target is approached at between 5 and 8 km/sec, with a lighting angle between 90° and 160°; there is a positive correlation between approach velocity and lighting angle. Forbes is encountered at about 4 km/sec, with a lighting angle less than 100°, depending on the date of encounter (the viewing angle during target acquisition is critical for comets only when the spacecraft is looking toward the sun). The communication distance for the second target can be greater than 4 AU, but this is a penalty which must be expected for any mission which seeks to sample targets near the outer edge of the asteroid belt.

Inclusion of a large asteroid like No. 49 at the start of the flyby sequence has important advantages. Acquisition at a large distance is assured, thereby minimizing terminal maneuvering requirements (No. 49 appears as a fifth magnitude object at a distance of about 6×10^6 km for the trajectories presented here). The crucial problem of mass determination is not difficult for a 100-km-diam object—Ref. 6 shows that for such a target a miss distance of 10^4 km will allow a mass determination to an accuracy of better than 10% with conventional *S*-band Doppler tracking. Measurements requiring only the total integrated light from the target—infrared temperature, polarimetry, photometry—can be done from a greater distance with a lower apparent motion for which to compensate.

Conceptually, it has been assumed that a modified Pioneer *F* and *G* spacecraft is the favored vehicle for performing multiple flyby missions. Propulsion requirements for some of the missions listed in Table 3 leave an ample performance margin for modified Pioneer vehicles. After the asteroid encounters are performed and the main retargeting maneuver is performed to intercept Forbes, any extra propellant beyond the terminal guidance allotment for Forbes could profitably be used to delay the arrival at Forbes, giving an encounter closer to perihelion and allowing more time for earth observation of Forbes prior to the encounter.

TRW Systems Group, in considering the applicability of modified Pioneer spacecraft to multiple asteroid flyby missions, has concluded that terminal maneuvering initiated 10^6 km from a target 10^4 km from its predicted position and moving at a 6-km/sec relative velocity can be performed with two or three separate maneuvers, the last being no later than 10 h from closest approach, for a total of 50 mps.[9] Halving the encounter distance approximately doubles the propulsion needed, as expected. For the missions presented here, the second target consumes the most propellant, as the lighting conditions are worse than for the other two targets. An allowance of 200 mps should be ample to cover the terminal maneuvering requirements for all three targets, regardless of which mission is selected from the set listed in Table 3.

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Advanced Applications of the Space Shuttle

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I. Introduction

THE projected Space Transportation System (STS) traffic models for the initial era of the Space Shuttle (1980–1990) display a large amount of traffic to and from synchronous orbit. Projected traffic models require the use of either expendable-type stages or a reusable Space Tug with the Space Shuttle to perform the Earth orbit high energy missions. Neither of these concepts can carry the largest future payloads to synchronous orbit on a single flight. In addition, no provision is made for man (should he be required) on these missions. With the large number and size of payloads projected for synchronous missions in the coming decades, it appears that a manned system which can deliver several payloads on a single mission, and thus reduce the total number of missions required, may be desirable. Such a system could be the Space Shuttle Orbiter to perform not only Earth-synchronous missions but also future manned lunar exploration.

The guiding philosophy for advanced applications of the Space Shuttle is to minimize any significant modifications and, hence, to minimize costs. The basic assumptions used in this Note are: a) The basic Shuttle Orbiter design will be utilized, i.e., mainframe, engine, tanks, b) The vehicle configuration and aerodynamic data are similar to Phase B concepts. c) The Shuttle Orbiter can be refueled in Earth orbit. d) The nominal 7-day design sortie can be extended up to 30 days by adding consumables which are charged against the payload.

The Space Shuttle is designed for a nominal 7-day mission in the near-Earth environment, terminating with a re-entry velocity of approximately 7600 m/sec; advanced applications will require missions approaching 30 days duration and re-entry speeds up to 11,000 m/sec.

