COMPARATIVE ATMOSPHERE STRUCTURE EXPERIMENT

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MR. SOMMER: We have heard quite a bit about pressure, temperature and accelerometers being used for probes for the outer planets. I thought I would take this opportunity to just review very briefly how we use these instruments to determine atmosphere structure, spend a few minutes to review very briefly the results that we have obtained from our PAET earth entry, and to then describe, again very briefly, some of the instruments that we have flown on PAET, that we will fly on Viking, and that we hope to fly on Pioneer Venus.

As indicated on Figure 8-20, in order to describe atmosphere structure determination, we divide the entry into two regimes, high speed and low speed. We measure acceleration and from the acceleration we determine density as a function of time. We integrate the equations of motion to determine velocity, flight path angle, and altitude as a function of time. Then we determine density as a function of altitude from the previous determinations of density and altitude as a function of time. We assume hydrostatic equilibrium to determine pressure as a function of altitude. Finally, we apply the equation of space to determine temperature as a function of altitude, if we know the mean molecular weight. We obtain the mean molecular weight independently from either the low speed experiment or from the composition experiments.

During the low speed portion of the flight, and by low speed I mean somewhere around mach one or two or where you can deploy a temperature sensor without destroying it, we measure pressure, temperature, and again, acceleration. We correct pressure and temperature to ambient values. We solve the equations of hydrostatic equilibrium and vertical motion, and obtain altitude and velocity as a function of time and mean molecular weight.

We compute pressure and temperature as a function of altitude, and we apply the equation of state to obtain density as a function of altitude.

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ATMOSPHERE - STRUCTURE DETERMINATION

HIGH SPEED

- MEASURE A_X TO DETERMINE $\rho(t)$
- INTEGRATE EQS. OF MOTION TO DETERMINE $V(t)$, $\gamma(t)$ AND $z(t)$
- DETERMINE $\rho(z)$ FROM $\rho(t)$ AND $z(t)$
- ASSUME HYDROSTATIC EQUILIBRIUM TO DETERMINE $P(z)$
- APPLY EQUATION OF STATE TO DETERMINE $T(z)$

LOW SPEED

- MEASURE P_T, T_R, AND A_X
- CORRECT P_T AND T_R TO AMBIENT VALUES
- SOLVE EQS. OF HYDROSTATIC EQUILIBRIUM AND VERTICAL MOTION TO OBTAIN $Z(t)$, $V(t)$ AND μ
- COMPUTE $P(z)$ AND $T(z)$
- APPLY EQUATION OF STATE TO OBTAIN $\rho(z)$

Figure 8-20

The next figure, Figure 8-21, indicates what we hope to obtain if we flew more than one probe at the same time, as Pioneer Venus does. I added molecular weight to the chart because this independent measurement can be used to compare with measurements made by the composition experiments. We hope to be able to get some insight on circulation of the global scale. We intend to be able to make some vertical wind determinations. We will attempt to measure atmospheric turbulence in the lower part of the atmosphere. If any of the four probes on Pioneer Venus survive impact, we hope to make some seismic measurements.

Now what I would like to do is run through some of the results that we have obtained from our PAET experiment. The first is a trajectory determination. Plotted on Figure 8-22 is velocity as a function of time from lift-off. The dots shown here are experimental points determined from the method that I showed you on the first slide, and is compared to radar tracking data obtained both from Bermuda and from Wallops. I have indicated the division between the high speed experiment and the low speed experiment. Velocity up to about this 576 seconds was determined solely from acceleration and from about 576 seconds on, from acceleration, pressure, and temperature measurements.

You will note that we have reasonably good agreement. The next Figure 8-23 shows altitude as a function of density. This is one of the primary measurements. The region above about twenty-six kilometers, where we reached a mach number of about two and deployed our temperature sensor, density was determined solely from the accelerometers whereas at lower altitudes, density was determined by using accelerations, pressures and temperatures. You will notice that the data covers over five decades of density. Since this is a log plot, we have plotted the difference between the measurements and meteorological data on the right hand side of the figure. Although local differences approach 20 percent, it turns out that meteorological data has much more uncertainty than this particular experiment.

ADDED EXPERIMENT CAPABILITY

- ATMOSPHERIC MEAN MOLECULAR WEIGHT
- CIRCULATION AT GLOBAL SCALE
- VERTICAL WIND DETERMINATION
- MEASURE ATMOSPHERIC TURBULENCE
- SEISMIC MEASUREMENTS

