CLOUD DETECTING NEPHELOMETER FOR THE PIONEER-VENUS PROBES

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MR. RAGENT: I would like to describe for you our experiences in developing a cloud detecting nephelometer for the Pioneer-Venus probes. Since this effort is still in progress, this is in the nature of a preliminary report and we are still involved in testing and proving the apparatus. Obviously, the nephelometer on the Pioneer-Venus probe will have a great deal in common with the nephelometers that have been suggested for the outer planet probe missions. Many of the problems to be faced on Pioneer-Venus are very similar to problems that will arise on the other planetary entry probes.

The presence of clouds in the Venus atmosphere, as well as in the atmospheres of the outer planets, has been well documented and the importance of these clouds in affecting the energy balance on the planet's surface and its atmosphere, as well as in strongly affecting atmospheric dynamics, has been extensively discussed. During the early spring of 1972, a Science Study Group attempting to define the experimental payload for the Venus mission strongly recommended that a cloud detecting nephelometer be investigated for possible inclusion into the small probe experiment package. A nephelometer is a device for measuring cloudiness or documenting an aerosol from a measurement of the amount of light scattered from an illuminated volume containing a sample of the cloud or aerosols. The purpose of this equipment was to be to document the presence of clouds, their vertical structure or extent, and from the multiple probe data, to provide some guides as to the global variability of this cloud structure. In their deliberations, the SSG considered a number of alternative approaches to cloud measurement and the recommendation for a nephelometer resulted. This was because only the nephelometer appeared to offer the promise of cloud detection without radically altering the design of the pressure shell of the probes, or requiring the erection of external equipment, while conforming to the requirements imposed by the mission constraints.

At that time, there was, and still remains, considerable doubt as to the composition of the clouds of Venus. The thin upper hazes, extending from altitudes of about 63 to 68 kilometers exhibit a layered structure, as shown by the Mariner 10 results. The uppermost cloud layers, starting at about 60 kilometers, appear to be composed of very concentrated sulfuric acid particles of modal radius about 1.0 microns, index of refraction 1.45 and concentrations estimated at anywhere from 50 to 500 per cubic centimeter, whereas particle concentration estimates for the hazes range from 1 to 100 particles per cubic centimeters. Conjectures about the composition of the deeper clouds involve, for example, such unpleasant compounds as various halides and sulfides of mercury, antimony and ammonia, carbonyl sulfide, and even extend to suggestions of clouds of pure mercury droplets.

In any event, the specifications for the instrument were, very severe, involving detection sensitivities for particulates from what, on Earth, would be called "clean room" conditions, corresponding to visibilities of 10 km or greater, all the way to cloud conditions which may be denser than any known on Earth. Because of the mission constraints, any such instrument would have to be capable of operation on probes entering in either sunlit or dark regions of the planet, be limited to mission physical constraints, including a launch weight of about 500 grams, an average power consumption after atmospheric entry and during the one-hour descent, of about one watt, a volume of about 500 to 700 cubic centimeters, be capable of surviving the severe entry environment into the Venus atmosphere involving decelerations of 400 to 500 G's, and to continue functioning as deep into the ambient atmosphere as possible, preferably to the surface, where conditions are approximately 750°C and 90 to 100 atmospheres. A summary of the required specifications is shown in Figure 8-41.

DESIGN GOALS

Total Instrument

Weight	454 grams
Volume	524 cm^3
Power	1 watt (average)
Data Transmission Rate	$\leq$ 16 bps (large probe) $\leq$ 16 bps above 30 km a (small probe) $\leq$ 4 bps below 30 km (small probe)
Internal Calibration	Must check instrument calibration during entry

Backscatter Channel

Least Count	$\leq$ 10%
Signal/Electronics Noise	$\geq$ 1 for 3 particles/cm^3 1.1μ radius, n = 1.45 (high altitude haze layer) >> 1 for 700 particles/cm 1.1μ radius, n = 1.45 (visible cloud tops)
Signal/Particle Shot Noise	$\geq$ 1 for 3 particles/cm 1.1μ radius, n = 1.45, unattenuated sunlight (high altitude haze layer)
Background/Signal	< 10^6 (limited by saturation of detector)
Dynamic Range	Detector: 10^6 Backscatter Channel: 10^5
Altitude Resolution	$\leq$ 300 meters

Background Channels

Wavelengths	Near UV Visible Near IR (if possible)

Monitor Channels

Window Contamination	Must monitor optical quality of windows
Temperatures	Must monitor temperatures of critical components

Figure 8-41

A very heavy emphasis in the Pioneer-Venus program has always involved reliability coupled with low cost and the assurance of low risk for cost overruns. These ground rules lead to a derived emphasis on off-the-shelf types of proven hardware or components where possible and a somewhat greater reluctance to rely upon long lead time development items or unproven approaches. We first conducted a feasibility study that convinced us that the desired instrument was within the state-of-the art, subject to all of the above constraints involving the mission costs and time.

