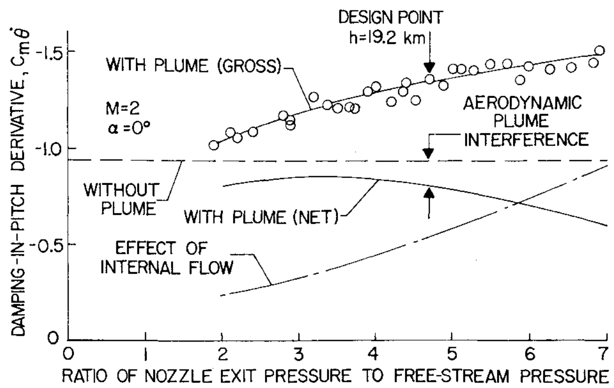

Fig. 12 Plume-interference effect on damping-in-pitch of delta-wing launch configuration.

Conclusions

In the range of experimental conditions investigated, the following applies: 1) Interference-free dimensional damping is substantially higher for the delta-wing than for the straight-wing shuttle configuration. 2) For both configurations during abort separation, the static-interference effects on damping are relatively small. 3) For the two vehicles in synchronous oscillation, the dynamic-interference effects are very large and may lead to negative damping conditions. The possibility of the orbiter "locking-in" with the oscillatory flowfield of the booster and developing rapidly diverging oscillation that could lead to collision during abort separation cannot be ruled out, and should be investigated further. More experimental data, as well as a realistic flight mechanics analysis, are needed. 4) The damping of the delta-wing launch configuration and of the booster alone are of the same order of magnitude. 5) Plume-interference effects on damping appear to be small. 6) The half-model technique appears to be uniquely suitable for oscillatory experiments involving two models in simultaneous motion and models with simulated plume effect.

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Entry Probe Descent to the Base of the Jovian Clouds

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A study was conducted to identify and describe feasible first-generation Jupiter entry probe missions that measure atmospheric phenomena below the cloud tops, and that tend to minimize engineering development. A principal groundrule for this study has been entry probe survival to the base of the cloud layer with remote sensing to provide information at greater atmospheric depths. The major tradeoffs that were considered include 1) entry probe release from a 1978 and 1980 flyby trajectory, and from a 1979 Grand Tour trajectory, 2) use of a TOPS or Pioneer F/G as an interplanetary bus, 3) direct and relay communication links, and 4) dayside and nightside entry. Many feasible missions were identified; use of remote sensing would extend the downward "reach" of the entry probe.

Introduction

THE approach taken for the investigation of a first-generation Jupiter atmospheric entry probe was to identify the key science and engineering tradeoffs. These tradeoff studies were intended to reveal those missions that combine good science with favorable engineering. Entry probe supporting systems and subsystem configurations were generated based on favorable mission combinations.

A principal groundrule for this study has been entry probe survival to the base of the cloud layer with remote sensing to provide information at greater atmospheric depths. This approach to the study of a Jupiter atmospheric entry probe mission is significantly different from the equally valid approach of entry probe survival to great depths within the atmosphere with in situ sensing. Descent to the cloud base eases the entry probe engineering design and development requirements. For example, in the nominal Jovian atmos-

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phere the cloud base occurs at a pressure of 17 atm and the ambient temperature at this level is 425°K. Deep descent is considered to be the 1000 atm level where the ambient temperature is 1425°K.

Another important mission groundrule was the consideration of 1978 and 1980 launch opportunities. For these launches, the trajectory targeting could be tailored to provide a set of planetary encounter conditions favorable to an entry probe. In addition, a 1979 launch opportunity was considered, but the encounter trajectory targeting was dictated by post-encounter requirements associated with a Jupiter-Uranus-Neptune Grand Tour Mission. Two types of spacecraft were considered, i.e., a TOPS and a Pioneer F/G. The TOPS (Thermoelectric Outer Planet Spacecraft) is a three-axis-stabilized, radioisotope-powered spacecraft that weighs 1450 lb. During Jovian encounter, the 14-ft high-gain antenna is oriented towards Earth. The Pioneer F/G is a spin-stabilized, radio isotope-powered spacecraft that weighs 550 lb. At Jupiter encounter, the 9-ft-high gain antenna is directed towards Earth. A Titan III family of boosters was considered. The basic building block of this family of boosters is the two-stage Titan III D. Two solid rocket motors of either five or seven segments are provided as a zero stage. The third stage is a Centaur, higher performance Stretched Centaur, or Agena, and the fourth stage is the Burner II or a higher performance stage designated as the Versatile Upper Stage. A range of Jovian model atmospheres were assumed, to bound the entry and descent environments, i.e., a nominal model, a high-temperature extreme, and a low-temperature extreme.

A critical area of probe design and mission selection concerns the performance of the heat shield. For shallow angle entry in the direction of the rotation of Jupiter, the entry velocity is 160,000 fps. This velocity is considerably advanced in terms of current analytical and test facility technology. Extrapolation of current heat shield technology to Jovian entry leads to thermal protection subsystem weight requirements that are two to three times greater than the entry probe system weight (without heat shield). Preliminary analysis of the thermal protection problem indicates that there exist self-limiting processes that block the transfer of energy to the probe and reduce the response of the ablator to the heat pulse.[1] If these processes are considered, then the thermal protection subsystem weight requirements are only 30–50% of the entry probe system weight.