Figure 8-21

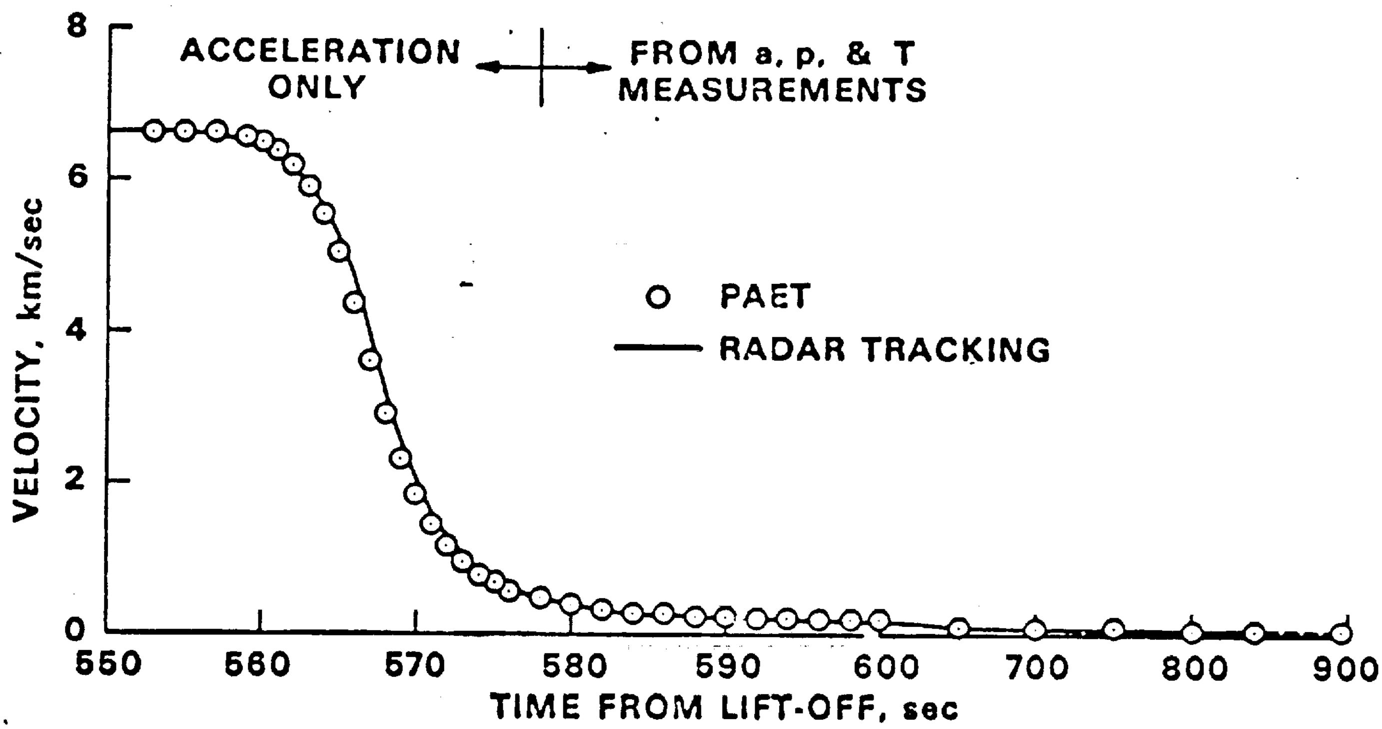

Figure 8-22

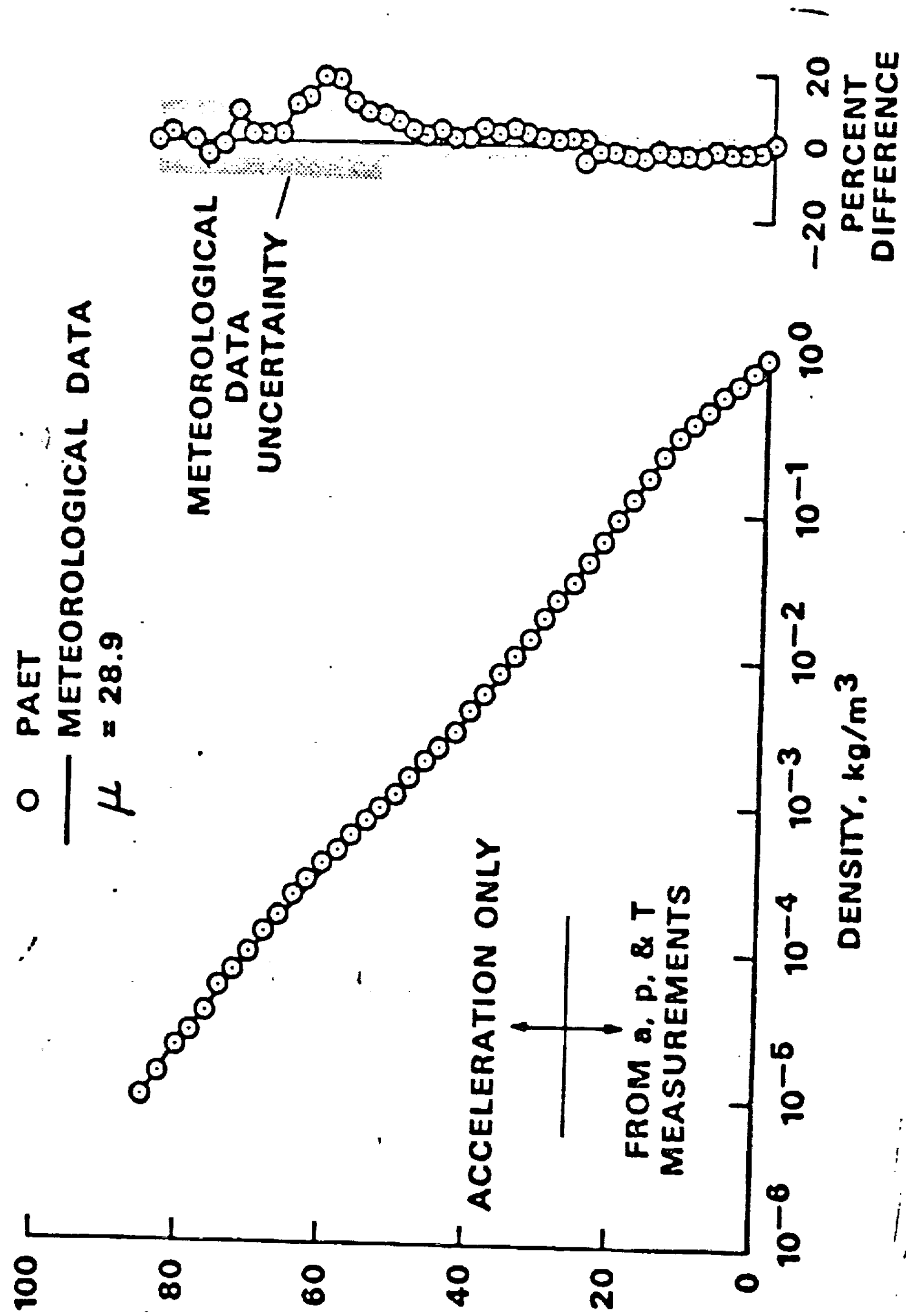
O PAET
— METEOROLOGICAL DATA
μ = 28.9
METEOROLOGICAL DATA UNCERTAINTY
ACCELERATION ONLY
FROM a, p, & T MEASUREMENTS
ALTITUDE, km
0
20
40
60
80
100
10−6
10−5
10−4
10−3
10−2
10−1
100
DENSITY, kg/m3
−20
0
20
PERCENT DIFFERENCE

Figure 8-23

The last of the data plots, Figure 8-24, from PAET is deduced temperature as a function of altitude, where temperature is determined from readings of the accelerometers. Essentially, from 26km up, the temperature data is deduced solely from the accelerometers and is compared to meteorological data from Viper Dart firings made about one hour before and one hour after PAET. Notice the similarity between the two sets of data and the almost perfect agreement with the meteorological data where direct measurements of temperature and pressure were made.