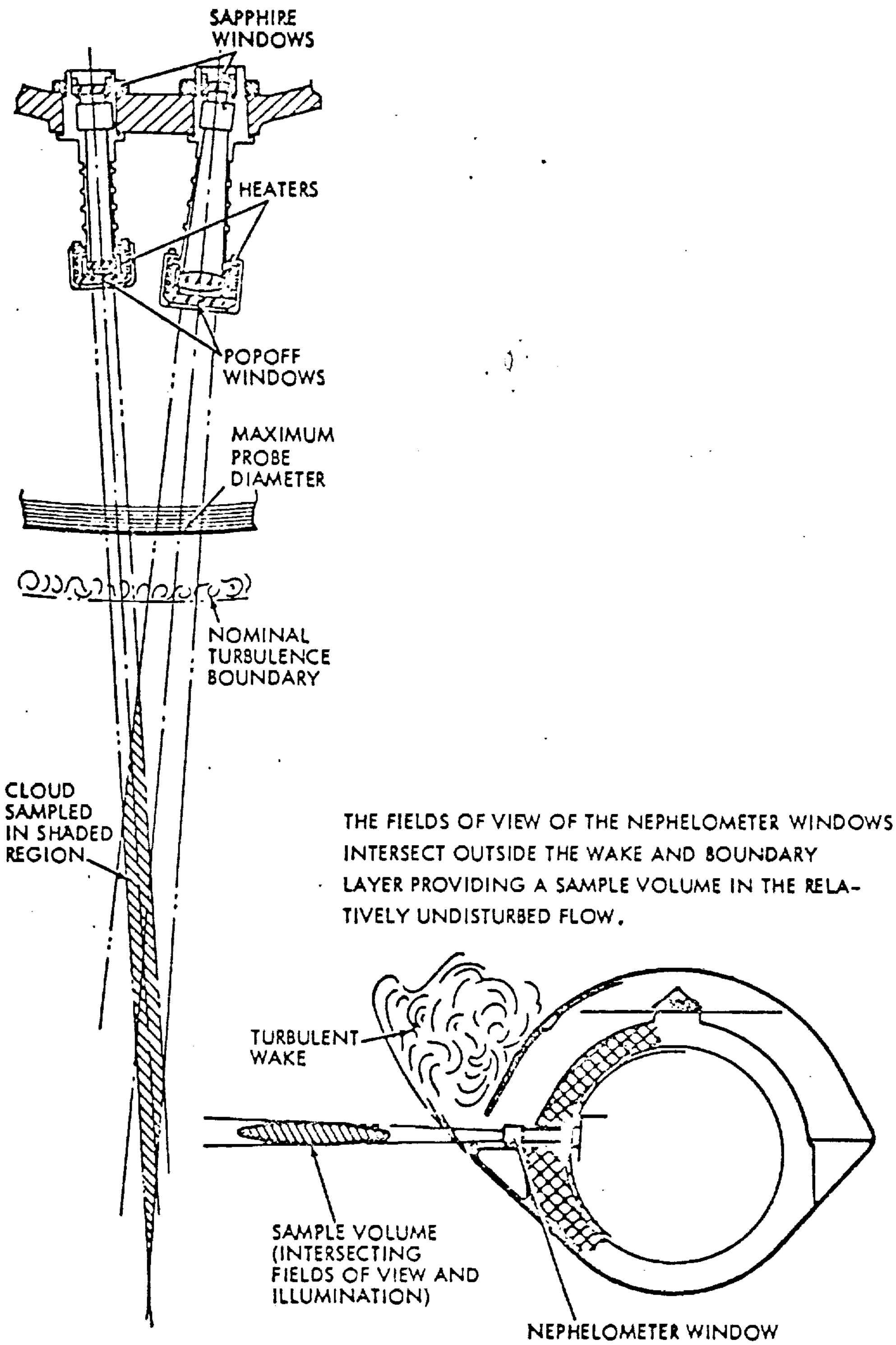
A number of conceptual designs were initially considered. Early ground rules based upon the above thoughts led us to de-emphasize concepts which involved the mechanical erection of any structures outside of the pressure vessel after the very severe deceleration and heating pulse associated with entry into the Venus atmosphere, and structural considerations for the probe made the construction of a "sampling" or reentrant design undesirable. We were, thus, faced with attempting to measure clouds from roughly within the available configuration of the pressure vessel. Since some of the probes were to enter on the dark side of the planet, it was necessary to include a light source as an essential component rather than relying upon ambient sources of radiation. The on-board source would then have to illuminate a sampled region and light-scattered from this region be detected on-board. Our self-imposed proscription against reentrant geometries, pumping samples on-board, or the erection of mirrors, or other optical elements, thus, limited us to scattering in the rearward direction at angles greater than 145° from the direction of incidence of the illuminating light. Again, availability of components and sensitivity considerations led us roughly to choose the visible range of wavelengths for consideration. Further investigation of the information to be obtained from multiple wavelength or polarization measurements made in the restricted range of available scattering angles (within the types of projected accuracies obtainable) led us to the conclusion that very little additional information was to be obtained about the nature of the clouds from multiple wavelength or polarization measurements. As a result, we chose to work at a wavelength of about 9000 Å, for which convenient, powerful solid state sources and sensitive solid state detectors are available and at a scattering angle near 180°, at which angle the scattering is greatest for backward scattered radiation.