Scientific Objectives

The scientific objectives that could be achieved by a first-generation entry probe are determination of the 1) chemical and isotopic composition of the atmosphere, 2) thermal structure of the clouds, 3) composition and structure of the clouds, 4) presence or absence of complex organic matter, and 5) nature of the coloring matter present in the clouds. Certainly objectives 3) and 5) can be satisfied by probe descent to the base of the clouds. Since the production of complex molecules requires an energy source such as solar uv light and/or lightning, and since lightning is generated within the cloud layers and uv light is absorbed within the cloud layers, objective 4) can also be satisfied by a probe that descends to the base of the cloud layers.

It has been determined that objective 1) can be substantially achieved by a probe that descends to the base of the cloud layer. Hydrogen, helium, carbon, nitrogen, oxygen, neon, sulfur, and argon or their compounds can exist over the local temperature and pressure conditions that are to be found within the cloud layers. That most components of the lighter elements can be found within the cloud layers is, in part, a consequence of the same physical phenomenon that permits the formation of clouds, i.e., the same vapor pressure-temperature physical characteristics that cause the volatility of compounds will also lead to the formation of clouds. Compounds of heavier elements like silicon, magnesium, and iron are nonvolatile at temperatures below 1500°K to 2000°K. In the nominal model atmosphere this temperature range occurs at atmospheric pressure levels that exceed 1000 atm.

Of the scientific objectives, only objective 2 cannot be totally determined by a direct measurement. A qualitative assessment of the problem has indicated that a combination of in situ sensing during descent through the clouds and remote sensing following emergence from the cloud base can provide information that would permit a preliminary assessment of the thermal structure of Jupiter's atmosphere. Achievement of this scientific objective can be divided into two separate areas of investigation. First, it is important to determine whether or not an internal heat source exists within the planet; second, it is necessary to identify the mechanism for transporting energy from the interior of the atmosphere to the clouds. The easiest way to resolve whether or not an internal heat source exists is to observe the total radiant flux emerging from Jupiter over the thermal wavelength region. This type of radiant measurement is ideally suited to a Jovian flyby or orbiter spacecraft instrumented with an infrared sensor. Determining the mechanism of heat transport would be conducted by instrumentation aboard the entry probe. It would be necessary to collect data that would permit determination of the lapse rate (the rate of change of temperature with respect to altitude) in the clouds and in the interior.

For example, a zero lapse rate below the clouds would imply that the atmosphere is isothermal and that the mechanism for the transport of thermal energy is radiation. A subadiabatic lapse rate would indicate that some combination of radiation and convection is available for transport of energy. The existence of a superadiabatic lapse rate would indicate that mass motion of the atmosphere exists, and that transport of thermal energy by the phenomenon of convection is dominant. The thermal structure of the cloud layers can be determined by in situ measurement, whereas the thermal structure of the interior must be inferred by remote sensing. By providing microwave radiometers that look towards the zenith and nadir, it is possible to determine the downward microwave brightness temperature and correct for the effects of microwave opacity of the atmosphere. From this remote brightness temperature, and in situ temperature, pressure, and composition measurements, it is possible to infer the downward lapse rate and hence the thermal structure and mechanism of energy transport.

Mission Description

The flight time to Jupiter for launch opportunities of interest from 1978 to 1980 can range from 450 to 1450 days. Entry probe separation occurs in the neighborhood of the sphere of influence at a range of 45 million km. Post-separation flight time, which can vary from 30 to 60 days, depends on the magnitude of the hyperbolic approach velocity at Jupiter. Entry is defined as the interval between $0.1g$ (increasing) and a Mach number of 0.7. During part of this time interval, the entry probe is in a state of communication blackout.

Entry times can vary between 20 and 100 sec; the former associated with a near vertical entry angle, and the latter with a shallow entry angle of $-15°$. At a Mach number of 0.7 the aeroshell is jettisoned, and the payload container descends through the clouds on a chute and samples the atmosphere and telemeters data back to Earth, or to the flyby spacecraft, depending upon the communication link selected. For most missions, the chute is jettisoned after passage through the water clouds to decrease the descent time to the base of the ammonium chloride clouds, the bottom cloud layer, and the point of termination of the mission.

Science Payload Tradeoffs

Three science payloads were formulated and designated as the nominal, small and expanded payloads. Both dayside and nightside entry was considered in the preparation of payloads.

A nominal dayside payload was defined based on the philosophy of achievement of the scientific objectives with some provision for functional redundancy. This payload is indicated in Table 1. Functional redundancy for instrumentation is defined as the ability to achieve the scientific objectives with two or more different types of measurements. The ion mass spectrometer provides information on the composition of the atmosphere for one minute prior to entry. This data is stored and transmitted after the deceleration phase and emergence from communication blackout. During deceleration, only the triad of accelerometers is sampling data, and this data is stored. Following emergence from blackout, and extraction of the payload container the other instruments are enabled. A magnetometer and turbulence indicator were added to provide some meteorology and engineering design data. The magnetometer measures the local field, and the output can be used to determine whether the atmosphere is coupled with the field. The turbulence indicator is an accelerometer, mounted on the longitudinal axis of the probe, and senses the gustiness of the atmosphere.

For the nominal nightside payload (Table 1), all the solar flux sensing, photometer instruments are removed, and a nephelmometer is added. The photometer uses the solar flux as the energy source for its detector, whereas the nephelometer instrument must provide its own light source as well as a detector. The solar photometer instruments are functionally redundant to the gas chromatograph and neutral particle mass spectrometer instruments. If the photometers are removed, then an independent measurement of atmospheric composition is lost.

