Tutorial on Ablative TPS Mission Analysis

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Outline

- Overview of Mission Analysis Design Drivers
  - Outer Planet Probes (Ballistic Entry)
    - Mission Overview
    - Design Drivers
      - Entry Heating/Heatshield Design
      - Science Payload, Data Collection
      - Communications and Descent Time
      - Entry Geometry
      - Probe Shape and Packaging
      - High Deceleration

Mission Analysis Information Sources

- Numerous reports and studies late 60s - early 90s
  - OP Probe Technology Workshop (1974)
  - 10 Bar Atmospheric Probe for OP Exploration (1974, ARC)
  - Saturn/Uranus Atmosphere Probe (1973, McDonnell Douglas)
  - Neptune Probe Deployment and Design Issues (1991, SAIC)
  - MEASURE-Jupiter (1994
  - Neptune Aerocapture (1996, ARC)
  - Saturn/Titan Probe (1982, Hughes)
  - Jupiter Atmosphere Entry Mission Study (1971, Martin Marietta)
  - Jupiter Entry Probe Mission Analyses (1970, GE)
  - Galileo Probe Mission
  - ….

OP Probe Technology Workshop (1974)

- Workshop Objectives
  - Review and summarize the SOA concerning mission definitions, probe requirements, system, subsystems, and mission-specific hardware
  - Explore mission and equipment trade-offs associated with a Saturn/Uranus baseline configuration and the influence of Titan and Jupiter options on both mission performance and cost
  - Identify critically required future R&D activities

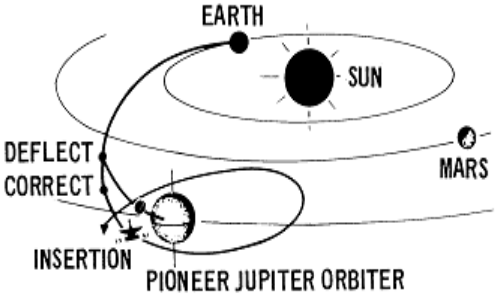
–10 Sessions

•Keynote	- Science Rationale
•Mission and Spacecraft design	- Probe design
•Aerodynamics and heating	- Heat Protection
•Communications	- Science Instruments
•Special Subsystem Design Problems	- Cost Estimation

Mission Analysis Discussion

- Provide an overview of key design drivers, mission study results, and overview of Outer Planet Probe missions.
  - Won't be able to cover all aspects in detail but intended to give audience an idea of the many factors/parameters that need to be considered when designing a probe mission
- Results presented are for illustrative purposes, i.e. don't quote specific values!

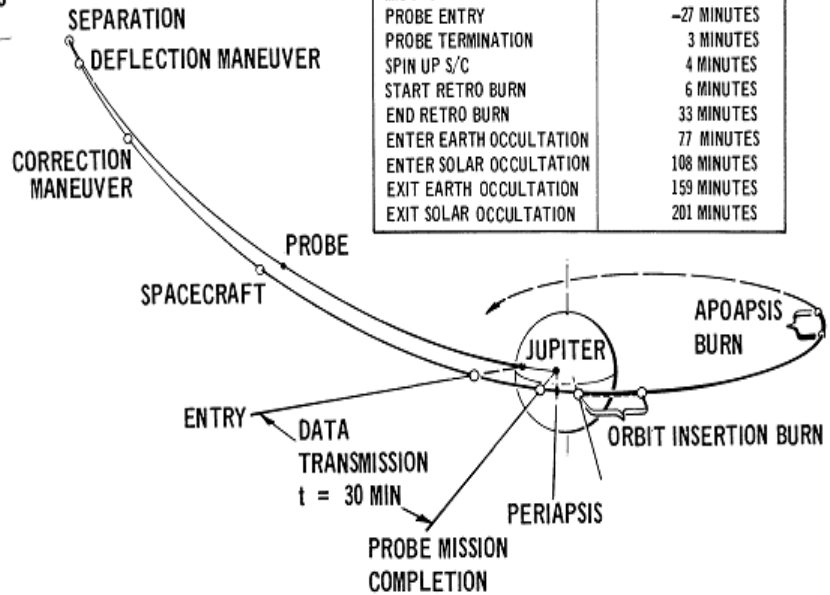
Reference Probe Mission



LAUNCH DATE:	21 DEC 81
ARRIVAL DATE:	24 NOV 84
SEPARATION MANEUVER:	500 R_J
SPACECRAFT DEFLECTION ΔV	56.4 m/sec
TIME TO PROBE ENTRY	57 DAYS
SPACECRAFT CORRECTION MANEUVER	260 R_J
CORRECTION ΔV	5 m/sec
TIME TO PROBE ENTRY	23 DAYS
PROBE ENTRY:	
ALTITUDE	450 km
PATH ANGLE	−7.5 DEG
LATITUDE	3.15 deg (N)
RELATIVE VELOCITY	47.2 km/sec
ANGLE OF ATTACK	3.55 deg (MAX)
ANGLE BEFORE TERMINATOR	28 deg

