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Lockheed

Probe-C
Critical Design Review
Data Package - Charts

PLPM-04 (part 1 of 3)

NASA

Relativity Mission

Science Payload Probe-C Critical Design Review
29 March 1995

Probe-C Critical Design Review

29 Mar 95

AGENDA

Topic	Presenter	start time	duration
Introduction	Calhoon	8:30 AM	0:10
Incremental Changes from B to C	Reynolds	8:40 AM	0:40
Probe-B Refurbishment	Dineen	9:20 AM	0:15
EMI shielding	Cliff	9:35 AM	0:20
Grounding	Cliff	9:55 AM	0:15
Optical Interface	Triebes	10:10 AM	0:40
Structural Analysis	Grover Vogel	10:50 AM	0:15
Thermal Analysis	Goodman	11:05 AM	0:20
Cleanliness	Mason	11:25 AM	0:15
Magnetics	Ross	11:40 AM	0:20
lunch		12:00 PM	1:00
Interfaces	Sands	1:00 PM	0:15
Cables	Dobrov	1:15 PM	0:50
Sunshade & Shutter	Vassar	2:05 PM	0:15
Windows	Chilese	2:20 PM	0:25
Temp Sensors & Heaters	Dineen	2:45 PM	0:15
External Plumbing	Will	3:00 PM	0:15
Cross Flange	Will	3:15 PM	0:20
Safety	Regimbal	3:35 PM	0:10
Reliability	Maxwell	3:45 PM	0:10
Mass Properties	Whelan	3:55 PM	0:10
Quality Assurance	Lepetich	4:05 PM	0:15
Verification & Test	Nakashima	4:20 PM	0:15
Schedule	Reynolds	4:35 PM	0:15
Action Item Closure	Ross	4:50 PM	0:10
adjourn		5:00 PM	

INTRODUCTION

Stuart Calhoon

Probe-C
Critical Design Review

- CDR emphasis on new designs, new subsystems
  - Incremental design review (as was the PDR on 12 Jul 94) in that only changes since Probe-B will be addressed
  - 80% carry-over from Probe-B design
- Probe-B “lessons-learned” incorporated
- Action items from the requirements review or PDR addressed in individual sections
- All open design issues presented
- Probe-B under test at Stanford (GTU-1)
- Full carry-over of Probe-B REE, designers,analysts, and technicians to Probe-C

PROBE-C
PHASED DESIGN EFFORT

- Probe design, fab, and assembly are split into four phases:
  - Phase 1 - saddles, **cables**, **fiber optics**, heat station rings
  - Phase 2 - quartz block support assembly, plumbing lines
  - Phase 3 - composite neck tube, top hat assembly
  - Phase 4 - cryo-pump, **windows**, **cross flange**, vacuum shell, **external plumbing**
- Assemblies requiring new or modified designs (delta design) are shown in **bold**
- Tighter magnetic constraints are affecting material selection for other parts (phosphor-bronze for plumbing lines, aluminum for the Quartz Block Support birdcage and saddles, plating)
- Design emphasis on delta designs -- re-releases only as needed to support long-lead procurements
- Long-lead orders placed -- cable insulators and connectors, aluminum extrusions, phosphor-bronze ingots

Nearly-completed Probe-B in LMSC clean room, 5/94.

Probe-B Summary

- Surpassed all vacuum, leak, and outgassing requirements.
- Passed room-temperature magnetic test at NASA Ames
- Delivered to Stanford on 8/1/94
- Fully functional when delivered (no cable problems)
- Integrated with quartz block assembly on 1/15/95
- Four gyros successfully suspended
- Integration into engineering development dewar in process

Incremental Changes

Probe-B to Probe-C

Gary Reynolds

Agenda

- Probe-B Heritage
- Changes for Probe-C
- Current status of probe-B hardware
  - level of integration with SIA
  - lessons-learned to date
- Probe-B test plans vs probe-C design schedule