An expanded payload was based on the philosophy that instruments would be added to increase the functional redundancy of the measurements that are made by the nominal payload.

The selection of the instrumentation complement for the small payload is premised on the philosophy of selection of a minimum number of instruments that can conduct measurements that are unique to a probe that descends below the cloud tops. Since no solar sensing instrument is included, there is no distinction between dayside and nightside operation. An ion mass spectrometer is added to allow for the possibility of returning of data from the upper thresholds of the atmosphere. In the event the probe does not survive entry, return of information on the composition of the upper atmosphere is of cosmological importance. This data, albeit limited, provides an important failure mode return. Note that in this small payload, the thermal structure of the atmosphere can only be determined down to the cloud base. The science payload characteristic are summarized in Table 2.

Table 1 Science payloads

INSTRUMENT	SCIENCE* OBJECTIVE ACHIEVED	SMALL	NOMINAL		EXPANDED	
			DAYSIDE	NIGHTSIDE	DAYSIDE	NIGHTSIDE
TEMPERATURE GAUGE	2,3	▨	▨	▨	▨	▨
PRESSURE GAUGE	2	▨	▨	▨	▨	▨
ION MASS SPECTROMETER	1	▨	▨	▨	▨	▨
GAS/CHROM & N. MASS SPEC.	1,3,4,5	▨	▨	▨	▨	▨
ACCELEROMETERS	2		▨	▨	▨	▨
AEROSOL PHOTOMETER	3		▨			
OPTICAL FLASH DETECTOR	4,5		▨	▨	▨	▨
H:D PHOTOMETER	1		▨		▨	
UV PHOTOMETER	1,2		▨		▨	
R.F. CLICK DETECTOR	4,5		▨	▨	▨	▨
NEPHELOMETER	3			▨		▨
IR RADIOMETER	2		▨	▨	▨	▨
MICROWAVE RADIOMETER	2		▨	▨	▨	▨
EVAPORIMETER/CONDENSIMETER	3				▨	▨
UV SPECTROMETER	1,2				▨	
MAGNETOMETER	-		▨	▨	▨	▨
TURBULENCE INDICATOR	-		▨	▨	▨	▨

*NUMBERS ARE KEYED TO PREVIOUS SECTION, TITLED SCIENTIFIC OBJECTIVES.

Table 2 Science payload characteristics

Characteristic	Small	Nominal Day-side	Nominal Night-side	Expanded Day-side	Expanded Night-side
Weight, lb	16	43	45	56	47
Power, w	15	34	36	48	46
Vol in.^{3}	450	1321	1379	1767	1449
Total bits	5200	27,700	25,900	43,000	38,600

Probe Targeting Tradeoffs

A first choice target for a Jupiter entry probe is a "typical" dark or light band. The Great Red Spot or any other discernible feature is very atypical and is, therefore, to be avoided. Latitudes near the equator and near the poles are excluded. Near the equator, the Coriolis forces that dominate the dynamics of the atmosphere vanish, and so the near equatorial zone is not typical. The higher and polar latitudes are not typical, since the insolation is reduced and the thermal structure of the atmosphere, as evidenced by the presence of "polar caps," could be expected to be significantly different. The total surface area at these high latitudes is considerably less than the area at the lower latitudes and is, therefore, not representative. Also, near the poles, the intense magnetic field may conceivably be dynamically coupled with the lower atmosphere.

Atmospheric descent between longitudes of $\pm 70°$ of the subsolar point is desirable to permit utilization of the sun as an energy source for the photometers. The allowable longitude zone is cut off 20° on the sunlit side of the terminator to allow for the reduction of the influence of cloud top irregularities on the photometer measurements.

It appears that darkside targeting is compatible with the achievement of the scientific objectives; however, dayside targeting is preferred so that the sunsensing photometers and their functionally redundant atmospheric composition measurements would be available. Also data gathered on the dayside by an entry probe can be used to corroborate Earth-based dayside observations.

Model Atmosphere Tradeoffs

Three model atmospheres were provided as a guideline for the mission study, and are termed the nominal model atmosphere, the cool/dense model atmosphere, and the warm/expanded model atmosphere. The temperature and pressure profiles and atmospheric constituents of these model atmospheres were used to construct the cloud models shown in Fig. 1. It is important to note that the base of the cloud layer occurs at a pressure of 17 atm in the nominal model atmosphere with a corresponding temperature of 425°K. This is a relatively benign environment in comparison to that encountered with a deep descent probe where a pressure of 1000 atm and a temperature of 1425°K will be experienced. In the cool/dense model atmosphere the corresponding values are 525 atm and 490°K in comparison with descent to 1000 atm and a temperature of 572°K. In the warm/expanded model atmosphere, corresponding values are 3.5 atm and a temperature of 387°K at the cloud base, whereas the temperature at the 1000 atm level is 3771°K.