Since some of the probes would be entering in the sunlight, a very high level of ambient light would be expected in the visible wavelengths, especially high in the atmosphere. As a result discrimination between ambient background and the on-board light source was necessary, leading to the requirement for a narrow wavelength band source and filtering for the detector. Even with optical filtering, because of the high possible background light levels, as well as for electronic considerations, a pulsed light source and synchronous detection techniques were essential in order to encompass the enormous range of expected signals and to provide the required stability. Since the expected range of signals extends at least over a range of 10^4, a dynamic range of 10^5 was the design goal.

From the start it was evident that sensitivity at the low end of the range was the major problem. Limitations on the available power and on the light sources made it mandatory that we design for the highest possible sensitivities from our detector, and as a corollary, the lowest electrical noise level in our electronics. The optical design, also, had to be very carefully considered with a view toward signal maximization. Low f/number optics are essential in order to collect as much of the light from the source as possible and focus it into the required sampling volume. The effective magnification of the source determined the size of the source beam at the sampling volume. Maximum signal considerations, then, dictated that the image of the detector at the sampling volume be of about the same size as the source, leading also to a low f/number optical system. Further, the size of collecting aperature had to be as large as possible, so as to effectively collect the scattered light. The physical configuration of the nephelometer and the entering probe is shown in Figure 8-42.

The actual limitation on the optics apertures was set by considering the power required to heat the sindows in order to isolate the instrument from the outer environment. A study performed by the Pioneer Office showed that because the probe surface is cool with respect to the atmosphere, condensation of the atmosphere onto a probe window is to be expected, unless the window surface is maintained at a temperature somewhat above the ambient. Because the window heating power is so large and goes as some power of the window diameter, it was desirable to minimize the window size. Considerations of signal-to-noise dictated a large window so that a compromise value had to be established. At this time, a value of 2.5 centimeters has been chosen for both the source and detector apertures. Further development in sources may allow us to reduce at least the source aperture.

For the typical configuration shown in Figure 8-42, an analysis of signal-to-noise was made using quoted source and detector characteristics, the geometry and a postulated aerosol haze composed of a narrow size distribution of spherical particles of modal radius 1.1 microns and index of refraction 1.45. The ambient background light was also calculated as a function of the angle of scatter from the sun into the detector (assuming only single scatter). The nosie contribution was calculated as coming from both electrical noise (Johnson noise, shot noise and 1/f noise) and noise due to functuations in the ambient background signal due to statistical fluctuations in the sampled volume caused primarily by the motion of the probe in moving the sampled volume. This latter noise is obviously dependent on the phase angle of the sun relative to the viewing path. These calculated values of signal-to-noise and background showed that the required values of sensitivity could be achieved.