MISSION TIME LINE

EVENT	TIME FROM PERIAPSIS
SEPARATION	−57 DAYS
DEFLECTION AND PHASING	–
MIDCOURSE ΔV	−23 DAYS
PROBE ENTRY	−27 MINUTES
PROBE TERMINATION	3 MINUTES
SPIN UP S/C	4 MINUTES
START RETRO BURN	6 MINUTES
END RETRO BURN	33 MINUTES
ENTER EARTH OCCULTATION	77 MINUTES
ENTER SOLAR OCCULTATION	108 MINUTES
EXIT EARTH OCCULTATION	159 MINUTES
EXIT SOLAR OCCULTATION	201 MINUTES

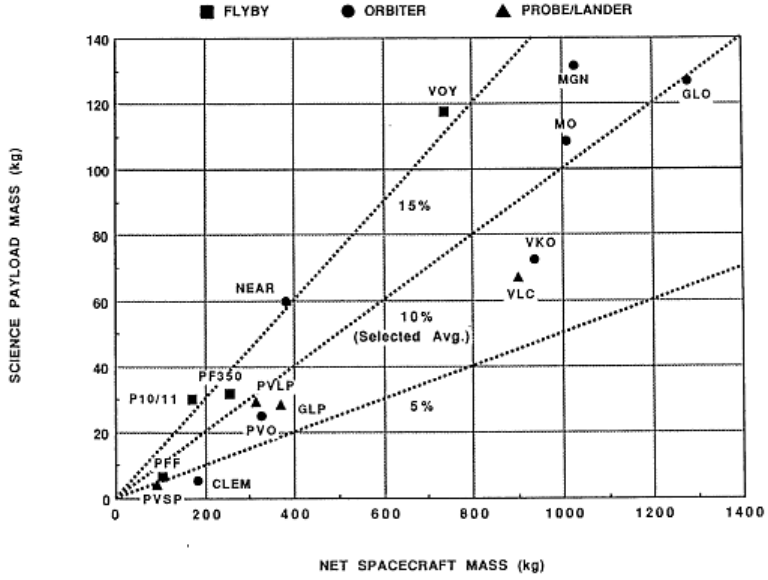


Outer Planet Probe Mission Comparison

Entry Conditions

	Jupiter	Saturn	Titan	Uranus	Neptune
Entry Velocity (km/sec)	59 to 61	36 to 38	5 to 12	22 to 25	25 to 28
Entry Angle (deg)	-15 to -30	-20 to -30	-60	-35 to -60	-20 to -30
3σ Entry Angle Dispersion (deg)	1.4	9 to 1	15	15 to 7	—
Max. Entry Inertial Loads (G)	1500	585	36	850	300
Max. Peak Dynamic Pressure (MN/m^2)	1.00	0.73	0.17	0.86	0.5
Max. Peak Heating Rate (MW/m^2)	352	120	11	170	68 est.
Max. Integrated Heating ($MW\text{-}sec/m^2$)	965	613	216	390	375