The influence of the model atmosphere on entry probe design with the nominal dayside payload is shown in Table 3. It can

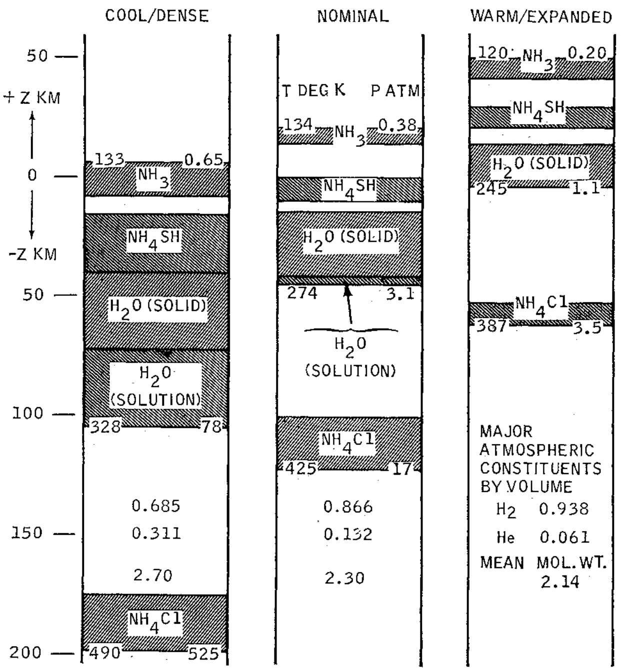


Fig. 1 Jupiter cloud models.

be seen that the G loads are greatest for entry into the cool/dense model atmosphere. This is a direct result of the small-scale height associated with the lower atmospheric temperature. As the model atmosphere varies from warm/expanded to nominal to cool/dense, the entry probe weight increases due to an increasing aeroshell structural weight, auxiliary structural weight, and pressure vessel weight. In the cool/dense model atmosphere, the relay link must operate at uhf to reduce r.f. transmission losses.

Table 3 Influence of atmospheric model on entry probe design (relay link, shallow entry angle, nominal dayside payload)

	Atmosphere		
Characteristic	Cool/ Dense	Nominal	Warm/ Dense
Maximum G	1250	525	260
Entry probe wt. at separation, lb	630	352	316
Relay link frequency	uhf	S	S
Transmitter output power, w	32	25	16
Total bits	34,000	27,000	24,000

Launch Opportunity

Launch opportunities in 1978, 1979, and 1980 were investigated and comparisons indicated that the injection energy requirements are reduced for the later opportunities. (Typical values are shown in Table 4.) This reduction is due to the closer proximity of Jupiter to the line of nodes in the later opportunities. The line of nodes is the intersection between the Earth's orbital plane and the Jovian orbital plane. As Jupiter encounter approaches the line of nodes, the component of the velocity normal to the Earth's orbital plane is reduced.

Table 4 Comparison of launch opportunities

Launch opportunity	Injection energy, Type I[a]	km^2/sec^2 Type II[b]
1978	106	96
1979	102	90
1980	97	80

[a] 140 Deg ~ Approach velocity angle and 650 day flight time
[b] 60 Deg ~ Approach velocity angle and 1400 day flight time

Both fast-Type I and slow-Type II interplanetary trajectories were considered in this study. A spacecraft launched along a Type I trajectory encounters Jupiter prior to apoapsis on the Earth-to-Jupiter transfer ellipse, whereas a spacecraft launched along a Type II trajectory encounters Jupiter after apoapsis passage along the transfer ellipse. The flight time for the Type I trajectory presented in Table 4 is about 650 days, and about 1400 days for the Type II trajectory selected.

Trajectory Targeting

For outer planet missions, the velocity vector of approach relative to the planet's is generally in a direction that is opposite to the planet's orbital velocity vector with respect to the sun. Type I trajectories typically approach the planet on the dayside of the orbital velocity vector whereas Type II trajectories typically approach from the nightside. Type II trajectories permit shallow angle targeting on the dayside, a very desirable feature. Also if a direct communication link is to be considered, then Type II trajectory targeting must be used to permit both shallow angle entry and entry in view of Earth. (At Jupiter the Earth line is never more than about 12° from the sun line.) The parameter that characterizes the lighting condition at encounter is termed the approach velocity angle, A, and is defined as the angle between the sun line vector and the hyperbolic approach velocity vector that has been extended through the planet. Table 4 was prepared based on typical values of Type I and Type II approach velocity angles.

From a scientific standpoint it is desirable to have the entry probe reach the base of the clouds at an entry longitude that is about 20° in front of the evening terminator to avoid problems associated with cloud top irregularities. Therefore, since a 1-hr probe mission is desirable and the planet rotates at a rate of 36 deg/hr, the probe should enter about 56° in front of the evening terminator for a dayside descent mission. Type II trajectory targeting is required to permit both dayside descent and shallow angle entry in the direction of the Jovian rotation. A simple relationship can be expressed to relate the angle from the terminator, ϕ, (where positive is on the dayside), the approach velocity angle, A, and the angular displacement of the entry point from the vertical entry point, B. The vertical entry point corresponds to the point at which the extended approach velocity first pierces the planet. This relationship is:

$$\phi = 270 - (A + B) \text{ deg} \quad (1)$$

For an entry angle of −15°, the angular displacement from the vertical entry point is about 141°. This large angle is caused by the strong gravitational attraction of Jupiter. Using the approach velocity angles, A, given in Table 4, it can be calculated from Eq. (1) that for the typical Type I trajectory considered, entry occurs 11° behind the evening terminator on the darkside. For the typical Type II trajectory shown in Table 4, entry occurs 69° in front of the evening terminator on the dayside.

The approach trajectory targeting factors—including 1) dayside or nightside entry, 2) steep or shallow entry angle, and 3) long or short interplanetary transfer time—are interrelated quantities, of which only two can be specified. From the viewpoint of science, dayside entry is most desirable. From the viewpoint of minimizing engineering requirements, shallow entry angles and short flight times are desirable.

