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March 8, 1983

Copy of Letter Sent To:
Henry Buijs
Dan LaPorte
Dave Murcray

Subject: HIS Aircraft Instrument Requirements Document

The enclosed HIS Aircraft Instrument Requirements Document is being sent for your review and comment. We have attempted to incorporate all the requirements that are known and settled at this time. We have also included our best guesses for requirements that are less well known, as well as indicating by TBD or blank paragraphs those that are not at all defined at this time. It is not always obvious into which catagory a particular requirement falls so it is important in this initial review to comment on any requirement that does not agree with your understanding of the proposed instrument. It is also important to note areas that have been omited, but which must be defined.

Please review the entire document, but give special attention to the areas most closely associated with the activity that represents your contribution to the program. We have attempted to provide some information even in those areas that will be primarily supplied by you. Please do not regard any of these requiements as fixed since they only represent our present understanding which may be flawed.

This document is, I emphasize, very preliminary. We wanted to get something out as quickly as possible to document our understanding of the results of the recent meeting and to stimulate your thinking with regard to your "unsolicited proposals" which we are looking forward to receiving soon. We hope to have updates of the document as new information becomes available. The document should be fairly complete by the time of PDR.

Sincerely,

Evan E. Richards

Evan E. Richards
HIS Instrument Manager

Dist: F. Best (SSEC)
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HIGH-RESOLUTION INTERFEROMETER SOUNDER (HIS) AIRCRAFT EXPERIMENT REQUIREMENTS DOCUMENT

Space Science and Engineering Center
University of Wisconsin-Madison

SSEC 4444-01

March 1983

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 SCOPE

This requirements document describes the HIS aircraft instrument performance, functional, operational, interface, and support requirements in sufficient detail to provide design definition.

NOTE: This document is preliminary. The purpose of this issue of the document is to identify all of the areas which will eventually require definition and to include as much as is known at this time. Many requirements are stated as defined but may only represent a "best guess". The reviewer should feel free to critique all requirements and to suggest additional areas that need to be included. This document will be updated as new information is received and as requirements become better defined. The goal is to have a reasonably complete document for PDR.

1.2 APPLICABLE DOCUMENTS

The following documents form part of this document to the extent referenced herein:

SBRC Systems Design and Performance Analyses for the HIS Aircraft Experiment (in preparation)

SBRC Optics Design for the HIS Aircraft Experiment (in preparation)

The HIS Experiment BOMEM Interferometer: Reference Manual (in preparation)

Documentation of the University of Denver Flight Recorder, including ground computer and housekeeping data interfaces (being assembled)

Documentation of the University of Denver Ground Support Equipment Design (being assembled)

U-2 Investigators Handbook, Volumes 1 and 2

U-2 Pod Interface for University of Denver Experiment (from Lockheed)

The following documents provide additional detailed information but are not formally included as part of this requirements document. In case of conflict between the following document and this document, this document shall take precedence:

TBD

1.3 GLOSSARY AND ACRONYM LIST

The following is a list of definitions for terms, abbreviations, and acronyms used in the HIS Aircraft Experiment Program. As a minimum, this list is intended to include all definitions of terms, acronyms, and abbreviations used in this document.

A/C	Aircraft
AMTS	Advanced Moisture and Temperature Sounder
EGSE	Electrical Ground Support Equipment
FOV	Field-of-view
GOES	Geosynchronous Orbiting Earth Satellite
GSE	Ground Support Equipment
HIS	High-resolution Interferometer Sounder
LEO	Low Earth Orbit
LHe	Liquid helium
LN_2	Liquid nitrogen
MGSE	Mechanical Ground Support Equipment
NEN	Noise equivalent radiance
nm	Nautical mile
OPD	Optical path difference
Sr	Steradian
TBD	To be determined
TBS	To be specified
ZPD	Zero path difference

2.0 EXPERIMENT SUMMARY

This section gives a general description of all aspects of the aircraft experiment, from the basic performance goals to the steps involved in data processing. It provides the basis for the more specific hardware requirements and design criteria presented in subsequent sections.

2.1 OBJECTIVES

The primary objective of the aircraft experiment is to demonstrate the feasibility of the HIS approach to improving the vertical resolution of geosynchronous temperature soundings.

The HIS conceptual design for geosynchronous applications is described in the SSEC proposal to NASA dated May 1981. Briefly, the design uses a scanning Michelson interferometer to obtain broad spectral coverage, high spectral resolution, and low noise with a compact instrument design. The basic interferometer design uses the following techniques developed by Henry Buijs at BOMEM, Inc., Quebec:

- An auto-alignment system to reduce Michelson mirror alignment errors by two orders of magnitude.
- Laser rate sampling (oversampling) to reduce sensitivity to scan mirror velocity variations, and
- on-board processing to reduce data volume.

In addition, the GOES design allows the time required for high vertical resolution temperature soundings to be reduced substantially using "optimum sampling". The optimum sampling concept is that the time spent sampling a given region of optical path difference (delay) should vary depending on the amount of atmospheric temperature information it contains. In the 15 micron CO_2 band, temperature sounding information is concentrated in narrow regions of delay, and simulations show that concentrating sampling time in these regions can reduce the time required for each sounding by about a factor of 7. To accomplish optimum sampling, the interferometer mirror scanning mechanism and position sensor were designed to allow programmable distribution of the number of scans in selected regions of delay.

The two major aspects of the design approach which are to be demonstrated by the aircraft experiment are

- The capability for an interferometer with spectral coverage of most of the region from 600~~0~~ to 2500 cm-1 and a spectral resolution of up to 0.5 cm-1 to operate as an accurate radiometer without the effective noise and calibration errors being dominated by interferometer induced errors, and

- The optimum sampling concept.

The performance of the hardware designed to perform optimum scanning will be demonstrated in a laboratory interferometer at the Santa Barbara Research Center (SBRC), and will not be included in the aircraft instrument.

The other objective of the HIS aircraft experiment is to collect high spectral resolution data sets for the evaluation of alternative instrument approaches to spacecraft sounding and for studies of mesoscale weather phenomena. Therefore, in addition to meeting the HIS requirements, the aircraft instrument should have the spectral coverage, spectral resolution, and noise performance required for the Advanced Moisture and Temperature Sounder (AMTS).

2.2 PERFORMANCE GOALS

2.2.1 Spectral coverage and resolution

The requirements of the HIS geosynchronous orbiting earth satellite (GOES) instrument design and the AMTS low earth orbit (LEO) instrument design should be met.

The HIS GOES requirements are:

	Range (cm^{-1})	Apodized Resolution (cm^{-1})	Max. Delay (cm)
Band 1	620-750	0.7	1.40
Band 2	890-1510	4.2	0.24
Band 3	2180-2700	4.2	0.24

The AMTS baseline IV and V requirements are shown in Tables 2.2.1-1 and 2.2.1-2.

The baseline goal for the HIS aircraft instrument is:

	Range (cm^{-1})	Apodized Resolution (cm^{-1})	Max. Delay ** (cm)
Band 1	600-900	0.5	±2.00
Band 2	900-1800	1.0	±1.00
Band 3	1800-2700	1.5	±0.70

**The ± indicates scanning equidistant on both sides of zero delay. This is not planned for the GOES instrument, but will add useful diagnostic information for the aircraft experiment.

TABLE 2.2.1-1

AMTS BASELINE IV IR CHANNEL SET

Band	Channel	Channel Wavelength	Spectral Frequency	Half-power Spectral Resolution	Equivalent Scene Temperature (K)			Molecular Constituents*	Main Channel Function
No.	No.	λ(μm)	$\upsilon(cm^{-1})$	$\Delta\upsilon(cm^{-1})$	T_{min}	T_{std}	T_{max}		
1	1	16.476	606.95	0.50	230	263.83	286	CO_2, N_2O, H_2O, O_3	CLOUD FILTERING
	2	16.046	623.20	0.50	229	260.15	283		
	3	15.929	627.80	0.50	218	236.51	260		
	4	15.765	634.30	0.50	211	226.46	256	CO_2, O_3, H_2O, N_2O	TEMPERATURE PROFILES (Stratosphere and upper troposphere)
	5	15.466	646.60	0.50	202	219.66	248		
	6	15.282	654.35	0.50	195	219.68	255		
	7	15.025	665.55	0.50	197	222.69	266		
	8	14.996	666.85	0.50	194	223.38	279		
	9	14.967	668.15	0.50	198	254.00	300		
	10	14.938	669.45	0.50	199	233.04	285		
2	11	9.606	1041.00	1.00	198	256.26	290	O_3, CO_2, H_2O	OZONE LOADING
	12	8.313	1203.00	1.00	231	285.42	327	N_2O, H_2O	H_2O WINDOW
	13	8.118	1231.80	1.00	231	285.40	327		
3	14	5.437	1839.40	1.50	232	259.32	282	H_2O, N_2O, CO_2	HUMIDITY PROFILES
	15	5.422	1844.50	1.50	212	228.25	249		
	16	5.403	1850.90	1.50	233	266.90	289		
	17	5.292	1889.57	1.50	220	240.40	263		
	18	5.181	1930.10	1.50	232	280.28	315	H_2O, N_2O, CO_2	SURFACE HUMIDITY
4	19	4.195	2384.00	2.00	214	229.56	274	CO_2, H_2O	TEMPERATURE PROFILES (low troposphere)
	20	4.191	2386.10	2.00	222	240.97	299		
	21	4.187	2388.20	2.00	229	254.69	313		
	22	4.184	2390.20	2.00	231	265.88	321		
	23	4.180	2392.35	2.00	232	273.30	325		
	24	4.176	2394.50	2.00	232	276.20	326		
	25	4.125	2424.00	2.50	232	281.38	331	N_2O, CO_2, H_2O	AIR-SURFACE ΔT
	26	3.992	2505.00	2.50	232	285.22	342	N_2O, CH_4, H_2O	SURFACE TEMPERATURE
	27	3.821	2616.50	2.50	232	286.57	354		
	28	3.723	2686.00	2.50	232	286.53	364		

* In order of decreasing line strengths

TABLE 2.2.1-2

AMTS BASELINE V IR CHANNEL SET

Band	Channel	Channel Wavelength	Spectral Frequency	Half-power Spectral Resolution	Equivalent Scene Temperature (K)			Molecular Constituents*	Main Channel Function
No.	No.	λ(μm)	$\upsilon(cm^{-1})$	$\Delta\upsilon(cm^{-1})$	T_{min}	T_{std}	T_{max}		
1	1	16.476	606.95	0.50	230	263.83	286	CO_2, N_2O, H_2O, O_3	CLOUD FILTERING
	2	16.046	623.20	0.50	229	260.15	283		
	3	15.929	627.80	0.50	218	236.51	260		
	4	15.765	634.30	0.50	211	226.46	256	CO_2, O_3, H_2O, N_2O	TEMPERATURE PROFILES (Stratosphere and upper troposphere)
	5	15.466	646.60	0.50	202	219.66	248		
	6	15.282	654.35	0.50	195	219.68	255		
	7	15.025	665.55	0.50	197	222.69	266		
	8	14.996	666.85	0.50	194	223.38	279		
	9	14.967	668.15	0.50	198	254.00	300		
	10	14.938	669.45	0.50	199	233.04	285		
	11		875.0	0.75				H_2O	Sea surf. T.
	12		1040.8	1.00	198	256.26	290	O_3, CO_2, H_2O	Ozone loading
	13		1231.6	1.00	231	285.40	327	N_2O, H_2O	Sea surf. T
	14		1650.1	1.50					
	15		1700.3	1.50					
	16		1839.4	1.50	232	259.32	282	H_2O, N_2O, CO_2	Humidity profiles
	17		1850.9	1.50	233	266.90	289		Humidity profiles
	18	5.181	1930.10	1.50	232	280.28	315	H_2O, N_2O, CO_2	SURFACE HUMIDITY
4	19	4.195	2384.00	2.00	214	229.56	274	CO_2, H_2O	TEMPERATURE PROFILES (low troposphere)
	20	4.191	2386.10	2.00	222	240.97	299		
	21	4.187	2388.20	2.00	229	254.69	313		
	22	4.184	2390.20	2.00	231	265.88	321		
	23	4.180	2392.35	2.00	232	273.30	325		
	24	4.176	2394.50	2.00	232	276.20	326		
	25	4.125	2424.00	2.50	232	281.38	331	N_2O, CO_2, H_2O	AIR-SURFACE ΔT
	26	3.992	2505.00	2.50	232	285.22	342	N_2O, CH_4, H_2O	SURFACE TEMPERATURE
	27	3.821	2616.50	2.50	232	286.57	354		
	28	3.723	2686.00	2.50	232	286.53	364		

* In order of decreasing line strengths

2.2.2 Telescope Field-of-view

The baseline angular field-of-view is 100 mr diameter.

The basis for this choice is qualitative . It gives a 2 km diameter spot size on the ground for an aircraft altitude of 70,000 feet. This should be small enough to provide cloud-free fields-of-view under many weather conditions and is large enough that the scene motion during a single scan (from zero to a maximum delay of 2 cm) is only 11% of the instantaneous field-of-view for a delay scan rate of 2 cm/sec and an aircraft speed of 440 knots.

2.2.3 Michelson mirror scan rate

The baseline optical path difference (OPD) scan rate is 2 cm/sec.

The primary performance consideration influencing the choice of scan rate is scene motion. As mentioned above, the baseline choice gives a nominal scene motion of 11% of a field-of-view during a single scan. The minimum acceptable scan rate for different scene characteristics will be investigated using the aircraft instrument. As discussed in Section 2.3, the aircraft design incorporates a BOMEM field model DA2.02 interferometer, for which the scan rate is switch selectable in the range from 0.02 to 9.2 cm/sec. The advantage of a slower scan rate is the reduced data volume requirement.

2.2.4 Interferometer field-of-view

TBD

For the aircraft instrument the angular field-of-view of the telescope (100 mr) is so much larger than that for the GOES instrument design (0.28 mr) that a different design criterion comes into play.

For the GOES instrument the energy throughput (the area solid-angle product) of the instrument is limited by the area of the telescope. The field-of-view of the interferometer required to match the interferometer throughput to the telescope throughput is quite small (14 mr) for practical interferometer mirror sizes. Therefore, there is no reason to make the interferometer field-of-view large enough that it reduces the fringe modulation of the interferometer (a finite field-of-view causes reduced modulation of an interferogram for a monochromatic source, because the delay for a given scan mirror position varies with the source position in the scene).

However, for the aircraft instrument with an interferometer area determined by the existing (or somewhat modified) BOMEM design, the throughput of the instrument is limited by the interferometer field-of-view. If the field-of-view becomes too large, the reduced fringe modulation of the interferometer causes calibration errors because the instrument response function becomes dependent on delay as well as wavenumber.

Therefore, the interferometer field-of-view is a critical performance parameter for the aircraft instrument. If a small value like the 14 mr (full angle) of the GOES design is used, the throughput of the instrument may be too small for desired noise and dwell time performance goals to be met economically. However, increasing the angular field-of-view by a factor of 2 or 3 has a large performance impact. The throughput is directly dependent on the square of the angular field-of-view of the interferometer, and if the f/# of the aft optics detector lens is assumed to be fixed, the dwell time to achieve a given noise equivalent radiance (NEN) is inversely proportional to the square of the angular FOV.

Preliminary calculations indicate that an angular field-of-view of 30 mr will probably turn out to be a reasonable compromise.

2.2.5 Calibration

Systematic errors in the brightness temperature corresponding to an atmospheric radiance measurement should be less than 1° C (1°is roughly equivalent to a radiance error of 1% in band 1, 2% in band 2, and 4% in band 3).

The reproducibility of the brightness temperature for a measurement should be ±0.1 degree C. This calibration goal is not meant to include the effect of radiometric noise (rapid variations with zero mean), which can be reduced by increasing the sampling time.

The interferometer introduces some different sources of calibration error from those normally encountered with a radiometer (e.g., calibration source temperature and emissivity uncertainties, detector and electronics linearity). The new error sources include,

- residual dispersion from imperfect beamsplitter compensation,
- deviations of the phase response of the analog electronics from a linear frequency dependence
- internal reflections off instrument windows and stops causing stray radiation to make two passes through the interferometer,
- non-flatness of the optical components, and
- field-of-view fringe modulation.

The first two sources of error cause the zero of delay to be wavenumber dependent and are design considerations for the beamsplitter and for the analog electronics. With careful design, their effects can probably be made acceptably small using standard techniques for phase correction in the data analysis. The third and fourth error sources can be made sufficiently small by proper optical design. The last error source can be made small by restricting the interferometer field-of-view.

2.2.6 Calibration frequency

Every 5 to 10 minutes.

This goal constrains the temperature and temperature stability of the optical stops which determine the stability of the self-emission from the instrument.

2.2.7 Detector noise

The noise equivalent radiance (NEN) requirements of the HIS GOES design and of the AMTS LEO design should be achievable with the aircraft instrument by averaging the scans for a 10 km ground swath. This is equivalent to a dwell time of about 45 seconds.

The following HIS GOES requirements are the noise equivalent radiances (NEN) used in retrieval simulations and are equal to the expected performance of the conceptual design:

Spectral range * (cm^{-1})	NEN (mW/m^2 sr cm^{-1})
601-770	0.014 **
890-1510	0.03
2180-2525	0.003

* Spectral range used in simulations
** NEN required to get the optimum scanning noise level in the CO2 resonance region centered at 1.3 cm delay.

The AMTS baseline IV requirements for random radiometric error is given in Table 2.2.7-1. The range of NEN values for different atmospheric temperatures and for different value of NEΔT is quite large. Table 2.2.7-2 gives a set of NEN's (for minimum atmospheric temperatures Tmin and a constant NEΔT = 0.3 K) which will be assumed as baseline goals for the aircraft HIS when they are more stringent than the HIS GOES requirements. AMTS requirements exceed the HIS requirements primarily in band 3.

The baseline goal for the HIS aircraft instrument is to achieve the following NEN's for a dwell time of 45 sec:

wavenumber (cm^{-1})	NEN (mW/m^2 sr cm^{-1})	wavenumber (cm^{-1})	NEN (mW/m^2 sr cm^{-1})
600	0.014	1800	0.005
700	0.014	1900	0.007
800	0.014	2000	0.005
900	0.030	2100	0.003
1000	0.030	2200	0.003
1100	0.030	2300	0.0004
1200	0.030	2400	0.0010
1300	0.030	2500	0.0007
1400	0.030	2600	0.0004
1500	0.030	2700	0.0003
1600	0.020		
1700	0.010		

TABLE 2.2.7-1

AMTS REQUIREMENT ON RANDOM ERRORS
RADIOMETRIC VALUES AS A FUNCTION OF EQUIVALENT TARGET TEMPERATURE AND NOISE EQUIVALENT ΔT

Band	CH	CH Wavelength λ (μm)	Spectral Frequency ν (cm^{-1})	CH-1/2 power Bandwidth $\Delta\nu_{1/2}$ (cm^{-1})	Equivalent Target Temperature			FOR T_{min}					FOR T_{std}					FOR T_{max}				
									NEΔT = .1K		NEΔT = .5K			NEΔT = .1K		NEΔT = .5K			NEΔT = .1K		NEΔT = .5K	
					T_{min} (K)	T_{std} (K)	T_{max} (K)	$N\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	$NEN\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	$NEN\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	$N\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	$NEN\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	$NEN\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	$N\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	$NEN\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	$NEN\nu$ $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR
	1	16.476	606.95	0.50	230	263.83	286	6.11×10^{-6}	1.03×10^{-8}	592	5.17×10^{-8}	118	1.01×10^{-5}	1.31×10^{-8}	768	6.58×10^{-8}	153	1.32×10^{-5}	1.48×10^{-8}	892	7.40×10^{-8}	178
	2	16.046	623.20	0.50	229	260.15	283	5.86×10^{-6}	1.02×10^{-8}	573	5.12×10^{-8}	114	9.48×10^{-6}	1.30×10^{-8}	731	6.50×10^{-8}	146	1.27×10^{-5}	1.48×10^{-8}	855	7.41×10^{-8}	171
	3	15.929	627.80	0.50	218	236.51	260	4.75×10^{-6}	9.18×10^{-9}	518	4.60×10^{-8}	103	6.61×10^{-6}	1.09×10^{-8}	605	5.47×10^{-8}	121	9.42×10^{-6}	1.30×10^{-8}	725	6.51×10^{-8}	145
	4	15.765	634.30	0.50	211	226.46	256	4.08×10^{-6}	8.47×10^{-9}	481	4.24×10^{-8}	96	5.50×10^{-6}	9.97×10^{-9}	552	4.99×10^{-8}	110	8.85×10^{-6}	1.27×10^{-8}	698	6.35×10^{-8}	139
1	5	15.466	646.60	0.50	202	219.66	248	3.25×10^{-6}	7.49×10^{-9}	434	3.76×10^{-8}	87	4.73×10^{-6}	9.26×10^{-9}	511	4.64×10^{-8}	102	7.74×10^{-6}	1.20×10^{-8}	645	6.01×10^{-8}	129
	6	15.282	654.35	0.50	195	219.68	255	2.69×10^{-6}	6.72×10^{-9}	400	3.37×10^{-8}	80	4.66×10^{-6}	9.22×10^{-9}	505	4.62×10^{-8}	101	8.53×10^{-6}	1.27×10^{-8}	673	6.34×10^{-8}	134
	7	15.025	665.55	0.50	197	222.69	266	2.74×10^{-6}	6.82×10^{-9}	402	3.42×10^{-8}	80	4.83×10^{-6}	9.46×10^{-9}	511	4.74×10^{-8}	102	9.86×10^{-6}	1.37×10^{-8}	718	6.87×10^{-8}	143
	8	14.996	666.85	0.50	194	223.38	279	2.53×10^{-6}	6.50×10^{-9}	389	3.26×10^{-8}	78	4.88×10^{-6}	9.52×10^{-9}	513	4.47×10^{-8}	102	1.17×10^{-5}	1.49×10^{-8}	785	7.47×10^{-8}	157
	9	14.967	668.15	0.50	198	254.00	300	2.79×10^{-6}	6.90×10^{-9}	404	3.46×10^{-8}	81	8.26×10^{-5}	1.26×10^{-8}	656	6.31×10^{-8}	131	1.50×10^{-5}	1.67×10^{-8}	898	8.37×10^{-8}	179
	10	14.938	669.45	0.50	199	233.04	285	2.85×10^{-6}	6.99×10^{-9}	408	3.50×10^{-8}	81	5.82×10^{-6}	1.05×10^{-8}	555	5.26×10^{-8}	111	1.26×10^{-5}	1.55×10^{-8}	814	7.74×10^{-8}	163
	11	9.606	1041.00	1.00	198	256.26	290	6.97×10^{-7}	2.67×10^{-9}	261	1.34×10^{-8}	52	3.90×10^{-6}	8.93×10^{-9}	437	4.48×10^{-8}	87	7.72×10^{-6}	1.38×10^{-8}	558	6.93×10^{-8}	111
2	12	8.313	1203.00	1.00	231	285.42	327	1.16×10^{-6}	3.75×10^{-9}	308	1.89×10^{-8}	61	4.83×10^{-6}	1.03×10^{-8}	469	5.16×19^{-8}	94	1.05×10^{-5}	1.70×10^{-8}	614	8.54×10^{-8}	123
	13	8.118	1231.80	1.00	231	285.40	327	1.04×10^{-6}	3.45×10^{-9}	301	1.73×10^{-8}	60	4.48×10^{-6}	9.78×10^{-9}	458	4.90×10^{-8}	91	9.90×10^{-6}	1.65×10^{-8}	600	8.26×10^{-8}	120
	14	5.437	1839.40	1.50	232	259.32	282	8.24×10^{-8}	4.06×10^{-10}	203	2.05×10^{-9}	40	2.74×10^{-7}	1.08×10^{-9}	254	5.43×10^{-9}	50	6.23×10^{-7}	2.07×10^{-9}	300	1.04×10^{-8}	60
	15	5.422	1844.50	1.50	212	228.25	249	2.74×10^{-8}	1.62×10^{-10}	169	8.18×10^{-10}	33	6.67×10^{-8}	3.40×10^{-10}	196	1.72×10^{-9}	39	1.76×10^{-7}	7.53×10^{-10}	233	3.79×10^{-9}	46
3	16	5.403	1850.90	1.50	233	266.90	289	8.21×10^{-8}	4.04×10^{-10}	203	2.30×10^{-9}	40	3.51×10^{-7}	1.31×10^{-9}	267	6.60×10^{-9}	53	7.52×10^{-7}	2.40×10^{-9}	313	1.21×10^{-8}	62
	17	5.292	1889.57	1.50	220	240.40	263	3.45×10^{-8}	1.94×10^{-10}	178	9.81×10^{-10}	35	9.85×10^{-8}	4.64×10^{-10}	212	2.34×10^{-9}	42	2.60×10^{-7}	1.03×10^{-9}	254	5.16×10^{-9}	50
	18	5.181	1930.10	1.50	232	280.28	315	5.22×10^{-8}	2.80×10^{-10}	193	1.41×10^{-9}	38	4.27×10^{-7}	1.51×10^{-9}	282	7.59×10^{-9}	56	1.27×10^{-6}	3.56×10^{-9}	357	1.79×10^{-8}	71
	19	4.195	2384.00	2.00	214	229.56	274	1.77×10^{-9}	1.33×10^{-11}	133	6.72×10^{-11}	26	5.23×10^{-9}	3.41×10^{-11}	153	1.73×10^{-10}	30	5.90×10^{-8}	2.70×10^{-10}	218	1.36×10^{-9}	43
	20	4.191	2386.10	2.00	222	240.97	299	3.11×10^{-9}	2.17×10^{-11}	143	1.10×10^{-10}	28	1.05×10^{-8}	6.23×10^{-11}	169	3.15×10^{-10}	33	1.67×10^{-7}	6.42×10^{-10}	260	3.23×10^{-9}	52
	21	4.187	2388.20	2.00	229	254.69	313	4.94×10^{-9}	3.24×10^{-11}	152	1.64×10^{-10}	30	2.24×10^{-8}	1.19×10^{-10}	188	6.01×10^{-10}	37	2.77×10^{-7}	9.73×10^{-10}	285	4.89×10^{-9}	57
	22	4.184	2390.20	2.00	231	265.88	321	5.57×10^{-9}	3.60×10^{-11}	155	1.82×10^{-10}	31	3.93×10^{-8}	1.91×10^{-10}	205	9.65×10^{-10}	41	3.62×10^{-7}	1.21×10^{-9}	299	6.08×10^{-9}	60
4	23	4.180	2392.35	2.00	232	273.30	325	5.87×10^{-9}	3.77×10^{-11}	156	1.90×10^{-10}	31	5.53×10^{-8}	2.55×10^{-10}	217	1.29×10^{-9}	43	4.10×10^{-7}	1.34×10^{-9}	306	6.72×10^{-9}	61
	24	4.176	2394.50	2.00	232	276.20	326	5.81×10^{-9}	3.73×10^{-11}	156	1.89×10^{-10}	31	6.26×10^{-8}	2.83×10^{-10}	221	1.43×10^{-9}	44	4.21×10^{-7}	1.37×10^{-9}	308	6.86×10^{-9}	61
	25	4.125	2424.00	2.50	232	281.38	331	5.02×10^{-9}	3.26×10^{-11}	154	1.65×10^{-10}	30	7.02×10^{-8}	3.10×10^{-10}	227	1.59×10^{-9}	45	4.50×10^{-7}	1.44×10^{-9}	314	7.21×10^{-9}	62
	26	3.992	2505.00	2.50	232	285.22	342	3.35×10^{-9}	2.25×10^{-11}	149	1.14×10^{-10}	29	6.09×10^{-8}	2.70×10^{-10}	225	1.36×10^{-9}	45	4.96×10^{-7}	1.53×10^{-9}	324	7.69×10^{-9}	64
	27	3.821	2616.50	2.50	232	286.57	354	1.91×10^{-9}	1.34×10^{-11}	143	6.80×10^{-11}	28	4.21×10^{-8}	1.93×10^{-10}	218	9.73×10^{-10}	43	5.14×10^{-7}	1.54×10^{-9}	332	7.76×10^{-9}	66
	28	3.723	2686.00	2.50	232	286.53	364	1.35×10^{-9}	9.69×10^{-12}	139	4.91×10^{-11}	27	3.20×10^{-8}	1.51×10^{-10}	212	7.62×10^{-10}	42	5.65×10^{-7}	1.65×10^{-9}	342	8.29×10^{-9}	68

2.4.12 Random radiometric error - The RMS (1σ) value of the random radiometric error due to all instrument error sources shall not exceed 0.5K NEΔT. As a design goal, this random radiometric error shall not exceed 0.1K NEΔT. Any variation in the absolute systematic radiometric error (Ref. Para. 2.4.13) within any 30-day period shall be considered to be a random radiometric error.