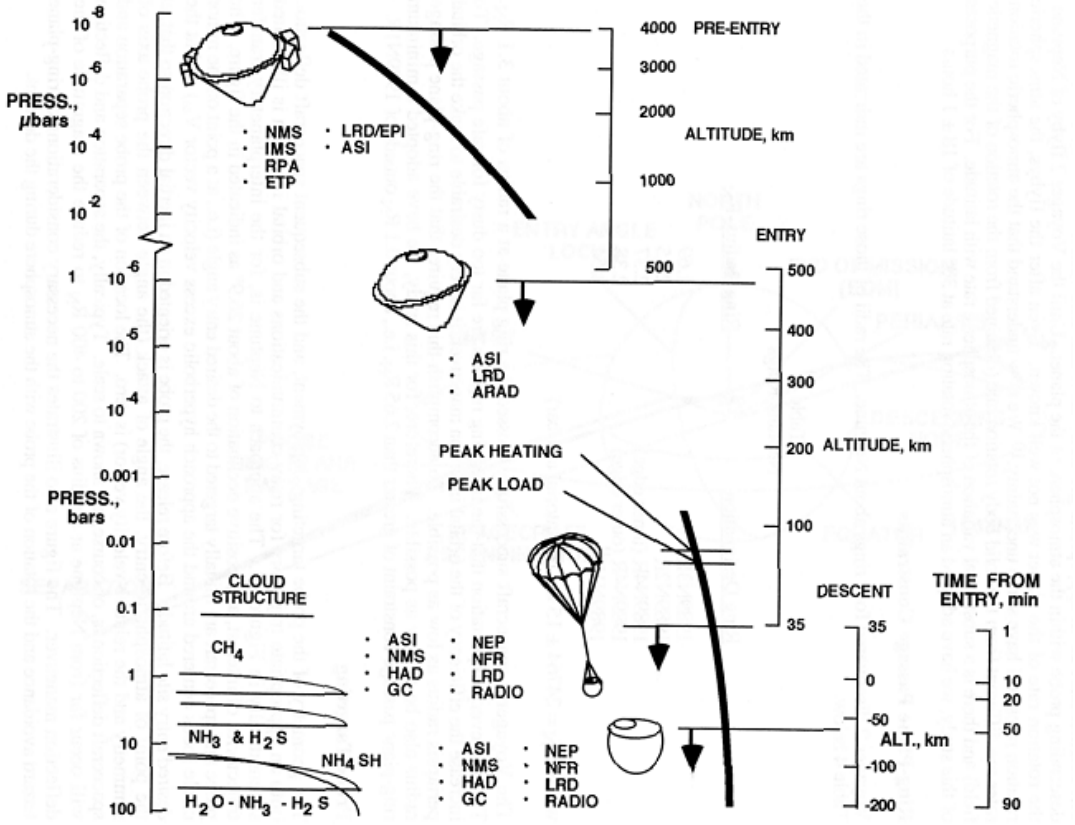
Science Payload Comparison



Science Portion of Net Spacecraft Mass - Past Missions +

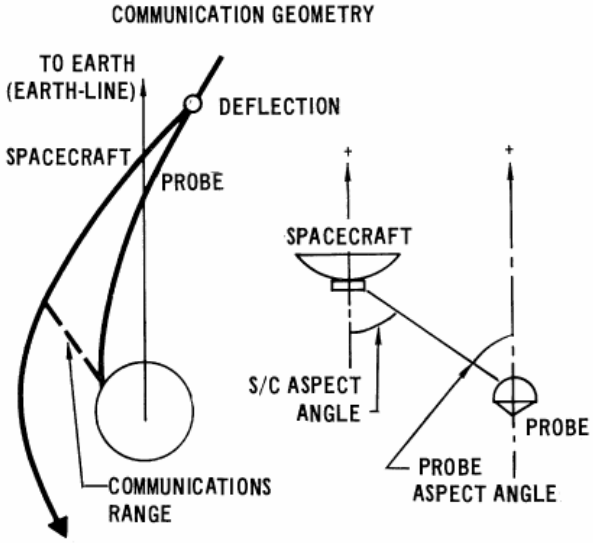
- In general, Probe missions have constrained science payloads.
- Problem gets worse when sending probes to outer planets.

‘Typical’ Probe Science Mission



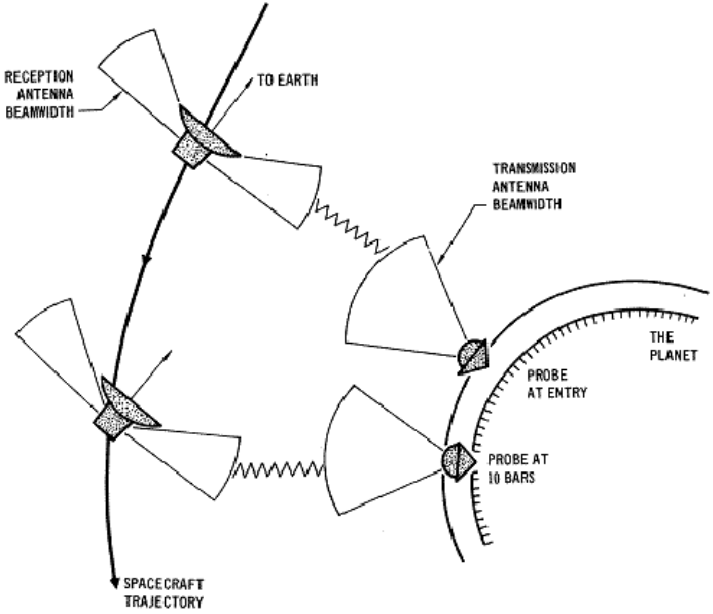
Communication and Link Geometry

- Nominally, target probe so that spacecraft is directly overhead halfway through descent phase
- Constraints:
  - Spacecraft and Probe antenna/gain geometries
  - Location of probe entry and descent
  - Duration of descent phase
- Mission design depends on whether spacecraft is flyby or orbiter.
  - Occultation
  - Propulsive insertion maneuver