Let me spend the rest of my few minutes comparing the instruments on the three missions that the Ames group has been, and is involved in; PAET, Viking, and Pioneer Venus. Figure 8-25 is a comparison of atmospheric temperature sensors for the three missions, comparing type, range, accuracy, and weight.

For PAET, we used chromel-alumel thermocouples, the range from 200 to 660 degrees kelvin. We had an accuracy of about one degree. We had two sensors that deployed through the heat shield, each weighing about six tenths of a pound.

Viking is carrying two temperature sensors for us, and the one that I am describing here is the one that comes out through the aeroshell before separation. It is also a chromel-alumel thermocouple with a range from 100 to 700 degrees kelvin. The accuracy is three and one half degrees plus the one percent of reading, and it weighs about one pound.

On Pioneer Venus, we are planning to use a resistance thermometer. The range, again, is very similar - 200 to 800 degrees kelvin. The accuracy requirement is much more severe. We feel that the temperature differences around the globe are small, and we are trying to determine what those are, thus the 1/4 degrees accuracy requirements; total weight is about 1/2 pound.

The way we plan to deploy the temperature sensor for Pioneer Venus is illustrated in the next two figures. Figure 8-26 shows a

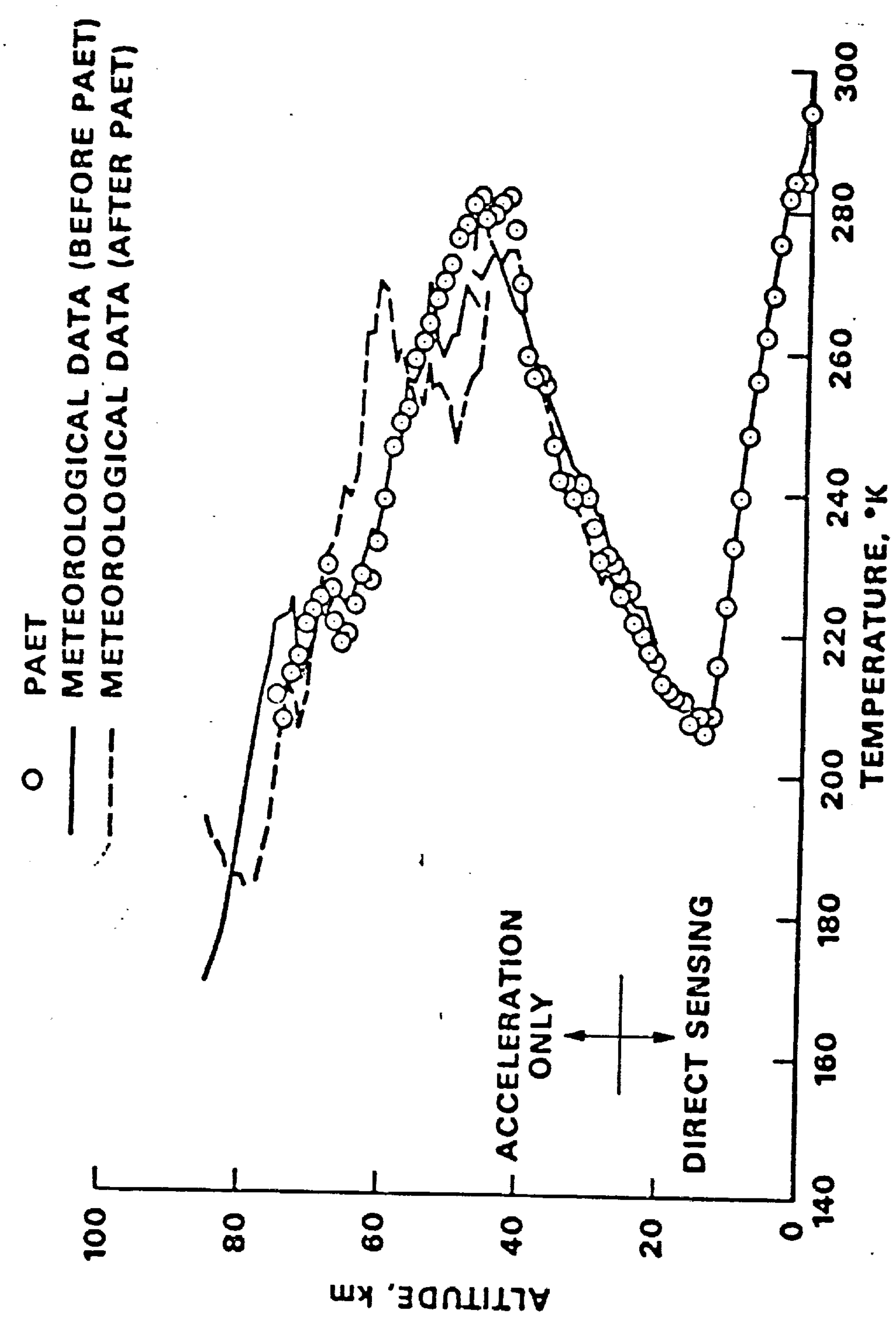
PAET
METEOROLOGICAL DATA (BEFORE PAET)
METEOROLOGICAL DATA (AFTER PAET)
ACCELERATION ONLY
DIRECT SENSING
ALTITUDE, km
0
20
40
60
80
100
TEMPERATURE, °K
140
160
180
200
220
240
260
280
300