TABLE 2.2.7-2

AMTS NOISE GOALS FOR A/C HIS

		CH Wavelength λ	Spectral Frequency ν	CH-1/2 power Bandwidth $\Delta\nu_{1/2}$	Equivalent Target Temperature			FOR T_{min}					*
								$N\nu$	NEΔT = .1K		NEΔT = .5K		NEN
Band	CH	(μm)	(cm^{-1})	(cm^{-1})	T_{min} (K)	T_{std} (K)	T_{max} (K)	$\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	NENν $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	NENν $\left(\frac{W}{cm^2 \cdot Sr \cdot cm^{-1}}\right)$	SNR	(mW/m^2 SR cm^{-1})
	1	16.476	606.95	0.50	230	263.83	286	6.11 x10 $^{-6}$	1.03 x 10^{-8}	592	5.17 x 10^{-8}	118	.31
	2	16.046	623.20	0.50	229	260.15	283	5.86 x10 $^{-6}$	1.02 x 10^{-8}	573	5.12 x 10^{-8}	114	.31
	3	15.929	627.80	0.50	218	236.51	260	4.75 x10 $^{-6}$	9.18 x 10^{-9}	518	4.60 x 10^{-8}	103	.28
	4	15.765	634.30	0.50	211	226.46	256	4.08 x10 $^{-6}$	8.47 x 10^{-9}	481	4.24 x 10^{-8}	96	.25
1	5	15.456	646.00	0.50	202	219.66	248	3.25 x10 $^{-6}$	7.49 x 10^{-9}	434	3.76 x 10^{-8}	87	.23
	6	15.282	654.35	0.50	195	219.68	255	2.69 x10 $^{-6}$	6.72 x 10^{-9}	400	3.37 x 10^{-8}	80	.20
	7	15.025	665.55	0.50	197	222.69	266	2.74 x10 $^{-6}$	6.82 x 10^{-9}	402	3.42 x 10^{-8}	80	.21
	8	14.996	666.85	0.50	194	223.38	279	2.53 x10 $^{-6}$	6.50 x 10^{-9}	389	3.26 x 10^{-8}	78	.20
	9	14.967	668.15	0.50	198	254.00	300	2.79 x10 $^{-6}$	6.90 x 10^{-9}	404	3.46 x 10^{-8}	81	.21
	10	14.938	669.45	0.50	199	233.04	285	2.85 x10 $^{-6}$	6.99 x 10^{-9}	408	3.50 x 10^{-8}	81	.21
	11	9.606	1041.00	1.00	198	256.26	290	6.97 x10 $^{-7}$	2.67 x 10^{-9}	261	1.34 x 10^{-8}	52	.065
2	12	8.313	1203.00	1.00	231	285.42	327	1.16 x10 $^{-6}$	3.75 x 10^{-9}	308	1.89 x 10^{-8}	61	.113
	13	8.118	1231.80	1.00	231	285.40	327	1.04 x10 $^{-6}$	3.45 x 10^{-9}	301	1.73 x 10^{-8}	60	.104
	14	5.437	1839.40	1.50	232	259.32	282	8.24 x10 $^{-8}$	4.06 x 10^{-10}	203	2.05 x 10^{-9}	40	.012
	15	5.422	1844.50	1.50	212	228.25	249	2.74 x10 $^{-8}$	1.62 x 10^{-10}	169	8.18 x 10^{-10}	33	.0049
3	16	5.403	1850.90	1.50	233	266.90	289	8.21 x10 $^{-8}$	4.04 x 10^{-10}	203	2.30 x 10^{-9}	40	.012
	17	5.292	1889.57	1.50	220	240.40	263	3.45 x10 $^{-8}$	1.94 x 10^{-10}	178	9.81 x 10^{-10}	35	.0058
	18	5.161	1930.10	1.50	232	280.28	315	5.22 x10 $^{-8}$	2.80 x 10^{-10}	193	1.41 x 10^{-9}	38	.0084
	19	4.195	2384.00	2.00	214	229.56	274	1.77 x10 $^{-9}$	1.33 x 10^{-11}	133	6.72 x 10^{-11}	26	.00040
	20	4.191	2386.10	2.00	222	240.97	299	3.11 x10 $^{-9}$	2.17 x 10^{-11}	143	1.10 x 10^{-10}	28	.00065
	21	4.137	2388.20	2.00	229	254.69	313	4.94 x10 $^{-9}$	3.24 x 10^{-11}	152	1.64 x 10^{-10}	30	.00097
	22	4.184	2390.20	2.00	231	265.88	321	5.57 x10 $^{-9}$	3.60 x 10^{-11}	155	1.82 x 10^{-10}	31	.00108
4	23	4.180	2392.35	2.00	232	273.30	325	5.87 x10 $^{-9}$	3.77 x 10^{-11}	156	1.90 x 10^{-10}	31	.00113
	24	4.176	2394.50	2.00	232	276.20	326	5.81 x10 $^{-9}$	3.73 x 10^{-11}	156	1.89 x 10^{-10}	31	.00120
	25	4.125	2424.00	2.50	232	281.38	331	5.02 x10 $^{-9}$	3.26 x 10^{-11}	154	1.65 x 10^{-10}	30	.00098
	26	3.992	2505.00	2.50	232	285.22	342	3.35 x10 $^{-9}$	2.25 x 10^{-11}	149	1.14 x 10^{-10}	29	.00068
	27	3.821	2616.50	2.50	232	286.57	354	1.91 x10 $^{-9}$	1.34 x 10^{-11}	143	6.80 x 10^{-11}	28	.00040
	28	3.723	2686.00	2.50	232	286.53	364	1.35 x10 $^{-9}$	9.69 x 10^{-12}	139	4.91 x 10^{-11}	27	.00029

*NEN goal is taken to be $(0.3\ K)\ \partial B_\nu/\partial T)|_{T_{min}}$

2.2.8 Interferometric noise

Interferometric noise refers to interferometer-induced temporal signal variations with time constants small compared to the time for a single interferogram scan and with a mean value of zero. The level of interferometric noise should be smaller than the detector noise, except very close to zero delay. Near zero delay, where the rate of change of the signal with delay is large, small delay sampling noise can cause larger errors. The design goal for these errors near zero delay is 0.1% of the zero delay signal in band 1, 0.2% in band 2, and 0.4% in band 3.

Potential sources of interferometric noise are residual mirror alignment errors and sample position errors caused by scan mirror velocity variations or noise in the sampling trigger system.

2.3 INSTRUMENTATION

This section gives an overview of the total system. A detailed description of individual components and design criteria is given in section 3.0.

2.3.1 Approach

The instrument will be built around a commercially available interferometer, the BOMEM DA2.02 field model. Because the operating principles of this instrument are the same as those of the conceptual design for GOES, the aircraft experiment will be a test of the validity of the HIS approach for the spacecraft design. The basic characteristics of the interferometer are standard to all BOMEM interferometers, but as described in Section 3.3 some modifications will be made for this application. The assemblies necessary to convert the BOMEM interferometer into a calibrated radiometer will be designed and built at SSEC according to a systems design and detailed optical design provided by the Santa Barbara Research Center (SBRC).

The instrument will be flown on either the NASA U-2 or the ER-2. The normal flight altitude of these aircraft (65,000 feet) will provide a good environment for instrument operation, and is high enough to sample the ozone layer. The HIS instrument will be packaged to fit into the small wing pod as well as the large pod to provide as much flexibility in flight times as possible. The only aircraft electrical interface will be power and a pilot operated on/off switch. A data recorder will be included as part of the instrument package. Whenever possible the approach to interfacing the instrument to the pod will make use of the designs for a similar interface being completed at the University of Denver.

The experiment will yield high-resolution spectra covering the region from 600 to 2700 cm^{-1} (3.7 to 16.6 microns). Unlike the spacecraft design, the interferometer will scan in delay at a uniform rate over a fixed delay region covering both sides of zero delay. The validity of the optimum sampling approach proposed for GOES application will be demonstrated by analysis of the data. The hardware approach for optimum sampling will be demonstrated on the ground with a separate

BOMEM interferometer at SBRC. This approach will save time because it allows the aircraft demonstration and the optimum scanning hardware performance demonstration to be performed in parallel.

2.3.2 Functional Description of Subsystems

A system level block diagram is shown in Figure 2.3.2. The long - short dashed line surrounds the components of the field model BOMEM interferometer.

The scene radiance is shown entering the system from an aperture in the probe at the top of the diagram. A moveable plane mirror allows the instrument field-of-view to be switched from the scene to a hot or a cold blackbody for calibration. The input radiance is imaged and collimated by a telescope to produce a parallel beam as input to the interferometer.

The basic interferometer is a Michelson interferometer, composed of a beamsplitter/compensator and two plane mirrors. The beamsplitter/compensator amplitude divides the input beam into two separate beams and, after each is reflected from one of the plane mirrors, recombines them into a single parallel beam. One of the two plane mirrors is moved back and forth at a constant velocity to change the optical path difference (or delay) between the two beams. As optical path difference is scanned, interference between the two beams causes the radiance of the combined beam to vary. The variation of radiance with delay is called an interferogram and is the basic signal of the instrument.

Several subsystems are critical to the operation of the basic interferometer. A laser beam and a white light source are introduced into the center of the interferometer input beam and detected after exiting the interferometer. The laser provides a monochromatic source for which the output varies sinusoidally with delay. This signal is the basis for controlling the sampling of the interferogram at equal, precisely defined intervals of delay. The white light source provides an output signal with a large narrow peak at zero delay which is used to detect the absolute delay. The laser beam is also used by a plane mirror dynamic alignment system. The plane mirrors of the interferometer must be aligned such that at any instant the optical path difference is the same at all positions in the beam. An auto-alignment system is used to adjust the orientation of the fixed mirror to follow the small alignment variations of the moving mirror. Misalignments are detected as differences in the laser signal detected at three locations in the beam. A servo system changes the orientation of the mirror to dynamically reduce any differences.

The scene radiance emerging from the interferometer enters the aft optics which bring the beam to the detectors. The aft optics consist of relay optics to guide the beam away from the interferometer and to reduce its diameter, two partially silvered or dichroic beamsplitters to divide the beam into three separate beams (one for each spectral band), cold filters to restrict the spectral bandpass to each detector, and focusing optics to image the aperture stop on each detector. The

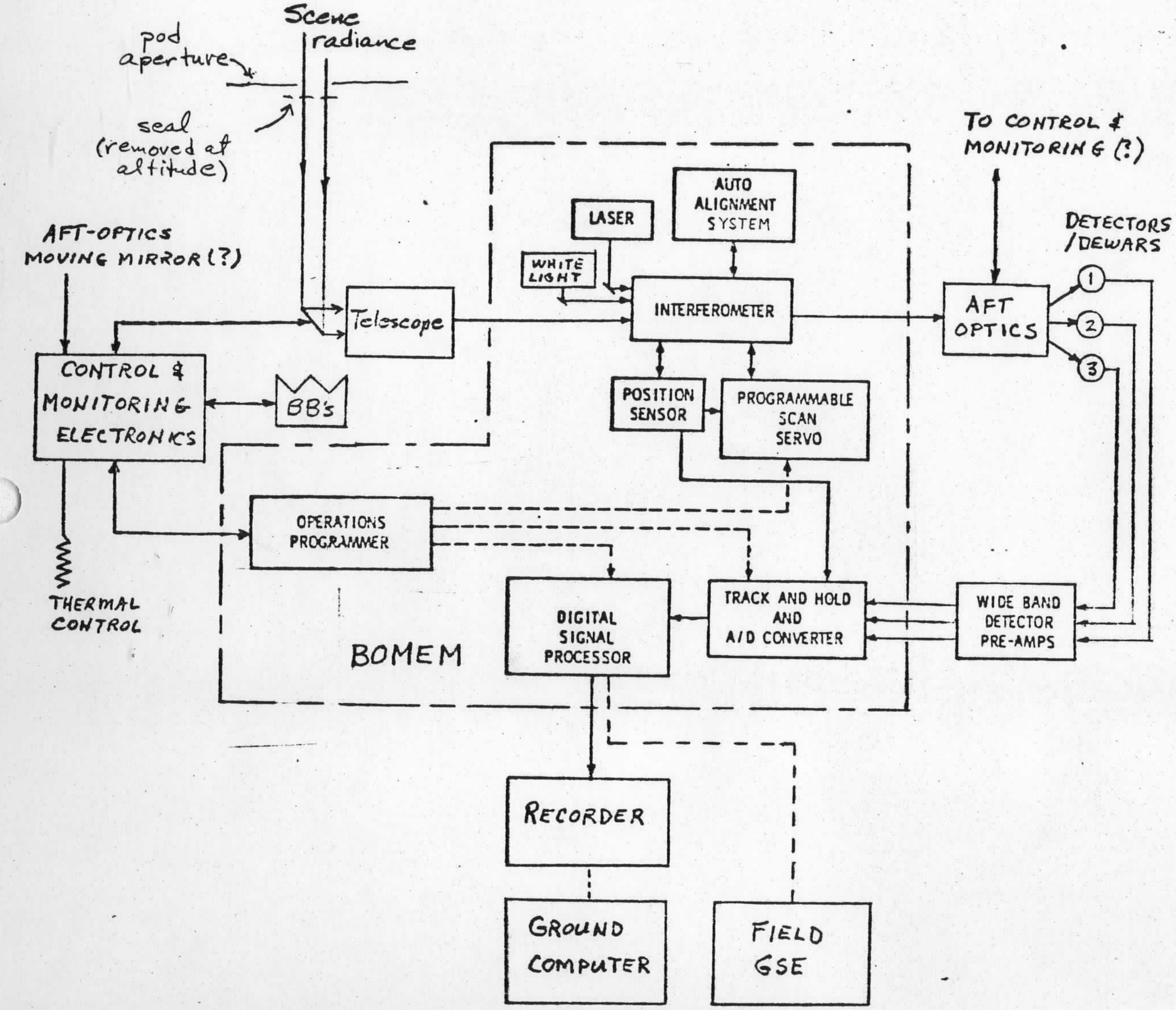

Figure 2.3.2 System Level Block Diagram

detectors are high performance cooled detectors which require a cryogenic dewar. The dewar will probably also contain all of the aft optics components except for the relay optics, to reduce the background radiation on the detectors. The three detector signals are amplified by wide-band preamplifiers located outside the cryogenic dewar, passed to the BOMEM sample and hold electronics, and A/D converted.

The interferometer operations are controlled by an operations programmer. It controls the operation of the delay scan servo, the analog sampling system, and the digital signal processor. A separate electronics package will control the motion of the scene selection mirror, the temperature of the blackbodies, heater power for any necessary active thermal control, and the opening of the aperture seal (if necessary). This package will also monitor the status and temperatures of various components and transfer the data to the BOMEM housekeeping system.

The digital signal processor reduces the data volume coming from the A/D converter by about an order of magnitude using digital filtering. Since the original sampling at the laser fringe rate (15,800/cm^{-1} provides many more samples than are necessary to characterize the information content of the interferograms, no information is lost in this process. The equivalent of multiplication by a filter in the spectral domain is accomplished by performing a convolution on the interferograms with a different function for each of the three spectral bands. Some of the data volume reduction will also result from ignoring the data for bands 2 and 3 beyond 1 cm and 0.7 cm delay, respectively.

Both interferogram and housekeeping data will be recorded on a small onboard cassette tape recorder. On the ground, access to the instrument output will be provided by portable ground support equipment. This equipment will be used to assess instrument health by monitoring its operations status and housekeeping data. In addition, it will be used to analyze a limited volume of interferogram data to yield calibrated interferograms and spectra, and limited accuracy temperature profiles. The ground support equipment will also include an interface to the tape recorder and the capability to write computer compatible tapes. Extensive data analysis will be performed on a mainframe computer.

2.4 INSTRUMENT OPERATING MODES

TBS

2.5 AIRCRAFT CHARACTERISTICS

TBS

2.6 MISSION CHARACTERISTICS

TBS

2.7 ANCILLARY DATA REQUIREMENTS

TBS

2.8 DATA HANDLING AND PROCESSING SEQUENCE

TBS

3.0 FLIGHT HARDWARE

The detailed requirements for the flight hardware are given in this section.

3.1 MECHANICAL LAYOUT - SYSTEMS LEVEL

This subsection describes the overall mechanical layout of the HIS aircraft experiment and outlines the mechanical constraints imposed by the wing pylon.

Figure 3.1-1 (TDB) shows the HIS assembly as mounted in the aircraft wing pylon. The following items are included in the figure:

- wing pylon envelope
- mounting interface
- wing pylon viewing aperture
- wing pylon viewing aperture door
- BOMEM instrument
- fore-optics
- aft-optics
- scene switching mirror
- blackbodies
- detectors/dewars
- control and monitoring electronics
- data recorders
- instrument center of gravity

The complete HIS experiment is supported on a common structure (i.e., a single piece of hardware mounts to the wing pylon). The use of the Lockheed Interferometer Installation Kit WAX III for the HIS experiment is TBD.

The total HIS experiment weight, including the pylon ballast, is not to exceed 300 lbs. (U-2 Investigators' Handbook, Volume 1).

The input and output optics are rigidly coupled to the BOMEM interferometer module in order to maintain a calibrated transmission characteristic.

Figure 3.1-1 General Mechanical Configuration (TBD)

3.2 OPTICAL DESIGN - FUNCTIONAL DESCRIPTION

The basic elements of the HIS optical system are specified in Figure 3.2.1. These naturally group into four subsystems: Input Optics, Interferometer, Aft Relay Optics, and Detector Optics. For descriptive convenience both Figure 3.2.1 and the following subsections assume specific optical configurations which may be revised following completion of the SBRC optical design.

3.2.1 Input Optics

The components and functions of the input optics are as follows:

- a moveable plane mirror to select radiation input from among three sources: the scene (atmospheric radiation from below the aircraft), the on-board hot blackbody, and the on-board cold blackbody.

- a primary mirror which forms a real image of the scene at the field plane.

- a field stop (located in the field plane) which defines the instrument field-of-view. (The full angle of the instrument FOV is $2 \tan^{-1}(d/(2 f_p))$, where d is the diameter of the field stop, and f_p is the focal length of the primary mirror.)

- a collimating mirror which fills the aperture of the interferometer with parallel radiation and, with the field stop, defines the interferometer FOV. (Although radiation from a single point in the scene does not diverge within the interferometer, radiation from different points within the instrument FOV pass through the interferometer at slightly different angles. The full-angle interferometer FOV is $2 \tan^{-1}(d/(2 f_{ci}))$ where f_{ci} is the focal length of the input collimating mirror.)

3.2.2 Interferometer

The interferometer accepts the collimated radiation from the input optics, splits the input beam into two equal components, delays one component by making it traverse a longer path, then recombines the two components into a common output beam so they can interfere.

The interferometer is sealed to protect it from ambient atmospheric contamination. This requires two windows as indicated in Figure 3.2.1.

A complete description of the interferometer assembly is provided in section 3.3.

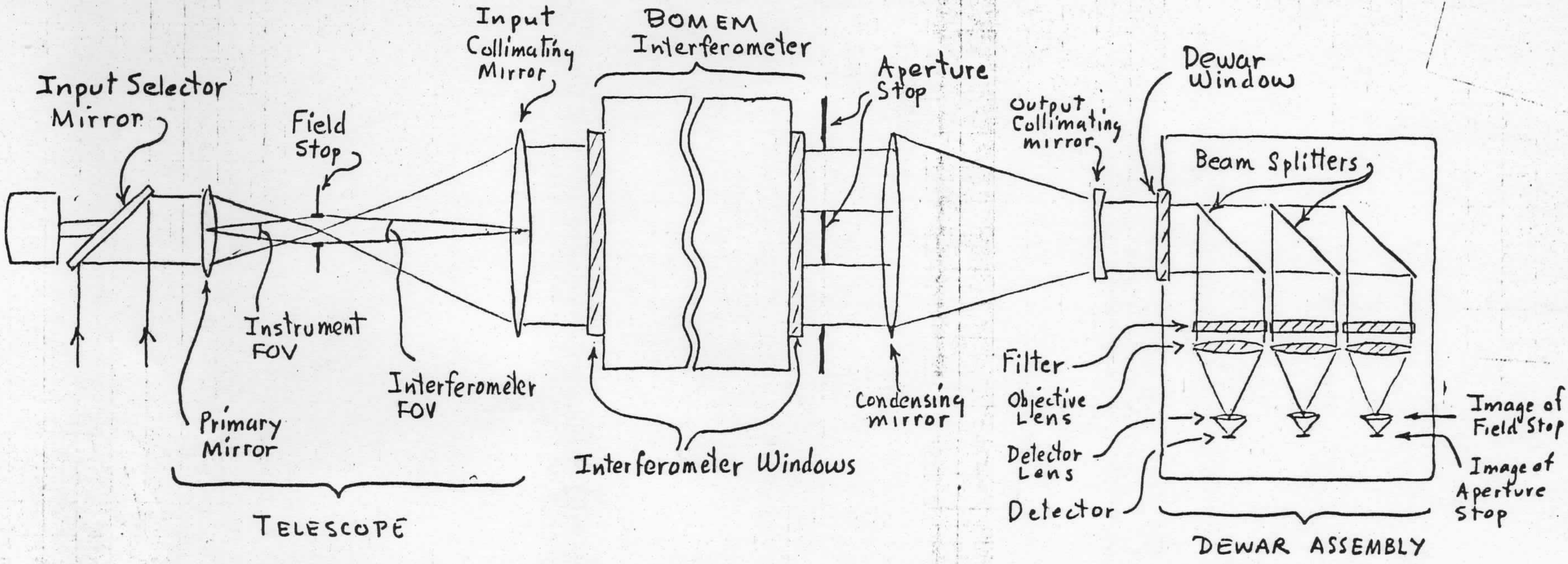

Figure 3.2.1 Functional Schematic of HIS Optics. Primary mirror condensing mirror, and collimating mirrors are shown as lenses for functional clarity.

3.2.3 Aft Relay Optics

The aft relay optics elements and functions are as follows:

- An aperture stop intercepts the output beam at the exit of the interferometer. This stop defines the area (and thus the energy throughput) of the output beam, and limits the amount of stray radiation which can enter the detector FOV. The inner obscuration is needed to mask the laser reference optics positioned at the center of the interferometer beam. Positioning the aperture at the exit of the interferometer is done to eliminate image motion at the detector plane due to beam steerage in the interferometer.

- A condensing mirror is used to reduce the beam diameter to a convenient size for interfacing to the necessarily compact dewar optics assembly.

- An output collimating mirror is used to provide parallel radiation input to the detector/dewar optics. This makes the energy input to the detector less susceptible to alignment variations between the dewar and the optical bench.

3.2.4 Detector/Dewar Optics

All detectors are located in a single dewar, isolated from ambient atmospheric contamination, and operated at liquid He temperatures. Although the SBRC detailed optical design may alter the specific configuration and number of optical elements, the basic optical elements and their functions are as follows:

- A sealed dewar window is required to prevent atmospheric water vapor from condensing on the cooled detector optics. (To prevent condensation on the dewar window it must be thermally decoupled from the cooled optics, and maintain a temperature greater than the ambient dewpoint.)

- Two beam splitters are required to distribute the output beam among three detector channels.

- A bandpass filter is used for each of the three detector channels. Since these filters are cooled they limit the amount of background radiation incident on the detectors. They also limit the information bandpass so that sample reduction can be performed.

- An objective lens is used in each detector channel to focus an image of the field stop on the corresponding detector lens.

- A detector lens is used in each channel to form an image of the aperture stop on the detector surface. (Since the image of the aperture stop uniformly scrambles radiation from the scene, errors due to detector non-uniformities are minimized. An additional benefit is that the image is not perturbed by beam steerage within the interferometer.)

3.3 ELECTRICAL LAYOUT-SYSTEMS LEVEL

TBD

3.4 INTERFEROMETER ASSEMBLY

The interferometer subsystem of the HIS instrument is a modified version of the BOMEM DA2.01, manufactured by BOMEM, Inc. of Quebec, Canada. The DA2.01 is described in the BOMEM document "Operational and Service Manual, Balloon-borne and Air-borne Interferometer System, Model BDBA2.01-1", March 1980, BOMEM Inc. (This reference will be replaced with the documentation for the HIS instrument when it becomes available.)

3.4.1 Customization Required for HIS Application

3.4.1.1 Symmetric Delay Scan

While the standard DA2.01 scans from an initial delay of -1cm to programmable positive delays up to 60 cm, the HIS requirement is for a continuous scan starting at a delay of -2.0 cm and ending at a delay of +2.0 cm. This requires moving the fixed interferometer mirror approximately 1 cm further away from the beam splitter and allows shortening the mirror carriage by approximately 20 cm.
The benefit of scanning both sides of zero delay is improved capability to correct phase errors without loss of observation efficiency.

The benefit of shortening mirror carriage is a significant reduction in instrument volume and weight.

3.4.1.2 Beamsplitter Cross-Section

The standard DA2.01 uses a circular beam splitter/compensator which presents an elliptical cross-section to the collimated beams within the interferometer (the beam splitter compensator is used at an angle of 30° to the input beam).

To maximize energy throughput for the HIS application, the beam splitter/compensator should have an elliptical figure which projects a circular cross-section to the collimated beams.