Probe-B Heritage

- Probe-B built to flight standards
  - Stress analysis, thermal analysis
  - Component quality
  - Material certs, build paperwork compatible with flight
- Probe-C design drawings copied from Probe-B in most areas
  - 543 of 912 total sheets have < 5% changes
  - Notes have been standardized, new magnetics requirements included
- Assembly and test procedures developed for Probe-B
  - Full test program except vibration
  - Review, minor revisions intended for Probe-C
  - In process and assembly testing similar to Probe-B

Probe - C Requirements Changes

		PCB
• Magnetics	Zone 2 hardware must pass more sensitive test requirements lessened in other zones	# 87
• Telescope detector	More twisted pairs for new detectors on telescope, multipin connector interface	# 62
• Charge control	Low voltage ground/uv bias (twisted pairs), redundant UV fiber optics, UV fiber optics for Proof Mass, larger fiber	# 65, # 64
• Optical	HR 5110 guide star baseline Change all windows to sapphire	# 63 #180
• Gyro readout	Increase SQUIDS to eight, all 24 cables 4 wire, redistributed functions	# 86
• Vacuum	Redundant Probe exhaust valves	# 181
• Suspension	Proof Mass cable capable of 1 g suspension	# 68

Probe C Hardware Changes (1)

PCB

- Raw materials development — # 87
  - Phosphor Bronze ingot
  - Refinement of gold and rhodium plating
- New telescope cable (similar to existing instrumentation cables) — # 62
  - Development of 26-pin D-style cold end connectors
  - Larger shield/bellows size required to allow for possibility of more wire count
- New ground/UV bias cables (similar to existing instrumentation cables) — # 65
  - LEMO has a 6-pin standard design available
- Cross flange
  - Aluminum to maximize thermal conduction, reduce weight — # 181
  - Provision for two 6" Vatterfly (Stanford provided)
  - Inclusion of spin-down port

Probe-C Hardware Changes (2)

PCB

- Improved windows/coatings
  - Sapphire chosen for Window 4 for strength, lack of luminescence, increased conductivity #181
  - Windows 1through 3 also Sapphire
  - Coatings must be narrower bandwidth to allow more throughput
  - 2° tilt on each window
- UV Fiber Optics
  - Much improved fiber optics with shields # 64
  - Change to single 300/360μ fiber, polyimide coating in seg 1, aluminum coating in seg 2

Probe-C General Changes

- Magnetics
  - Gradiometer testing (Zone 2B) or cryogenic testing (Zone 2A)
  - 100% testing for Zone 2 parts with more sensitive instruments
  - Streamlined testing operation, documentation
- Cleaning processes
  - New water-based system
- Quality control
  - DPRO oversight, inspection

Lessons Learned

- GSE
  - Minor Genie difficulties regarding ease of use
- SIA integration
  - Lemo connector pairs need more positive isolation design
  - Full fit checks required for actual mating connectors
  - Instrumentation pins difficult to remove, longer pins required
  - Identification of pin numbers on instrumentation blocks
  - More modular routing/hook-up design desired for Probe-C
  - Better clamps, supports etc. for stowing movable parts during integration steps
- Probe installation into EDD
  - More thorough study of relationships of Probe to GSE required

Early Testing of Probe-B

- SIA integration
  - No interferences with Quartz Block or telescope
  - Bolting up procedure very easy
  - SIA centering within +/- .003"
- Some problems encountered with Stanford jumper installation
  - Lessons learned list compiled, replies worked
- Leak check/outgassing verification after SIA integration
  - Very good results: No leaks greater than $5x10^{-9}$ Torr(not including o-rings) $2x10^{-7}$ Torr vacuum achieved (10 days of pumping), $2x10^{-6}$ Torr-liters/sec outgassing rate(5000x better than requirement)
- Successful levitation and low-speed spin-up of all 4 gyros