Both shallow entry angle and Type I trajectories are required to satisfy all goals. However, only long flight times with shallow entry angles, or short flight times with steep entry angles will permit dayside entry. From the viewpoint of engineering development, the combination of shallow entry angle with long flight time is preferred because it avoids high-G and reduces heating in an unknown environment. The development of subsystems with long shelf life can be accomplished with no special facilities requirements.

Probe Entry Angle

The probe flight path angle at entry has a direct influence on the probe weight and also on dispersions in lead time, entry longitude, and entry angle. From Fig. 2 it can be seen that the auxiliary structure weight increases slowly whereas the aeroshell structure weight increases quite rapidly. These weights were calculated based on a constant entry probe diameter of 4 ft. Aeroshell structure weight is dependent on both entry angle and ballistic parameter. For a constant-diameter probe, and invarient nominal payload, the ballistic parameter increases as the entry angle is increased; therefore, these two parameters combine to cause a rapid increase in the weight of the aeroshell structure. Based on titanium honeycomb construction, it was determined that entry angles steeper than about $-70°$ are not feasible.

Entry probe deflection maneuver errors result in dispersions in entry angle, entry location, and entry time. For a relay communication link, these entry dispersions will also result in variations of communication range and communication angle. Considering error sources consistent with 1975 technology, an entry angle dispersion of 7° (3σ) will result for entry angles in the vicinity of the skip boundary (about $-6°$). Therefore, nominal probe targeting should not be considered for entry angles less than about $-15°$ to ensure a high probability of probe capture by the atmosphere. The entry angle dispersion is strongly dependent upon the entry angle and decreases to about 2° (3σ) for a $-30°$ entry angle.

Communication Link Selection

The communication system requirements are based on the 27,000-bit data content of a nominal dayside science payload that must gather and transmit data from entry to the bottom of the cloud layers. A link is deemed satisfactory if the signal strength levels at the worst point in the mission (typically at the base of the clouds) exceeds the receiver threshold by an amount at least equal to the linear sum of the adverse tolerances.

The r.f. propagation losses from below the Jupiter cloud layers have been assessed over a range of transmission frequencies from 10^8 to 10^{10} Hz. The results are presented in Fig. 3 for the three model atmospheres. The principal loss mechanism in these profiles at the smaller wavelengths is the absorption of gaseous ammonia, which increases with decreasing wavelengths. At the larger wavelengths the ionospheric effects, which increase with increasing wavelength, become the main component of the loss profile.

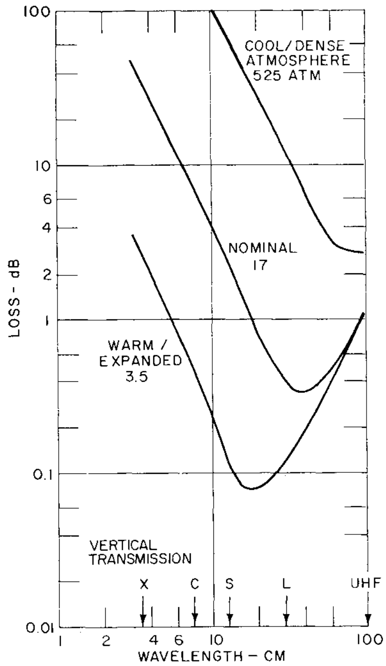


Fig. 3 r.f. propagation losses from bottom of Jupiter clouds.

The sensitivity of the propagation losses to the transmission frequency is significant and plays a major role in the selection of an optimum relay link transmission frequency. For direct link communications, where the link frequency is constrained to S-band, it can be said that no link capability will exist at the base of the clouds in the presence of the cool/dense atmosphere.

Direct Link

There is a unique interplanetary geometry that will provide both minimum range (about 630 million km) and allow for a shallow entry angle in the vicinity of the sub-Earth point. This geometry was examined for both a 1978 and 1980 launch opportunity. A Type II trajectory with a transfer time of about 1275 days provides the necessary encounter geometry. The variation of data rate with entry angle is shown in Fig. 4 for 50 w of transmitted power, a simple conical reflector probe antenna, and the favorable DSN

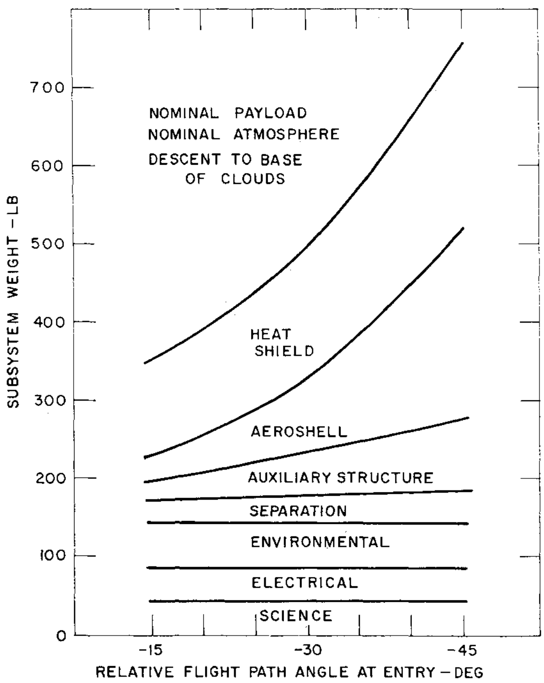


Fig. 2 Probe separation weight.