3.4.1.3 Mounting Fixtures

The heavy aluminum baseplate which serves as the optical bench of the interferometer will also be used for mounting of fore-optics and aft-optics. This requires an optical bench extension as defined in Figure 3.4.3. (TBD)

3.4.1.4 Data Channels

The data processing part of the BOMEM interferometer package will include provision for 3 simultaneous data channels, one for each of the three detectors.

3.4.1.5 Interferometer Windows

Tilt angle TBD

Material TBD

Coating TBD

Mounting TBD

3.4.2 Mechanical Interfaces

3.4.2.1 Optical Bench Mount to Aircraft Pod Fixture

TBD

3.4.2.2 Mounting and Alignment of Fore-Optics

The fore-optics package will be assembled and aligned as a subsystem.

Alignment of telescope and interferometer will be insured by precision locator pins on the optical bench plate. The telescope subsystem will be bolted to the optical bench.

Provision for fine adjustments of telescope position to account for out-of-spec or thermally perturbed focussing characteristics: TBD.

3.4.2.3 Mounting and Alignment of Aft Relay Optics

Aft relay optics will be bolted to the optical bench of the interferometer after being aligned by precision locator pins.

3.4.2.4 Alignment of Internal Interferometer Elements.

As described in BOMEM manual.

3.4.2.5 Mounting and alignment of Dewar Assembly

TBD

3.4.3 Thermal Interfaces

The interferometer, fore-optics, and aft-optics (excluding detector optics) are meant to be operating at ambient atmospheric temperatures of 230-240° K at cruise altitude. This will be accomplished by providing a reasonably good thermal coupling between these components and the pod.

The interferometer temperature must be constant within ±TBD degrees during a 5 min period.

See section 5.6.1

3.4.4 Electrical Interfaces

3.4.4.1 Detector Signal Channels

TBD

3.4.4.2 Housekeeping

TBD

3.4.4.3 Window Heaters

TBD

3.4.4.4 Digital Control

TBD

3.4.4.5 Flight Data Recorder

TBD

3.5 NON-BOMEM SUBASSEMBLIES

3.5.1 Telescope

3.5.1.1 General Configuration

The general configuration of the telescope is illustrated in Figure 3.5.1.1. The telescope must collect radiation along a horizontal axis from the input selector mirror, define both the instrument and interferometer fields-of-view (as specified in Section 2.2), and feed the interferometer input with a horizontal beam filling the interferometer aperture.

The vertical position and direction of the output beam of the telescope are determined by the interferometer mounting position. The vertical position and direction of the input axis of the telescope are determined by constraints on the input selector mirror position (see Section 3.5.3).

To eliminate chromatic aberrations and maintain high transmission at all wavelengths the telescope must use all reflective optics in a folded configuration (no beam obscurations are allowed).

The primary mirror, folding mirror, and collimating mirror must be assembled and aligned as a unit, which is rigidly mounted to the interferometer optical bench.

3.5.1.2 Optical Design Parameters

The primary and collimating mirrors will be off-axis paraboloids. Focal length, position, size, and orientation are TBD.

The folding mirror position, size, and orientation are TBD.

Position and size of baffles are TBD.

3.5.1.3 Alignment of Telescope Components

The optical elements of the telescope must be provided with mechanisms which allow fine adjustment of focus and alignment. Alignment and focus requirements are TBD. Procedures are TBD.

3.5.1.4 Optical Materials

Mirror material is TBD.

Mirror protective coating is TBD.

3.5.1.5 Aperture Stop

Design and materials are TBD.

3.5.2 Pod Aperture Seal

TBD

3.5.3 Scene Switching Mirror

The input selector mirror will be a plane mirror of elliptical shape which presents a circular cross-section of radius TBD at a 45° angle.

A stepper motor is used to rotate the mirror about a horizontal axis to any of three viewing positions as shown in Figure 3.4.3. These are as follows: nadir (0° angle) for viewing atmospheric radiation, cold blackbody (45° angle), and hot blackbody (180° angle). The mirror material, flatness, and coating are TBD.
Mirror position accuracy requirement is TBD.

3.5.4 Blackbodies

There will be two calibration blackbodies at different temperatures.

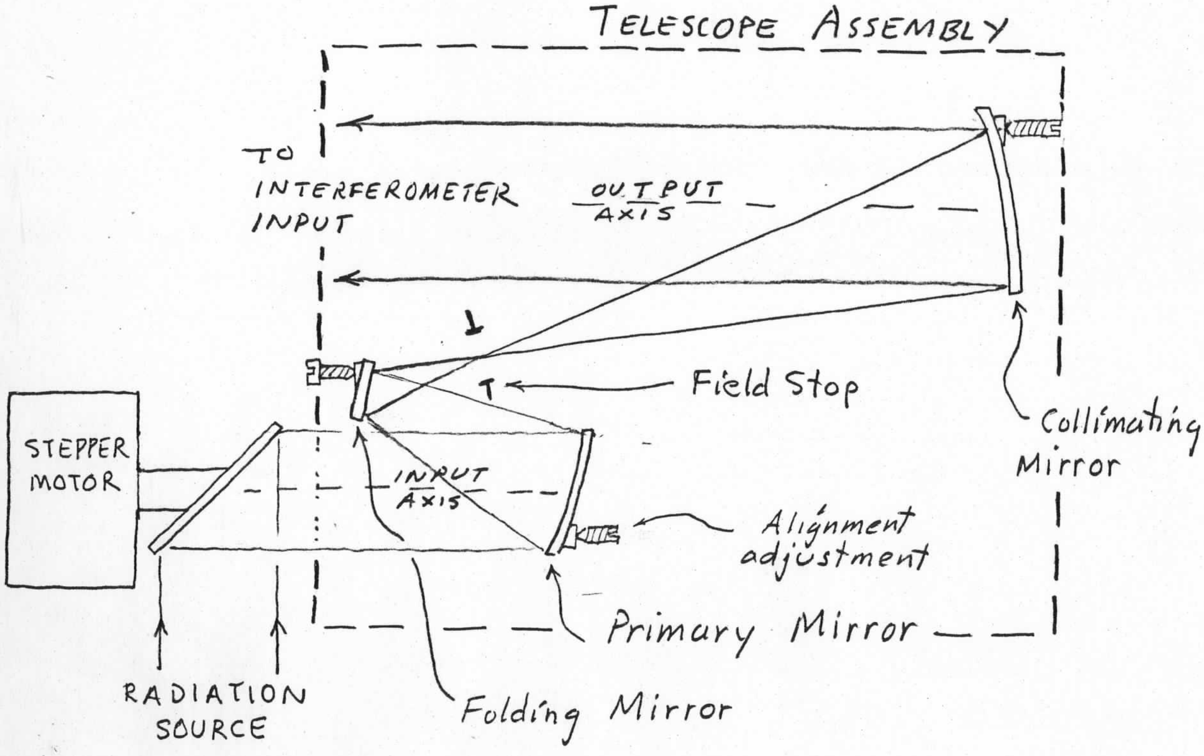

Figure 3.5.1 General Configuration of Telescope

3.5.4.1 Performance Goals

The baseline performance goals for the calibration sources are that there be one hot and one cold blackbody with the following characteristics:

	Hot	Cold (Option 1)	Cold (Option 2) 190 K (above frost point)
Nominal set temperature	300±TBD K	77 K (LN2)	
Temp. variability	TBD	TBD	TBD
Temp. uncertainty	±0.1 K	±0.2 K	TBD
Nominal emissivity	0.995	0.995	.995
Emissivity uncertainty	±0.005	±0.005	±.005

For Option 1, the most difficult criteria to meet will probably be the emissivity uncertainty of the LN_2 blackbody, because of the effect of frost. An ambient temperature cold blackbody may still be a reasonable option, although the brightness temperature calibration errors get large fast for scene temperatures below 200 K. Also laboratory operation of the instrument would require a method of cooling the blackbody.

Option 2 avoids the potential frost problem of Option 1 by electrically heating the LN_2 blackbody above the ambient dewpoint at flight altitude.

3.5.4.2 Orientation of Blackbodies

To minimize convective heat transport from the cavity surfaces (to maximize temperature stability), the hot cavity aperture should face downward, and the cold cavity aperature should face upwards. This is illustrated in Figure 3.4.3.

3.5.4.3 Cavity Apertures

TBD

3.5.4.4 Temperature Control

The 77 K cold blackbody (Option 1) would be passively controlled by being in thermal contact with LN_2. The LN_2 dewar must have adequate capacity for 6 hours of operation.

The heated cold blackbody (option 2) would be actively controlled above the maximum expected dewpoint temperature of TBD degrees.

The hot blackbody must be actively controlled by an electric heater servo system with sufficient power to drive the cavity from a cold start at 200°K to the desired operating temperature within 5 minutes. Temperature stability at the control point must be ±.05° over a 5 min period.

The Option 1 cold blackbody may need a heating element for evaporating frost accumulations which might occur.

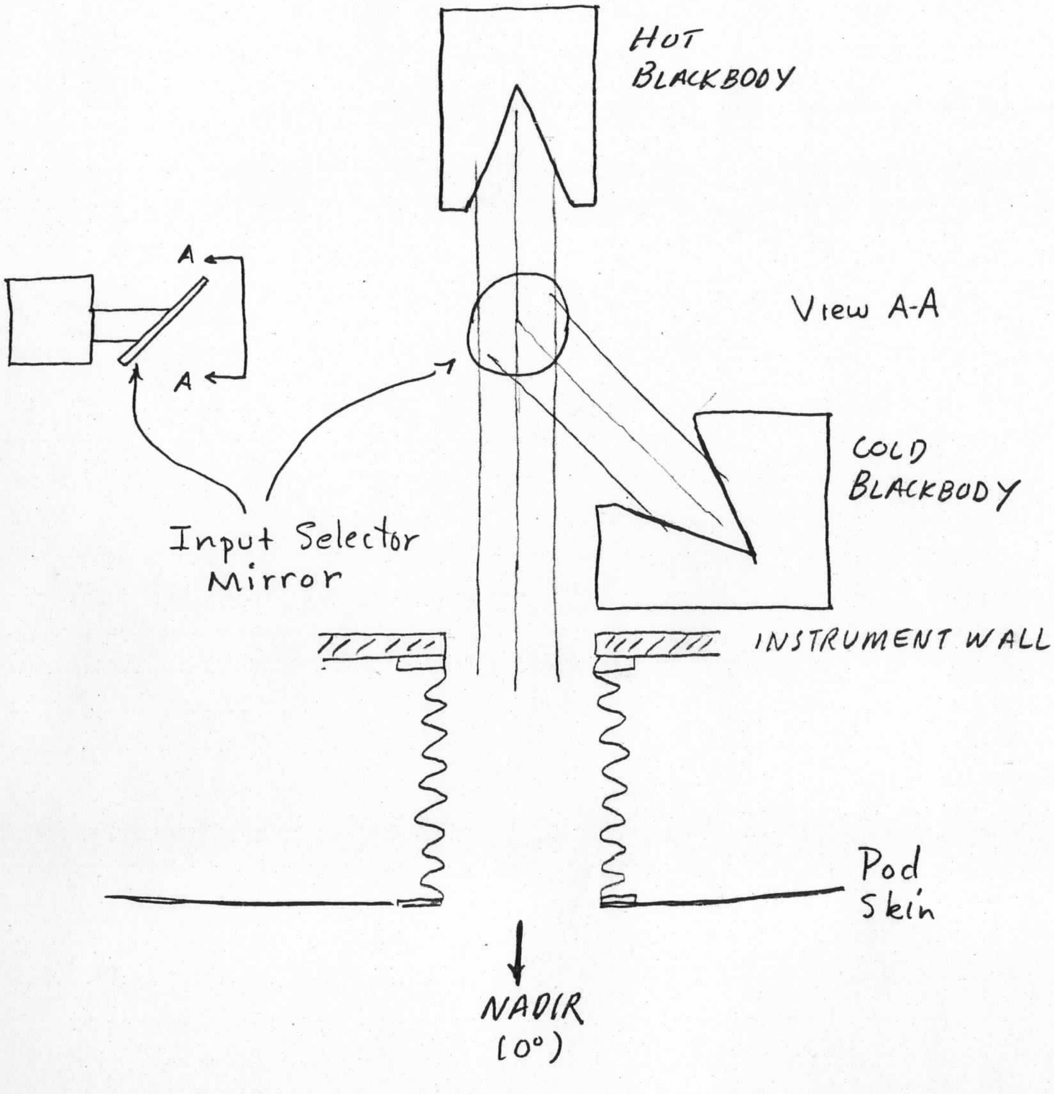

Figure 3.5.3 Calibration Blackbodies

3.5.4.5 Temperature Monitor

The hot blackbody temperature must be monitored with an absolute accuracy of 1°K and a relative accuracy of ±.05°K within a 5 min observation period.

The cold blackbody temperature must be monitored with an absolute accuracy of ±5°K for Option 1 and TBD for Option 2. 3.5.4.6 Condensation Control For the Option 1 77 K Cold Blackbody

The 77 K cold blackbody has a radiating surface which will be below the dewpoint (frostpoint) temperature of the atmosphere at all anticipated operating altitudes; thus condensation of frost on the Option 1 cold blackbody can be expected. However, due to the low absolute density of water vapor at the nominal operating altitude, the rate of condensation will be very small.

A possible approach in operating a 77 K cold blackbody is summarized as follows:

- Provide an electrically controlled loose-fitting cover for the cold blackbody aperture which remains in place at all times except during calibration.
- Maintain a dry N_2 purge to flush water vapor out of the cavity through the loose-fitting cover.
- Immediately before calibration command the cover to the open position.
- Perform instrument calibration.
- Immediately after calibration command the cover to the closed position.
- Periodically heat the cold cavity above the dewpoint to drive off possible frost accumulations.

Frost will not be a problem during ascent because the pod will be filled with dry N_2 on the ground and its aperture sealed with a removable door.

3.5.5 Aft Relay Optics

The aft relay optics define the interferometer exit beam area with an aperture stop, reduce the exit beam diameter, and convey the exit beam to the detector dewar assembly.

3.5.5.1 General Configuration

The aft relay optics will be bolted to the interferometer optical bench. The optics will contain two off-axis parabolic mirrors in a folded configuration as indicated in Figure 3.5.5.1.

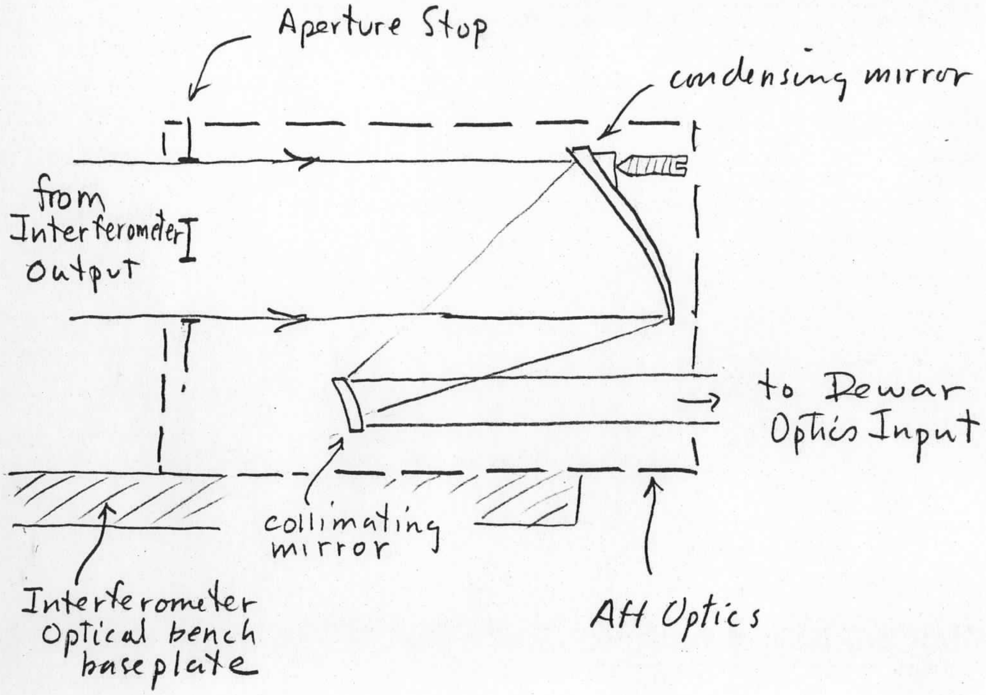

Figure 3.5.5.1 Aft Relay Optics Configuration

3.5.5.2 Detailed Design

TBD

3.5.5.3 Alignment Procedures

TBD

3.5.6 Detector Dewar Assembly

3.5.6.1 General

The general configuration of the dewar assembly is shown in Figure 3.5.6. The interior vessel of the deware contains a reservoir of liquid He (at 4.2°K) which is thermally isolated from the outer wall (at ambient temperatures) by evacuating the space between the inner and outer walls of the vessel, and using an intermediate shield to reduce radiative heat losses. The detector and detector optics package is mounted in close thermal contact with the 4.2°K reservoir.

3.5.6.2 Installation and Alignment

TBD

3.5.6.3 Electrical Feed-through

Three detector channels and one temperature monitor must be fed through the outer wall of the dewar. Detailed requirements TBD.

3.5.6.4 Mounting in Pod

Requirements:

- achieve and maintain alignment between detector optics and aft relay optics; detailed requirements TBD.
- access to fill aperture within one hour of aircraft take-off.

3.5.6.5 Time to Reach Operating Temperature: Within TBD Minutes of Fill

3.5.6.6 Hold Time: 6 hours.

3.5.7 Beamsplitters

Two options are being considered: (1) non-spectral division of total beam energy among three detector channels (using the equivalent of partially silvered mirrors); and (2) a combination of energy division and spectral division (using a crude dichroic mirror to separate bands 1 and 3 after a fraction of the beam energy is split off for band 2 using a "partially silvered" mirror).

Specific configuration TBD.

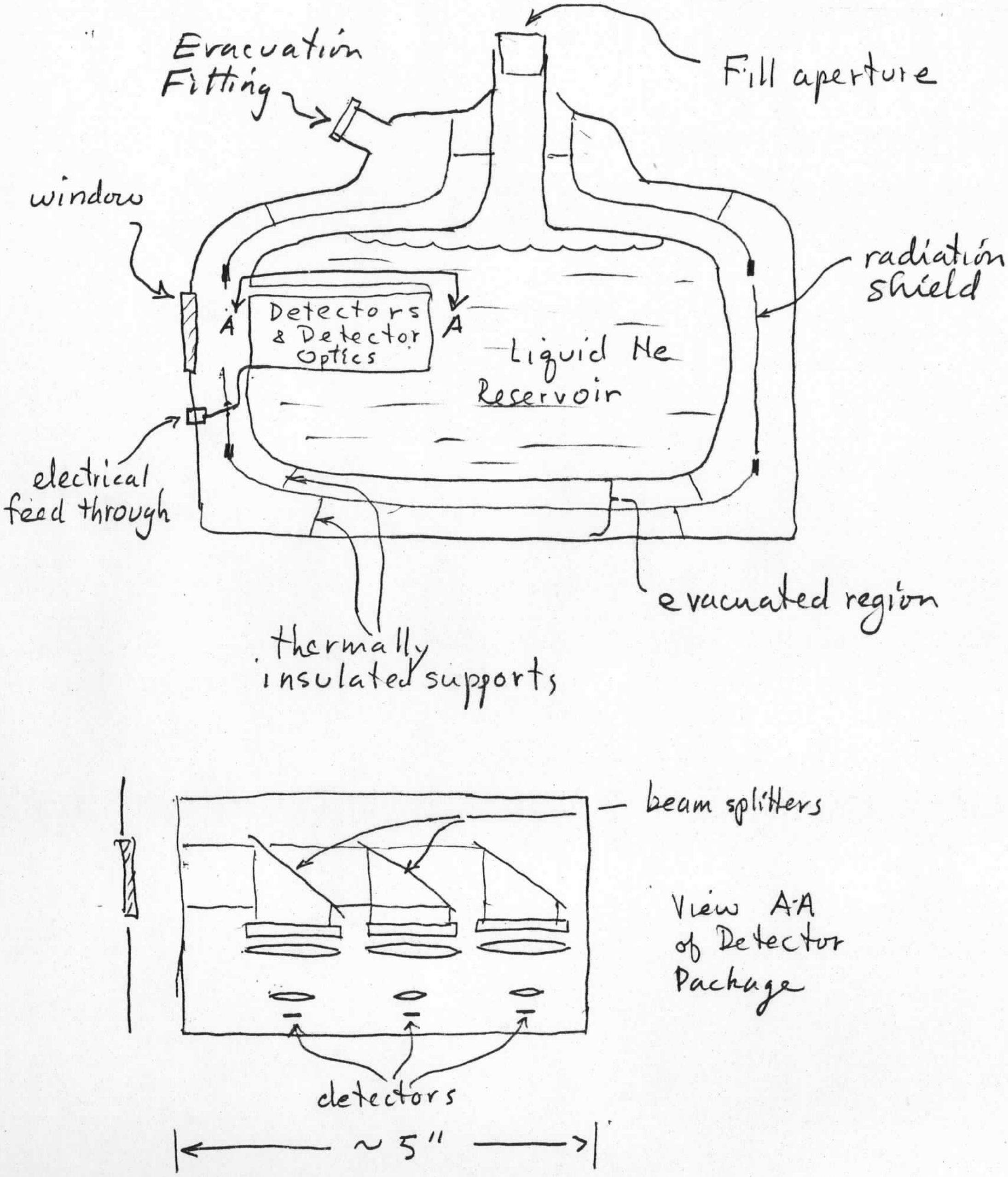

Figure 3.5.6 Detector Dewar Assembly

3.5.8 Filters

3.5.8.1 Transmission

Filter transmission requirements are specified in the following table:

Channel	½ Power Limits	.1% Limits	Out of Band Transmission	In-band Spectral-flatness
#1	600-900cm^{-1}	TBD	TBD	TBD
#2	900-1800cm^{-1}	TBD	TBD	TBD
#3	1800-2700cm^{-1}	TBD	TBD	TBD

3.5.8.2 Physical Requirements

Diameter TBD

Thickness TBD.

3.5.9 Detectors & Preamps

3.5.10 Control and Monitoring Electronics

3.5.11 Data Recorder

The baseline design is to use two University of Denver 3-M cassette recorders.

3.5.11.1 Data Rate and Volume Requirements

The baseline requirement is to have the capability for at least two hours operation with a delay scan rate of 3 cm/sec.

The baseline parameters for rate and volume calculations are:

Band #	Compression Factor	Free-spectral Range (cm^{-1})	Max. Delay (cm)	16-bit Words Output
1	16	444-988	2.0	1975
2	4	0-1975	1.0	3950
4	5	1580-3160	0.7	2212

This implies the following:

Scan Rate (cm/sec)	Mean Data Rate (K bytes/sec)	One-hour Data Volume (M bytes)
1	8.2	29.3
2	16.3	58.7
4	32.6	117.4

These requirements can be met by using two University of Denver 3-M recorders with the capability to handle a rate of 17 K bytes/sec and a volume of 67 M bytes/cassette.

3.5.11.2 Interface to Aircraft Instrument

TBD (need information on University of Denver system)

3.5.11.3 Interface to Ground Computer

TBD (need information on University of Denver system)

3.5.11.4 Environmental Considerations

TBD

3.5.11.5 Accessibility

TBD

3.6 ELECTRICAL INTERFACES TO POD

3.6.1 Aircraft Systems Required

The instrument is electrically interfaced to the aircraft wing tank via trunk line experiment a single connector plug, MS83723-24R2811N, with MS83723-34N28 backshell. The connector contains four 12-gauge contacts, used for 400 Hz power, and eighteen 16-gauge contacts, used for DC power, signal and control lines. Pin assignments for the wing tank experiment trunk line connector are given in Table 3.6-1 (TBS).

The instrument utilizes the 400 Hz 3-phase power source and the TBD lines for on/off control, as shown in Figure 3.6.1.

TABLE 3.6-1

INTERFACE CONNECTOR PIN ASSIGNMENTS

PIN	FUNCTION

(DATA TBS)

Figure 3.6.1 HIS Instrument Electrical Interface (TBD)

3.6.2 Electrical Power

3.6.2.1 Power Bus Characteristics

The instrument operates from the aircraft 400 Hz power source with the following characteristics:

Frequency	380 Hz to 420 Hz
Voltage	208/120 ±5 volts
Connection	3-phase wye
Phase Rotation	ABC

This source and the instrument power interface meet the requirements of MIL-STD-704B.

3.6.2.2 Power Utilization

Electrical power input to the instrument is limited to TBD watts average, and TBD watts peak. Turn-on (starting current) is limited to TBD amperes. Power factor is not less than TBD.

3.6.2.3 Fusing

The instrument contains fuses to prevent damage to the instrument should internal shorts occur. These fuses are indicated in Figure 3.6.1. Fuse ratings are TBD.

3.7 ENVIRONMENTAL CONSIDERATION

This section discusses the mechanical, thermal, and humidity requirements for the various subcomponents of the HIS experiment. The drivers behind these requirements and the means for control are also discussed.

3.7.1 Mechanical

The HIS instrument and all of its subcomponents will be designed for the load conditions called out in section 5.1 of the U-2 Investigators' Handbook Volume 1.

Fastener and welding standards, materials specifications and assembly practices called out in Section 6 of the above mentioned document will be followed.

In order to maintain high precision mirror alignment the BOMEM Interferometer unit must be vibration isolated for frequencies above 100 Hz. The auto-alignment control loop can maintain stability for vibration frequencies below 100 Hz.

3.7.2 Thermal

Table 3.7.2 lists the temperature critical components within the HIS package, their required temperature environment and the means for controlling their temperature.

TABLE 3.7.2

TEMPERATURE-CRITICAL COMPONENT REQUIREMENTS

Component	Temperature Range (°C)			Temperature	Means of Control
	Non-operating	Descent	Operating	Stability	
Blackbodies:					
Hot	NC	TBD	TBD	TBD	Servo-controlled electrical heater.
Cold	NC	TBD	TBD	TBD	LN_2 servo-controlled heater.
Field Stop	NC	NC	TBD	TBD	Strong thermal coupling to optical bench
Interferometer optics:					Strong coupling to optical bench.
Beamsplitter/Comp	NC	NC	TBD	TBD	
Plane mirrors	NC	NC	TBD	TBD	
Windows	TBD	TBD	TBD	TBD	Descent: possibly heat to protect from humidity
Aperture Stop	NC	NC	TBD	TBD	Strong coupling to optical bench.
Aft Optics Dewar Assembly:					
Window	TBD	TBD	>frost point	TBD	Mount design. Descent: possibly heat.
Internal optics	TBD	TBD	TBD	TBD	Coupling to dewar through mount.
Detectors	TBD	TBD	TBD (6-7 K)	TBD	Conductive coupling to pod.
Optical Bench	NC	NC	<TBD	TBD	Strong thermal coupling to pod.
Laser	TBD	TBD	TBD	TBD	
Recorder	TBD	> atmos. temp.	TBD	NC	Passive--insulate and water heat pipe.
Electronics Packages:					Passive--insulate and water heat pipe.
BOMEM	TBD		0-70	NC	
Control and Monitoring	TBD		TBD	NC	

NC = Not critical

In general the optics need to be temperature stabilized in order to minimize background radiance changes. The detector characteristics are improved at temperatures near that of liquid Helium. A liquid Nitrogen blackbody will also be required. The cryogenically cooled subponents will need to be sufficiently insulated to protect other subcomponents and to prevent excessive boil-off. Also, the temperature of the window on the detector/aft optics dewar must be above the frost point at flight altitude.