For the synchronous orbit missions, requirements may be

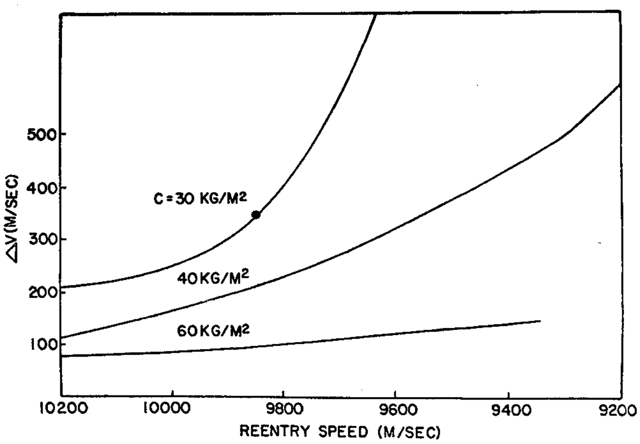

Fig. 1 Speed loss for skipping re-entry trajectory.

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Table 1 Round-trip mission ΔV requirements

Item	Mission: Geo-synchronous		Mission: Sun-synchronous		Mission: Lunar
Earth departure orbit (circular)					
alt (km)	185	185	185	185	185
inclination (deg)	28	0	28	90	28
Destination orbit (circular)					
alt (km)	35,000	35,000	1700	1700	—
inclination (deg)	0	0	104	104	—
Type of transfer	Genl'zd Hohmann	Genl'zd Hohmann	Genl'zd Hohmann	Genl'zd Hohmann	Coplanar
Total propulsive ΔV, no aerobraking (m/sec)	8600	7900	17,300	4200	7900
Total propulsive ΔV, 100% aerobraking (m/sec)	5800	5400	9000	2500	4900
Potential ΔV "savings" (m/sec)	2800	2500	8300	1700	3000

categorized with respect to the following three areas: 1) transfer from nominal low Earth orbit to synchronous orbit; 2) on-station activities (e.g., multipayload placement, servicing, etc.); and 3) transfer from synchronous orbit to low Earth orbit.

The Shuttle Orbiter mission ΔV requirements for transferring to and from synchronous orbit are not the same since the return leg of the mission will involve aerobraking in addition to purely impulsive maneuvers. Typical mission ΔV requirements are summarized on Table 1 for round-trip missions between a 185 km, 28° inclined Earth circular parking orbit and geo-synchronous and sun-synchronous orbits. The potential ΔV "savings" by using the Orbiter's aerobraking capability on the return leg of the geo-synchronous mission may be as much as 2800 m/sec; as a point of comparison, lunar mission requirements are also specified.

Having defined a set of basic requirements, we now examine the methodology required to accomplish these. Once the Orbiter has obtained a nominal earth parking orbit (EPO), the next objective is to achieve refueling sufficient for transfer to the target orbit. The fuel load is determined primarily by two factors: a) the payload delivered to and returned from the target orbit, and b) the aerodynamic deboost capability of the Oribter, this latter factor being the more important of the two.

The single pass aerobraking capability of the Orbiter is determined by operational constraints, with maximum effective skin temperature (or maximum heating rate) controlling the trajectory.

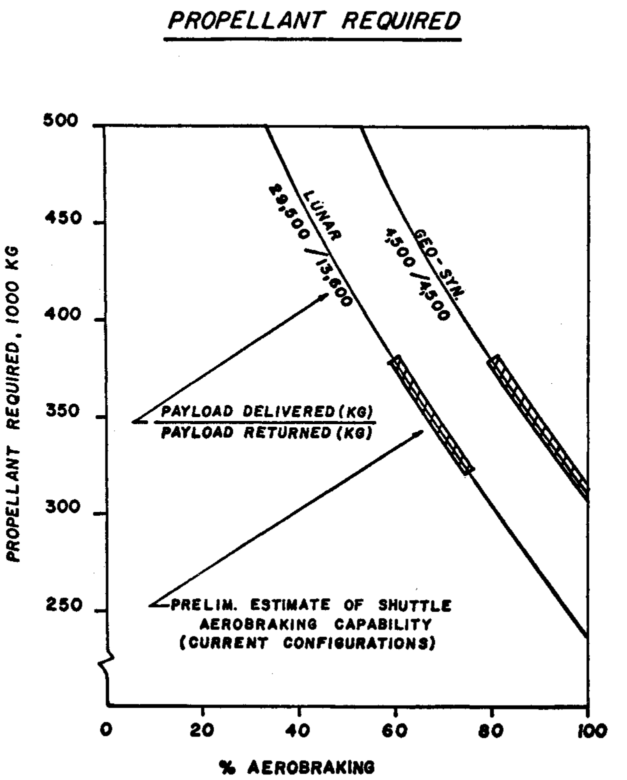

Fig. 2 Propellant requirements as a function of aerobraking capability.