Nephelometer Field of View and the Turbulent Wake

Figure 8-42

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It was now necessary to actually build a laboratory instrument to demonstrate the feasibility of the proposed design. A crude breadboard instrument was constructed and tested. The design for this breadboard was based on an initial, hurried design study which included recommendations for component hardware, and which was later verified by a more detailed study conducted by TRW Systems Group. A typical breadboard device is shown in Figure 8-43. The units consist of solid state light source, a solid state detector, source and detector optics, an optical filter in the detector channel, appropriate driver and signal processing electronics and a mechanical structure to properly contain and orient the components.

Two versions of the initial device were built, the first using a novel (but space-unqualified) double heterostructure GaAs solid state laser, capable of operation at peak powers of several hundred milliwatts with microsecond pulses at duty cycles of 5 to 10%q and a second using a space-qualified, high powered GaAs light emitting diode. Both units used a silicon PIN photodiode as a detector. Appropriate electronics using synchronous detection techniques were developed and tested. In this mode of operation, the detector output only contributes to the output of the detector when the light source is pulsed. It is, thus, possible to use the output of the detector when the light source is off as a measure of the ambient light striking the detector. This feature was also built into the design.

The first breadboard was crudely tested on the laboratory bench by mapping out the extent of the sampling volume and attempting to use targets with roughly known scattering cross-sections and a bench type of small fog chamber. It was then tested in a better defined fog environment in the fog chamber at the University of California, Richmond Field Site. Figure 8-44 shows such a test in progress. The instrument is attached to a boom ahead of the cab vehicle and is then "flown" into a pre-calibrated fog of known characteristics. In another type of test,