Figure 8-24

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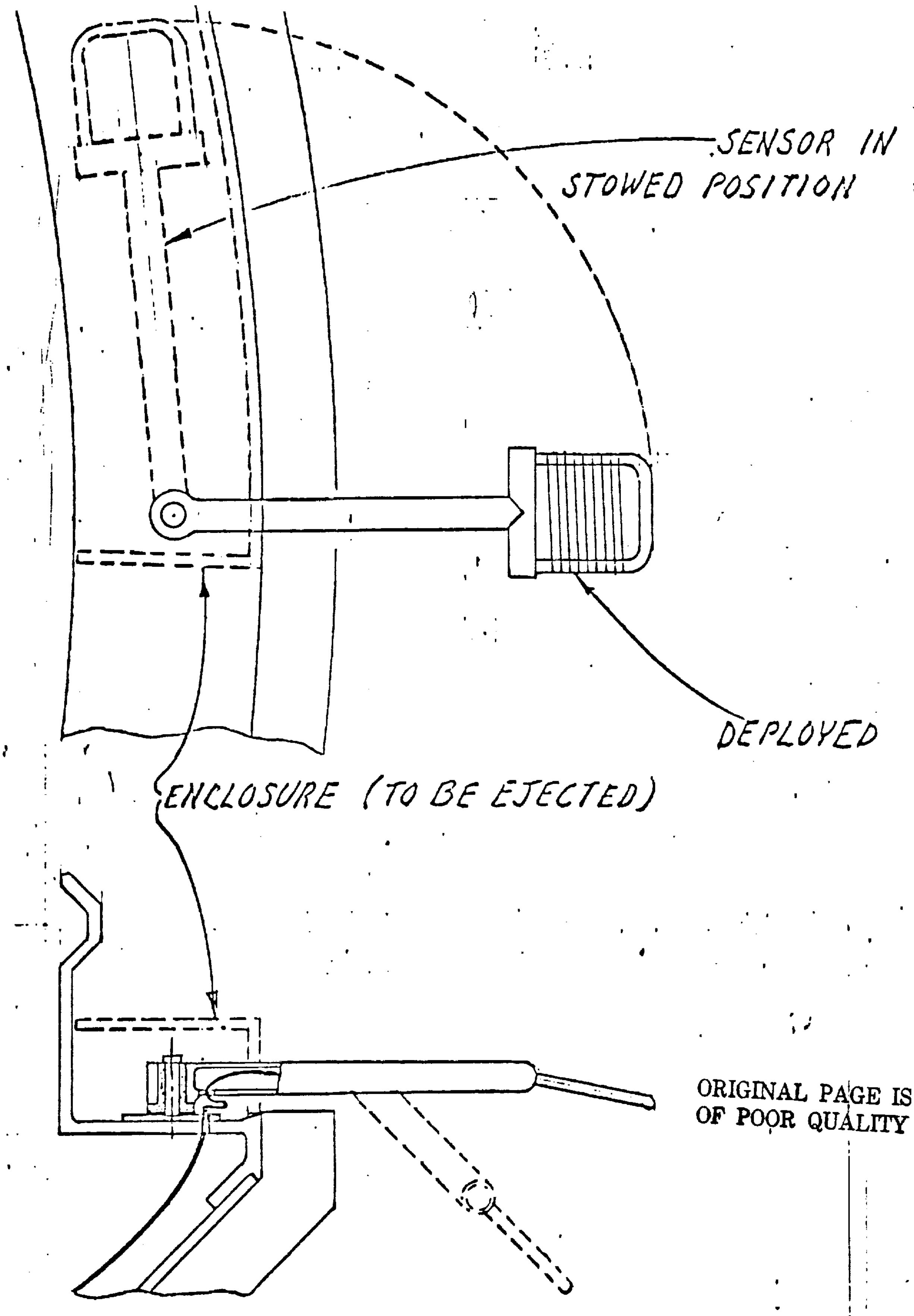
COMPARISON OF ATMOSPHERIC TEMPERATURE SENSORS

ON THREE MISSIONS

MISSION	SENSOR TYPE	TEMP. RANGE, ^{o}K	ACCURACY	WEIGHT, lbs.
PAET	THERMOCOUPLES CHROMEL-ALUMEL	200^{o} - 660^{o}	$\sim 1^{o}K$	0.64 (ea) 2 SENSORS
VIKING	THERMOCOUPLES CHROMEL-ALUMEL	100^{o} - 700^{o}	$<[3.5^{o}K+1\%RDNG]$	0.96
PIONEER VENUS	RESISTANCE THERMOMETER	200^{o} - 800^{o}	$<\frac{1}{4}^{o}K$	0.52

Figure 8-25



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TEMPERATURE SENSOR IN SMALL PROBE

Figure 8-26

plan view of a deployable arm that is located within the afterbody cover. The arm comes out and bends down so that the sensor sees the flow around the body outside the boundary layer before it comes to the afterbody. This is one of the concepts that we are contemplating.