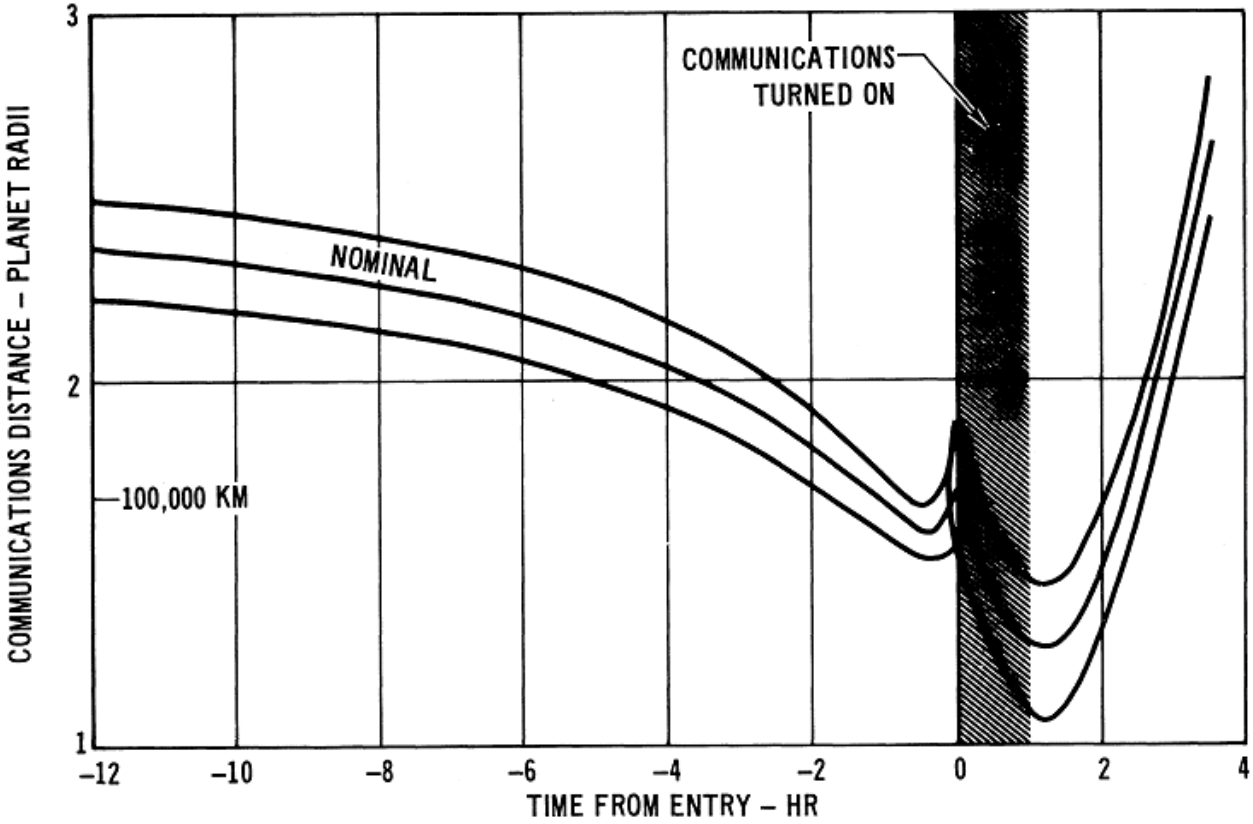


Communication and Link Geometry-2

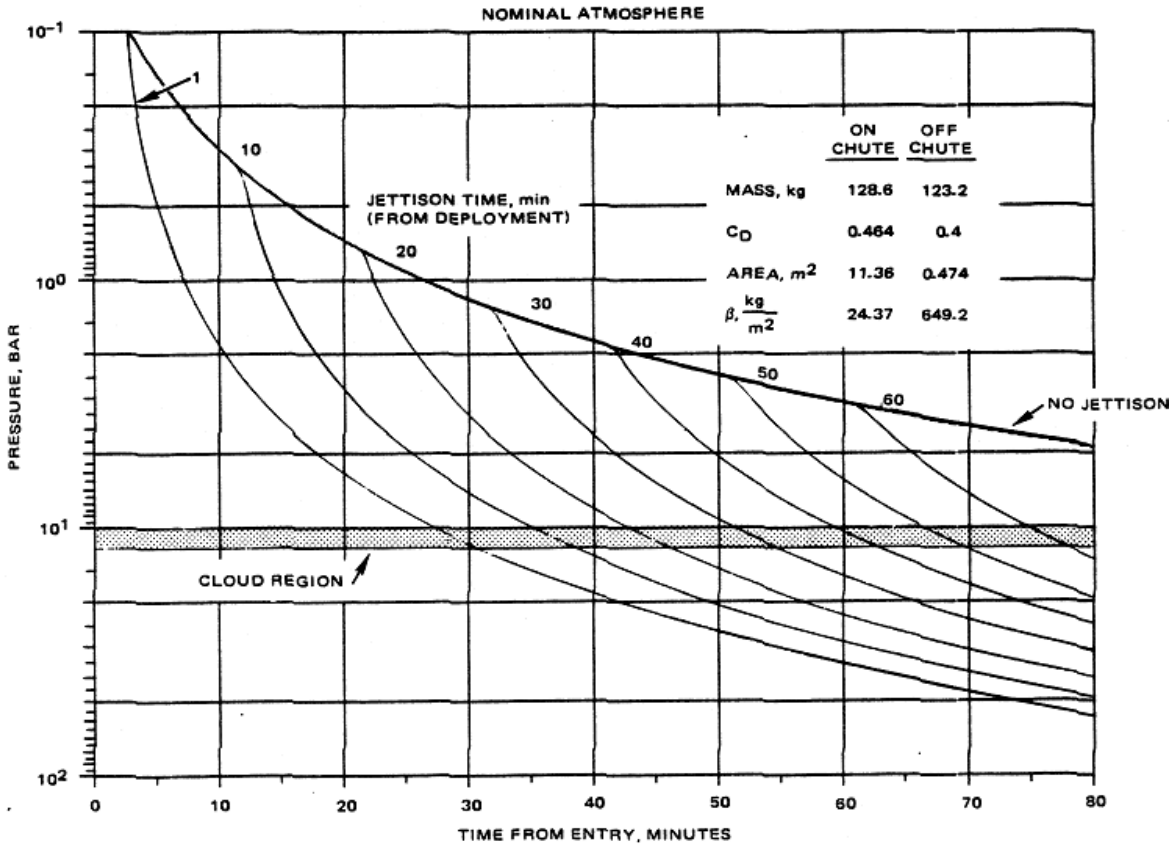
- Probe entry takes advantage of planet rotation, especially for Jupiter and Saturn
  - Increase duration of communication beam coverage
- Multi-probe missions are challenged by desire to enter at various latitudes
  - Desire to keep probe entry locations co-planar with spacecraft insertion orbit
- Communications data rates and transmitter and receiver design will be a major factor in scalability of 'mini' probes.