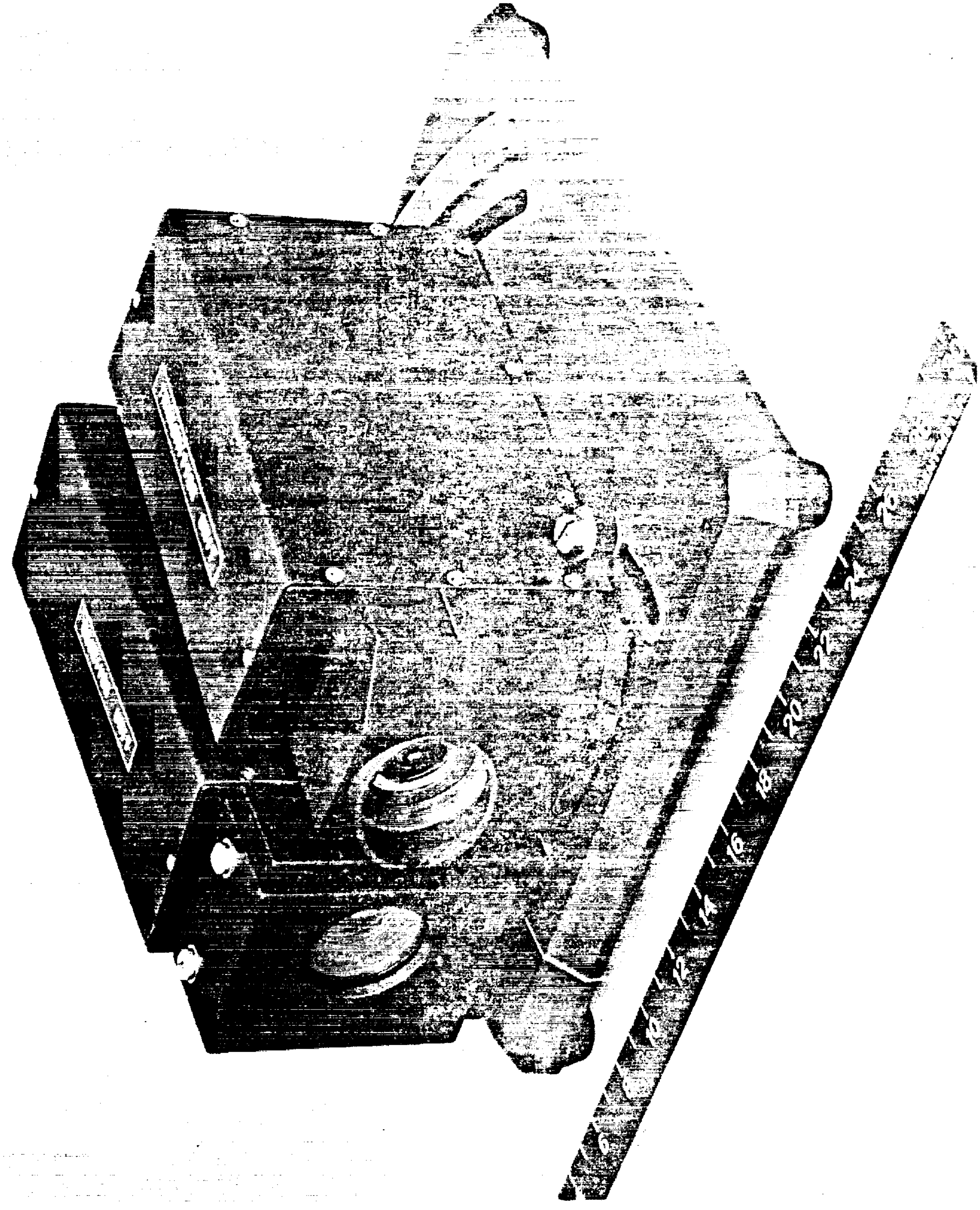

Figure 8-43

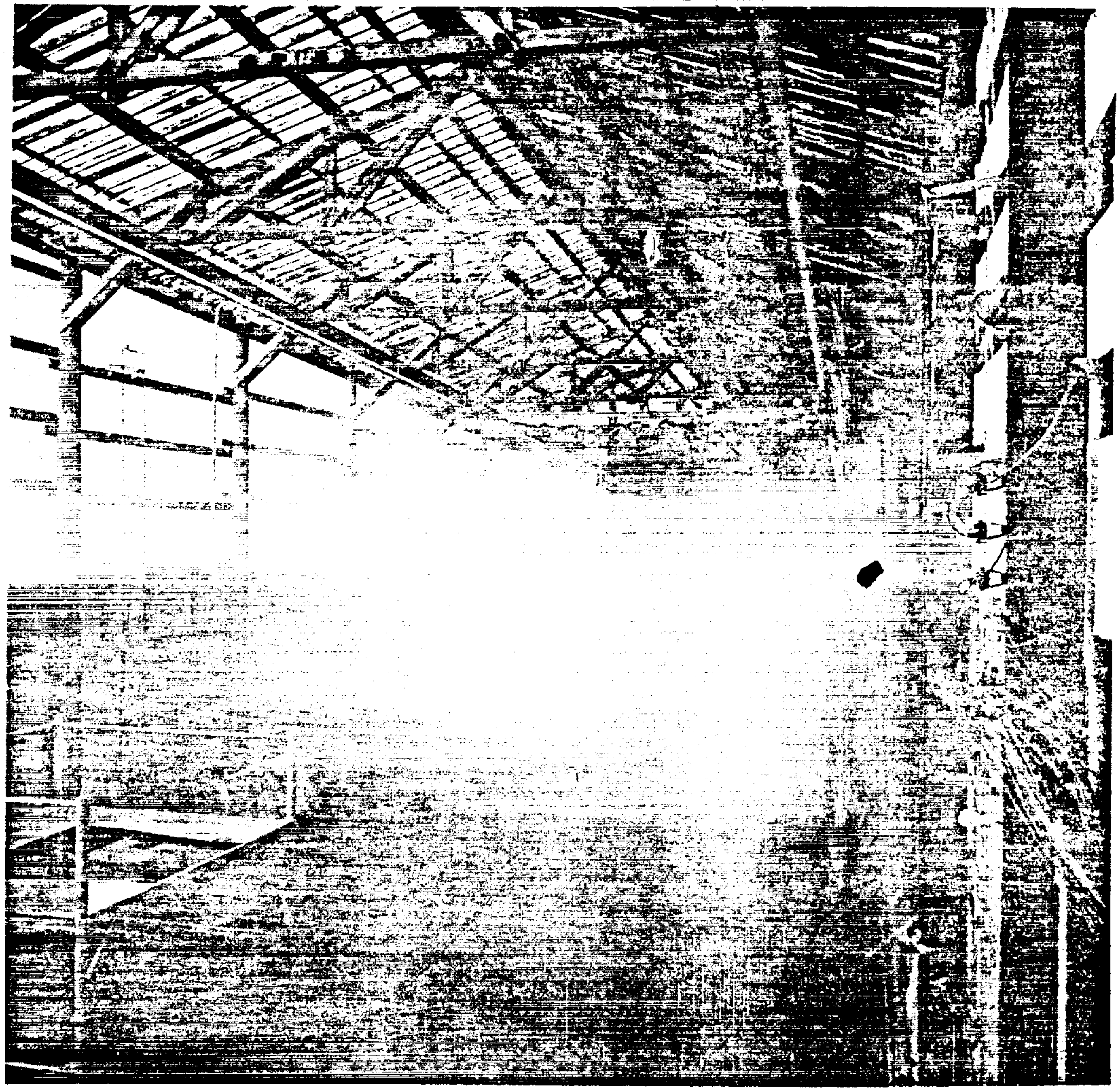

Figure 8-44

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