Consideration must be given to subcomponent temperatures during changes in atmospheric conditions, specifically humidity. This topic is discussed in the next section.

3.7.3 Humidity and Condensation Control

Humidity and condensation pose a number of potential problems. Condensation of moisture or frost from the atmosphere could fog windows and could cause electrical shorts in the electronics, recorders or mechanisms. Frost formation may also cause moving parts to lock-up. Another potential problem is the formation of frost on the cold black body viewing surface. Frost formation here would introduce an emissivity uncertainty. In addition some attractive window and beamsplitter materials are hydroscopic and can be damaged by humidity.

In view of all these potential problems, the condensation control plan is to purge the pod on the ground with dry nitrogen, then load the detector and blackbody cryogens. When the aircraft has reached altitude the pod viewing aperture door will be opened, thus exposing the inside of the pod to the atmosphere. During the flight the cold blackbody will probably be controlled to a temperature warmer than the dewpoint (Option 2, Section 3.5.4), thus eliminating the possibility of frost build-up on its viewing surface.

The interferometer itself will be dry nitrogen filled and separately sealed with windows to protect the beamsplitter. It will be valved to allow pressure equalization in flight. The detector-dewar assembly will also be separately sealed with a window to protect the aft optics beamsplitters and detectors. The dewar work volume will be evacuated.

Upon descent, the relatively cool pod equipment will again see warm and moist air. The option of pre-heating the critical components (using electrical heaters) before descent will be investigated.

Power dissipated from the various electronics modules will be utilized to keep them, as well as the data recorders, above the dewpoint.

The control requirements are summarized in Table 3.7.3.

TABLE 3.7.3

HUMIDITY AND CONDENSATION CONTROL REQUIREMENTS

Component	Means of Control			
	Ground	Ascent	Flight Operation	Descent
Blackbodies:				
Hot	Non required	Fill pod with dry N_2	Non required	None or maintain heat.
Cold-Option 1 (77K)	Environmental control	↓	See 3.4.4.6	None.
Option 2 (190K)	Environmental control	↓	Non required	None or heat.
Interferometer:				
Windows	Environmental control	↓		Heat (?)
Beamsplitter/comp. (hydroscopic)	Environmental control or dry N_2 fill.	Dry N_2 fill-valve to ambient P.	Dry N_2 fill	Dry N_2 fill-valve prevents pressurization.
Aft optics dewar assembly:				
Window		↓		Heat (?)
Internal Elements	Environmental control or evacuation.	Evacuation	Evacuation	Evacuation
Laser	None required	↓	None required	Operating temperature above maximum atmospheric temperature.
Recorder		↓		
Electronics packages: BOMEM Control and Monitoring		↓		

4.0 GROUND SUPPORT EQUIPMENT

4.1 ELECTRICAL GROUND SUPPORT EQUIPMENT (EGSE)

The EGSE provides the means for performing tests, adjustment, calibrations, performance checks, and data quality monitoring during field operation of the HIS experiment. It also provides the capability of transcribing instrument data tapes to computer-readable tapes for subsequent processing and analysis.

4.1.1 Functional Requirements

TBD

4.1.2 System Description

TBD

4.2 MECHANICAL GROUND SUPPORT EQUIPMENT

This section describes the functional requirements and the description of the various components of the Mechanical Ground Support Equipment (MGSE).

4.2.1 MGSE Functional Requirements

The MGSE provides a safe and convenient means for handling, servicing, and transporting the assembled experiment package. In addition, the MGSE supports the installation and removal of HIS from the aircraft pod as well as the pre-flight preparation.

The MGSE shall consist of a handling dolly which will be used to transport the HIS locally within SSEC or at the flight preparation sight. This handling dolly must be rigidly attached to the HIS assembled package in such a way as to allow convenient servicing of the major subsystems (e.g., Bomeur instrument, recorders, black bodies, dewars, electronics).

A protective shipping container for non-local transportation is required for the HIS assembled package. The shipping container will provide a shock absorbing interface and a clean dry environment for the HIS instrument. The purge requirements for the shipping container are TBD. The shipping container must be compatible with the following types of transportation: (TBD).

Lifting hardware is to be used in conjunction with an overhead crane to move the HIS to and from its handling dolly, shipping container and the aircraft pod. The lifting hardware must be functionally compatible with all these devices.

The MGSE will consist of any special tools necessary for general servicing or pre-flight preparation of the HIS experiment. Pre-flight purge gas, LHe and LN_2 supply are also required.

4.2.2 MGSE Description

This section describes the methods of attachments, physical dimensions, weight and operational features of the various MGSE components.

4.2.2.1 HIS MGSE Hardpoints

TBD

4.2.2.2 Handling Dolly

TBD

4.2.2.3 Shipping Container

TBD

4.2.2.4 Lifting Hardware

TBD

4.2.2.5 General Servicing and Pre-Flight Preparation Tools

TBD

4.2.2.6 Pre-Flight Purge Gas, LHe and LN_2 Supply Equipment

TBD

5.0 LABORATORY TESTING

This section describes the tests required to verify proper operation of the HIS instrument and to provide adequate calibration data before shipment to the flight operations site.

5.1 PROCEDURES

5.1.1 HIS Functional Test

TBD

5.1.2 HIS EMC/Power line susceptibility test

TBD

5.1.3 HIS Thermal Test

TBD

5.1.4 Other tests

TBD

5.2 FACILITIES AND SPECIAL HARDWARE REQUIRED

This section describes the facilities and special support equipment required beyond the usual GSE.

5.2.1 Blackbodies/Calibration sources

TBD

5.2.2 Power Supplies/Signal generators

TBD

5.2.3 Thermal (Vacuum?) Chamber

TBD

5.2.4 Other

TBD

5.3 PRE-SHIP CHECKOUT

The pre-ship checkout is intended to verify proper functioning of the HIS just before shipment and to serve as a check of the preflight calibration baseline. The following tests are performed: TBD.

6.0 PRE-FLIGHT FIELD OPERATIONS

The operations required before flight after arrival at the field site are as follows:

- Unload HIS from shipping container
- Perform aliveness test
- Integrate HIS with aircraft pod (includes electrical integration test)
- Load cryogenics
- Put HIS in launch configuration (i.e. tape rewound, etc.)
- Close Pod.

6.1 PROCEDURES

TBD

6.2 INSTRUMENT OPERATION PROCEDURES

At time t1, throw switch to ON position. At time t2, throw switch to OFF position. ??TBD.

6.3 FACILITIES AND SPECIAL HARDWARE REQUIRED.

TBD

7.0 FLIGHT OPERATIONAL SEQUENCE

7.1 TAKEOFF, CLIMB, AND PRE-DATA GATHERING FLIGHT

TBD (heaters?)

7.2 DATE COLLECTION

TBD (Throw one switch?)

7.3 DESCENT, APPROACH LANDING, TAXI

(Heaters? Purge?)

8.0 POST-FLIGHT FIELD OPERATIONS

8.1 SERVICING REQUIREMENTS FOR REFLIGHT

TBD

8.2 PROCEDURES FOR HIS REMOVAL FROM POD, PACKING, AND SHIPPING

TBD

8.3 FACILITIES AND SPECIAL SUPPORT HARDWARE REQUIREMENTS

TBD

9.0 POST-FLIGHT DATA ANALYSIS

The flight data is played back from the HIS flight recorder via the EGSE to the TBD computer which records the data on standard nine-track tape. The data can then be analyzed. The following are the hardware and software requirements for this operation:

9.1 HARDWARE REQUIREMENTS

TBD

9.1.1 Computer

TBD

9.1.2 Tape drive

TBD

9.1.3 EGSE link to computer

TBD

9.1.4 Other

9.2 SOFTWARE REQUIREMENTS

9.2.1 EGSE software

9.2.2 Computer software (data quality, preprocessing, analysis algorithms)

TBD

U-2/ER-2: FL650 (~60mb, level = 17) HM Woolf

AIRCRAFT HIGH RESOLUTION SOUNDER (HIS)
KICK-OFF MEETING

DATE: February 17-18, 1983

PLACE: Space Science and Engineering Center (SSEC), Room 351
1225 West Dayton Street, Madison, Wisconsin

OBJECTIVE: Identify critical instrument design considerations and revise and augment program plans.

Thursday

AGENDA: February 17, 1983

9:00 a.m. ✓ Welcome [Bill Smith and Bob Fox ~~Verner Suomi~~]

9:15 a.m. ✓ Aircraft HIS applications and requirements [Bill Smith]

9:45 a.m. ✓ Data analysis techniques and data reduction plans [Bill Smith]

10:15 a.m. ✓ Coffee

✓ NASA aircraft (CV990, WB-57, ER-2) [Bob Curran]

10:30 a.m. ✓ NASA's plans for HIS [Ed Hurley] (Bob Curran)

10:45 a.m. ✓ NOAA's plans for HIS ~~[Jim Fischer]~~ [Hank Schmidt]

11:00 a.m. ✓ Instrument fabrication: Approach, schedule and summary of critical design areas [Hank Revercomb]

12:00 noon ✓ Lunch

1:30 p.m. ✓ Aircraft system design, expected performance, and critical tradeoffs [Dan LaPorte]

2:30 p.m. ✓ The BOMEM DA2.02(U-2) and the modifications planned for HIS (special beamsplitter fabrication, laser beam repositioning, and data system) [Henry Buijs]

3:30 p.m. ✓ Aircraft interface considerations: thermal control, data recording system, condensation problems, and vibration isolation [Dave Murcray]

6:30 p.m. ✓ Dutch Treat Dinner

Friday

February 18, 1983

9:00 a.m. ✓ Tour of SSEC instrument fabrication facilities [Evan Richards]

10:30 a.m. ✓ Discussion of critical design factors and revision of program plans

12:00 noon Lunch

Afternoon Open

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HM Woolf

WHERE WE'VE BEEN

A BRIEF HISTORY OF HIS
(1977 - PRESENT)

EARLIEST EFFORTS (1977 - 1979)

- BASED ON "TEMPERATURE SOUNDINGS WITH PARTIALLY SCANNED INTERFEROGRAMS"

  T. G. KYLE, FEBRUARY 1977 APPLIED OPTICS

- SIMULATIONS BY THE NESS GROUP AT UW (BILL SMITH, HAL WOOLF, BEN HOWELL) SHOWED SIGNIFICANTLY IMPROVED VERTICAL RESOLUTION USING:

  - 15 MICRON BAND ONLY (600-650 CM^{-1})
  - 50 DELAY INTERVALS IN 1.3 CM RESONANCE,
    + 0 DELAY IN 4 AND 11 MICRON WINDOWS
  - 500 TO 1 SIGNAL TO NOISE RATIO
    (COMPARABLE TO CONVENTIONAL RADIOMETER).

REFINED RESULTS PUBLISHED IN JAS, APRIL 1979.

1977 - 1979, CONTINUED

- Instrument considerations in exploratory phase.
  - Multiple fixed delays
  - Staircase Michelson mirror
  - Retarding plates for high delay regions
  - Refractively scanned (CIMATS)

  Calibration concept not well defined.

- Formed basis for first proposal to NASA for a three-phase program to develop a spacecraft sounder.

  Submitted July 1978
  Revised June 1979

PHASE I HIS (1980 - 1982)

- Joint NOAA and NASA funding of HIS began early in 1980

- RFP to industry issued April 1980

  - Calibration concept

    Design interferometer with as little delay dependent response as possible

    Use blackbodies

  - Scanning Michelson interferometer strongly recommended.

  - Partial sampling had almost completed transition to "optimum" sampling

PHASE I, CONTINUED

- SBRC/BOMEN SELECTED AUGUST 1980-- ALREADY HAD TECHNOLOGY FOR DELAY SCANNING WITHOUT EXCESSIVE ERRORS FROM

  - DELAY SAMPLING AMBIQUITIES DURING TURN AROUND.

  - SCAN MIRROR VELOCITY VARIATIONS

  - SCAN MIRROR WOBBLE

  POINTED OUT OPTION FOR DIRECT CALIBRATION OF INTERFEROGRAM BY CONVOLUTION.

- THE FEASIBILITY STUDY (SEPTEMBER 1980 - JULY 1981)

  - REMARKABLY PRODUCTIVE.

  - LED TO PHASE II PROPOSAL.
    SUBMITTED APRIL 1981
    REVISED JULY 1982
    REVISED DECEMBER 1982

GEO INSTRUMENT DESIGN

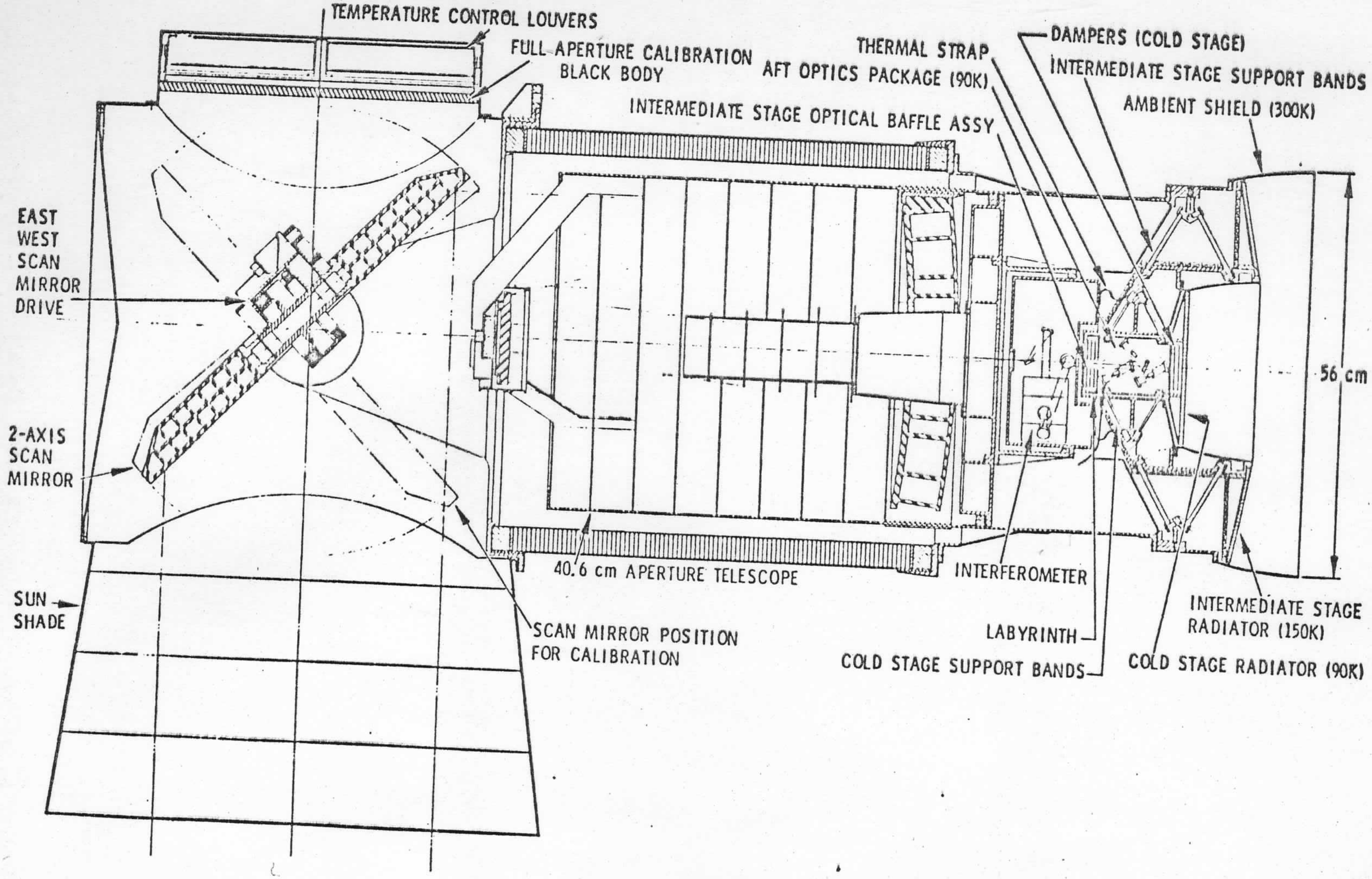
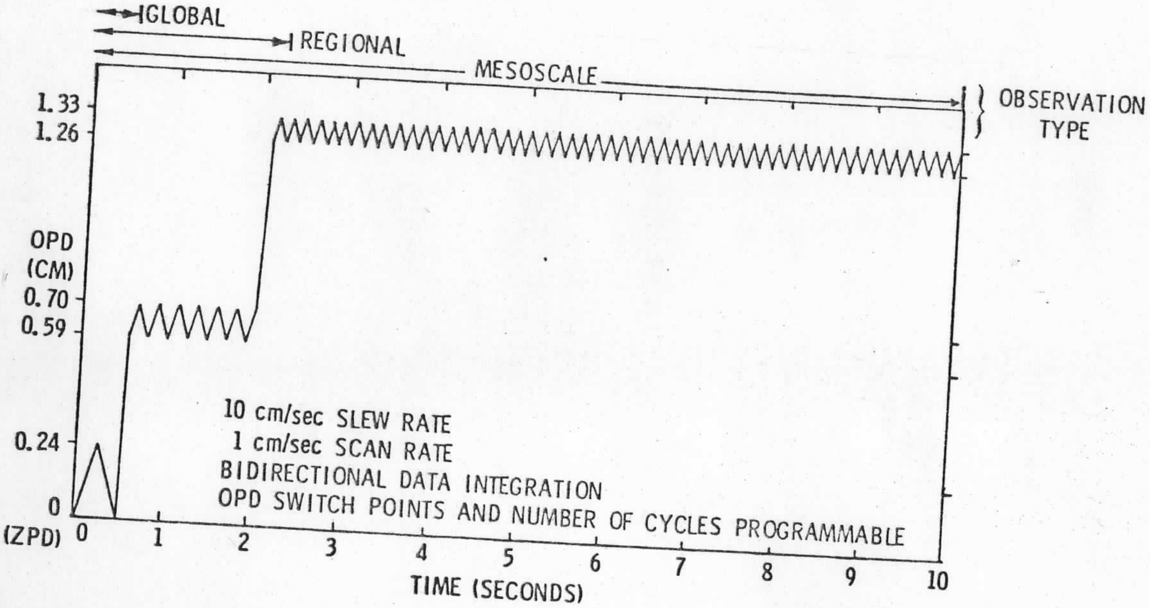


Figure 1-6. HIS GEO Instrument Concept

OPTIMUM SAMPLING

- SHACK INTERFEROMETER POSITION SENSOR (SIPS) ALLOWS SCAN MIRROR TO DO

THE SBRC JIG



10 cm/sec SLEW RATE
1 cm/sec SCAN RATE
BIDIRECTIONAL DATA INTEGRATION
OPD SWITCH POINTS AND NUMBER OF CYCLES PROGRAMMABLE

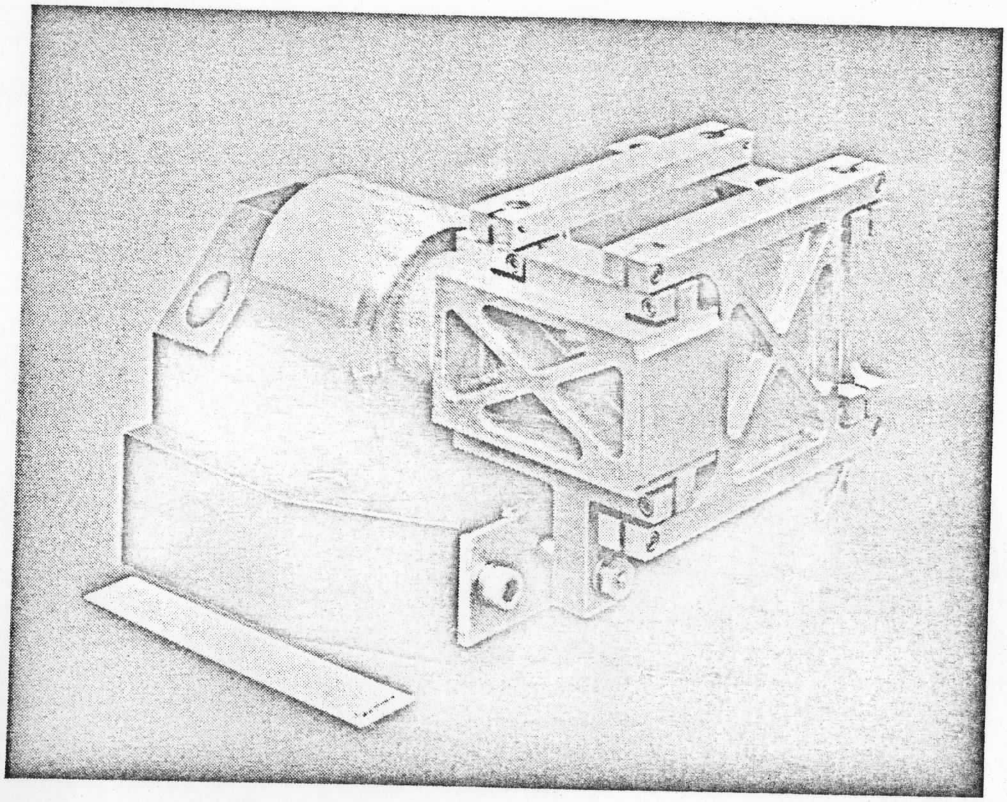
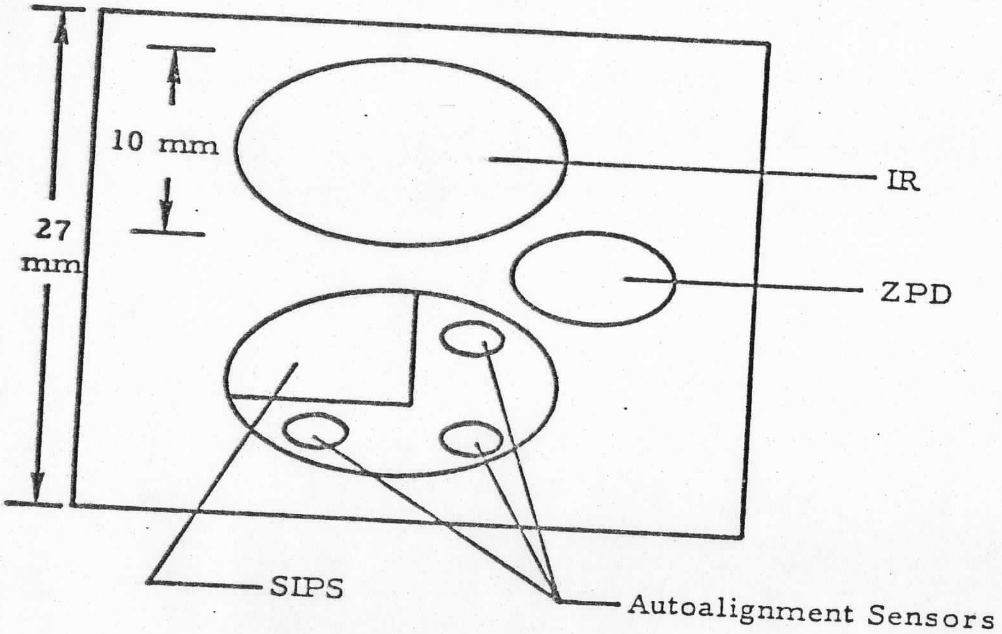


Figure 1-4. Optical Path Difference Mirror Drive Actuator for HIS GEO Application

BOMEM APPROACH TO INTERFEROMETRY

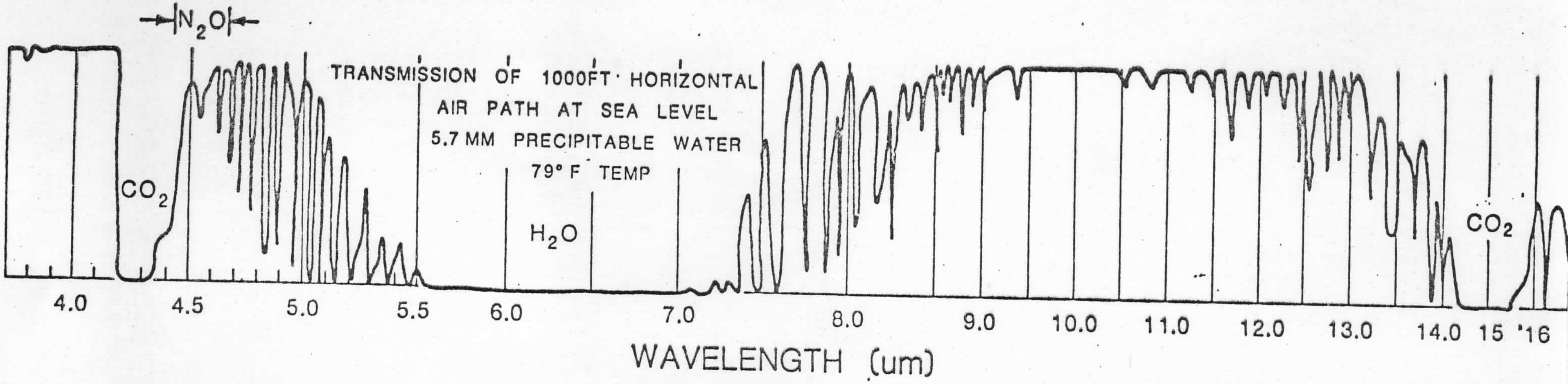


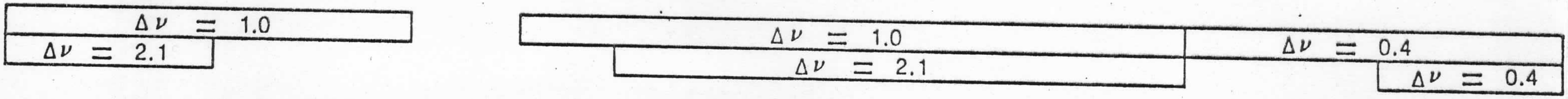
- AUTO-ALIGNMENT TO REDUCE MICHELSON MIRROR ALIGNMENT ERRORS BY TWO ORDERS OF MAGNITUDE.
- LASER RATE SAMPLING (OVERSAMPLING) TO REDUCE SENSITIVITY TO SCAN VELOCITY VARIATIONS.
- ONBOARD PROCESSING TO REDUCE DATA VOLUME.

