TEN BAR PROBE TECHNICAL SUMMARY

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MR. ELLIS: I am going to start with the conclusions of the study. That way, if Tom pulls out the hook and removes me from the podium, at least the major points will have been covered.

In preparation of this report, we read and reviewed a stack of material done by most of the people in the room over the past five years or so, a stack about six feet tall, when piled up, and tried to, in 25 words or less, summarize this material, to provide a management-level technical review and summary.

The major conclusions that we reached, after digesting all of this material, are shown on Figure 4-1. This set of conclusions was reached prior to the Pioneer 10 mission and there are some modifications that must be made to them, as a result of the Pioneer 10 data.

The most significant conclusion was that a common probe design looks quite possible for the five bodies we were considering; that is, Jupiter, Saturn, Neptune, Uranus, and Titan, except possibly for Jupiter since the design for Jupiter is quite a bit heavier. The heat shield fraction is so large that it didn't really make good sense to try to combine Jupiter with the other planets in a common probe mission.

A similar kind of thing, at the other end of the spectrum, could be said for Titan; that is that Titan doesn't quite require the heat shield fraction that is required for Saturn, Uranus and Neptune, and you are paying a penalty in trying to go to Titan with a common probe. But it looked to us that in that case, it was probably worth it, rather than going to a completely new design.

OUTER PLANET ATMOSPHERIC PROBE

CONCLUSIONS

- OUTER PLANET ENTRY PROBE MISSIONS FEASIBLE BEGINNING IN 1979 – 1980
- COMMON PROBE DESIGN POSSIBLE EXCEPT FOR JUPITER
- BASIC TECHNOLOGY EXISTS EXCEPT JUPITER HEAT SHIELD
- PROBE WEIGHT CLASS – 113 kg (250 lb)
- PIONEER CLASS BUS PRODUCES LIGHTER SPACECRAFT
- MARINER CLASS BUS PROVIDES BETTER BUS SCIENCE AND PROBE BUS COMMUNICATIONS
- STAGING DURING ENTRY UNNECESSARY

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Figure 4-1.

The Probe weight for the common probe was in the 250 pound class. We did look at the two bus concepts, and I classify them here as Pioneer and Mariner. I am really talking about a spinning bus versus a 3-axis stabilized bus, of which the Pioneer and Mariner are the prime samples.

The Pioneer bus produced a lighter overall spacecraft, able to be launched using smaller launch vehicles. The Mariner class provided slightly better probe communications and a more stable platform for the bus science.

Another significant conclusion, contrary to much of the work that had been done prior to this review, was that staging during entry appeared unnecessary except possibly, again at Jupiter.

A common science payload (Figure 4-2) appeared consistently throughout most of the study work. It included the five instruments that have become quite familiar to everyone, pressure sensor, temperature sensor, accelerometer, neutral mass spectrometer and nephelometer. The science objectives are shown and each instrument is related to the particular science objective that it would primarily accomplish by the deltas on the chart. The cases where an instrument is a secondary instrument for a particular science objective are noted by the X's on the chart.

A couple of other instruments were examined very briefly. One of them was the solar radiometer. It appeared from most of the work that had been done, that the sun angle during probe descent was quite poor in practically every case. And, therefore, while it was a very desirable instrument, perhaps as a replacement for the nephelometer, it was not included.

Figure 4-3 reviews, basically, the sampling rate and shows how the various instruments are sampled during entry and descent.