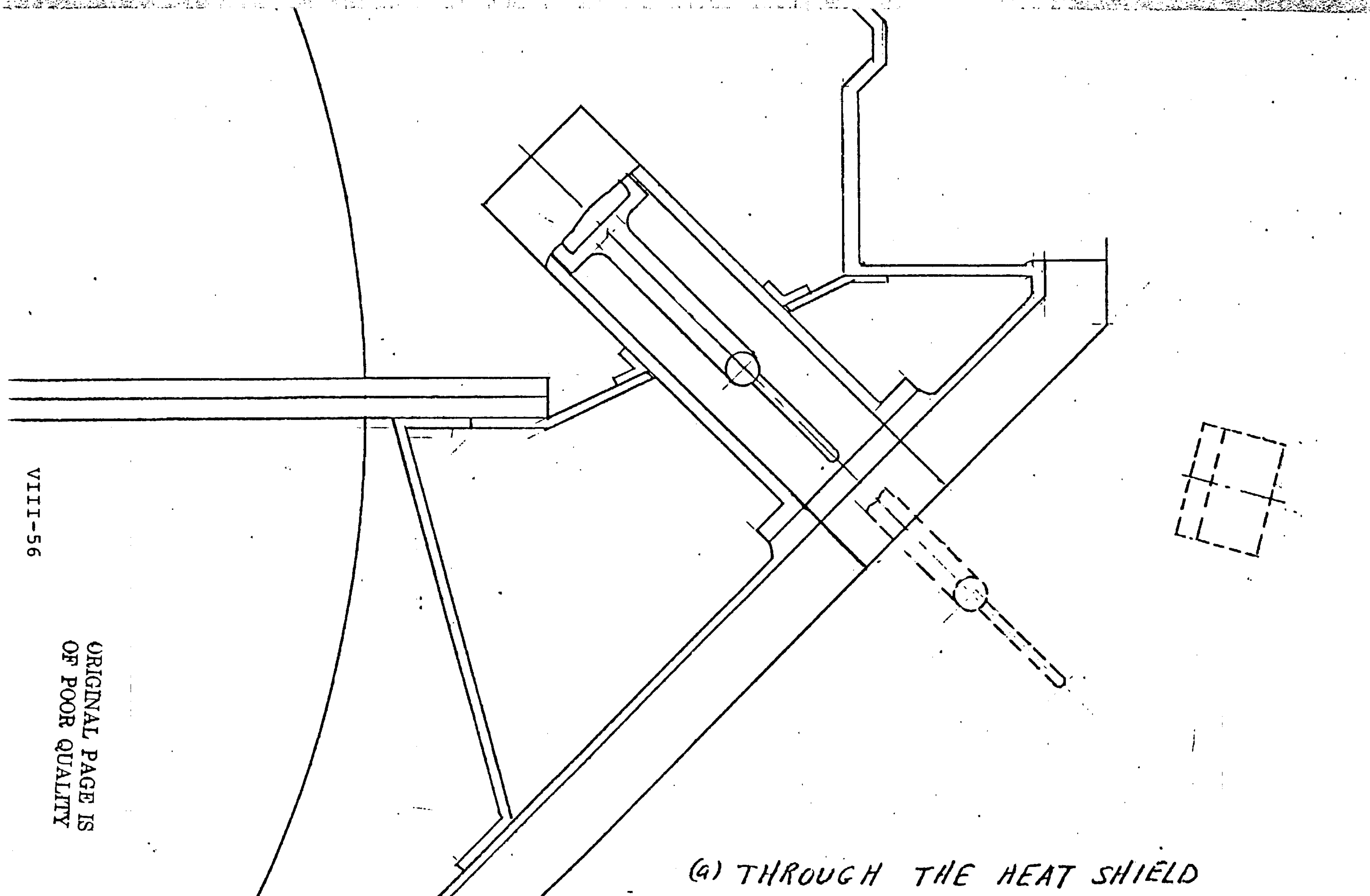
The other is illustrated on Figure 8-27, which is the concept that we have used on PAET that will be used on Viking and could be used on Pioneer Venus and/or any of the other planets.

Next, Figure 8-28 contains a similar comparison of the pressure sensors. For PAET, we used a vibrating diaphragm pressure sensor which measured pressures from a .001 to one atmosphere with an accuracy of about one percent of reading. There again, we carried two sensors, each one weighing about seven tenths of a pound.

On Viking, for the entry vehicle, we are carrying a stainless steel, conventional type diaphragm pressure sensor. The pressures to be measured are from .001 to only .15 atmosphere. Accuracy is about 2 percent of reading and weighs very close to a pound.

For Pioneer Venus, we are planning to carry a number of miniature silicon diaphragm diffusion-bonded wheatstone bridge-type sensors. They are sensors about a quarter of an inch in diameter, weighing a few grams. We are contemplating carrying anywhere from six to twelve in order to cover the range from 30 millibars to about 100 atmospheres. The goal is an accuracy of about 1/2 percent of reading. The weight of that entire system, including electronics, is on the order of 0.8 pound.

Figure 8-29 illustrates how we intend to sample the pressure, either through the heat shield at the stagnation point or through tubing opening adjacent to the temperature sensor. When the temperature sensor is deployed, then that pressure sensor will make its readings starting at that time.