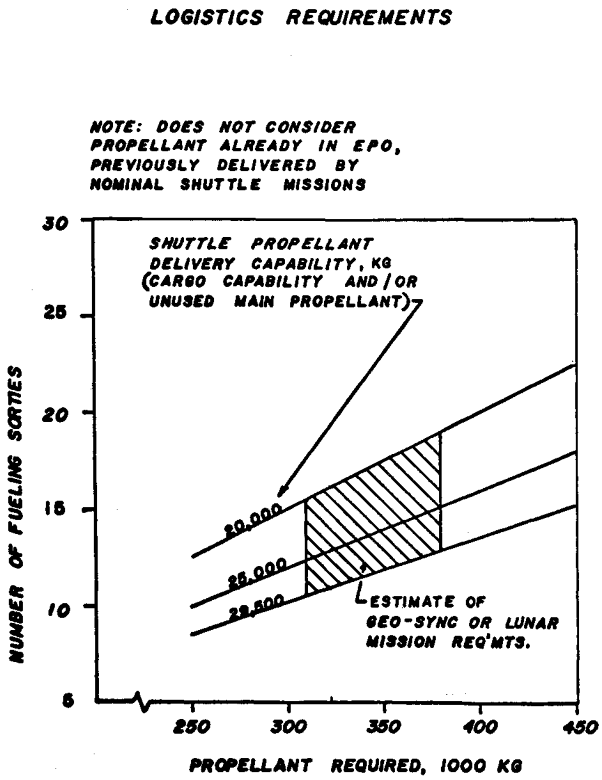

Fig. 3 Number of shuttle sorties required for propellant delivery.

However if current heating constraints are satisfied the trajectory will skip out of the atmosphere for re-entry speeds in excess of approximately 9200 m/sec. Figure 1 shows the speed loss during a single re-entry pass for various aerodynamic configurations of the Orbiter. For re-entry speeds higher than 9200 m/sec, two options are available: a) propulsive deboost prior to re-entry to reduce re-entry speed, or b) multiple skips through the atmosphere. The second procedure is highly desirable from the logistical refueling viewpoint; however, the navigational and targeting requirements for this procedure need to be investigated.

In addition to aerobraking re-entry profiles, the Shuttle lift capability could be utilized to perform plane change maneuvers, i.e., to go from a nominal EPO to a sun-synchronous orbit ($i = 103°$). However, the net plane change achievable, even if the lift vector orientation is completely free to optimize the plane change, is small compared with the total required. The so-called synergetic maneuvers, combining atmospheric thrusting with aerodynamic maneuvering has not been investigated.

For specific payload requirements, the Orbiter main propellant requirements as a function of aerobraking capability may be defined. Figure 2 shows the propellant required for the geo-synchronous and lunar missions as a function of the fraction of the final deboost that may be accomplished aerodynamically. The required propellant weight may, in turn, be related to a specific number of Shuttle flights as is shown in Fig. 3.

Assuming a 50% average payload factor (average load factor = payload delivered/maximum payload capability) to low Earth orbit, approximately 18–25 nominal Shuttle missions would be required, in order to deliver sufficient propellant to perform the Orbiter geo-synchronous missions.

To illustrate the potential capability of performing advanced missions, a typical mission model was constructed for synchronous missions. Using a total baseline list of potential future NASA payloads, a list of 131 payloads was extracted. This data was used to determine how many Shuttle flights would be required, per year, to deliver all of these payloads over a 12-year span. Initial results of the analysis indicate that two Orbiter missions per year would be required.

