Lateral Turns for a Re-entry Glider," Aerospace Engr., March 1962.
8. Slye, R. E., An Analytical Method for Studying the Lateral Motion of Atmospheric Entry Vehicles, National Aeronautics and Space Administration, TN D-325, September 1960.
9. Loh, W.H.T., "Dynamics and Thermodynamics of Re-entry," J. Aero. Sci., October 1960.
10. Baradell, D. L., and C. H. McLellan, "Lateral Range and Hypersonic Lift-Drag-Ratio Requirements for Efficient Ferry Service from a Near-Earth Manned Space Station," Proc. 2nd Manned Space Flight Meeting, AIAA-NASA, April 22-24, 1963, Dallas, Texas.
11. Love, E. S., and E. B. Pritchard, "A Look at Manned Entry at Circular to Hyperbolic Velocities," Proc. 2nd Manned Space Flight Meeting, AIAA-NASA, April 22-24, 1963, Dallas, Texas.
12. Pinkel, B., "How to Buy an Advanced Propulsion System," Astronautics and Aeronautics, October 1966.
13. Von Braun, W., The Mars Project, University of Illinois Press, Urbana, 1953.
14. Berman, Arthur I., The Physical Principles of Astronautics, John Wiley and Sons, Inc., New York, 1961.
15. Clauss, J. S., Jr., and R. D. Yeatman, Effect of Heating Restraints on Aeroglide and Aerocruise Synergetic Maneuver Performance, AIAA Paper No. 67-169, January 23, 1967.