Spacecraft/Probe Separation Distance
Saturn 1979 mission

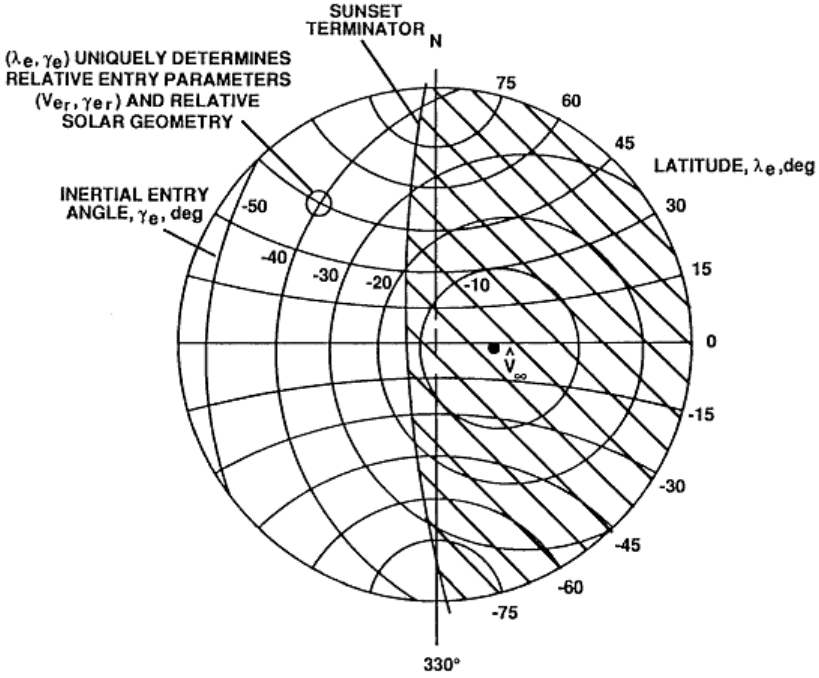


Descent Time Design
Effects of Parachute Jettison (Saturn Mission)