GEO INSTRUMENT DESIGN

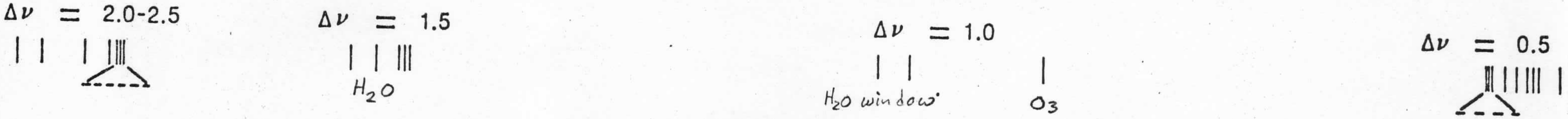
- HIGH SPECTRAL RESOLUTION
  - UP TO 0.4 CM^{-1} UNAPODIZED
  - SUFFICIENT TO RESOLVE WINGS OF INDIVIDUAL ABSORPTION LINES.
- BROAD SPECTRAL COVERAGE
- LOW NOISE WITH COMPACT DESIGN
  - OPTIMUM SAMPLING CAN REDUCE DWELL TIMES BY FACTOR OF 3 TO 7.
- PROGRAMMABLE SPECTRAL RESOLUTION AND NOISE TO SERVE MULTIPLE APPLICATIONS.

SPECTRAL COVERAGE

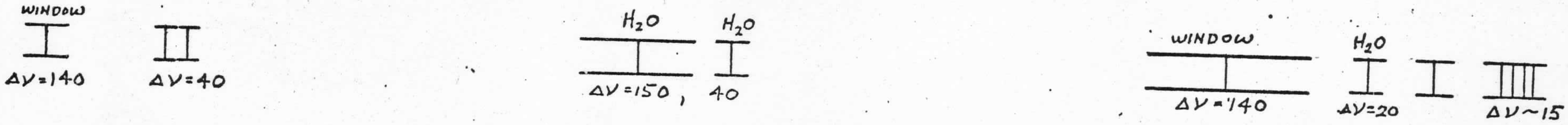




HIS SPECTRAL COVERAGE (UPPER BAR = AIRCRAFT, LOWER = GOES)



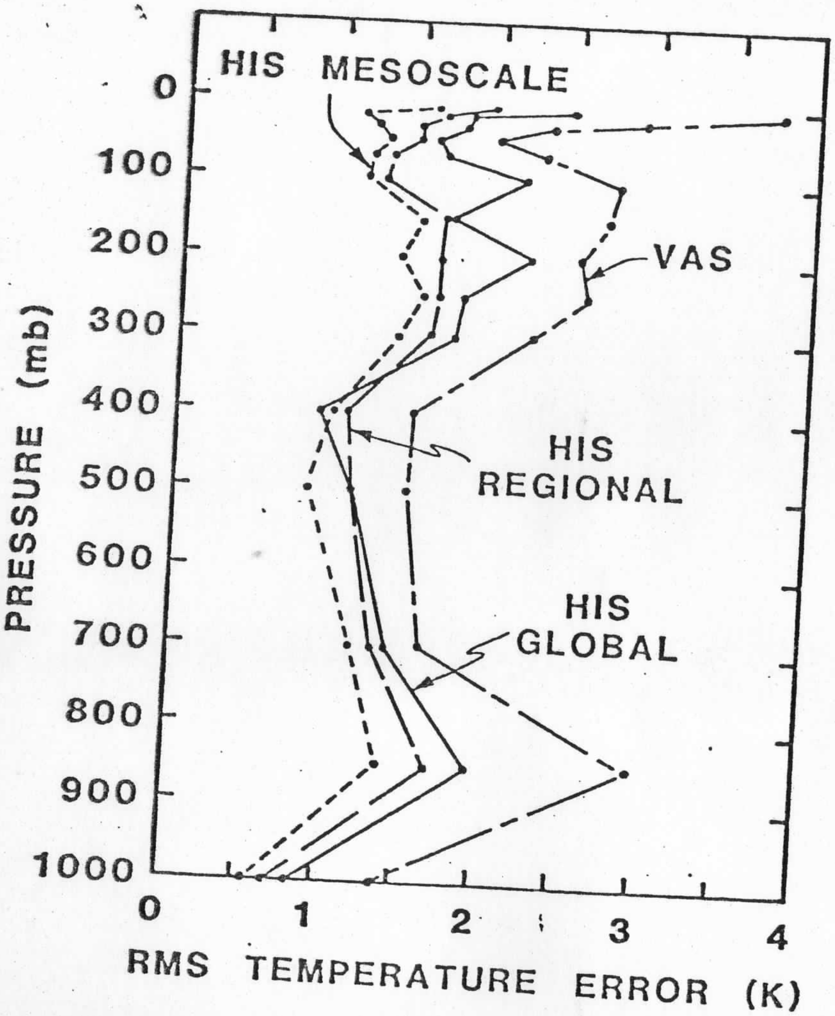
AMTS SPECTRAL COVERAGE



VAS SPECTRAL COVERAGE

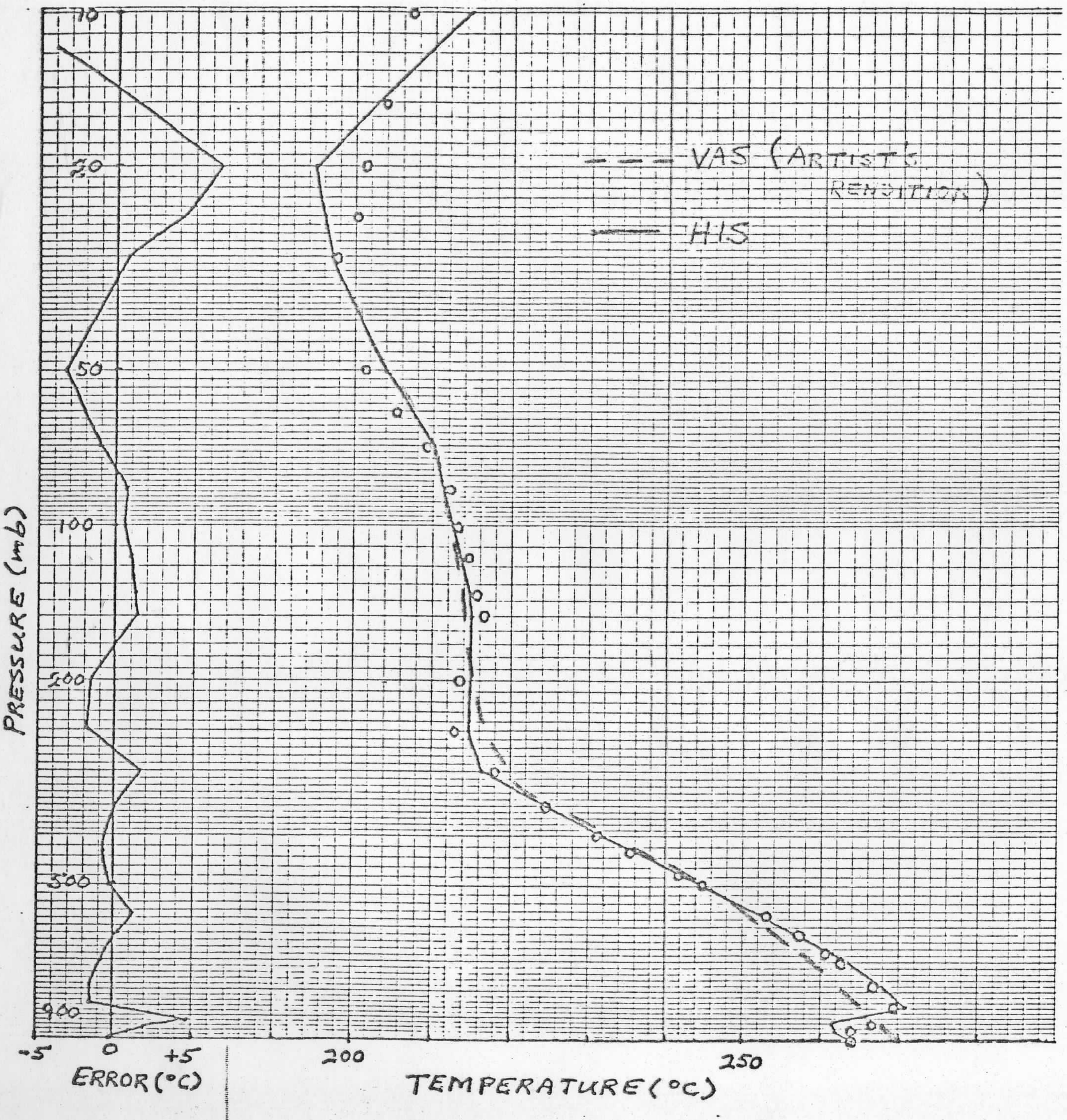
HIS SIMULATED PERFORMANCE:

STATISTICAL RETRIEVAL, BAND 1 ONLY



PHYSICAL RETRIEVAL:

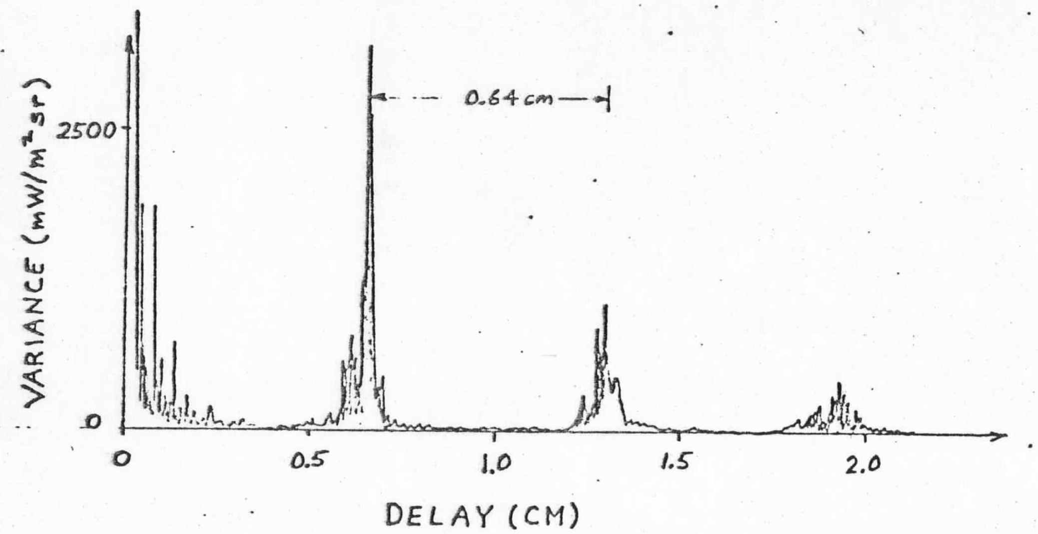
PROFILE 797, BANDS 1 & 3



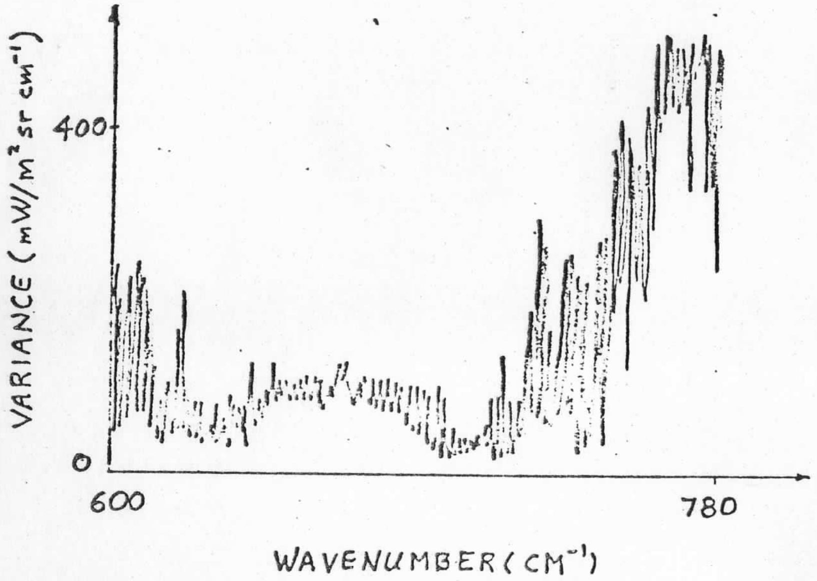
✓

BASIS FOR HIS OPTIMUM SAMPLING:

TEMPERATURE INFORMATION CONCENTRATED IN CO_2 RESONANCES



INTERFEROGRAM VARIANCE



SPECTRUM VARIANCE

(FOR 33 WINTER MIDLATITUDE PROFILES REPRESENTING TEMPERATURE EXTREMES)

PERFORMANCE WITH OPTIMUM SAMPLING

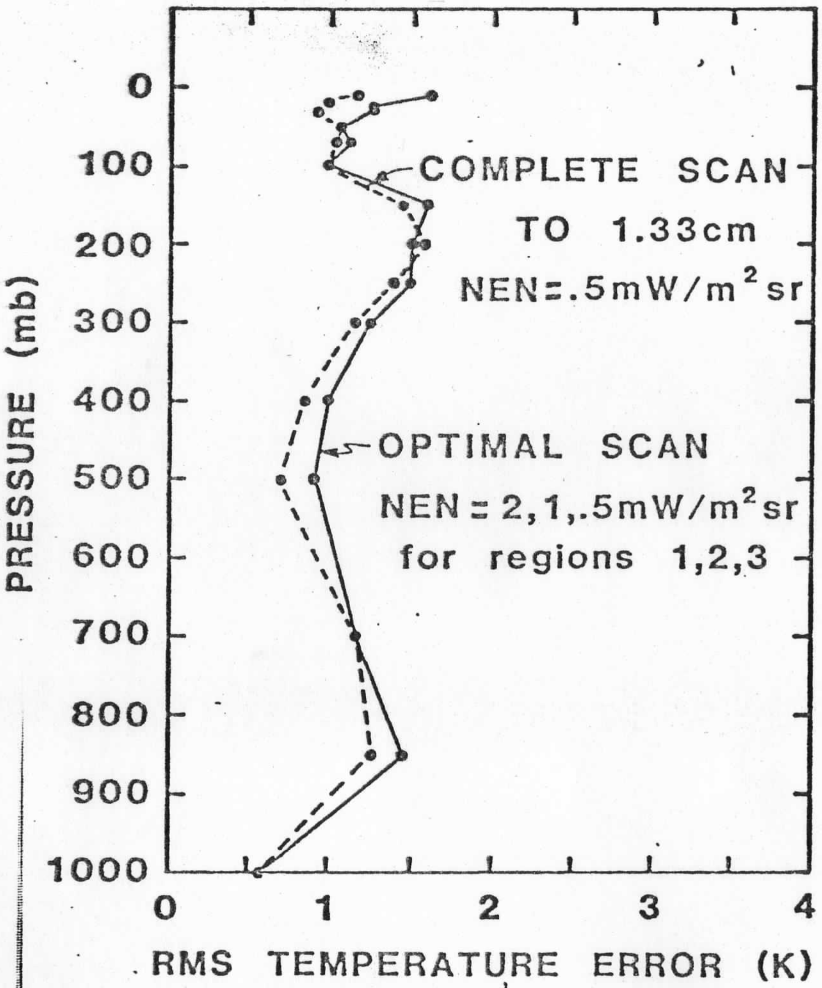


TABLE 3.3 Dwell Time Advantage of Optimal Scanning

Case	Delay Limits* (cm)	No. Scans	NEN (mW/m2 sr)	Dwell Time (sec)	Dwell Time Ratio
(1) Optimal Scanning (HIS)	0.-0.24	2	2.	0.52	
	0.59-0.70	8	1.	1.04	
	1.26-1.33	32	0.5	5.73	
				0.12**	
			TOTAL	7.41	1.0
(2) All Delays, non-uniform noise(NOISE OPTIMIZED MICHELSON)	0.-0.33	2	2.	0.66	
	0.33-0.97	8	1.	5.12	
	0.97-1.62	32	0.5	20.80	
			TOTAL	26.58	3.6
(3) All Delays, constant noise (STANDARD MICHELSON)	0.-0.33	32	0.5	10.56	
	0.33-0.97	32	0.5	20.48	
	0.97-1.62	32	0.5	20.80	
			TOTAL	51.84	7.0

* Actual regions scanned are larger by 300 fringes (0.02 cm) to allow for digital filter convolution and mirror turnaround

** Time for delay scan between partially scanned regions at 10 cm/sec

AIRCRAFT INSTRUMENT DESIGN

HIS AIRCRAFT EXPERIMENT

ADVANTAGES

(1) LOW COST

- USES OFF-THE-SHELF INTERFEROMETER SYSTEM.
- AIRCRAFT INTERFACE FOR SIMILAR INSTRUMENT WILL HAVE BEEN COMPLETED BY DAVE MURCRAY.

(2) WILL YIELD HIGH QUALITY SOUNDING DATA SET WITH GENERAL APPLICABILITY

- HIGH SPECTRAL RESOLUTION.
- BROAD SPECTRAL COVERAGE.
- WILL PERMIT EVALUATION AND REFINEMENT OF DIFFERENT INSTRUMENT APPROACHES.

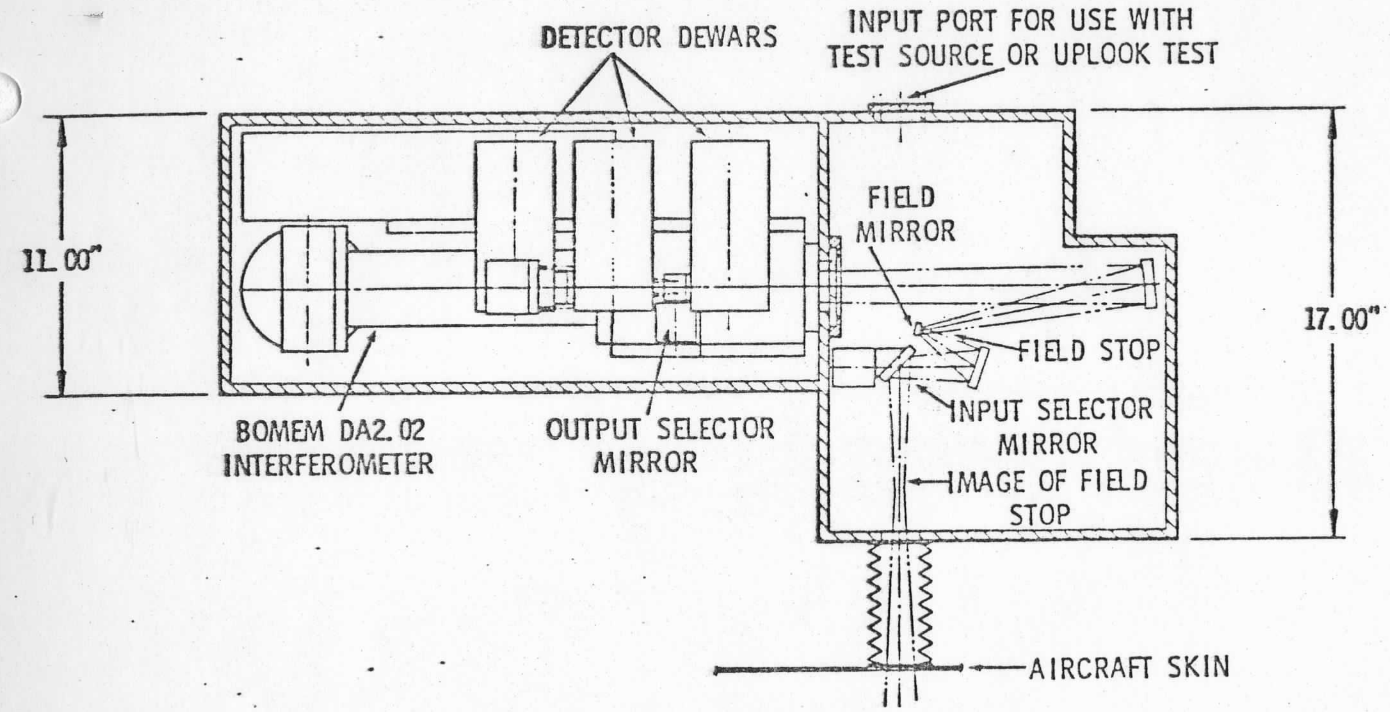


Figure 10-1a. Side View of BOMEM DA2.02 Interferometer with Input and Output Optics for Use in the NASA Lear Jet

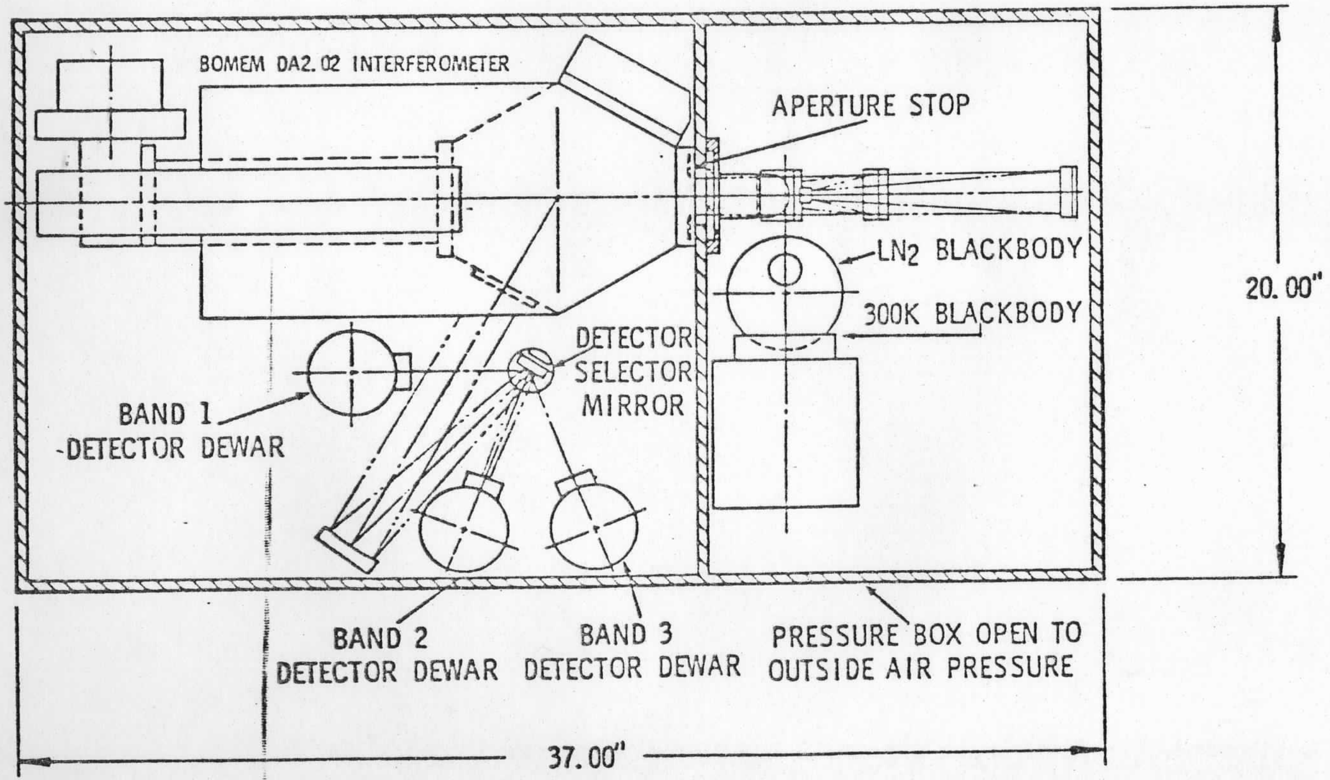


Figure 10-1b. Top View of BOMEM DA2.02 Interferometer with Input and Output Optics for Use in the NASA Lear Jet

Table 5.1 Aircraft Model HIS parameters and performance

Spectral range (cm-1):	
Band 1	600- 900
Band 2	890-1650
Band 3	1830-2700
Maximum optical delay (cm):	
Band 1	1.4
Bands 2 and 3	0.5
Unapodized spectral resolution (cm-1):	
Band 1	0.36
Bands 2 and 3	1.0
Field of view diameter (mr):	
Telescope	100. (1.2 km)
Interferometer	14.
Primary telescope mirror diameter (mm):	4.2
Michelson mirror scan rate (cm/sec):	0.01-2.0
Reference laser wavenumber (cm-1): (equals analog sample frequency)	15800
Michelson mirror dimension (mm):	30.0
Beamsplitter material:	KCl
Optical transmission:	0.2
Detector dimension (cm):	0.05 *
Nominal Temperatures (K):	
Interferometer	300
Ambient blackbody	270
Detectors and cold blackbody	77
Spectral noise equivalent radiance for a single 1 cm/sec scan to the maximum delay (mW/m2 sr cm-1):	
Band 1	0.13
Band 2	0.012
Band 3	0.0016

(The noise is reduced to the desired level by adding the interferograms from several scans.)

* Detector dimension of 0.1 cm assumed in enclosed SBRC document is a conservative value chosen because a ray trace of the optical system has not yet been performed. Matching the area solid angle product for an f/1.2 optics gives a beam diameter of 0.047 cm. SBRC believes it will be possible to use their standard 0.05 cm detector.

PHASE II THE HIS EXPERIMENT
1983 - 1984

OBJECTIVES:

- DEMONSTRATE FEASIBILITY OF HIS APPROACH TO GEOSYNCHRONOUS TEMPERATURE SOUNDING WITH HIGHER VERTICAL RESOLUTION*
- COLLECT HIGH SPECTRAL RESOLUTION DATA SETS FOR
    - MESOSCALE STUDIES AND SOUNDING RESEARCH, AND
    - EVALUATION OF ALTERNATIVE APPROACHES TO SPACECRAFT SOUNDER

*FEASIBILITY OF PARTIAL SCANNING WILL BE DEOMONSTRATED WITH SIPS INSTALLED IN BOMEM INSTRUMENT AT SBRC

PERFORMANCE GOALS

- Spectral coverage and resolution: meet HIS and AMTS requirements

(1) HIS GEO

	Range (cm^{-1})	Res. (cm^{-1})
Band 1	620-750	0.7
Band 2	890-1510	4.2
Band 3	2180-2700	4.2

(2) AMTS.

Band 1	623.2-669.5	0.5 (9 channels)
Band 2	1040.8, 1231.6	1.0
Band 3	2384-2686	≥2.0 (10 channels)
Other	606.95	0.5
	875	0.75
	1650,1700,1839 1851,1930	1.5

<u>Baseline</u>

	Range (cm^{-1})	Res. (cm^{-1})	Max. Delay (cm)
Band 1	600-900	0.5	2.0
Band 2	900-1750	1.5	1.0
Band 3	1830-2700	1.5	0.7

PERFORMANCE GOALS CONT.

- TELESCOPE FOV: SMALL TO LOOK BETWEEN CLOUDS
  LARGE TO MINIMIZE SCENE MOTION EFFECTS.