SCIENTIFIC MEASUREMENT OBJECTIVES

SCIENTIFIC OBJECTIVE	PRESS.	TEMP.	ACC.	NMS	NEPH.
ATMOSPHERIC DENSITY	X	X	△	X	
ATMOSPHERIC TEMPERATURE	X	△	X	X	
ATMOSPHERIC PRESSURE	△	X	X	X	
ATMOSPHERIC CONSTITUENTS	X	X		△	X
CLOUD LOCATION/STRUCTURE	X	X	X	X	△
CLOUD COMPOSITION	X	X	X	△	X
ATMOSPHERIC TURBULENCE	X	X	X		X

△ DIRECT MEASUREMENT
X RELATED MEASUREMENT

Figure 4-2

DATA RATE REQUIREMENTS

DATA TYPE	SAMPLE INTERVAL (SEC)		WORD LENGTH (BITS)	SAMPLE LENGTH (WORDS)	DATA RATE (BITS/SEC)	
	ENTRY	DESCENT			ENTRY	DESCENT
PRESSURE	–	50	10	1	–	0.2
TEMPERATURE	–	50	10	1	–	0.2
ACCELERATION						
LONGITUDINAL	0.2	50	10	1	50	0.2
LATERIAL (EACH AXIS)	0.2	50	7	1	35	0.14
NEUTRAL MASS	–	405	9	634	–	14
SPECTROMETER						
NEPHELOMETER	–	30	10	4	–	2
			6	3		
ENGINEERING AND						
CALIBRATION	0.83	VARIOUS	6	1	30	2
HOUSEKEEPING	–	–	–	–	30	3.12
TOTAL ENTRY DATA RATE					180	
ENTRY DATA PLAYBACK						22
TOTAL DESCENT DATA RATE						44

Figure 4-3

The entry data being stored, (the data sampled during entry) is then played back during descent at 22 bits per second. The main body of data being taken during descent also yields 22 bits per second giving it a net 44 bit per second data rate. The sample design we have in our report is basically the McDonnell-Douglas conceptual design as it most nearly approximated the characteristics necessary for this mission.

In reviewing the communications geometry, Figure 4- 4, the communications range at entry and end of mission shown here are the maximum conditions of any of the various missions from all the reports, with the exception of a few where there were special requirements. There are a few missions flown at extremely high spacecraft flyby periapsis, that exceeded these ranges, but most of the missions were within the constraints shown here; also true of the maximum range of probe look angle excursion of 60 degrees and the maximum bus look angle excursion of 45 degrees.

These conditions set the tone for the communications system and the major trades, Figure 4- 5, which showed up in the various studies that were done. To a large degree, I think these trades have been covered by previous speakers.

The bus relay link antenna for the 3-axis stabilized bus, is a dish, in the typical design the dish had a 40-degree half angle pencil beam with about 12 db gain.

In the spinning spacecraft, you have a choice between trying to duplicate that pattern with a despun antenna, which is just about impossible to integrate into the spinning spacecraft design, or using an axisymmetric antenna, as shown in the baseline design. It has a gain of about one and a half db and a 50-degree half angle. This makes the spinning spacecraft appear to have like a 10 1/2 db deficiency in comparison to the 3-axis

COMMUNICATIONS GEOMETRY	
MAX. COMMUNICATIONS RANGE AT ENTRY	120,000 km
MAX. COMMUNICATIONS RANGE AT EOM	105,000 km
MAX. PROBE LOOK ANGLE	60 deg
MAX. BUS LOOK ANGLE EXCURSION	45 deg
MAX/MIN RANGE RATE	25/–20 km/sec
MAX/MIN RANGE ACCELERATION	8/–1 m/sec^2
DATA RATE	44 bits/sec

Figure 4-4

MAJOR COMMUNICATION TRADES

- BUS ANTENNA
- FREQUENCY
- MODULATION TECHNIQUE
- CODING SCHEME

Figure 4-5

stabilized spacecraft, but about three and a half db is recovered because of the difference in the planet noise received. If a dish antenna is looking right at the planet, the entire planet disc is within the beam width of the antenna and a much higher planet noise contribution is received, whereas the axisymmetric pattern looks all the way around the spacecraft; only a small bit of that antenna pattern intercepts the planet disc and the planet noise contribution in the receiver is much less. So that the net difference is about 7 db between the two.