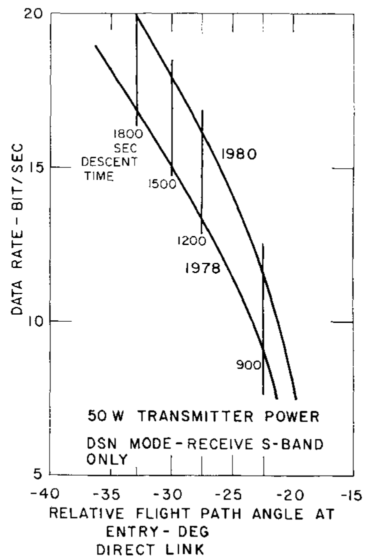


Fig. 4 Direct link performance.

MISSION	FREQUENCY	TRANSMITTER POWER	DESCENT TIME
TOPS FLYBY	S	25 W	1.0 HR.
TOPS J-U-N	S	50	0.5
PIONEER F/G FLYBY	L	50	1.0

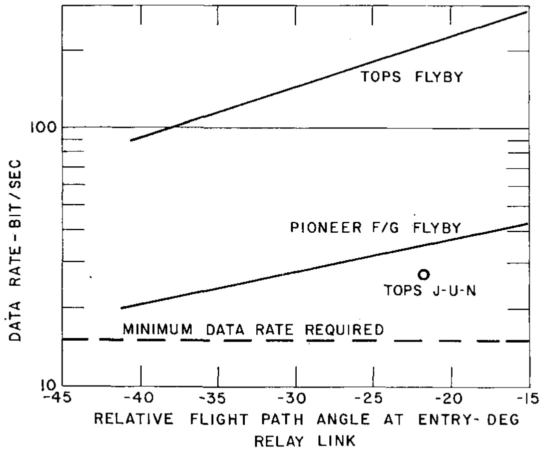


Fig. 5 Relay link performance.

receive-only S-band mode. Note that in 1980 a shallower entry angle can be used to achieve a given data rate. In 1978 an entry angle of almost −33° and a descent time of 1700 sec combine to provide a total output of 27,000 bits, and in 1980 an entry angle of −29° and a descent time of 1600 sec yield 27,000 bits. The basic reason for the decrease in link performance with a decrease in entry angle can be attributed to the fact that the probe entry longitude moves further away from the sub-Earth longitude. This effect tends to increase the antenna look angles and hence reduce the link signal strength, resulting in a lowered data rate and a lowered descent time within which to conduct the mission.

Relay Link

For a relay link mission, the data transfer requirement of 27,000 bits can more than adequately be met by a TOPS flyby mission, a TOPS J-U-N mission, or a Pioneer F/G flyby mission. Relay link mission performance for these three missions is shown in Fig. 5. These results are applicable for any opportunity and trajectory type.

Of the three missions studied, the TOPS flyby performance is superior simply due to the fact that the TOPS spacecraft relay link receiving antenna requirements can be satisfied by a high-gain narrow beamwidth gimbaled dish. The spinning Pioneer F/G spacecraft, on the other hand, requires both a despun antenna and considerably larger beamwidth requirements than the TOPS spacecraft. The lower data rate performance achievable by a TOPS J-U-N mission can generally be attributed to the increased communication range. For a flyby mission the periapsis radius is about two Jovian planetary radii, whereas for the J-U-N mission the periapsis radius is 6.8.

As the entry angle increases, the data rate capability shown in Fig. 5 decreases. It was found that for steep entry angle missions, the probe descent longitudes are generally further displaced from the longitude of spacecraft periapsis passage and, therefore, result in increased communication range. Also as the entry angle increases, the lead time (the time differential between the spacecraft periapsis passage and probe entry) dispersions increase, resulting in increased communication angles which are reflected as increased antenna beamwidth requirements.

Spacecraft Selection

Both TOPS and Pioneer F/G can serve as a bus for a Jupiter entry probe. The weight differential between the spin-stabilized Pioneer F/G and the three-axis stabilized TOPS is 900 lbs. This differential is reduced, however, since the weight penalties for probe integration is greater for Pioneer F/G than for TOPS. The entry probe-to-spacecraft adapter weight ratio is greater for the Pioneer F/G due to the necessity for providing an adapter structure that carries the Pioneer F/G launch loads around the entry probe into the Burner II stage. In the case of the TOPS, the entry probe is attached to the payload compartment, and the resulting adapter is comparatively smaller. Attitude control propellant requirements are also greater for the Pioneer F/G because the entry probe substantially increases the spin moment of inertia of the spacecraft and the angular momentum. More propellant must, therefore, be expended to precess the spacecraft. The relay antenna for the Pioneer F/G is an electronically despun array of elements and heavier than the two-axis, gimbaled, elliptical, parabolic dish that is used on TOPS. For both spacecraft the margin in available power near planetary encounter is sufficient to support a relay link mission.

It is estimated that the total weight penalty for integration of a probe to a TOPS spacecraft is about 72 lb, whereas the weight penalty for a Pioneer F/G is about 145 lb. This larger penalty reduces the weight advantage of Pioneer F/G from 900 to 827 lb.