  BASELINE = 100 MR = 2 KM AT 70,000 FEET

- MICHAELSON MIRROR SCAN RATE: FAST ENOUGH TO MAKE SCENE MOTIONS TOLERABLE.

  BASELINE = 2 CM/SEC OPD
  (GIVES 1.0 SEC/INTERFEROGRAM
  0.23 KM OR 11 MR FOV MOTION
  COMPARED TO
  7 MR/SEC AIRCRAFT STABILITY)

- INTERFEROMETER FOV: PRELIMINARY CRITERION--SMALL ENOUGH THAT SPECTRAL BRIGHTNESS TEMPERATURES ARE PERTURBED LESS THAN 0.1 K BY THE FINITE FOV EFFECT.

  BASELINE = 16 TO 40 MR (RANGE CORRESPONDS TO FACTOR OF 6
  DIFFERENCE IN TIME TO ATTAIN NEN)

PERFORMANCE GOALS CONT.

- CALIBRATION SOURCES

  HOT

  SET TEMPERATURE 300 K

  TEMPERATURE UNCERTAINTY ±0.1 K

  EMISSIVITY = 0.995

  UNCERTAINTY ±0.005

  COLD

  SET TEMPERATURE 230 K (AMBIENT)

  TEMPERATURE UNCERTAINTY ±0.1 K

  EMISSIVITY = 0.995

  UNCERTAINTY ±0.005

PERFORMANCE GOALS CONT.

- NOISE: <u>BASELINE</u>

  ATTAIN BEST REQUIRED NOISE PERFORMANCE BY AVERAGING FOR 10 KM GROUND SWATH OR ABOUT 45 SECONDS ~ 36 SCANS. THIS IMPLIES NEEDING

  NEN COMPARABLE TO HIS GEO
  GLOBAL MODE FOR EACH SCAN

IE.

		NEN (mW/M^{2}SR CM^{-1})	
BAND #	RANGE	ONE SCAN	36 SCANS
1	600-900	0.08	0.014 (HIS)
2	900-1800	0.02	0.002
3	1830-2700	0.002	0.0003 (AMTS)

- INTERFEROMETRIC NOISE: SHOULD NOT LIMIT PERFORMANCE

<u>BASELINE</u> - EMPIRICAL APPROACH FEASIBILITY STUDY SUGGESTED BOMEM DESIGN ADEQUATE--CHARACTERIZE WITH AIRCRAFT INSTRUMENT.

H M Woolf

AIRCRAFT HIS FABRICATION PROGRAM

SUPPORT - $455,000

PERIOD - 15 FEBRUARY 1983 - 15 APRIL 1984

AGENCY - NASA GODDARD WITH

$205,000 FROM NOAA
$250,000 FROM NASA HEADQUARTERS

I. APPROACH - SUMMARY OF PROPOSAL--TO BE REVISED AND AUGMENTED BASED ON DISCUSSIONS.

II. INSTRUMENT DESIGN CONSIDERATIONS

I. APPROACH

- Build instrument around BOMEM DA2.02 (U-2) according to SBRC design.
- Design for use in U-2/ER-2 small pods and use as much of University of Denver U-2 interface design as possible.
- Assemble instrument at University of Wisconsin.

SBRC--AIRCRAFT INSTRUMENT SYSTEMS DESIGN. THE BASIC AIRCRAFT INSTRUMENT DESIGN PRESENTED IN THE SBRC FINAL REPORT OF THE DESIGN FEASIBLITY STUDY FOR THE HIS WILL BE RE-EVALUATED FOR THE ER-2 APPLICATION AND SPECIFIED IN MORE DETAIL, INCLUDING A DETAILED OPTICS DESIGN SUPPORTED BY RAY TRACING.

BOMEM, INC.--PROVIDE THE BOMEM DA 2.02 INTERFEROMETER DESIGNED FOR U-2 APPLICATIONS WITH A DATA SYSTEM REDESIGNED TO ACCOMMODATE THE THREE HIS SPECTRAL BANDS. BOMEM MANUFACTURES AN INSTRUMENT, RUGGEDIZED FOR AIRCRAFT USE, WHICH INCORPORATES AN AUTO-ALIGNED INTERFEROMETER VERY WELL SUITED TO THE NEEDS OF THIS PROGRAM.

UNIVERSITY OF DENVER--THE UNIVERSITY OF DENVER WILL PROVIDE SCIENCE SUPPORT, CONSULTING ON THE AIRCRAFT INTERFACE, AND SUPPORT OF FIELD OPERATIONS. THE UNIVERSITY OF DENVER MAY ALSO PROVIDE PART OF THE INTERFACE HARDWARE, AS DETERMINED EARLY IN THE PROGRAM FROM THE AIRCRAFT HIS SYSTEM DESIGN REQUIREMENTS AND FROM THE FLIGHT PERFORMANCE OF THEIR PRESENT SYSTEM.

NESDIS DEVELOPMENT LAB --

PERFORM DESIGN TRADEOFF EVALUATIONS

THE SPACE SCIENCE AND ENGINEERING CENTER (SSEC) OF THE UNIVERSITY OF WISCONSIN-MADISON WILL MANAGE THE PROGRAM, IN CONCURRENCE WITH THE PRINCIPAL INVESTIGATOR. SSEC WILL ALSO:

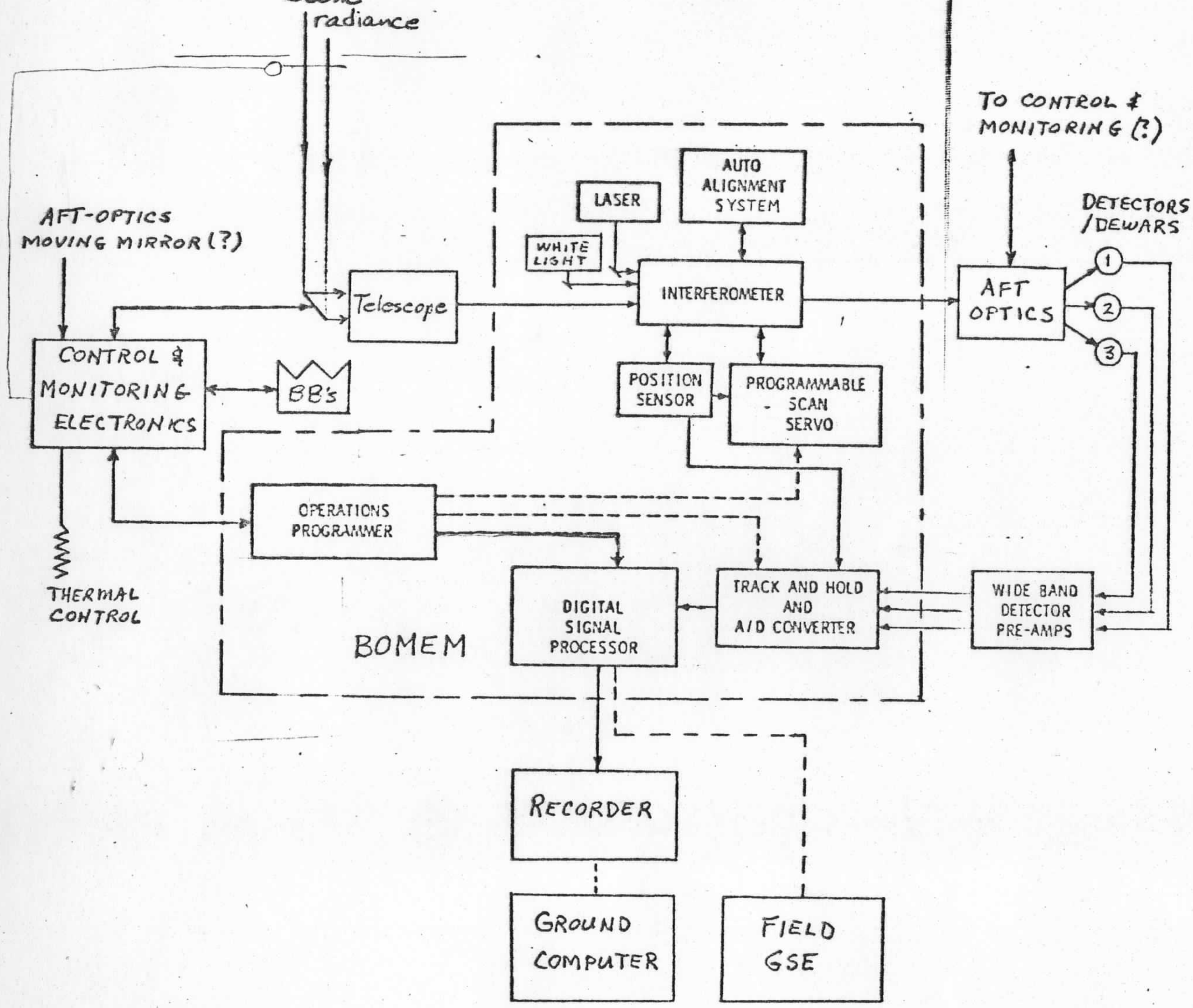
(1) INTEGRATE THE BOMEM INTERFEROMETER (INCLUDING DATA SYSTEM) AND THE OTHER REQUIRED INSTRUMENT COMPONENTS (INCLUDING TELESCOPE, CALIBRATION BLACKBODIES, AFT OPTICS, DETECTOR ASSEMBLIES, AND CASSETTE TAPE RECORDER);

(2) PERFORM THERMAL, MECHANICAL AND ELECTRICAL INTERFACING TO THE ER-2 WINGTIP TANK;

(3) PROVIDE AN INTERFACE FROM FLIGHT CASSETTE RECORDER TO GROUND COMPUTERS;

(4) PROVIDE A DATA SYSTEM FOR FUNCTIONAL FIELD TESTS, AND;

(5) CONDUCT THE FLIGHT EXPERIMENTS.



Scene radiance
AFT-OPTICS MOVING MIRROR (?)
CONTROL & MONITORING ELECTRONICS
BB's
THERMAL CONTROL
Telescope
LASER
AUTO ALIGNMENT SYSTEM
WHITE LIGHT
INTERFEROMETER
POSITION SENSOR
PROGRAMMABLE SCAN SERVO
OPERATIONS PROGRAMMER
DIGITAL SIGNAL PROCESSOR
TRACK AND HOLD AND A/D CONVERTER
BOMEM
TO CONTROL & MONITORING (?)
DETECTORS /DEWARS
AFT OPTICS
1
2
3
WIDE BAND DETECTOR PRE-AMPS
RECORDER
GROUND COMPUTER
FIELD GSE

INTERFACES

TO BOMEM DA 2.02

● Optical:	Telescope to interferometer Interferometer to aft-optics
● Mechanical:	Vibration isolation for bomem int. Packaging
● Thermal:	Thermal control of bomem electronics
● Electrical:	Detector/preamps to sample and hold Digital signal processor (DSP) to recorder DSP to field GSE processor Control and monitoring electronics to operations programmer and or DSP.

TO UNIVERSITY OF DENVER HARDWARE

● Electrical:	Recorder to BOMEM DSP Recorder to UW ground computer Field GSE to BOMEM DSP

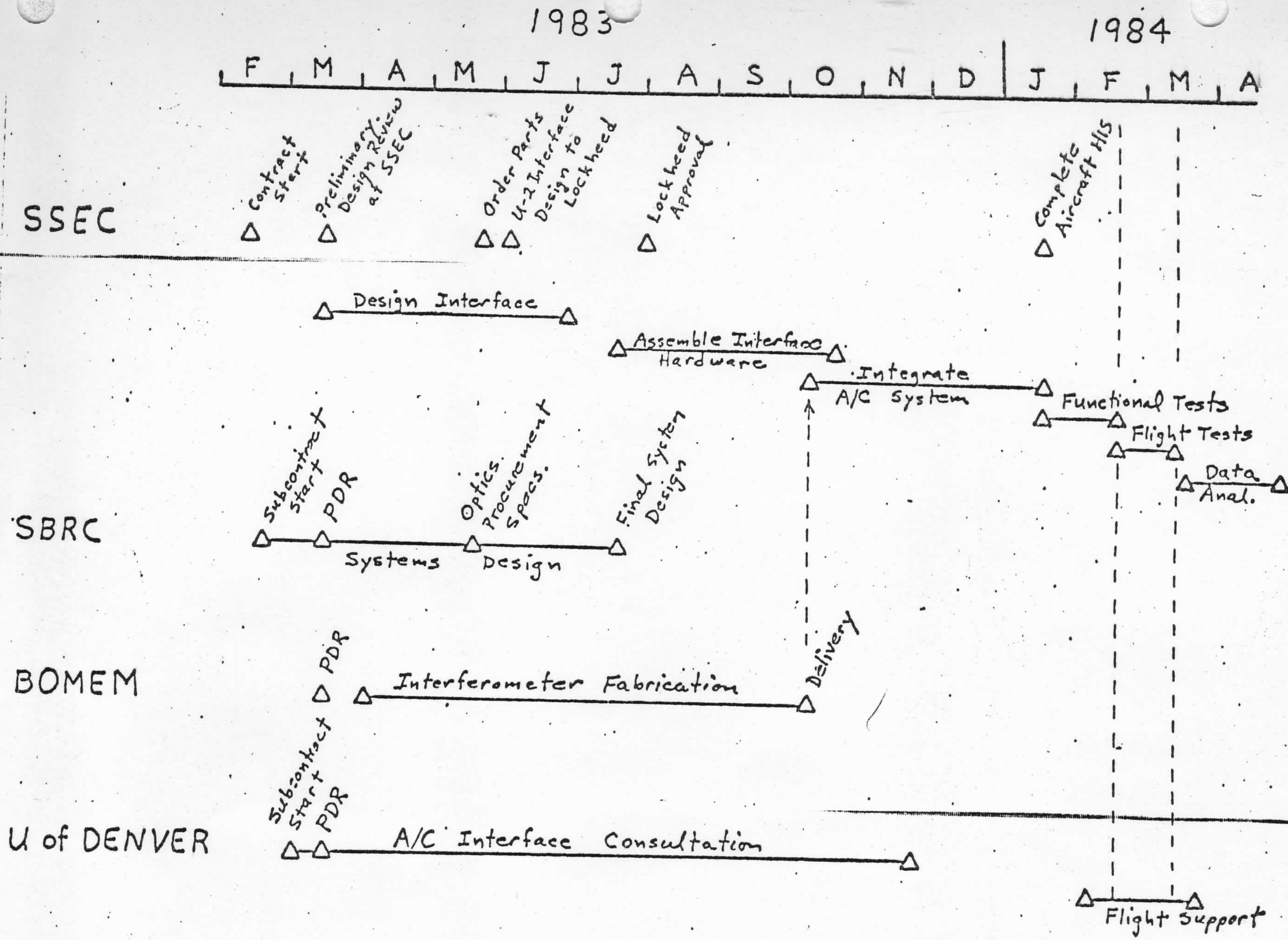


FIGURE 1. SCHEDULE

II. DESIGN CONSIDERATIONS FOR DISCUSSION

- PERFORMANCE TRADE-OFFS
- AREAS WHERE DESIGN APPROACH NEEDS DEFINITION

PERFORMANCE TRADE-OFFS/DECISIONS

- AFT-OPTICS DETECTOR SWITCHING MIRROR VS DICHROICS
  (POSSIBLE IMPACT ON SPECTRAL COVERAGE, NOISE PERFORMANCE, AS WELL AS RELIABILITY AND DATA VOLUME)

- MAXIMUM ALLOWABLE INTERFEROMETER FOV
  (TRADE-OFF BETWEEN NOISE PERFORMANCE AND DELAY DEPENDENT RESPONSIVITY)

- SCAN RATE SELECTION
  (NOMINAL HAS BEEN 1 CM/SEC ODP - FASTER SCAN RATES WOULD REDUCE THE IMPACT OF NON-UNIFORM SCENES, BUT INCREASE RECORDER REQUIREMENTS AND...)

- DETECTOR TYPE
  (HIGH PERFORMANCE HELIUM COOLED DETECTORS COULD IMPROVE NOISE PERFORMANCE AND MIGHT EFFECT NUMBER OF SPECTRAL BANDS NEEDED)

INTERFEROMETER FIELD-OF-VIEW

- SIGNAL-TO-NOISE PROPORTIONAL TO ANGULAR FOV OF INTERFEROMETER FOR HIS AIRCRAFT INSTRUMENT.

- PREVIOUS HIS DESIGNS HAVE ASSUMED VERY SMALL FOV TO KEEP MODULATION TRANSFER FUNCTION SO CLOSE TO 1 THAT DELAY DEPENDENT EFFECTS CAN BE IGNORED.

- IF DELAY DEPENDENCIES ARE ALLOWED, BUT CORRECTED FOR DURING DATA ANALYSIS, SIGNIFICANT PERFORMANCE IMPROVEMENTS ARE POSSIBLE (UP TO FACTOR OF 6 IN DWELL TIME).

- TEMPERATURE RETRIEVAL SIMULATIONS WILL BE USED TO EVALUATE THE LIMITS OF THIS APPROACH.

INTERFEROMETER FIELD-OF-VIEW

$$F'(x) = \int_0^\infty I(\nu)\left(\frac{\sin \pi\nu x\, b^2/2}{\pi\nu x\, b^2/2}\right)\cos[2\pi\nu x(1-b^2/4)]\, d\nu$$

b = 1/2-ANGLE OF INTERFEROMETER FOV

EXPAND $\dfrac{\sin \pi\nu x\, b^2/2}{\pi\nu x\, b^2/2} = 1 + \frac{1}{6}(\pi\nu x\, b^2/2)^2 + \frac{1}{120}(\pi\nu x\, b^2/2)^4 - \ldots$

THEN

$$F'(x) = F(x) - \frac{1}{6}(\pi\nu_n X\, b^2/2)^2\left(\frac{x}{X}\right)^2\left[F(x) * FT\left(\frac{\nu^2}{\nu_n^2}\right)\right]$$
$$+ \frac{1}{120}(\pi\nu_n X\, b^2/2)^2\left(\frac{x}{X}\right)^4\left[F(x) * FT\left(\frac{\nu^4}{\nu_n^4}\right)\right]$$

WHERE

$$F(x) = \int_0^\infty I(\nu)\cos 2\pi\nu x\, d\nu$$

X = MAXIMUM DELAY

ν_n = NYQUIST FREQUENCY

DEFINING $I'(\nu)$ TO BE THE COS TRANSFORM OF $F'(x)$

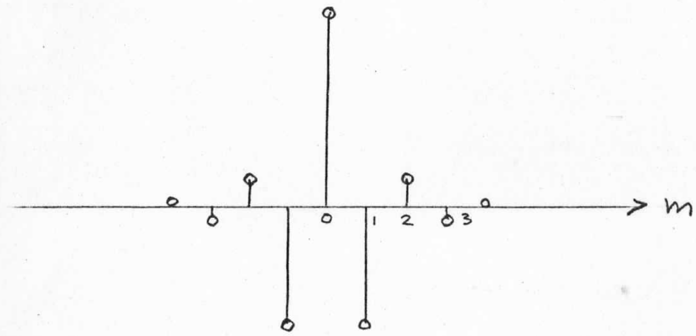
$$I'(\nu) = I(\nu) - \frac{1}{6}(\pi\nu_n X\, b^2/2)^2\, FT\left(\frac{x^2}{X^2}\right) * \left[\frac{\nu^2}{\nu_n^2} I(\nu)\right]$$
$$+ \frac{1}{120}(\pi\nu_n X\, b^2/2)^4\, FT\left(\frac{x^4}{X^4}\right) * \left[\frac{\nu^4}{\nu_n^4} I(\nu)\right] - \ldots$$

ITERATION GIVES:

$$I(\nu) = I'(\nu) + \frac{1}{6}(\pi\nu_n X\, b^2/2)^2\, FT\left(\frac{x^2}{X^2}\right) * \left[\frac{\nu^2}{\nu_n^2} I'(\nu)\right]$$
$$- \frac{1}{120}(\pi\nu_n X\, b^2/2)^4 \left\{\frac{10}{3} FT\left(\frac{x^2}{X^2}\right) * \left[\frac{\nu^2}{\nu_n^2} FT\left(\frac{x^2}{X^2}\right) * \frac{\nu^2}{\nu_n^2} I'(\nu)\right]\right.$$
$$\left. + FT\left(\frac{x^4}{X^4}\right) * \left[\frac{\nu^4}{\nu_n^4} I'(\nu)\right]\right.$$

INTERFEROMETER FIELD-OF-VIEW (CONT.)

$$\frac{1}{2X} FT(x^2/X^2) = \begin{cases} 1/6 \,, & \nu = 0. \\ \frac{(-)^m}{(m\pi)^2} \,, & \nu = \frac{m}{2X} \quad m \neq 0. \end{cases}$$



CONVOLUTION OF x^2/X^2 with a CONSTANT IS ∝

$$\frac{1}{6} + 2 \sum_{m=1}^{\infty} \frac{(-)^m}{(m\pi)^2} = 0$$

CONVOLUTION WITH $\cos \pi m$ IS ∝

$$\frac{1}{6} + 2 \sum_{m=1}^{\infty} \frac{1}{(m\pi)^2} = 1/2$$

∴ ASSUME

$$FT\left(\frac{x^2}{X^2}\right) * \left[\frac{\nu^2}{\nu_n^2} I(\nu)\right] \leq 1/2 \; I(\nu)$$

→ FRACTIONAL RADIANCE ERROR

$$\frac{\delta I(\nu)}{I(\nu)} \leq \frac{1}{12} \left(\pi \nu_n X b^2/2\right)^2$$

INTERFEROMETER FIELD-OF-VIEW (CONT.)

$$\frac{\delta I(\nu)}{I(\nu)} \le \frac{1}{12}\left(\pi \nu_n \mathrm{X} \; b^2/2\right)$$

$$= \frac{\pi^2}{12\,C^2}$$

WHERE C IS DEFINED SUCH THAT

$$\text{INT. FOV} = 2b = \frac{4}{\sqrt{C(2\nu_n \mathrm{X})}} = \frac{4}{\sqrt{CM}}$$

DEFINE MAXIMUM MODULATION FUNCTION

$$R = \frac{\sin \pi \nu_n \mathrm{X}\, b^2/2}{\pi \nu_n \mathrm{X}\, b^2/2} = \frac{\sin \pi/C}{\pi/C}$$

C	R	$\frac{\pi^2}{12C^2}$	$\frac{\pi^4}{120\,C^4}$	$2b$ $(2\nu_n\mathrm{X} = 2048)$
2	.637	.206	.042	62 mr
4	.900	.052	.004 .1%	44
6	.955	.023	.0005	37
8	.974	.013		31
10	.984	.008		28
20	.996	.002		20
30	.998	.001	.1%	16
40	.999	.0005		14

DWELL TIME TO REACH NEN $\propto$ C.

DESIGN QUESTIONS

- APPROACH TO CONDENSATION PREVENTION
  - IS THE FOLLOWING REASONABLE?
    1. POD APERTURE DOOR + NITROGEN FILL TO PROTECT BLACKBODY DURING ASCENT. NO PROTECTION FOR DESCENT.
    2. SEALED INSTRUMENT (INTERFEROMETER AND DETECTOR SECTIONS) WITH NITROGEN FILL. TO PROTECT BEAMSPLITTER AND AFT OPTICS.
    3. RECORDER--NO PROTECTION DURING DESCENT.

- CAN THE UNIVERSITY OF DENVER CASSETTE RECORDER (OR MULTIPLE RECORDERS) DO THE HIS JOB?

- WHAT SHOULD THE GSE CONSIST OF? DOES INSTRUMENTATION ALREADY EXIST AT THE UNIVERSITY OF DENVER?