(a) THROUGH THE HEAT SHIELD

FIGURE 8-27. POSSIBLE DEPLOYMENT MECHANISMS FOR THE TEMPERATURE SENSOR ON THE SMALL PROBE

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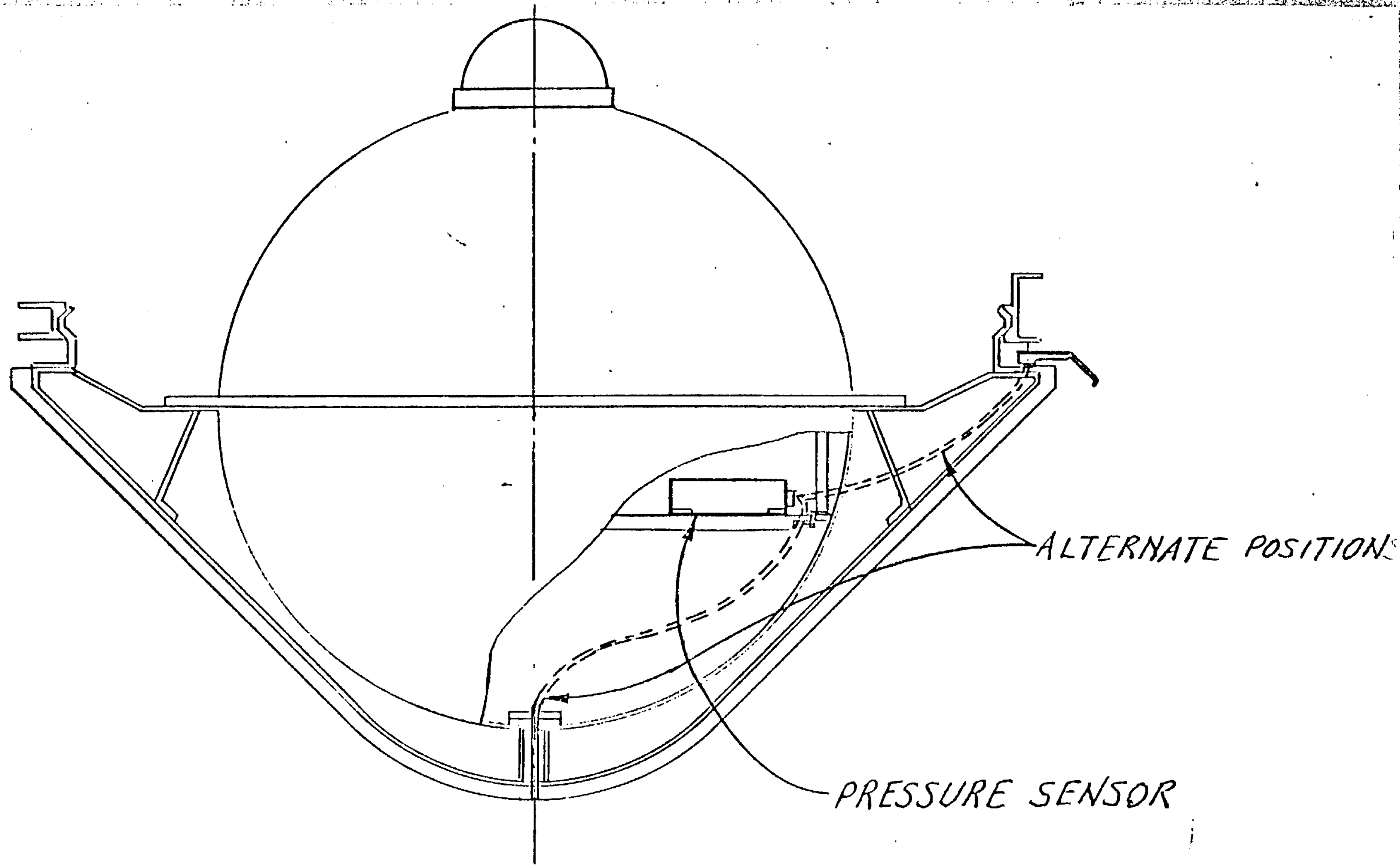
COMPARISON OF PRESSURE SENSORS ON THREE MISSIONS

MISSION	SENSOR TYPE	PRESSURE RANGE, ATM.	ACCURACY, % OF RDG	WEIGHT, lbs.
PAET	VIBRATING DIAPHRAGM	0.001 TO 1.0	~1	0.73 (ea) 2 SENSORS
VIKING	STAINLESS-STEEL DIAPHRAGM	0.001 - 0.15	~2	0.93
PIONEER VENUS	MINIATURE SILICON DIAPHRAGM (DIFFUSION-BONDED WHEATSTONE BRIDGE)	0.03 TO 100	~0.5	0.80

Figure 8-28



SMALL PROBE INLET TUBE LOCATIONS

Figure 8-29

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Finally, Figure 8-30 compares the accelerometers. Again, I have compared the PAET, Pioneer Venus, and Viking sensors. They are all force rebalance type sensors. The electronics are not shown. The accelerometer that we used on PAET, which was designed for a range of about 80 G maximum on the axial accelerometer, was capable of up to several hundred G's. It weighed about 0.4 pound. The Viking instrument, where the maximum acceleration expected is less than 22 G's, is shown in the middle figure. Since this instrument is already developed, it is the leading candidate for Pioneer Venus. The people who have built, designed, and flown these instruments have been working for about the past year and a half on a sub-miniature instrument that has exactly the same capabilities, weighing about fifteen grams. When this instrument is qualified, it will be a leading candidate for planetary entry acceleration measurements.