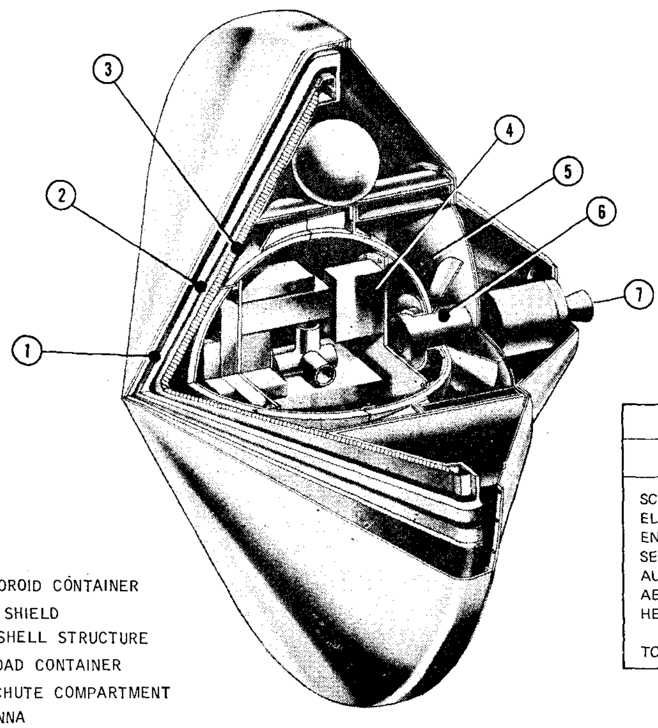
Sample Jupiter Probe Missions

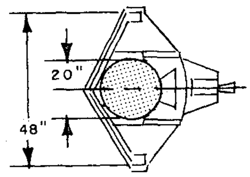
Five sample missions were selected to cover a range of interesting mission options. The characteristics and performance associated with these sample missions are summarized in Table 5.

Table 5 Sample Jupiter probe missions (nominal payload, nominal atmosphere, descent to cloud base)

Characteristic	Missions 1	2	3	4	5
Year/trajectory type	1978/II	1979/I	1978/I	1980/II	1980/II
Solar longitude at entry,[a] deg	+8	+100	+50	+25	+25
Spacecraft bus	Pioneer F/G	Tops	Pioneer F/G	Pioneer F/G	Tops
Communication link	Direct	Relay	Relay	Relay	Relay
Flight time, days	1265	528	870	1350	1350
Atmospheric descent time,[b] sec	1600	1800	1800	3600	3600
Entry angle, deg	−33	−22	−33	−15	−15
Booster configuration	T5/A/B	T5/C/V	T7/C/B	T5/A	T5/A/B
Installed probe weight, lb	770	572	803	596	508
Total bits transmitted	27,000	49,000	135,000	155,000	1,000,000

[a] Measured from the Jovian sub-solar point with positive being in the direction of rotation.
[b] Separated probe weight plus weight of all spacecraft modifications to accommodate probe.





PROBE WEIGHT AT SEPARATION	
SUBSYSTEM	WEIGHT – LB.
SCIENCE	42
ELECTRICAL	35
ENVIRONMENTAL	71
SEPARATION	25
AUX STRUCTURE	25
AEROSHELL STRUCTURE	34
HEAT SHIELD	120
TOTAL	352

Fig. 6 Jupiter entry probe configuration.

Mission 1 is a direct communication link mission, based on the use of a Pioneer F/G spacecraft during a 1978 launch opportunity. It was determined that this particular combination would result in the shallowest entry angle and smallest launch vehicle requirement.

Mission 2 is TOPS/entry probe mission that is targeted from a Jupiter-Uranus-Neptune Grand Tour trajectory. A relay communication link must be used for this nightside entry mission since the probe enters 10° behind the evening terminator.

Mission 3 was selected because it will allow for an early return of data. The entry probe will encounter Jupiter in February/March 1982. Entry angle and descent time have been tailored so that a dayside mission can be accomplished with a Type I trajectory without resulting in a steep entry angle. Both TOPS and Pioneer F/G can be considered as a spacecraft bus for this mission. With TOPS, the bits transmitted total 225,000, which is favorable; however, a larger launch vehicle, the T5/C/V, must be used.

Mission 4 was selected because it exemplifies a good Pioneer F/G mission. It combines shallow angle entry, long descent time, large data output, and small launch vehicle requirements.

Mission 5 is a good TOPS spacecraft mission. The transmitted bit potential of the mission is very large, and the mission can be accomplished with the use of a medium-size launch vehicle.

Sample Jupiter Entry Probe Configuration.

A typical entry probe configuration is shown in Fig. 6. The nominal dayside science payload is packaged within a 20-in. diameter pressure vessel that is designed to resist the pressure associated with the base of the Jupiter clouds (17 atm in the nominal model atmosphere). The weight summary is based on a probe designed to enter the Jovian atmosphere at −15°. An internal pressure, slightly in excess of 1 atm is provided by a gas such as sulfur hexafluoride. This gas is added both to inhibit voltage breakdown and to provide a convective heat-transfer coupling between the several subsystems. External to the pressure vessel is a layer of Min-K insulation that retards the flow of heat from the atmosphere into the payload. This external insulation together with the internal phase change salts that are packaged with the payload limits the temperature excursion during descent to a range between +60 to +160°F. This payload, pressure vessel, and insulation subsystem is packaged within a 60° (half-angle) aeroshell. An aeroshell diameter of 4 ft was selected since this dimension resulted in the location of the entry probe center of gravity at the maximum diameter. Static stability requirements are satisfied since the center of pressure of a 60° cone is aft of the maximum diameter of the aeroshell.