FACTORS AFFECTING RECORDER JOB

- Delay scan rate (less than 4 cm/s)
- Spectral resolution
- Spectral band boundaries and number

<u>Example</u>

Band No.	Wave Number Range (cm^{-1})	Max Delay (cm)	Sample No.	Sample Freq. (cm^{-1})
1	600-900	2.00	2048	1024
2	900-1750	1.14	2048	1800
3	1830-2700	1.14	2048	1800

Worst case bit rate = (15800 samples/cm-channel)(3 channels)
(16 bits/sample)(4 cm/sec)(415 retrace)
= 2430 K B/S

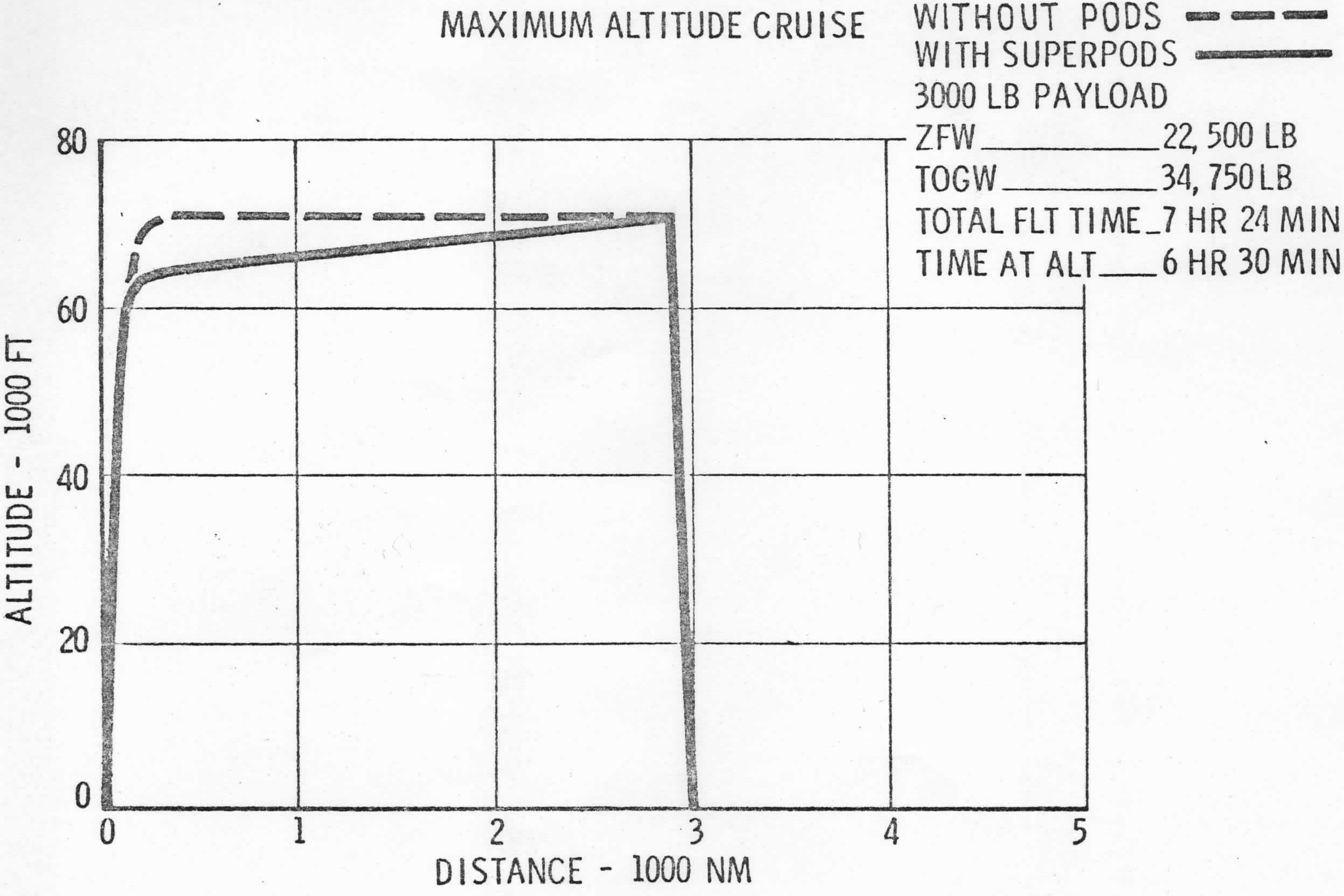
Volume = 4.36×10^4 M bits (5 hours)

$$\text{Reduction factor} = \frac{(2.00)(15800)}{2048} = 15.4$$

		Scan Rate (OPD)		
	Worst	4 cm/s	2 cm/s	
Mean Rate	2430	157	79	K B/S
5 hr. Volume	4.36×10^4	2826	1413	M bits

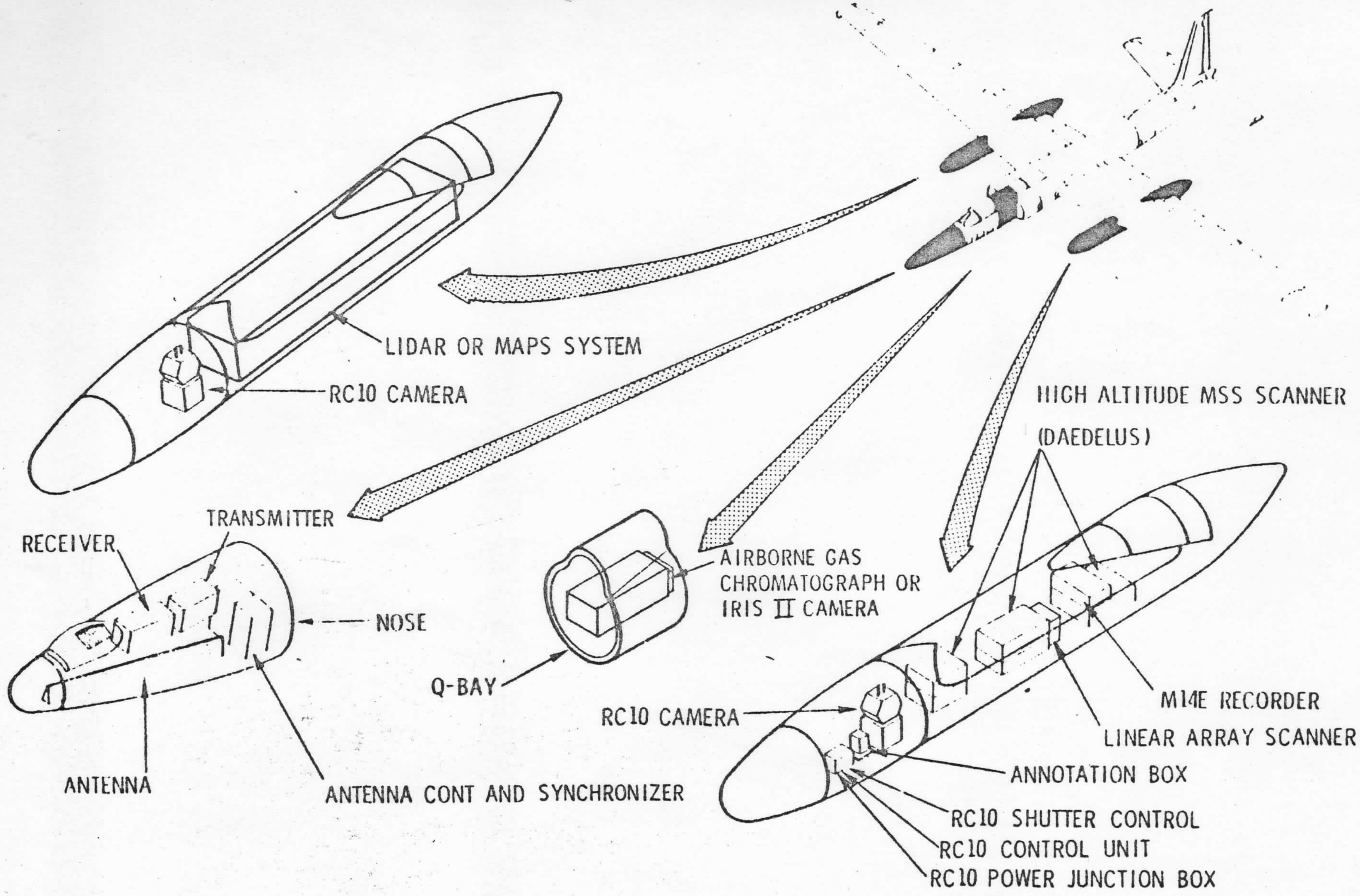
ER-2 MISSION PROFILE WITH SUPERPODS

MAXIMUM ALTITUDE CRUISE



HMWoolf

TYPICAL MULTIPLE PAYLOAD
COMBINATION RADAR-PHOTOGRAPHIC-INFRARED AIR SAMPLING MISSION



2371-3 A

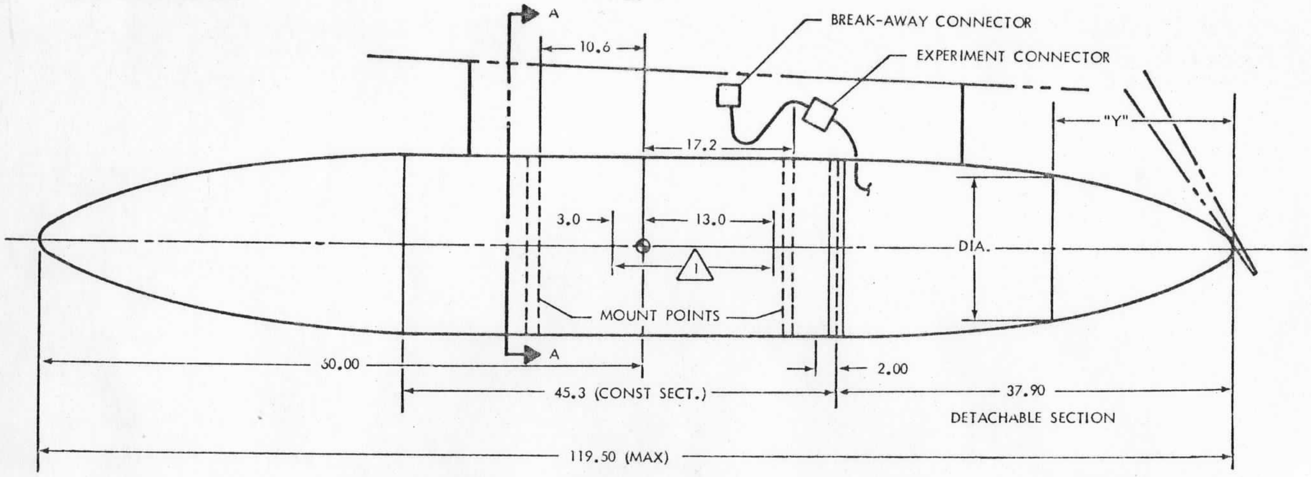
"Y"	5.00	10.50	14.0	18.0	24.0	30.0	35.0	36.3
DIA.	6.23	10.07	11.94	18.74	15.51	16.6	17.41	17.60

NOTE: THIS TABLE APPLIES TO NOSE SECTION ALSO. DIMENSIONS SHOWN ARE MAXIMUM FOR THE EXPERIMENT ENVELOPE.

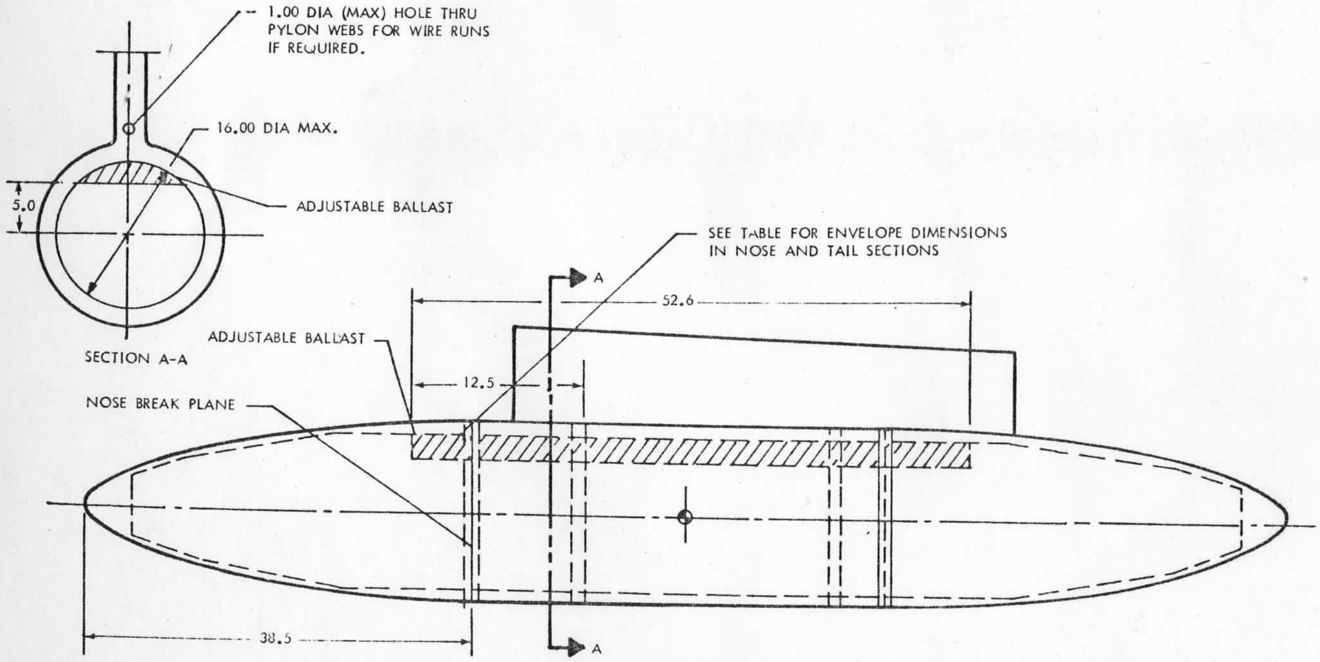
NOTE : 1 CENTER OF GRAVITY OF EXPERIMENT WEIGHT WILL BE HELD WITHIN LIMITS SHOWN.

MAXIMUM WEIGHT OF ENTIRE EXPERIMENT INCLUDING EXPERIMENT, EXPERIMENT STRUCTURE, ELECTRICAL HARNESSES AND BALLAST FOR TANK, SHALL NOT EXCEED 300 POUNDS.

2 ALL MODIFICATIONS TO TANK REQUIRED TO ACCEPT EXPERIMENT PACKAGES SHALL BE DONE BY L.A.C.



WING TANK DIMENSIONS



SECTION A-A

WING TANK CONFIGURATION (SEE NOTE #2)

FIGURE 1.8

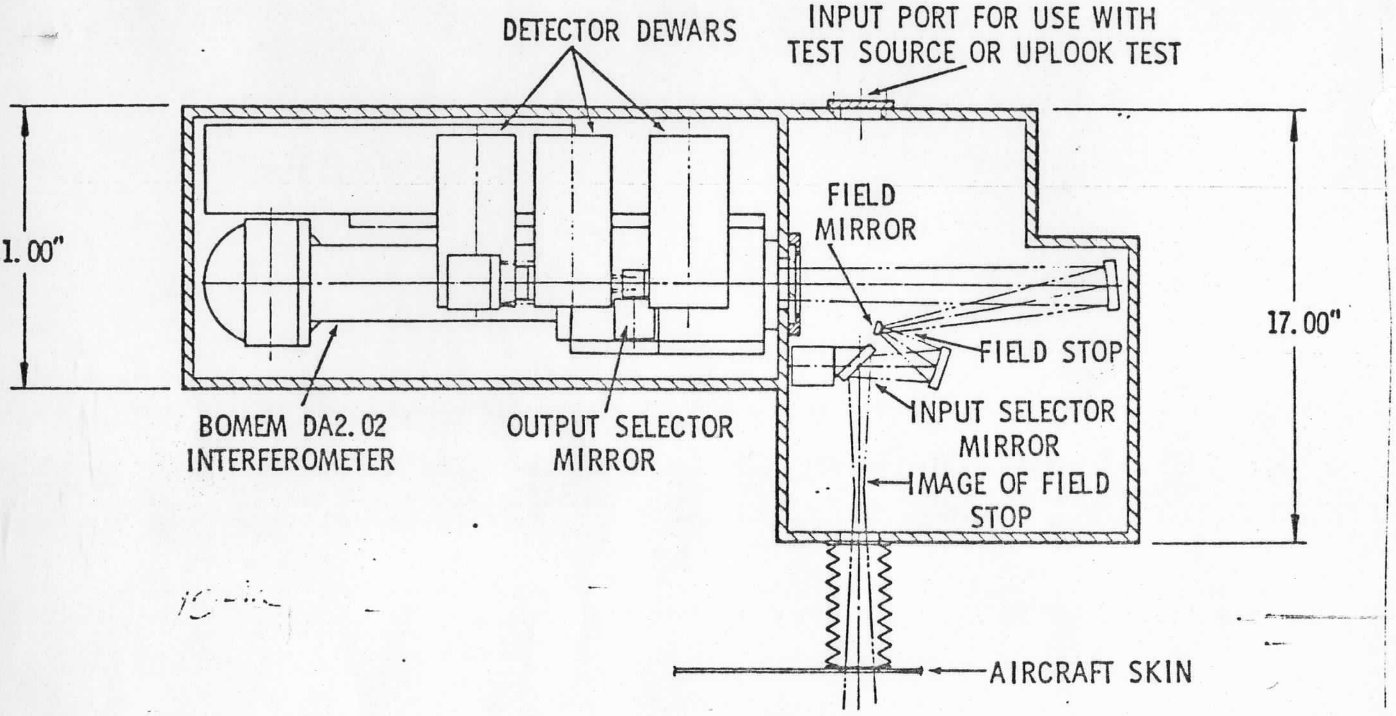


Figure 10-1a. Side View of BOMEM DA2.02 Interferometer with Input and Output Optics for Use in the NASA Lear Jet

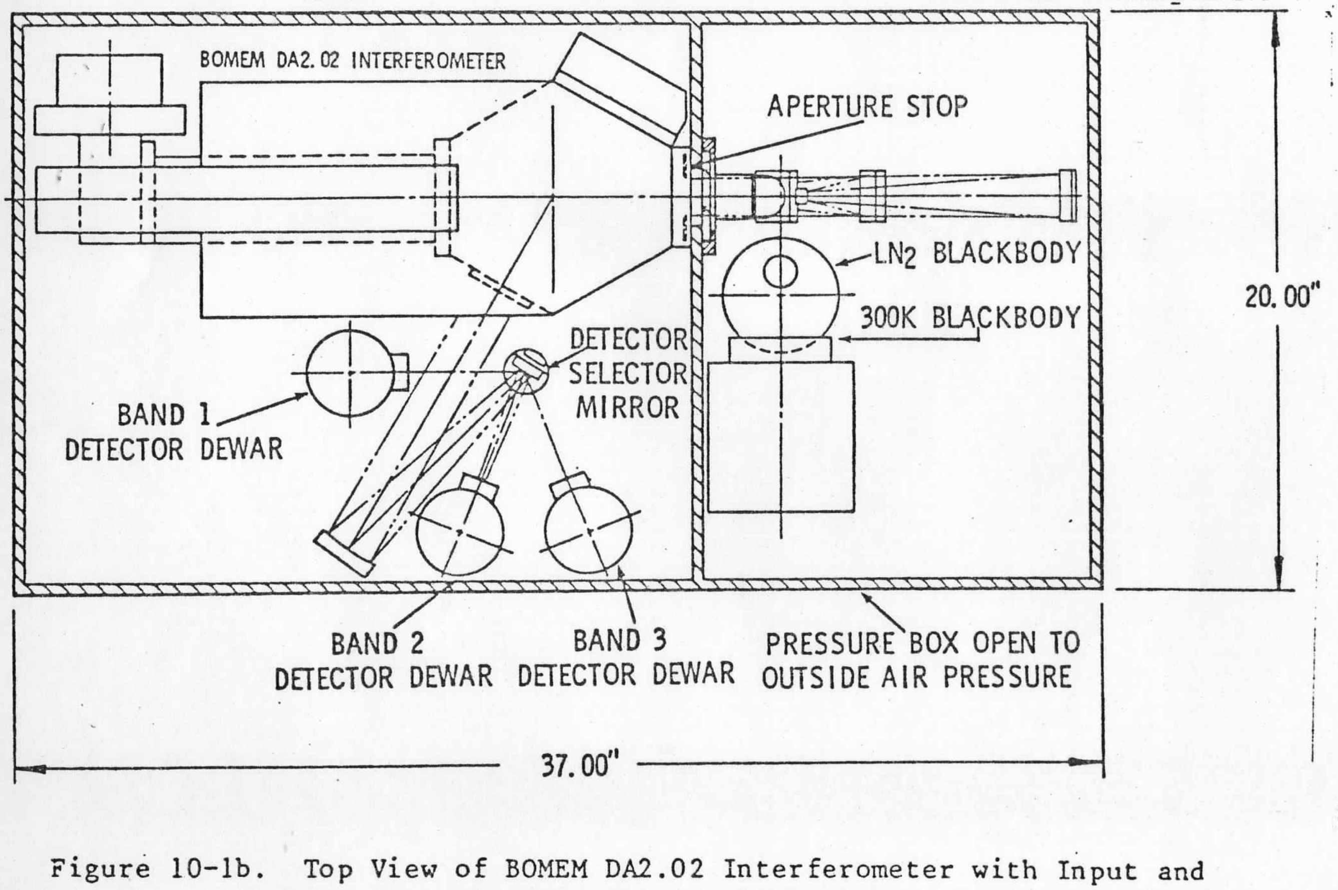


Figure 10-1b. Top View of BOMEM DA2.02 Interferometer with Input and Output Optics for Use in the NASA Lear Jet

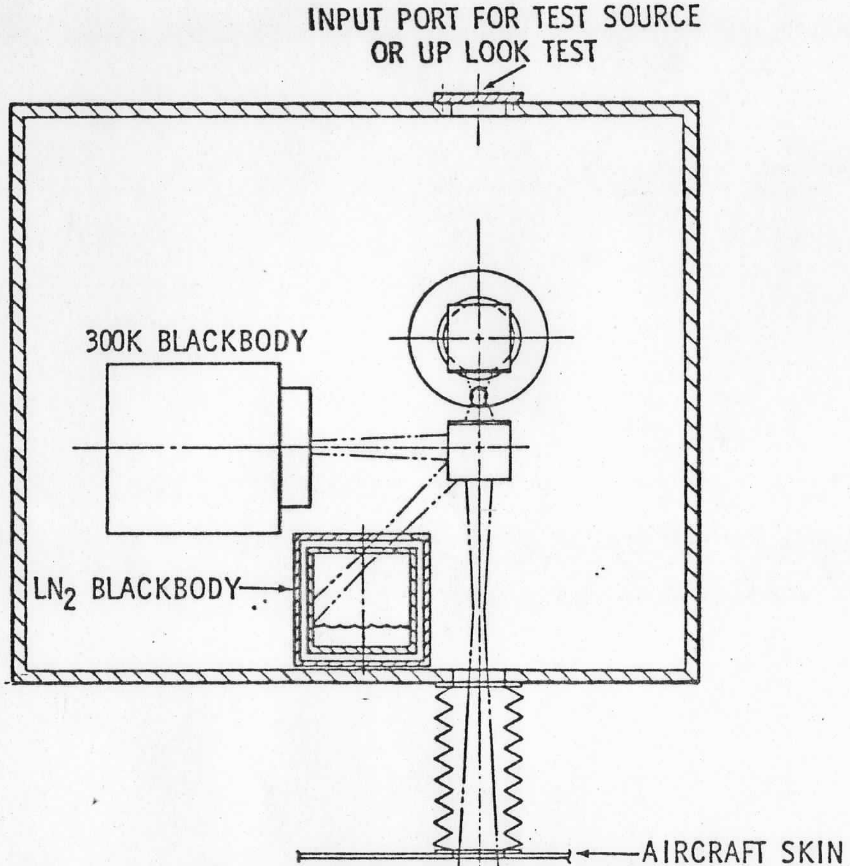


Figure 10-1c. End View of BOMEM DA2.02 Interferometer with Input and Output Optics for Use in the NASA Lear Jet

B. OPTICAL CONSIDERATIONS

For the interferometer to be employed as a calibrated spectral radiometer, the input/output optics must be planned in accordance with the concepts described in Section 2 of the HIS Feasibility Study. Briefly stated, these are as follows:

1. The input beam at the telescope should be imaged, via a field lens/mirror and the collimator, at the entrance to the interferometer module. At this location, the beam is defined by an aperture stop which is smaller than the interferometer optics. Note that in normal operation of the DA2.02 interferometer, the laser and white light beam are introduced in the center of the IR beam. This causes an obscuration at the input and the output of the interferometer. In order to eliminate path difference dependent vignetting these beams may be placed outside the aperture stop. In this case, a clear aperture of 30 mm can be maintained at the aperture stop. The position offset between the center of the IR beam and the laser sampling will be 22 mm.
2. The aperture stop is imaged through the interferometer via the output camera mirror and a small field lens onto the detector face. In this manner the beam topology fringes are illuminated by the radiance field received at the input telescope and imaged on the detector face.

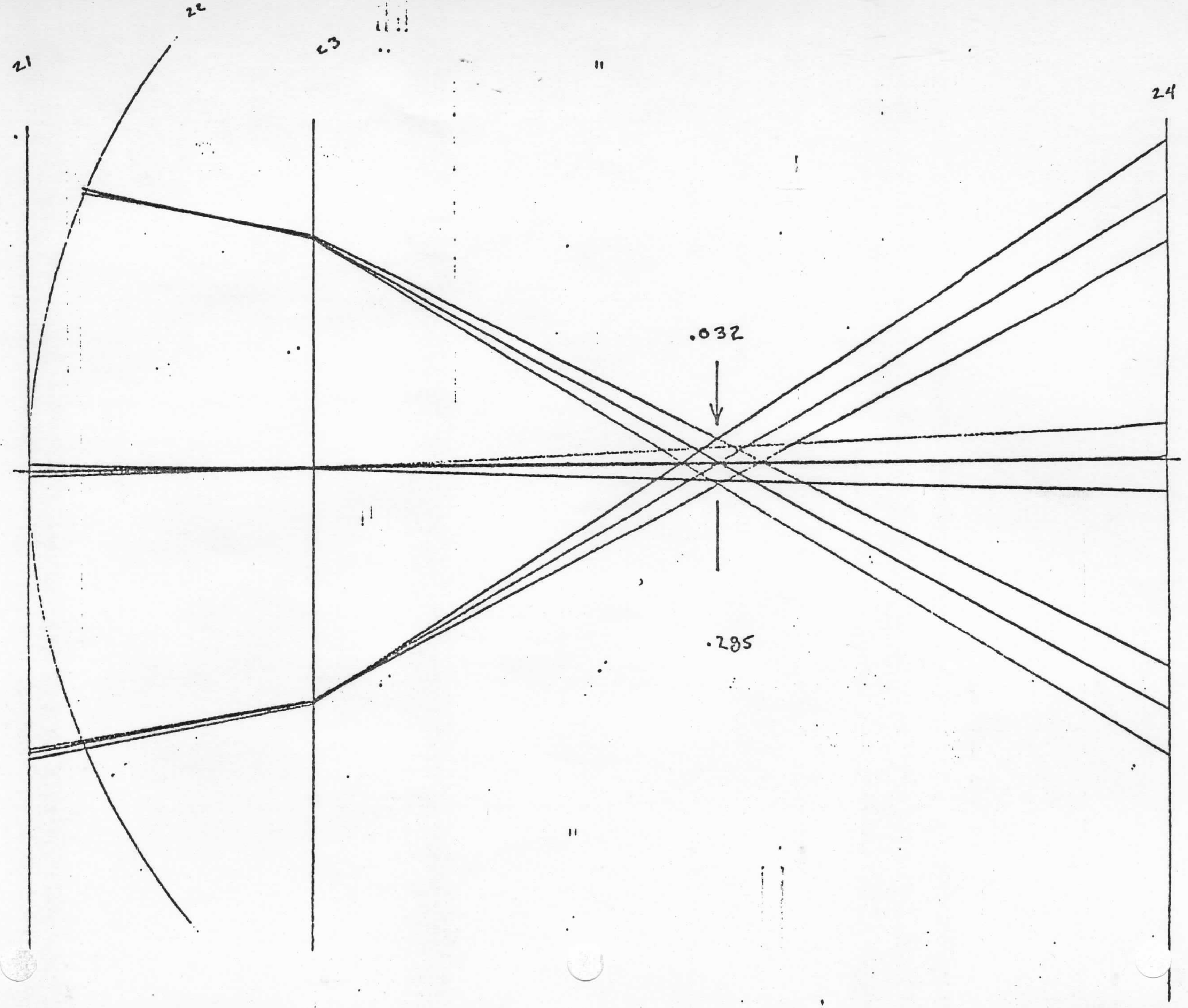
The field-of-view fringes occur at the surface of the output field lens. This latter lens or its image at the input field lens/mirror may be restricted in diameter to form the field stop of the system.

```
 SAME AS PROPROSED      HIS ER2 MODEL         2/15/83           KCL & DICHROICS
*INT FULL FOV(rad)         0.014           *INT DIAM cm              2.98
   Ao (cm2 ster)         1.07E-03      *INPUT App Diam(cm)           0.789
  *OPD Scan rate            1          Full Angle FOV(rad)         5.288E-02
   *Retrace Rate            4           *"Flight Alt (km)           19.80
                                          Foot Print (km)            1.05
-----------------------BAND 1 -MCT---------BAND 2 -MCT-------BAND 3 -InSb---
                                           5.120E-03            5.120E-03
*DET Size (cm2)f1.0      5.120E-03
 *NUMBER OF COADDS          6                  6                    6
     *OPD (CM)             1.33               0.5                  0.5
  INTEGRATION (SEC)        7.98              3.00                 3.00
   TOTAL DATA TIME         9.98              9.98                 9.98
     * CM-1 MAX            850               1650                 2700
     * CM-1 MIN            600               890                  1830
 OPTICS TRANSMITION       0.150             0.140                0.160
    *NOISE FACTOR          1.02              1.02                 1.02
    *DETECTOR D*        2.000E+10         1.400E+11            1.000E+12
 NEN(mw/m2 st cm-1)      0.10777           0.01011              0.00124
```

```
OPD IN CM-1 ? 1.33              OPD IN CM-1 ? .5                OPD IN CM-1 ? .5
MAX WAWNUM IN CM-1 ? 850        MAX WAWNUM IN CM-1 ? 1650       MAX WAWNUM IN CM-1 ? 2700
%MOD          FULL ANGLE(RAD)   %MOD          FULL ANGLE(RAD)   %MOD          FULL ANGLE(RAD)
 1              .001             1              .001             1              .001
 .999997        .003             .999999        .003             .999996        .003
 .999979        .005             .999989        .005             .999971        .005
 .999921        .007             .999958        .007             .999888        .007
 .999785        .009             .999885        .009             .999693        .009
 .999519        .011             .999744        .011             .999314        .011
 .999062        .013             .9995          .013             .998663        .013
 .998338        .015             .999115        .015             .99763         .015
 .997259        .017             .99854         .017             .996092        .017
 .995725        .019             .997722        .019             .993907        .019
 .993624        .021             .996601        .021             .990915        .021
 .990833        .023             .995112        .023             .986943        .023
 .987218        .025             .993181        .025             .981803        .025
 .982634        .027             .990729        .027             .975291        .027
 .976929        .029             .987673        .029             .967197        .029
 .969939        .031             .983923        .031             .957298        .031
 .961498        .033             .979383        .033             .945368        .033
 .951431        .035             .973955        .035             .931175        .035
 .939565        .037             .967535        .037             .914494        .037
 .925722        .039             .960018        .039             .895103        .039
```

```
?4i   PUSHED SYSTEM        HIS ER2 MODEL          2/15/83          KCL & DICHROICS
*INT FULL FOV(rad)           0.021           *INT DIAM cm              3.57
  Ao (cm2 ster)            3.47E-03       *INPUT App Diam(cm)          0.789
   *OPD Scan rate              1          Full Angle FOV(rad)       9.502E-02
    *Retrace Rate              4           *"Flight Alt (km)          19.80
                                            Foot Print (km)            1.88
----------------------BAND 1 -MCT---------BAND 2 -MCT-------BAND 3 -InSb---
*DET Size (cm2)f1.0     6.150E-03             6.150E-03            6.150E-03
 *NUMBER OF COADDS          1                     1                    1
     *OPD (CM)             1.33                  0.5                  0.5
 INTEGRATION (SEC)         1.33                  0.50                 0.50
  TOTAL DATA TIME          1.66                  1.66                 1.66
    * CM-1 MAX              850                  1650                 2700
    * CM-1 MIN              600                   890                 1830
OPTICS TRANSMITION         0.150                 0.140                0.160
   *NOISE FACTOR           1.02                  1.02                 1.02
   *DETECTOR D*         2.000E+10             1.400E+11            1.000E+12
 NEN(mw/m2 st cm-1)       0.08959               0.00841              0.00103

?4i
```