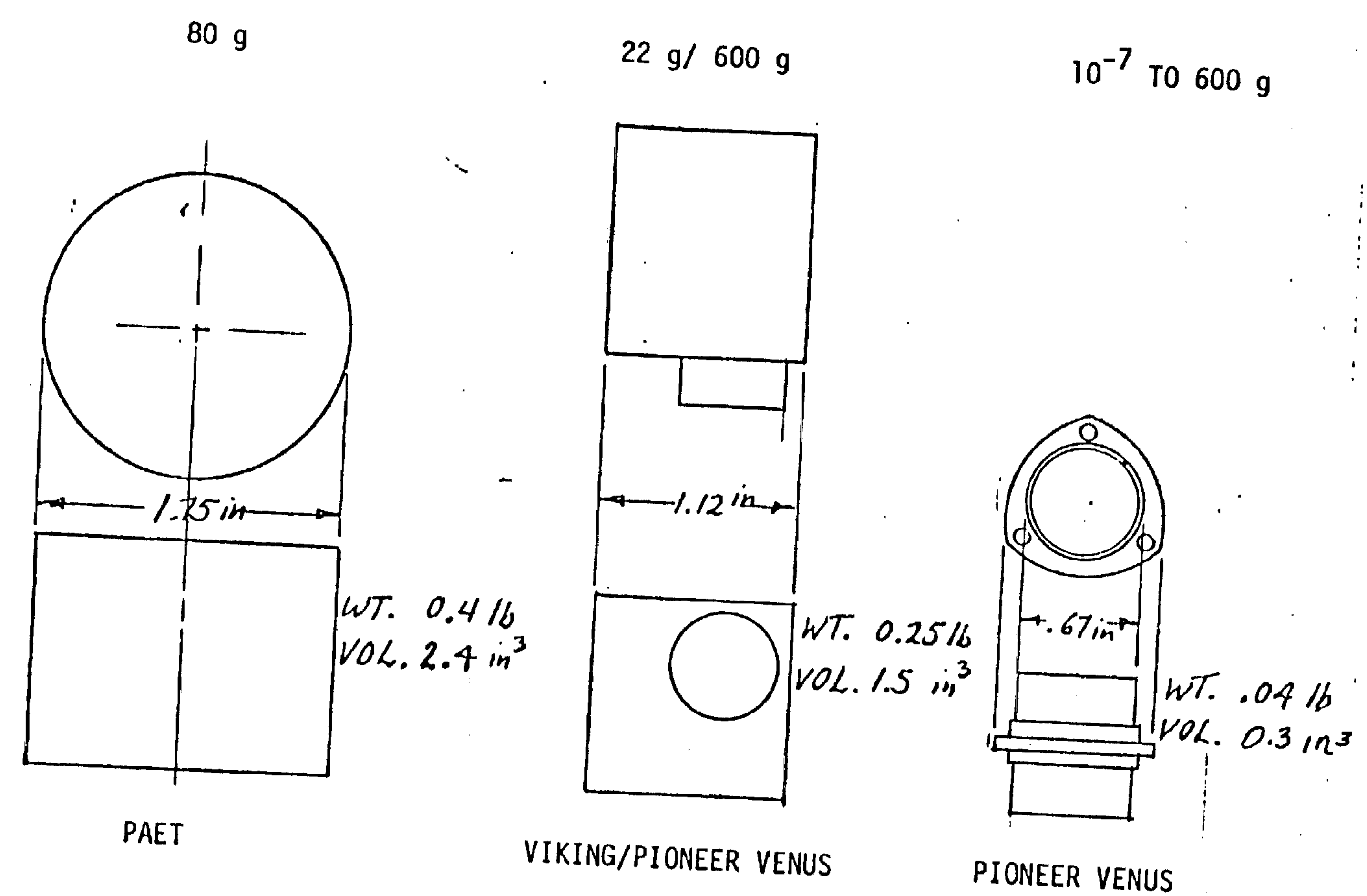
Figure 8-31 shows a blow-up of the Viking instrument. It has over one hundred parts including alnico and magnet housing. I want to compare that to a schematic (Figure 8-32) of what the accelerometer manufacturer calls the model eleven, that has about nine parts. The primary reason for the simplicity, they say, in this is in the magnet, It is made out of a rare earth material, samarium cobalt. An instrument of this type has been built, and is ready for test.

In conclusion, I would like to say that instrumentation for atmosphere structure determination is available with very little modification for application to outer planet exploration.

QUESTION: What is the name of that vendor with the super-light instrument?