A titanium honeycomb aeroshell is provided to resist the aerodynamic pressure loads, and a high-density graphite ablator/low-density carbonaceous insulator composite heat shield provides thermal protection. A parachute is packaged within the entry probe afterbody. The entry probe forebody is enveloped in a double-walled aluminum container to protect the heat shield against the meteoroid hazard. A hydrazine-fueled attitude control subsystem is used to decrease spin rate and null the angle of attack prior to entry. To the meteoroid container is attached an end-burner grain, solid-rocket motor that is used to deflect the entry probe from a flyby of Jupiter onto an impact trajectory. Also attached is an RTG (radio-isotope generator) which supplies electrical energy for check-out and energy for thermal control during the post-separation cruise.

Table 6 Jupiter entry probe flight article weights

Element	Spacecraft, LB Tops		Pioneer F/G	
Entry probe at separation		352		352
Spacecraft support		72		145
Adapters	32		63	
Relay communications	26		38	
Propulsion	14		44	
Installed probe		424		497
Contingency (20%)		84		99
Spacecraft		1450		547
Flight article		1958		1143

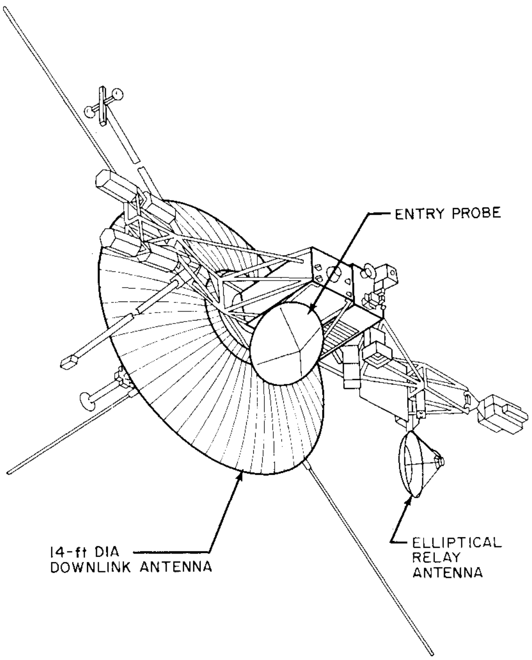


Fig. 7 TOPS/entry probe configuration.

Entry Probe/Spacecraft Configurations

A TOPS/entry probe configuration is presented in Fig. 7. A 48-in. diameter probe is shown mounted to the equipment compartment. The dimensions of the two-axis gimbaled elliptical relay link antenna are 31 × 41 in.; the peak antenna gain is 25 db.

A Pioneer F/G entry probe configuration is shown in Fig. 8. The entry probe in this configuration is mounted along the Pioneer F/G longitudinal axis. An electronically despun, L-band circumferential antenna is utilized to provide the high-gain performance required for the relay link antenna. Either a photometer or an output from the spacecraft encounter sensors must be provided to switch the proper antenna elements to enable high-gain operation in the direction of the planet. This antenna is mounted to that half of the flight vehicle containing the Burner II adapter that remains with the spacecraft after separation. This circumferential antenna array has a diameter of 50 in., a length of 14 in., and a peak again of 17 db.

A launch vehicle weight summary for each spacecraft configuration is presented in Table 6 for the shallow entry angle probe configuration shown in Fig. 6.

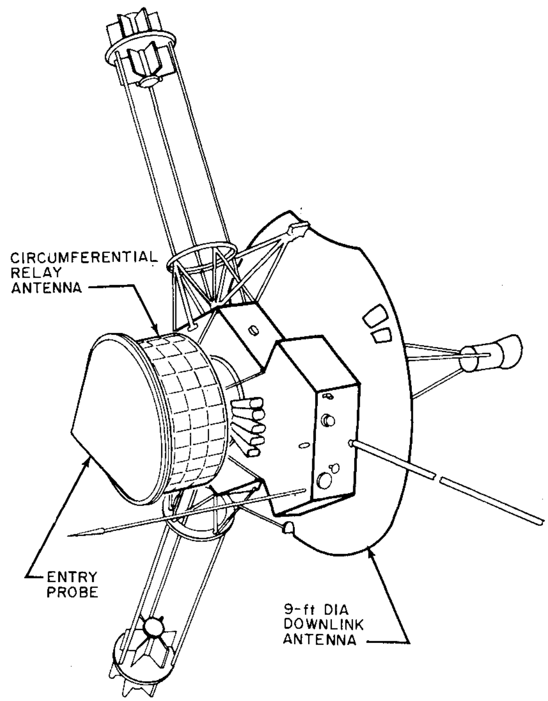


Fig. 8 Pioneer F/G entry probe configuration.

Conclusions

Feasible entry probe missions have been found for 1978 and 1980 flyby missions, and for a 1979 Jupiter-Uranus-Neptune Grand Tour opportunity. Both TOPS and Pioneer F/G can be used as an interplanetary bus for an entry probe. Use of a relay communication link is feasible for all model atmospheres considered whereas a direct link is feasible for only the nominal and warm/expanded model atmospheres. Dayside missions offer more advantageous science measurements; however, a nightside mission will result in achievement of the science objectives.

Qualitative evaluation of the ability of a probe that descends and survives to the base of the cloud layers to achieve the scientific objectives has indicated that the concept is feasible.

Reference

[1] Tauber, M. E. and Wakefield, R. M., "Heating Environment and Protection During Jupiter Entry," *Journal of Spacecraft and Rockets*, Vol. 8, No. 6, June 1971, pp. 630–636.