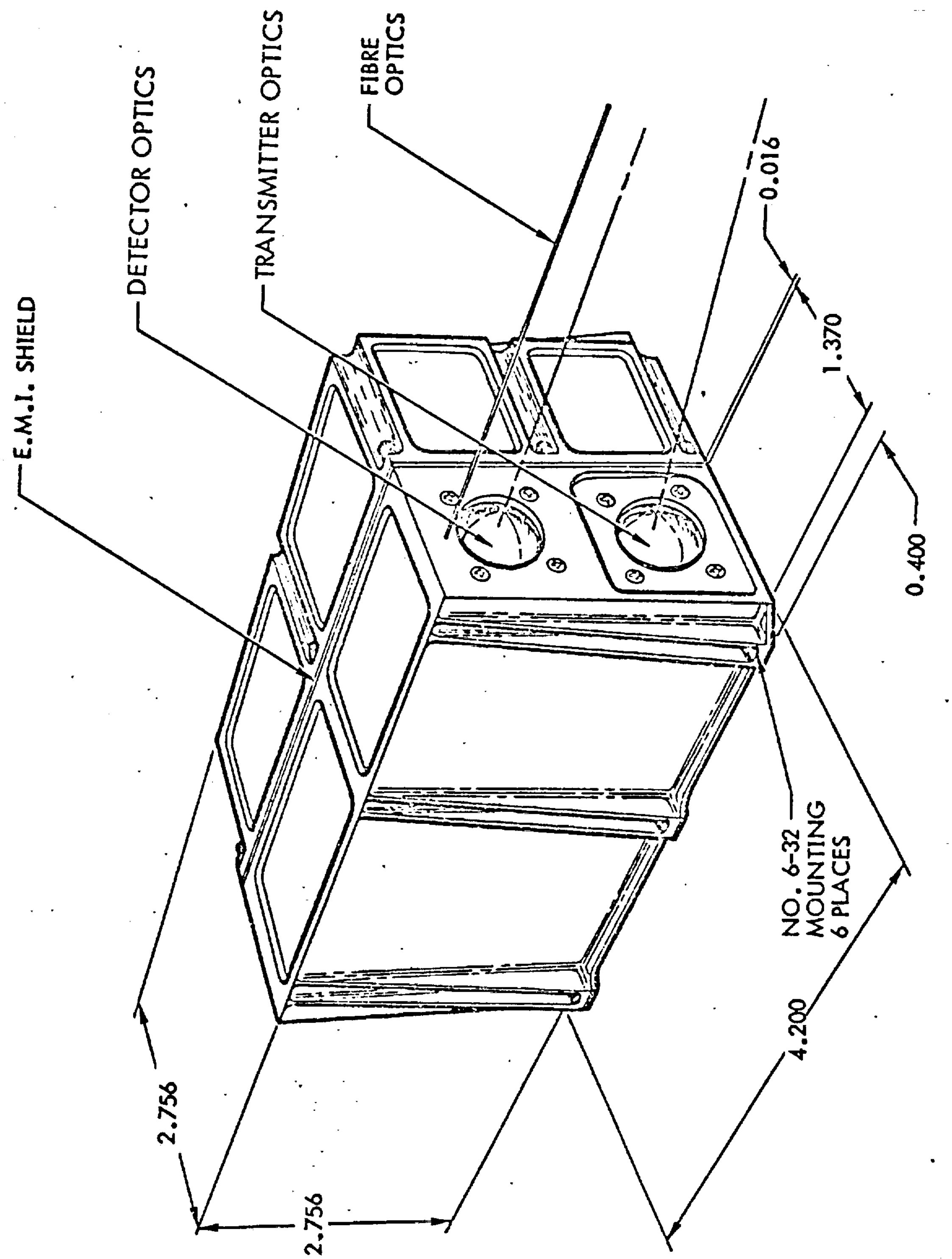
the unit was mounted on the top of an automobile and driven through a naturally occurring fog on the Northern California Coast.