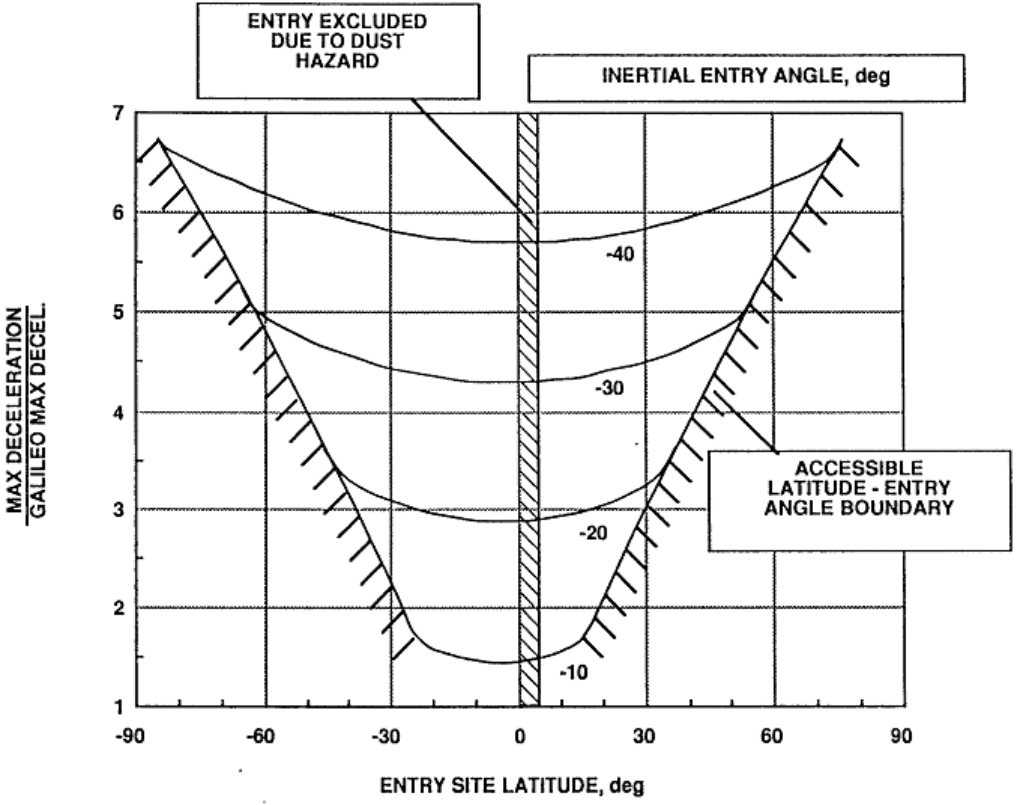


Probe Entry Geometry Constraints

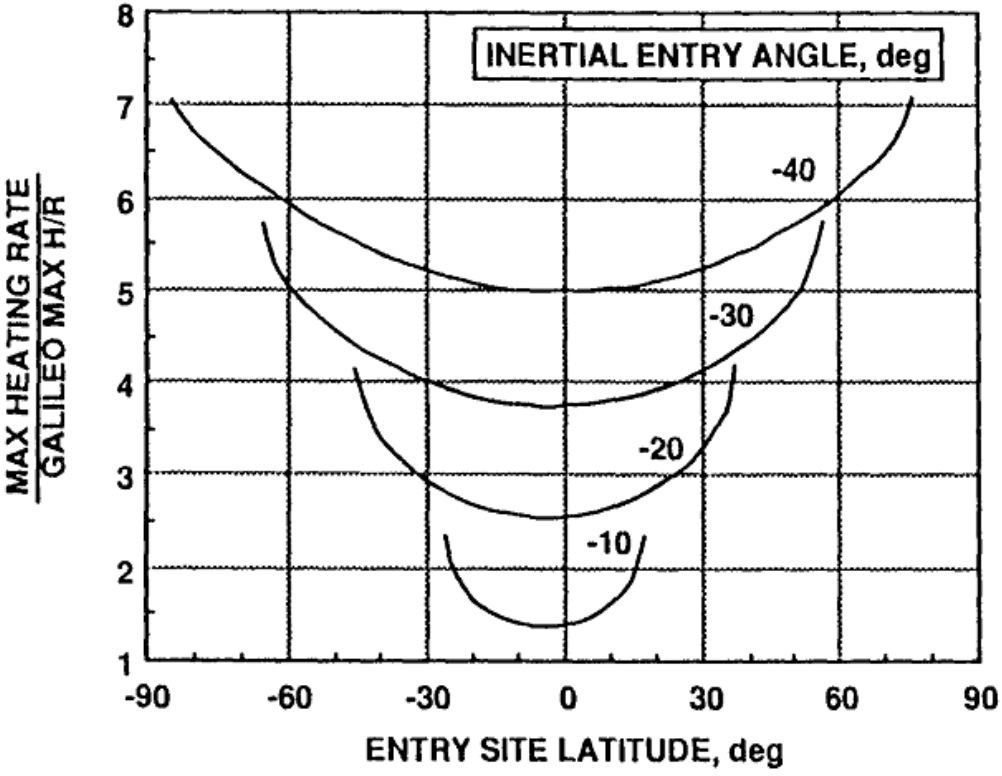
- Arrival geometry of probe driven by interplanetary trajectory
  - Earth/Sun geometry
  - Orientation of approach-velocity vector
- Latitude availability driven by entry angle limits, solar terminator, communications link geometry