Many of the studies were done at 400 megahertz, and others were done at 860; a few were done at 1,000; and here and there there were some S-band systems. But the principal case could be made for the 860 megahertz frequency and the 400 megahertz frequency. The principal difference here was related, again, to the spacecraft configuration and the spacecraft antenna size. There is a set of communication design link charts in the report that compare the spinning spacecraft with a 400 megahertz communications system with the 3-axis stabilized spacecraft at 860 megahertz, and basically demonstrate that either of these systems can do the job within the design constraints that I showed two slides ago.

Also, in the modulation technique area, both PSK PM and FSK systems were used and, again, both can do the job. There are some advantages and disadvantages to each, mostly relating to the fading conditions that are assumed for the atmosphere. And these are probably not too significant if you consider only the upper atmosphere of these planets, becoming most significant if you try to enter into Jupiter's atmosphere.

In terms of staging, there appeared to be quite a difference when we started looking at the different staging designs and one of the things that emerged very quickly was that some studies were using a staging altitude that was basically trying to reach some low G-level descending; that is, to exit from entry above the tropopause. Others were trying to reach some G-level at a particular velocity; typically, something like Mach .7 above 100 milibars pressure. And when you start looking at what these different ground rules mean on the different planets with the different model atmospheres that have previously been discussed, the design conditions for exit from entry become quite different. For example, all of these shown on Figure 4- 6 are 100 milibar altitudes in kilometers; that is, reference altitude in the model atmospheres. The pressures, if you started talking about coming out above the tropopause, are quite a bit higher.

In trying to compare the results of these studies using different ground rules, we ran into a lot of apple-and-orange problems. As shown in Figure 4- 7 , we did conclude that, with the exception of Jupiter, staging was probably not required. Staging does provide a better science mission in that you can use one ballistic coefficient to arrive at some pressure altitude prior to exposing most of the main science instruments, and then change the ballistic coefficient for descent and optimize the time you spend in the atmosphere, optimize the data sampling rate for the various instruments, and optimize your communications geometry and communications time perhaps a little better. But that is quite a penalty to pay to gain these small improvements.

Unstaged entry turns out to be lighter, in most cases, and we are basing these numbers on our 250-pound probe, by about 15 or 16 kilograms in weight, and removes all of the complexity associated with the parachute design, heat shield jettisoning, and all of the associated mechanisms.

Staged entry accommodates the conflicting ballistic coefficient requirements better. It improves the ability to expose sampling inlets after entry, and while these are advantages, they certainly don't outweigh the advantages of unstaged entry.

DESIGN CONDITIONS FOR EXIT FROM ENTRY

	TROPOPAUSE COOL DENSE ATMOS.		100 mbar COOL DENS ATMOS.
	ALT (km)	PRESSURE (mb)	ALT (km)
JUPITER	19.4	259	31.1
SATURN	35.3	204	48.2
URANUS	35.8	330	50.4
NEPTUNE	15.2	660	30.6

Figure 4-6

MAJOR STAGING TRADES

UNSTAGED ENTRY	STAGED ENTRY
• STAGING COMPLICATES DESIGN PARACHUTE DEPLOYMENT AND HEAT SHIELD JETTISON QUESTION-ABLE RELIABILITY	• BETTER ACCOMMODATES CONFLICTING BALLISTIC COEFFICIENT REQUIREMENTS
• LIGHT WEIGHT ~ 16 kg	• EXPOSES SAMPLING INLETS AFTER ENTRY
• AEROSHELL PROTECTS EQUIPMENT DURING DESCENT	• UNCOVERS COMMUNICATIONS ANTENNA
	• SLOWER DESCENT RATE FOR MORE SCIENCE DATA

Figure 4-7

Now, in terms of heat shield, Figure 4- 8 summarizes very briefly the entry conditions we found at the various planets, and the ranges of these planets. I won't dwell on this because it is all in the report.