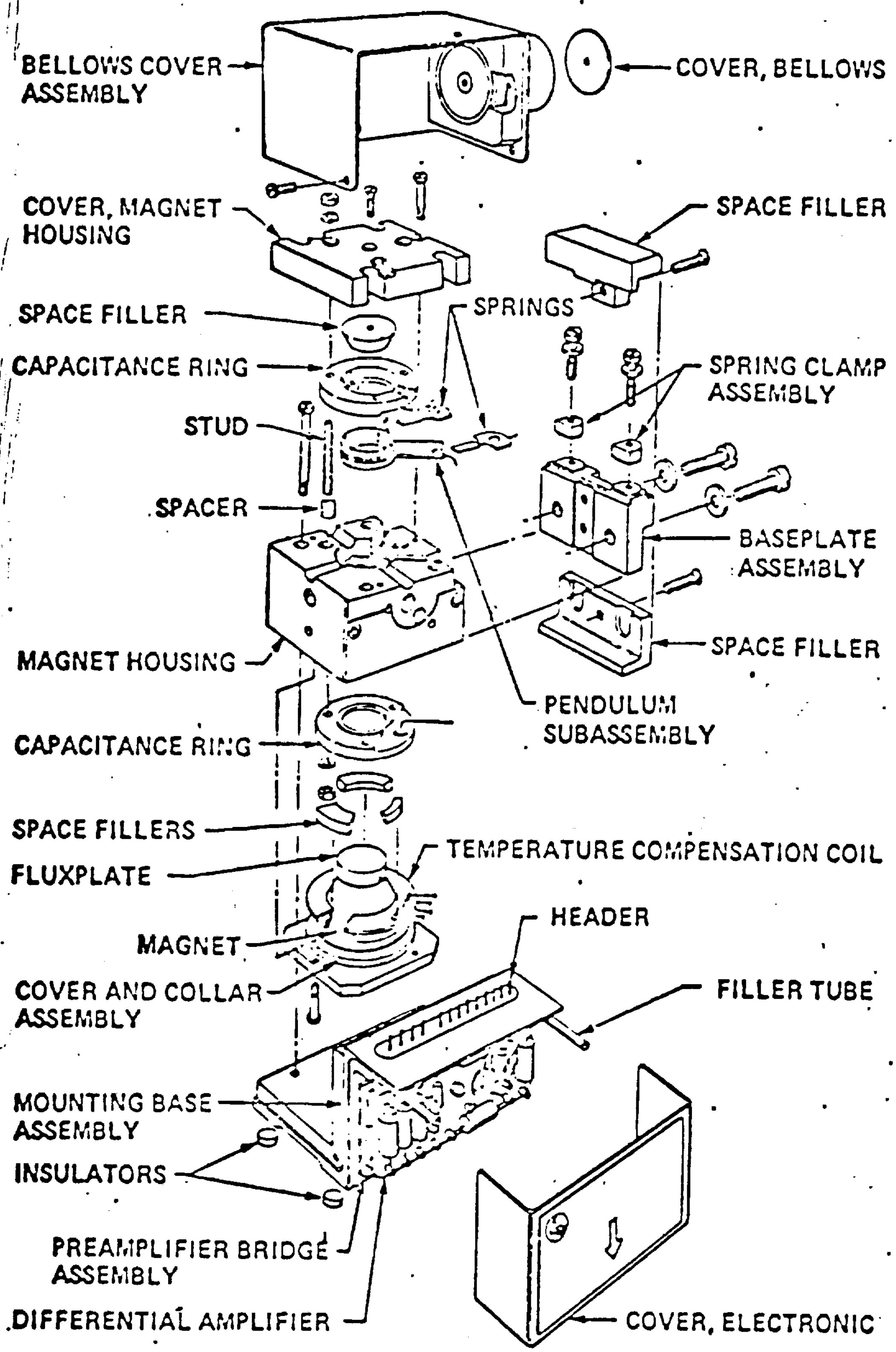
CHAIRMAN: Bell Aerospace

QUESTION: What is the altitude range you hope to get turbulence measurements on?



COMPARISON OF ACCELEROMETERS ON THREE MISSIONS

Figure 8-30



ACCELEROMETER MODEL IX
-7 CONFIGURATION

Figure 8-31

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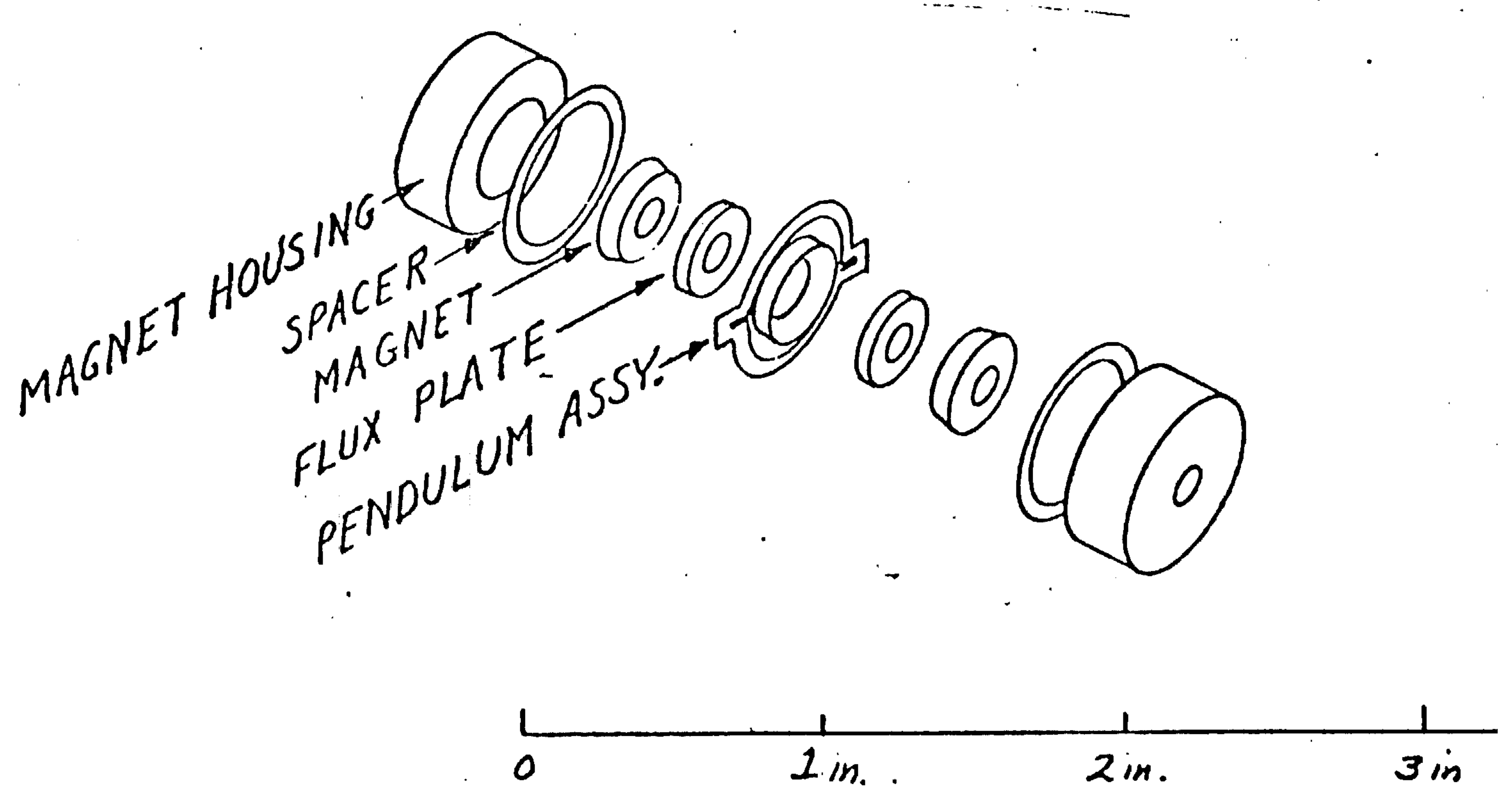

MODEL XI ACCELEROMETER

Figure 8-32

MR. SOMMER: Anywhere during terminal descent for Pioneer Venus, from around 70 km to as close to the surface as we can go. That kind of turbulence measurements we hope to make are really statistical measurements. In other words, we are going to try to count the number of times that the vehicle will feel accelerations above pre-selected values. We will sum those up over a period of time, transmit those back, and then analyze the data. That is the only kind of data capability that we have available for that experiment.