Probe Entry Geometry Constraints-2



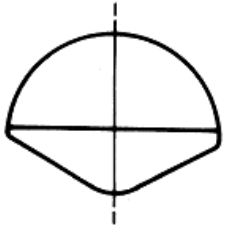
Probe Entry Geometry Constraints-3

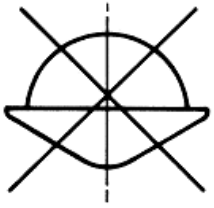


Probe Shape Selection Options

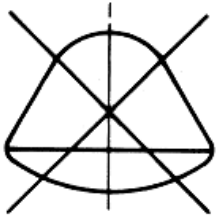
MISSION REQUIREMENTS
- AERODYNAMIC STABILITY
- HIGH DRAG
- EFFICIENT PACKAGING

• SELECTED BASELINE



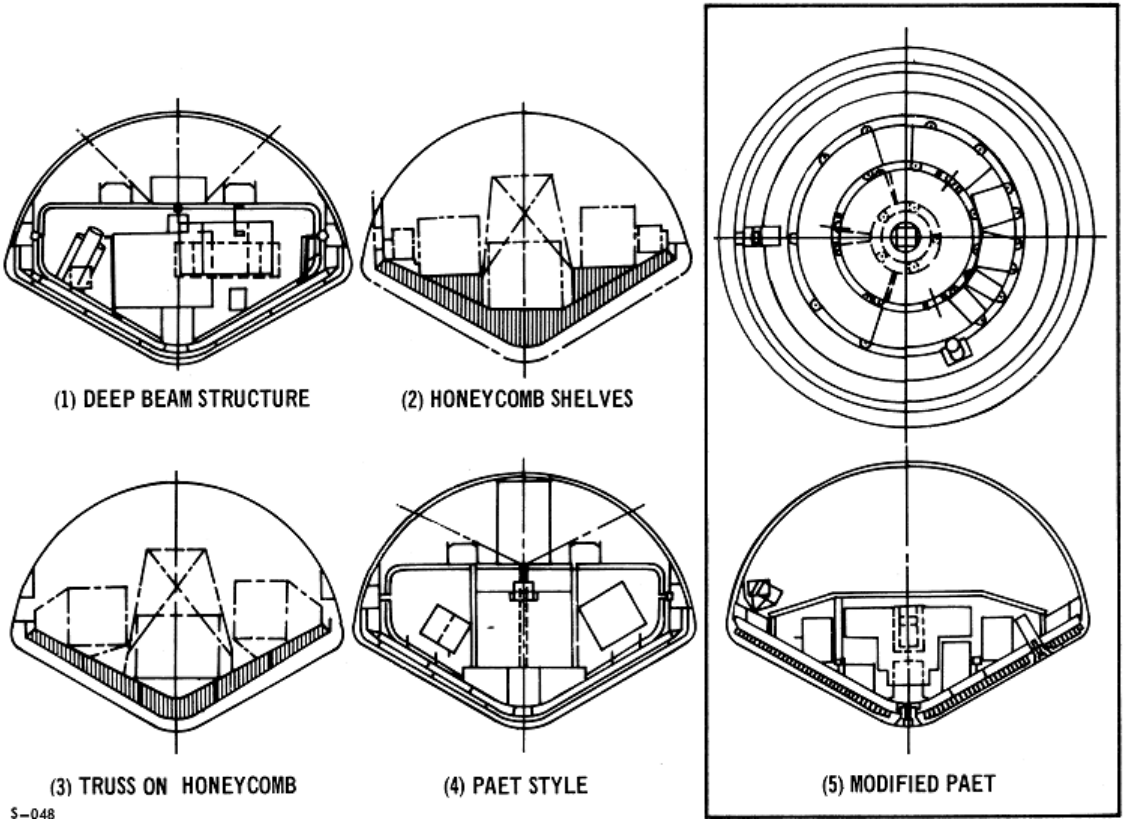


• APOLLO



PRO	• HIGH DRAG • CONSISTENT WITH PAET • ARC MODEL TESTS	• HIGH DRAG • REDUCED VOLUME • ATTACHMENT (INTERFACE) SIMPLICITY • SUBSONIC STABILITY • INSTRUMENT DEPLOYMENT	• HIGH DRAG • EFFICIENT PACKAGING
CON	• EXCESS VOLUME	• DYNAMICALLY UNSTABLE (TRANSONIC)	• UNCERTAINTY IN FLIGHT OF LIFTING BODY IN UNKNOWN ATMOSPHERE

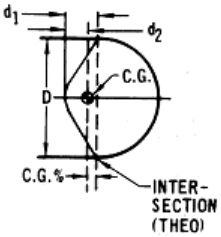
Probe Packaging Options



Probe Packaging Options-2

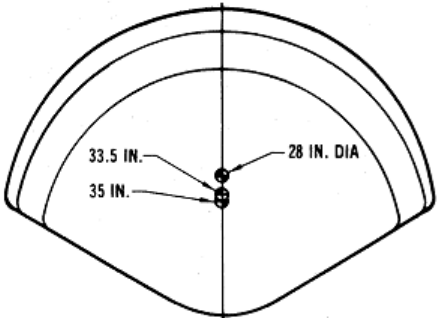
AEROSHELL DIAMETER STUDY

$$C.G. = \frac{d_1 - d_2}{D} \times 100$$



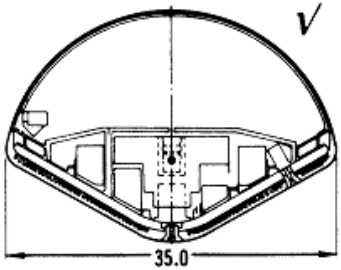
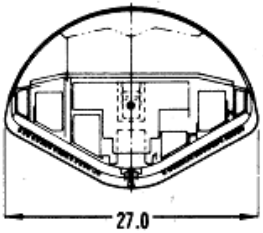
	MOST ALLOWABLE AFT C.G.	C.G. OF BASELINE ARRANGE-MENT	C.G. LOCATION %	REMARKS
28 IN. DIAMETER (EQUIPMENT SIZE LIMIT)	7.02	9.72	−9.6	• MINIMUM PRACTICAL SIZE • INSUFFICIENT MARGIN FOR CATEGORY 2 SCIENCE
33 1/2 IN. DIAMETER	8.40	9.78	−4.1	• PREVIOUS BASELINE • VOLUME MARGIN FOR CATEGORY 2 SCIENCE
35 IN. DIAMETER (ENVELOPE LIMIT)	8.78	9.77	−2.8	• MOST ADAPTABLE TO INTERNAL ARRANGEMENTS • VOLUME MARGIN FOR CATEGORY 2 SCIENCE
35 IN. DIAMETER	8.78	8.59	0.5	• CURRENT CONFIGURATION

S-47

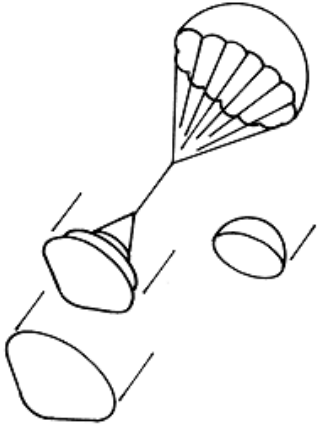


Probe Packaging Options-3

PROBE DIAMETER COMPARISON

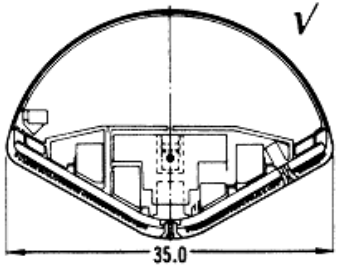
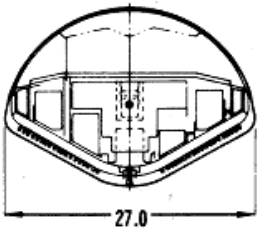
• NOTE: IDENTICAL EQUIPMENT SIZE, PACKAGING AND ARRANGEMENT COMPARISON		
WEIGHT	250 LB	205 LB
M/C_DA	0.776 SLUGS/FT^2	1.063 SLUGS/FT^2
PIONEER ADAPTER		4 INCHES SHORTER
PIONEER C.G.		BETTER
STAGING INTERFACE		SIMPLER
STRUCTURE		MORE UNIFORM LOADING
DESCENT STABILIZATION	NONE REQUIRED	(REQUIRES STABILIZATION)
HEAT SHIELD DEVELOPMENT	SAME	SAME
TEMPERATURE CONTROL		LESS SURFACE AREA – SHORTER CONDUCTION PATHS
HANDLING		SMALLER – LIGHTER
TESTING	MORE ACCESSIBLE	
REPAIR/CHECKOUT	MORE ACCESSIBLE	
FUTURE GROWTH	BETTER	SMALL
$I_{ROLL}/I_P, I_Y$	1.55	1.42