Based on the payload characteristics approximately 20 nominal low Earth orbit Shuttle missions (to the same orbit area) would be required annually, to deliver propellant (in addition to their payload) for each Orbiter mission. Current Shuttle traffic models project an eventual frequency of 25–30 flights, annually, to low Earth orbit. However, as a large number of these are to polar inclinations an increase in the annual projected number of flights to lower inclinations is required to achieve two Orbiter missions/year to synchronous orbit without additional refueling missions.

II. Study Results and Conclusions

As a result of this study, it is concluded that the use of the Space Shuttle for manned advanced missions from low Earth orbit is feasible and may be competitive with other proposed concepts. It is recognized that the cost effectiveness of this concept is sensitive to any system modifications required, the frequency of nominal low Earth orbit Shuttle flights, the actual Shuttle payload load factor to low Earth orbit, and the characteristics of the orbit itself.

The potential advantages of this concept are 1) significant reduction in over-all transportation costs; 2) the capability to deliver several payloads or payload clusters on a single mission to synchronous orbit; 3) manned capability to synchronous orbit (and to the moon); 4) potential reduction in synchronous orbit payload RDT & E costs; and 5) potential savings in new, upper stage RDT & E costs.

In addition the following is also noted: 1) the concept takes advantage of uniquely developed Shuttle technology (i.e., aero/thermo system, main propellant tank, etc.); 2) the main propellant tank, with modifications, could form the nucleus of an orbital propellant depot; 3) the concept is compatible with the Shuttle Booster; and 4) the cost effectiveness of the concept increases with increasing Shuttle utilization.

Prediction of Pressure Fluctuation in Sounding Rockets and Manifolded Recovery Systems

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Background

BAROMETRIC sensors are used to determine altitude in sounding rocket applications. In addition, some scientific payloads are sensitive to rapid pressure fluctuation and must be specially packaged to prevent large pressure differentials from developing. Consequently, a method for predicting such pressure fluctuations would be of considerable practical utility.

This paper presents a method for predicting the pressure-time response of a volume subjected to airflow through from one to four tubes or orifices using simplified energy equations. Nonetheless, these equations have been successfully used for prediction in a variety of analyses. The following assumptions are made in developing the equations used in this analysis.

1) The pressure, density, and temperature are distributed evenly and instantaneously throughout the manifold.

2) The pressure, density, and temperature at the port(s) is/are known for all time.

3) The specific heats, C_v and C_p, are constant.

4) The volume of the manifold is much greater than the volume of any tube leading into it.

5) Continuum flow exists through the system.

6) Entrance effects have a negligible effect upon the tube flow.

7) An approximate equation for compressible adiabatic flow with friction can be used to calculate a mean value for velocity, given the mean density.

8) Mass continuity is satisfied, i.e., no mass addition in the manifold other than from the tubes.

9) Steady flow exists over the integration interval.

10) The behavior of air can be closely approximated by treating it as a perfect gas.

Development of Equations

Consider the flow case shown in Fig. 1a. Where: T = temperature, t = time, P_m = pressure in the manifold, $\dot{m}_{i,e}$ = mass flow rate, i = inlet, e = exit, and m = manifold.

Using the first law of thermodynamics for an open system

$$\dot{m}_i\left(h_i + \frac{\bar{V}_i^{\,2}}{2g}\right) = \dot{m}_e\left(h_e + \frac{\bar{V}_e^{\,2}}{2g}\right) + \frac{d}{dt}\left(U_m + m_m\frac{\bar{V}_m^{\,2}}{2g}\right)$$

plus the equations for internal energy, $U_m = M_m C_v T_m$, and specific enthalpy, $h_m = C_p T_m$, we may arrive at Eq. (1).

$$\dot{T}_m = (C_p \Sigma_n \dot{m}_n T_n - C_p T_m \dot{m}_m)/C_v m_m \tag{1}$$

where $\dot{m}_m = \Sigma \dot{m}_n$, i.e., there are no mass changes in the manifold other than those introduced by the flow.

The mass flow rate in the tubes is determined using an approximate equation for compressible adiabatic flow with friction where ρ_a and $\bar{V}_a$ are mean values and i may be replaced by e where applicable.

ρ_a is determined by taking the average of the densities of air

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