The breadboard model constructed by TRW was the result of a much more extensive study than our early one and involved careful consideration of the optical design, component selection, component performance and component environmental tests, the electronics system design, and mechanical design. Actual cloud measurements using this unit are now being planned in conjunction with a Colorado State University Flight Research aircraft which has been instrumented for cloud and other atmospheric measurements. We also hope to fly this breadboard on the same flights with an instrument being developed for particle size analysis on the Pioneer-Venus large probe. We hope to fly these tests in June and July.

Finally, the specific implementation of such a nephelometer for use aboard the Pioneer-Venus small probes was considered. Packaging, including minimization of weight and volume, power, monitoring of major components and window conditions, data formatting and other necessary parameters were carefully considered. A concept of the final flight package is shown in Figure 8-45. Because there must be a very intimate interfacing of our instrument with the probe window structure to be provided by the probe contractor, the final design, especially of the interfaces, must await final decisions on probe configurations.

I also wish to mention that in this experimental package, we have incorporated a small subsidiary experiment. We have added two additional off-axis detectors and filters to the detector package. These will be used to measure the ambient light level in ultraviolet and visible spectral regions in order to provide some data on the optical thickness of the atmosphere at these wavelengths. Mariner 10 pictures and Earth-based observations have indicated upper atmospheric structural features, but showed none in the visible.



PIONEER VENUS NEPHELOMETER

Figure 8-45

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The design status of the instrument, as compared with the originally drawn set of requirements, is shown in Figure 8-46. The weight and power are somewhat larger than our original estimates, but are subject to possible downward revision, depending on probe interfacing questions.

Figure 8-46. Nephelometer Design Status

Quantity	Requirement	Status	Determined by
Weight	454 grams	600 grams	Packaging Design and Analysis
Volume	524 cm^3	524 cm^3	Packaging Design and Analysis
Power	1 watt (ave)	1.33 watts (ave)	Analysis
Data Transmission Rate	≤ 16 bps (large probe)	16 bps (large probe)	Design
	≤ 16 bps above 30 km (small probe)	16 bps above 30 km (small probe)	
	≤ 4 bps below 30 km (small probe)	4 bps below 30 km (small probe)	
Internal Calibration	Must check instrument calibration during entry	Relative calibration of all detectors and LED source strength checked approximately every 10 minutes	Design

Figure 8-46 **Nephelometer Design Status (Continued)**

Backscatter Channel

Quantity	Requirement	Status	Determined by
Least Count	$\leq$ 10%	< 10%	Design of Coding Schema
Signal/Electronics Noise	> 1 for 3 particles/cm^3 1.1μ radius, n = 1.45 (high altitude haze layer)	$\geq$ 1.07 ~ 0.8	Analysis Test*
	>> 1 for 700 particles/cm 1.1μ radius, n = 1.45 (visible cloud tops)	$\geq$ 251 ~ 180	Analysis Test*
Signal/Particle Shot Noise	> 1 for 3 particles/cm 1.1μ radius, n = 1.45, unattenuated sunlight (high altitude haze layer)	> 1 for at least 1/2 of the azimuth	Analysis
Background/Signal	< 10^6 (limited by saturation of detector)	< 10^6 for at least 2/3 of the azimuth	Analysis
Dynamic Range	Detector: 10^6 Backscatter Channel: 10^5	> 10^6 10^5	Test Design of Data Processing System, Test
Altitude Resolution	$\leq$ 300 meters	< 300 meters	Selection of Sampling Rates

Figure 8-46. Nephelometer Design Status
(continued)

Background Channels

Quantity	Requirement	Status	Determined by
Wavelengths	Near UV	3200 Å to 3900 Å	Absorption Corning Glass 7-37
	Visible	4600 Å to 5900 Å	Filter Selection Corning Glass 4-64
	Near IR (if possible)	Eliminated	Trade-off of Science Return Vs. Weight, Volume, and power penalties

Monitor Channels

Window Contamination	Must monitor optical quality of windows	Cleanliness of LED window monitored	Design*
Temperatures	Must monitor temperatures of critical components	Monitor three temperatures corresponding to detector block, LED heat sink, preamplifiers	Design

*Two different techniques for monitoring window contamination have been proposed. The technique used in the flight instrument will be determined, in part, by the spacecraft contractor.