Heatshield Separation Trades

FRAGMENTED HEATSHIELD	PARACHUTE REMOVAL	RETAINED HEATSHIELD NON-JETTISON ✓
		
• RELEASE FORWARD HEATSHIELD WITH SHIELDED MILD DETONATING CORD • JETTISON FORWARD HEATSHIELD BY SEGMENTING WITH SHIELDED MILD DETONATING CORD • STABILIZATION REQUIRED • ΔWEIGHT = +37.83 LBS	• RELEASE FORWARD AND AFT HEATSHIELD WITH SHIELDED MILD DETONATING CORD • REMOVE INNER BODY WITH LARGE CHUTE • Δ WEIGHT = + 33.22 LBS	• RETAIN HEATSHIELDS • EXTEND PROBE PYROTECHNICALLY THROUGH PLUG IN HEATSHIELD • STABLE CONFIGURATION • Δ WEIGHT = 0 LBS (REFERENCE)

Probe Packaging Options-3

PROBE DIAMETER COMPARISON

• NOTE: IDENTICAL EQUIPMENT SIZE, PACKAGING AND ARRANGEMENT COMPARISON		
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	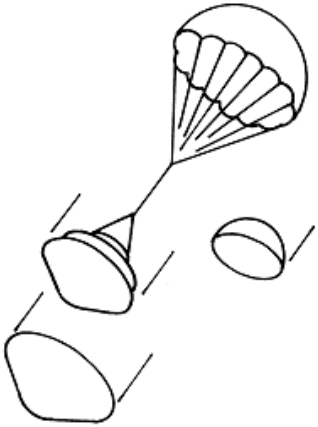	
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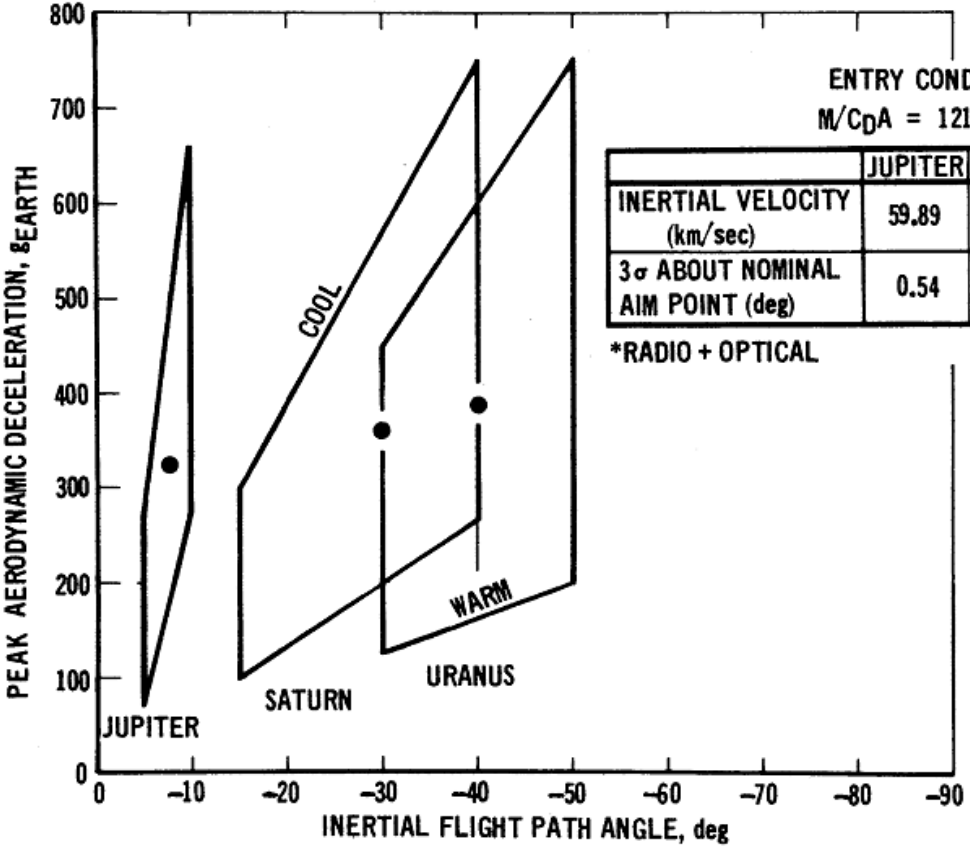
Probe Deceleration Comparison



ENTRY CONDITIONS

$M/C_DA = 121.8\ kg/m^2$

	JUPITER	SATURN	URANUS
INERTIAL VELOCITY (km/sec)	59.89	26.76	24.95
3σ ABOUT NOMINAL AIM POINT (deg)	0.54	8.04	15.86*

*RADIO + OPTICAL

Additional Design Considerations

- Spacecraft Bus Design
  - Spin Stabilized or 3-axis Stabilized
    - Spin-Stabilized is simpler, lower weight, complicated probe delivery
    - 3-axis stabilized has better performance in comm-link, navigation, probe delivery
- Overall Probe Design
  - In general, given similar science instrument payload, ‘common’ probe design for Saturn, Uranus, and Neptune is possible
  - Jupiter probe is specialized due to higher deceleration loads, heatshield design