Figure 4- 9 shows the principal reason for excluding Jupiter prior to the preliminary information from the Pioneer 10 encounter. Without the ability to go to very shallow entry angles and with the atmospheric model that had been projected prior to Pioneer 10, the Jupiter heat shield mass ratio is just completely out of tune with the heat shield mass ratios for the rest of the missions.

Also, the ability to simulate those heating conditions is quite limited. The heating conditions associated with Jupiter entry as shown on the convective heating and radiative heating plot of Figure 4-10 and the simulation capability shown reveal the very limited simulation capability that exists and this also led us to the feeling that Jupiter should be postponed.

I think I will move ahead to the last, Figure 4-11. (The only thing that I am skipping is the spacecraft interplay, and that was covered very thoroughly just a few minutes ago.)

The impact of the Pioneer 10 data on our conclusions has to a degree been covered already. The potential change in atmospheric model should reduce the entry heating rates. The improved ephemeris should allow a much shallower entry and further reduce the heating rates. And the fact that the radiation environment is now better known should improve the ability to design both the probe and the bus for a Jupiter mission.

MR. CANNING: Are there any questions that would be other than lead to revisions to the Ten Bar Probe Summary?

OUTER PLANET 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

Figure 4-8

COMPARISON OF HEAT SHIELD MASS FRACTIONS FOR ENTRY INTO THE OUTER PLANETS

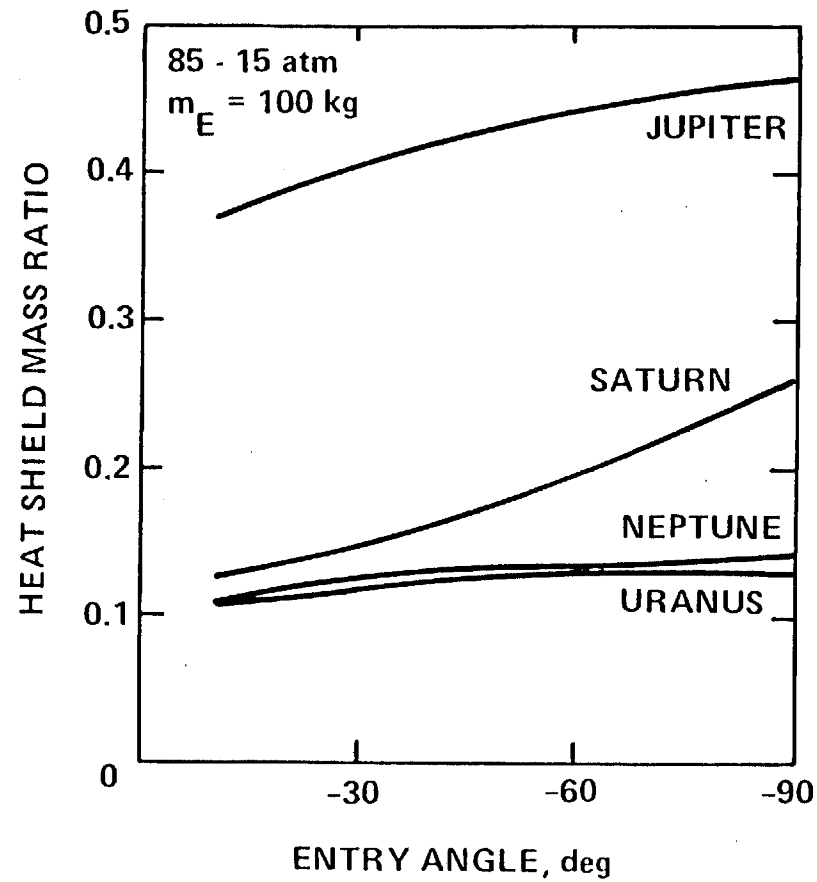

Figure 4-9

EXISTING HEATING SIMULATION CAPABILITIES
AND JUPITER ENTRY REQUIREMENTS

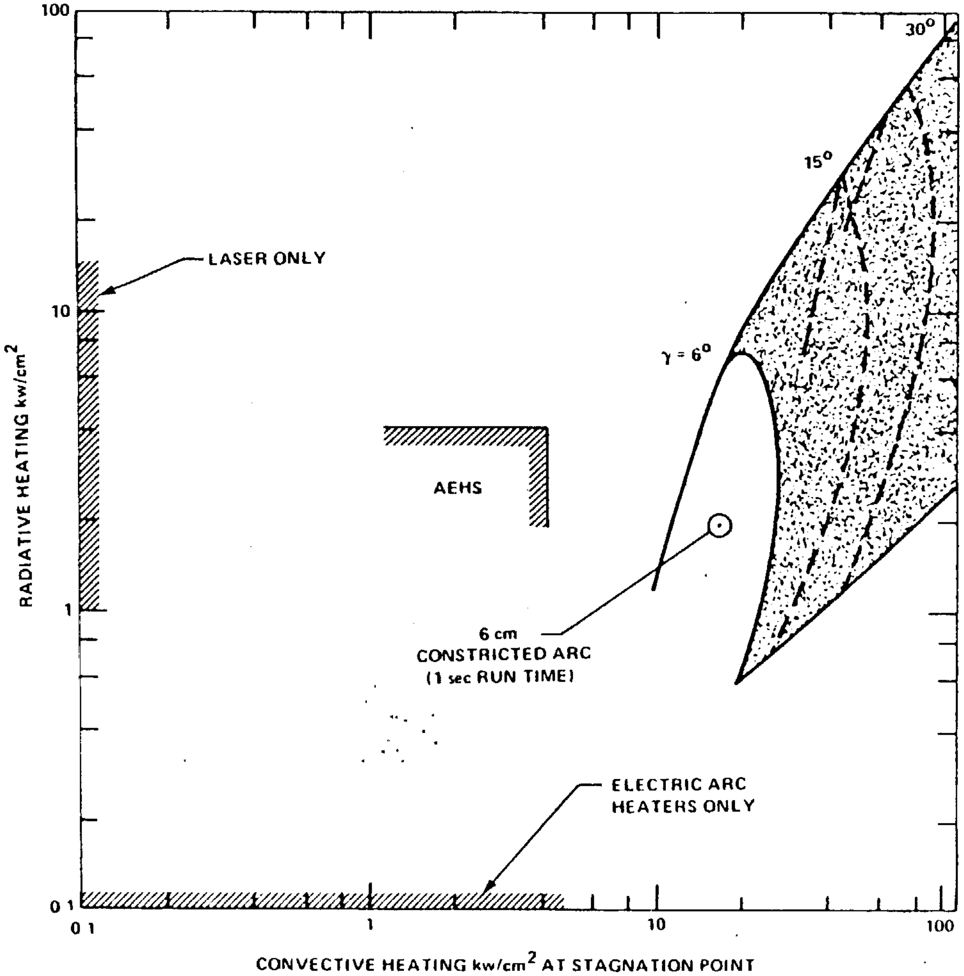

Figure 4-10

PIONEER 10 IMPACT

- ATMOSPHERIC MODEL
- EPHEMERIS
- RADIATION ENVIRONMENT

Figure 4-11

MR. HERMAN: Not a question, but a comment. What I have seen on the charts indicates why, up to the Pioneer 10 encounter we did not plan a Jupiter entry program until 1985; primarily, because test facilities did not exist in the United States to simulate the entry conditions. And one key issue of this workshop, and subsequent studies, would be another assessment: is a Jupiter entry probe at a shallow entry angle conceivable, from a commonality standpoint, with that of a Saturn and Uranus probe?

MR. CANNING: Yes, I think that you would find that the commonality would be less expensive than indicated by the earlier study.

MR. HERMAN: But is it real? I am still skeptical.

MR. CANNING: It is likely that a Jupiter probe would still be "non-common."