21
22
23
24
.032
.285

```
>LEPRT#FOB.-1#RPXYZ ALL,0 1 -1

INTERFEROMETER SPECTROMETER

BASIC LENS DATA

SURF        RD              TH          MEDIUM                      RN          DF
  0      0.000000    0.319198E+06     AIR

  1      0.000000       -4.000000     REFL

  2      8.000000        4.000000     REFL

  3      0.000000        0.150000     KCL                      1.504000      4.759
  4    -50.000000       17.854700     AIR

  5    -35.900000      -22.500000     REFL

  6      0.000000       -2.000000     AIR

  7      0.000000       -0.060000     KCL                      1.504000      4.759
  8      0.000000       -0.060000     AIR

  9      0.000000       -0.060000     KCL                      1.504000      4.759
 10      0.000000        0.000000     AIR

 11      0.000000       -2.000000     AIR

 12      0.000000        2.000000     REFL

 13      0.000000        0.060000     KCL                      1.504000      4.759
 14      0.000000        0.060000     AIR

 15      0.000000        0.000000     REFL

 16      0.000000       -0.060000     AIR

 17      0.000000       -0.060000     KCL                      1.504000      4.759
 18      0.000000        0.000000     AIR

 19      0.000000      -20.000000     AIR

 20     36.000000       17.900000     REFL

 21      0.000000        0.000000     AIR

 22      0.575000        0.200000     ZNSE                     2.400000      1.293
 23      0.000000        0.600000     AIR

 24      0.000000        0.000000     AIR
```

```
REFRACTIVE INDICES

SURF       N1          N2          N3          N4          N5          ABBE
  3     1.504000    1.512000    1.437000    1.000000    1.000000    6.720000
  7     1.504000    1.512000    1.437000    1.000000    1.000000    6.720000
  9     1.504000    1.512000    1.437000    1.000000    1.000000    6.720000
 13     1.504000    1.512000    1.437000    1.000000    1.000000    6.720000
 17     1.504000    1.512000    1.437000    1.000000    1.000000    6.720000
 22     2.400000    2.400000    2.400000    1.000000    1.000000    1.400000

CC AND ASPHERIC DATA

SURF        CC              AD             AE             AF             AG
  2   -1.00000E+00
  5   -1.00000E+00
 20   -1.00000E+00

TILT AND DEC DATA

SURF   TYPE          YD           XD         ALPHA        BETA        GAMMA
  2    DEC       -1.60000     0.00000
  6    DEC       -7.17151     0.00000
  7    TILT       0.00000     0.00000     30.0000      0.0000      0.0000
 11    TILT       0.00000     0.00000    -30.0000      0.0000      0.0000
 13    TILT       0.00000     0.00000     30.0000      0.0000      0.0000
 19    TILT       0.00000     0.00000     30.0000      0.0000      0.0000
 20    DEC        7.20145     0.00000
 21    TILT       0.00000     0.00000     22.6000      0.0000      0.0000
 22    DEC       -0.03859     0.00000

PICKUPS

SURF   TYPE     J      A           B
 12    TH      11   -1.0000     0.000000

REF OBJ HT                       REF AP HT    OBJ SURF   REF SURF   IMG SURF
0.15000CE+05 (   -2.69 DG)        0.13339        0          1         24

    EFL            BF        F/NBR       LENGTH        OID           T-MAG
  -3.2587        0.6000     -12.21      44.6800   319189.9443      0.000010

WAVL NBR             1           2           3           4           5
WAVELENGTH       13.80000     7.85000     4.42000     0.00000     0.00000
SPECTRAL WT       1.0000      1.0000      1.0000      1.0000      1.0000

APERTURE STOP AT SURF  1

LENS UNITS ARE INCHES

EVALUATION MODE IS FOCAL

CONTROL WAVELENGTH IS 1

PRIMARY CHROMATIC WAVELENGTHS ARE 2 - 3

SECONDARY CHROMATIC WAVELENGTHS ARE 2 - 1
```

```
>FOB.1#RPXYZ ALL.0 1 -1#FOB#RPXYZ ALL,0 1 -1#FOB,-1#RPXYZ.0 .1 -1

MODIFIERS ARE   ALPHA---ALL
                WORD 1--X OFFSET
                WORD 2--DELTA Y
                WORD,3--STARTING Y
                WORD 4--PRINT SURFACE
                WORD 5--PRINT SUURFACE

RAY AT WAVL 1  - (YR,XR) = (-1.00, 0.00)

SURF        Y             X             Z          YANG(DG)       XANG(DG)
  1    -0.133390      0.000000      0.000000    -177.309467    180.000000

  2     1.283476      0.000000      0.102957     -20.919629      0.000000

  3    -0.206190      0.000000      0.000000     -13.733467      0.000000
  4    -0.242705      0.000000     -0.000589     -20.763110      0.000000

  5    -6.770120      0.000000     -0.638364     179.403966    180.000000

  6     0.628816      0.000000      0.000000     179.403966    180.000000

  7     0.754652      0.000000      0.000000     160.219433    180.000000
  8     0.776230      0.000000      0.000000     149.403966    180.000000

  9     0.811708      0.000000      0.000000     160.219433    180.000000
 10     0.833287      0.000000      0.000000     149.403966    180.000000

 11     0.717313      0.000000      0.000000     179.403966    180.000000

 12     0.738119      0.000000      0.000000       0.596035      0.000000

 13     0.871100      0.000000      0.000000     -19.052771      0.000000
 14     0.850378      0.000000      0.000000     -29.403965      0.000000

 15     0.816565      0.000000      0.000000    -150.596035    180.000000

 16     0.816565      0.000000      0.000000    -150.596035    180.000000

 17     0.782751      0.000000      0.000000    -160.947229    180.000000
 18     0.762029      0.000000      0.000000    -150.596035    180.000000

 19     0.663901      0.000000      0.000000     179.403966    180.000000

 20    -6.335286      0.000000      0.557442      20.557488      0.000000

 21     0.158031      0.000000      0.000000      -2.042512      0.000000

 22     0.195401      0.000000      0.034219     -12.538990      0.000000
 23     0.158529      0.000000      0.000000     -31.402674      0.000000

 24    -0.207751      0.000000      0.000000     -31.402674      0.000000
```

```
RAY AT WAVL 1  - (YR,XR) = ( 0.00, 0.00)

SURF        Y             X             Z          YANG(DG)       XANG(DG)
  1     0.000000      0.000000      0.000000   -177.309491    180.000000

  2     1.417934      0.000000      0.125659    -22.792156      0.000000

  3    -0.210065      0.000000      0.000000    -14.926085      0.000000
  4    -0.249884      0.000000     -0.000624    -22.627565      0.000000

  5    -7.376531      0.000000     -0.757844    179.405149    180.000000

  6     0.020713      0.000000      0.000000    179.405149    180.000000

  7     0.048184      0.000000      0.000000    160.220153    180.000000
  8     0.069761      0.000000      0.000000    149.405149    180.000000

  9     0.105238      0.000000      0.000000    160.220153    180.000000
 10     0.126815      0.000000      0.000000    149.405149    180.000000

 11     0.109167      0.000000      0.000000    179.405149    180.000000

 12     0.129932      0.000000      0.000000      0.594852      0.000000

 13     0.172973      0.000000      0.000000    -19.053496      0.000000
 14     0.152251      0.000000      0.000000    -29.405148      0.000000

 15     0.118435      0.000000      0.000000   -150.594852    180.000000

 16     0.118435      0.000000      0.000000   -150.594852    180.000000

 17     0.084620      0.000000      0.000000   -160.946504    180.000000
 18     0.063898      0.000000      0.000000   -150.594852    180.000000

 19     0.055669      0.000000      0.000000    179.405149    180.000000

 20    -6.945087      0.000000      0.669920     22.433460      0.000000

 21     0.155669      0.000000      0.000000     -0.166540      0.000000

 22     0.194161      0.000000      0.033773    -11.712938      0.000000
 23     0.159698      0.000000      0.000000    -29.158036      0.000000

 24    -0.175054      0.000000      0.000000    -29.158036      0.000000
```

```
RAY AT WAVL 1  - (YR,XR) = ( 1.00, 0.00)

SURF        Y            X            Z         YANG(DG)      XANG(DG)
  1     0.133390     0.000000     0.000000   -177.309515    180.000000

  2     1.552499     0.000000     0.150641    -24.655378      0.000000

  3    -0.214378     0.000000     0.000000    -16.103099      0.000000
  4    -0.257490     0.000000    -0.000663    -24.481836      0.000000

  5    -7.983598     0.000000    -0.887714    179.406517    180.000000

  6    -0.588219     0.000000     0.000000    179.406517    180.000000

  7    -0.659237     0.000000     0.000000    160.220985    180.000000
  8    -0.637661     0.000000     0.000000    149.406517    180.000000

  9    -0.602186     0.000000     0.000000    160.220985    180.000000
 10    -0.580610     0.000000     0.000000    149.406517    180.000000

 11    -0.499816     0.000000     0.000000    179.406517    180.000000

 12    -0.479098     0.000000     0.000000      0.593483      0.000000

 13    -0.526146     0.000000     0.000000    -19.054334      0.000000
 14    -0.546870     0.000000     0.000000    -29.406517      0.000000

 15    -0.580687     0.000000     0.000000   -150.593483    180.000000

 16    -0.580687     0.000000     0.000000   -150.593483    180.000000

 17    -0.614504     0.000000     0.000000   -160.945666    180.000000
 18    -0.635228     0.000000     0.000000   -150.593483    180.000000

 19    -0.553413     0.000000     0.000000    179.406517    180.000000

 20    -7.555905     0.000000     0.792940     24.300557      0.000000

 21     0.153573     0.000000     0.000000      1.700557      0.000000

 22     0.193155     0.000000     0.033413    -10.911740      0.000000
 23     0.161041     0.000000     0.000000    -27.020672      0.000000

 24    -0.144947     0.000000     0.000000    -27.020672      0.000000
```

```
MODIFIERS ARE  ALPHA---ALL
               WORD 1--X OFFSET
               WORD 2--DELTA Y
               WORD,3--STARTING Y
               WORD 4--PRINT SURFACE
               WORD 5--PRINT SUURFACE

RAY AT WAVL 1  - (YR,XR) = (-1.00, 0.00)

SURF       Y              X              Z           YANG(DG)        XANG(DG)
  1    -0.133390      0.000000       0.000000    -179.999976     180.000000

  2     1.466609      0.000000       0.134434     -20.776938       0.000000

  3    -0.000002      0.000000       0.000000     -13.642213       0.000000
  4    -0.036404      0.000000      -0.000013     -20.753450       0.000000

  5    -6.574087      0.000000      -0.601931     179.999143     180.000000

  6     0.597747      0.000000       0.000000     179.999143     180.000000

  7     0.690259      0.000000       0.000000     160.582122     180.000000
  8     0.711409      0.000000       0.000000     149.999143     180.000000

  9     0.746052      0.000000       0.000000     160.582122     180.000000
 10     0.767202      0.000000       0.000000     149.999143     180.000000

 11     0.664411      0.000000       0.000000     179.999143     180.000000

 12     0.664441      0.000000       0.000000       0.000858       0.000000

 13     0.767258      0.000000       0.000000     -19.416831       0.000000
 14     0.746109      0.000000       0.000000     -29.999142       0.000000

 15     0.711469      0.000000       0.000000    -150.000858     180.000000

 16     0.711469      0.000000       0.000000    -150.000858     180.000000

 17     0.676829      0.000000       0.000000    -160.583170     180.000000
 18     0.655680      0.000000       0.000000    -150.000858     180.000000

 19     0.567840      0.000000       0.000000     179.999143     180.000000

 20    -6.633319      0.000000       0.611124      20.881167       0.000000

 21    -0.035380      0.000000       0.000000      -1.718833       0.000000

 22     0.003209      0.000000       0.000009      -0.902679       0.000000
 23     0.000058      0.000000       0.000000      -2.166855       0.000000

 24    -0.022644      0.000000       0.000000      -2.166855       0.000000
```

```
RAY AT WAVL 1  - (YR,XR) = ( 0.00, 0.00)

SURF        Y               X              Z           YANG(DG)       XANG(DG)
  1     0.000000        0.000000       0.000000      180.000000     180.000000

  2     1.600000        0.000000       0.160000      -22.619865       0.000000

  3     0.000000        0.000000       0.000000      -14.816745       0.000000
  4    -0.039674        0.000000      -0.000016      -22.593727       0.000000

  5    -7.171506        0.000000      -0.716302      179.999933     180.000000

  6     0.000025        0.000000       0.000000      179.999933     180.000000

  7     0.000032        0.000000       0.000000      160.582605     180.000000
  8     0.021182        0.000000       0.000000      149.999933     180.000000

  9     0.055823        0.000000       0.000000      160.582605     180.000000
 10     0.076973        0.000000       0.000000      149.999933     180.000000

 11     0.066660        0.000000       0.000000      179.999933     180.000000

 12     0.066663        0.000000       0.000000        0.000067       0.000000

 13     0.076978        0.000000       0.000000      -19.417313       0.000000
 14     0.055828        0.000000       0.000000      -29.999933       0.000000

 15     0.021187        0.000000       0.000000     -150.000067     180.000000

 16     0.021187        0.000000       0.000000     -150.000067     180.000000

 17    -0.013454        0.000000       0.000000     -160.582687     180.000000
 18    -0.034603        0.000000       0.000000     -150.000067     180.000000

 19    -0.029967        0.000000       0.000000      179.999933     180.000000

 20    -7.231395        0.000000       0.726293       22.716005       0.000000

 21    -0.038595        0.000000       0.000000        0.116005       0.000000

 22    -0.000005        0.000000       0.000000        0.048598       0.000000
 23     0.000165        0.000000       0.000000        0.116636       0.000000

 24     0.001387        0.000000       0.000000        0.116636       0.000000
```

```
RAY AT WAVL 1   - (YR,XR) = ( 1.00,  0.00)

SURF         Y               X               Z            YANG(DG)       XANG(DG)
  1      0.133390        0.000000        0.000000      179.999976     180.000000

  2      1.733391        0.000000        0.187790      -24.451013       0.000000

  3      0.000002        0.000000        0.000000      -15.974499       0.000000
  4     -0.042932        0.000000       -0.000018      -24.422081       0.000000

  5     -7.768792        0.000000       -0.840587     -179.999074     180.000000

  6     -0.597637        0.000000        0.000000     -179.999074     180.000000

  7     -0.690122        0.000000        0.000000      160.583211     180.000000
  8     -0.668973        0.000000        0.000000      150.000926     180.000000

  9     -0.634333        0.000000        0.000000      160.583211     180.000000
 10     -0.613184        0.000000        0.000000      150.000926     180.000000

 11     -0.531038        0.000000        0.000000     -179.999074     180.000000

 12     -0.531070        0.000000        0.000000       -0.000926       0.000000

 13     -0.613270        0.000000        0.000000      -19.417920       0.000000
 14     -0.634421        0.000000        0.000000      -30.000926       0.000000

 15     -0.669063        0.000000        0.000000     -149.999074     180.000000

 16     -0.669063        0.000000        0.000000     -149.999074     180.000000

 17     -0.703705        0.000000        0.000000     -160.582081     180.000000
 18     -0.724856        0.000000        0.000000     -149.999074     180.000000

 19     -0.627738        0.000000        0.000000     -179.999074     180.000000

 20     -7.829497        0.000000        0.851403       24.538986       0.000000

 21     -0.041860        0.000000        0.000000        1.938986       0.000000

 22     -0.003270        0.000000        0.000009        0.997886       0.000000
 23      0.000214        0.000000        0.000000        2.395504       0.000000

 24      0.025314        0.000000        0.000000        2.395504       0.000000
```

FOB,-1
RPXYZ All, 0 1 -1

```
MODIFIERS ARE  ALPHA---ALL
               WORD 1--X OFFSET
               WORD 2--DELTA Y
               WORD,3--STARTING Y
               WORD 4--PRINT SURFACE
               WORD 5--PRINT SUURFACE

RAY AT WAVL 1  - (YR,XR) = (-1.00, 0.00)

SURF         Y            X            Z        YANG(DG)      XANG(DG)
  1     -0.133390     0.000000     0.000000   177.309515    180.000000

  2      1.646617     0.000000     0.169459   -20.570706      0.000000

  3      0.209046     0.000000     0.000000   -13.510233      0.000000
  4      0.173078     0.000000    -0.000300   -20.682351      0.000000

  5     -6.355126     0.000000    -0.562502  -179.394995    180.000000

  6      0.584726     0.000000     0.000000  -179.394995    180.000000

  7      0.646853     0.000000     0.000000   160.952727    180.000000
  8      0.667568     0.000000     0.000000   150.605005    180.000000

  9      0.701369     0.000000     0.000000   160.952727    180.000000
 10      0.722084     0.000000     0.000000   150.605005    180.000000

 11      0.629156     0.000000     0.000000  -179.394995    180.000000

 12      0.608036     0.000000     0.000000    -0.605005      0.000000

 13      0.681870     0.000000     0.000000   -19.786023      0.000000
 14      0.660286     0.000000     0.000000   -30.605005      0.000000

 15      0.624795     0.000000     0.000000  -149.394995    180.000000

 16      0.624795     0.000000     0.000000  -149.394995    180.000000

 17      0.589304     0.000000     0.000000  -160.213978    180.000000
 18      0.567719     0.000000     0.000000  -149.394995    180.000000

 19      0.488662     0.000000     0.000000  -179.394995    180.000000

 20     -6.916966     0.000000     0.664506    21.147290      0.000000

 21     -0.233233     0.000000     0.000000    -1.452710      0.000000

 22     -0.195512     0.000000     0.034260    11.160559      0.000000
 23     -0.162813     0.000000     0.000000    27.680565      0.000000

 24      0.151935     0.000000     0.000000    27.680565      0.000000
```

```
RAY AT WAVL 1  - (YR,XR) = ( 0.00, 0.00)

SURF        Y             X              Z         YANG(DG)       XANG(DG)
  1      0.000000      0.000000       0.000000    177.309491    180.000000

  2      1.778679      0.000000       0.197731    -22.379411      0.000000

  3      0.213095      0.000000       0.000000    -14.664012      0.000000
  4      0.173923      0.000000      -0.000302    -22.493927      0.000000

  5     -6.941733      0.000000      -0.671137   -179.393724    180.000000

  6     -0.001218      0.000000       0.000000   -179.393724    180.000000

  7     -0.025687      0.000000       0.000000    160.953505    180.000000
  8     -0.004973      0.000000       0.000000    150.606276    180.000000

  9      0.028827      0.000000       0.000000    160.953505    180.000000
 10      0.049541      0.000000       0.000000    150.606276    180.000000

 11      0.043166      0.000000       0.000000   -179.393724    180.000000

 12      0.022002      0.000000       0.000000     -0.606276      0.000000

 13      0.000974      0.000000       0.000000    -19.786795      0.000000
 14     -0.020612      0.000000       0.000000    -30.606276      0.000000

 15     -0.056105      0.000000       0.000000   -149.393724    180.000000

 16     -0.056105      0.000000       0.000000   -149.393724    180.000000

 17     -0.091597      0.000000       0.000000   -160.213205    180.000000
 18     -0.113183      0.000000       0.000000   -149.393724    180.000000

 19     -0.097421      0.000000       0.000000   -179.393724    180.000000

 20     -7.502237      0.000000       0.781716     22.937125      0.000000

 21     -0.237711      0.000000       0.000000      0.337125      0.000000

 22     -0.198912      0.000000       0.035501     12.084722      0.000000
 23     -0.163693      0.000000       0.000000     30.162807      0.000000

 24      0.184994      0.000000       0.000000     30.162807      0.000000
```

```
RAY AT WAVL 1   - (YR,XR) = ( 1.00, 0.00)

SURF        Y              X              Z          YANG(DG)       XANG(DG)
  1     0.133390       0.000000       0.000000     177.309467     180.000000

  2     1.910640       0.000000       0.228159     -24.174136       0.000000

  3     0.217554       0.000000       0.000000     -15.800070       0.000000
  4     0.175195       0.000000      -0.000307     -24.292079       0.000000

  5    -7.527482       0.000000      -0.789178    -179.392265     180.000000

  6    -0.586271       0.000000       0.000000    -179.392265     180.000000

  7    -0.697194       0.000000       0.000000     160.954400     180.000000
  8    -0.676481       0.000000       0.000000     150.607735     180.000000

  9    -0.642684       0.000000       0.000000     160.954400     180.000000
 10    -0.621971       0.000000       0.000000     150.607735     180.000000

 11    -0.541941       0.000000       0.000000    -179.392265     180.000000

 12    -0.563156       0.000000       0.000000      -0.607735       0.000000

 13    -0.678931       0.000000       0.000000     -19.787683       0.000000
 14    -0.700518       0.000000       0.000000     -30.607735       0.000000

 15    -0.736013       0.000000       0.000000    -149.392265     180.000000

 16    -0.736013       0.000000       0.000000    -149.392265     180.000000

 17    -0.771507       0.000000       0.000000    -160.212317     180.000000
 18    -0.793094       0.000000       0.000000    -149.392265     180.000000

 19    -0.682633       0.000000       0.000000    -179.392265     180.000000

 20    -8.086597       0.000000       0.908237      24.712421       0.000000

 21    -0.242527       0.000000       0.000000       2.112421       0.000000

 22    -0.202577       0.000000       0.036867      13.024772       0.000000
 23    -0.164840       0.000000       0.000000      32.744486       0.000000

 24     0.221011       0.000000       0.000000      32.744486       0.000000
```

```
>CG TH.23 .285

>FOB.1#SPD.100#SPD BR


NBR SPOTS =    96   NBR FAILURES =     0
CENTROID DATA
 Y =       0.000518762    X =      0.000000000
DY =     -0.000172223   DX =      0.000000000
RMS SPOT SIZE      0.009843398

PERCENT DISTORTION    Y  -96.78   X     0.00


NBR SPOTS =     0   NBR FAILURES =     0

>SPD BFR

SPOT DIAGRAM NOT IN STORAGE

>SPD,100#SPD BFR

NBR SPOTS =    96   NBR FAILURES =     0
CENTROID DATA
 Y =       0.000518762    X =      0.000000000
DY =     -0.000172223   DX =      0.000000000
RMS SPOT SIZE      0.009843398

PERCENT DISTORTION    Y  -96.78   X     0.00


   FOCUS         RMS X        RMS Y        RMS R
 -0.293886    0.0004326    0.0003982    0.0005879

>RED CENT.10

RADIAL EGY DISTRIBUTION - RADIUS IS LINEAR - FOCUS  =  0.00000

CENTER DISPLACEMENT -   Y =        -0.000172  X =        0.000000

PERCENT ENERGY              RADIUS                DIAMETER
    10.00                 0.004234              0.008468
    20.00                 0.005914              0.011829
    30.00                 0.007582              0.015163
    40.00                 0.008861              0.017722
    50.00                 0.009957              0.019914
    60.00                 0.010418              0.020836
    70.00                 0.011361              0.022722
    80.00                 0.012381              0.024761
    90.00                 0.012950              0.025900
   100.00                 0.015953              0.031906
```

```
>FOB,-1#SPD,100#RED CENT,10


NBR SPOTS =    96   NBR FAILURES =      0
CENTROID DATA
 Y =        0.002140148     X =      0.000000000
DY =        0.000206645    DX =      0.000000000
RMS SPOT SIZE      0.009989949

PERCENT DISTORTION    Y -113.29   X     0.00


RADIAL EGY DISTRIBUTION - RADIUS IS LINEAR - FOCUS  =  0.00000

CENTER DISPLACEMENT -  Y =         0.000207  X =          0.000000

PERCENT ENERGY              RADIUS                  DIAMETER
    10.00                 0.004299                0.008598
    20.00                 0.005982                0.011963
    30.00                 0.007691                0.015381
    40.00                 0.008970                0.017941
    50.00                 0.010103                0.020206
    60.00                 0.010566                0.021132
    70.00                 0.011527                0.023053
    80.00                 0.012505                0.025009
    90.00                 0.013187                0.026374
   100.00                 0.016291                0.032582

>EXIT

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SCI-COMMAND: LO
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