Probe-B Tests in Support of Probe-C Design

- Cryotesting of Probe-B at Stanford (GTU-1, March-July ‘95)
  - Low temperature Bakeout, ultimate vacuum (Cryopump, heater performance)
  - Overall SQUID noise(SQUID cable shielding, EMI filters)
  - Trapped field in gyros after flux flushing (Magnetic performance)
  - Pressure drop in spin-up exhaust system

- Vibration test (Sept/Oct ‘95)
  - Workmanship test of cables, plumbing, QBS

- Integration and testing in Science Mission Dewar (GTU-2A,July ‘96-Feb ‘97)
  - Checkout of Probe installation into flight Dewar
  - Cryogenic operations (including superfluid)

- Vibration test of Probe-B in SMD (March ‘97)

- Further operational testing (GTU-2B, March-May ‘97)

Probe-B Potential Upgrades for Flight

Paul Dineen

Probe-B Refurbishment

- Replace windows 1 thru 3
- Reassign existing wires to support telescope detectors
- Modify detector fiber optics for use on Proof Mass
- Add UV bias and ground wires as retrofit
- Use Probe-C cross flange
- Replace spin-up filter assemblies
- Probe-B parts that cannot be refurbished for flight status
  - Gyros 1thru 4 UV fiber optics have no spares
  - Proof Mass cables can support 1G suspension but have high dissipation factor

Functional Difference from Probe-C

- Cables
  - Cabling for 6 DC SQUIDs rather than 8
  - Different external cables for DC SQUIDs
  - 20 Pr-B wires versus 110 Pr-C wires for telescope detector
    - » Reassign approximately 20 existing Pr-B instrumentation wires for telescope detector use
- UV fiber optics for Gyro Charge Control
  - Low light carrying capability
  - No redundancy for gyros 1 thru 4
  - No fiber optics for proof mass
    - » Modify installed detector fiber optics for UV fiber optic use
  - Different external interface for fiber optics
  - Lacks two UV Bias wires needed for each gyro
    - » Retrofit in additional wiring

Functional Difference from Probe-C

- Optics
  - Probe-B windows 1 thru 3 not polished to flight level, made of calcium fluoride and broadband coating used
    - » Windows are replaceable
- Actuated Vent and Exhaust Valves
  - Replace manual vent and exhaust valves with actuated valves
  - Modify Probe-B valve interface for 2.5" actuated valves
- Quartz Block interface changed
  - Probe-B Interface - Station 158.053*
  - Probe-C Interface - Station 158.24*

Probe-B Upgrade Issues

- Magnetics
  - Magnetic properties of Probe-B assembly not yet measured at cryogenic temperatures
  - Not all Probe-B piece parts pass magnetics testing requirements implemented for Probe-C
- Structural
  - Probe-B piece parts not vibration tested
  - Probe-B assembly vibration test still to be performed
  - Results of Probe-C stress analysis using 35g secondary loads indicate need for additional cable brackets in top hat
  - Probe-B/Quartz Block interface cold vibration test not performed until GTU-2 testing

Probe B Upgrade Issues

- Other
  - –Performance of Probe B-heaters during GTU-1 and GTU-2 testing
    - »Do heaters generate enough heat
    - »Does heater operation interfere with DC SQUID operation
  - –Ability of Probe-B temperature sensors to measuring critical temperatures
    - »Are mounting locations for temperature sensors correct

Probe-B Upgrade Summary

- Changes required to make Probe-B a flight back-up identified
- Probe B can be retrofitted for flight

EMI Shielding

Rodger Cliff

Agenda

- Probe Shielding Philosophy
- Probe Shielding Configuration
- Probe Shielding Requirements
- Probe EMI Testing
- Top Hat External Electrical EMI Filters

Shielding Philosophy

- The probe contains the most EMI-sensitive parts of the payload
  - The science gyro readout detectors (SQUIDs)
  - The science telescope readout detectors (PIN diodes generating 7 f~~p~~A)
  - The gyro position sensing bridges
- Prevent EMI from entering the probe
  - All of the outer surfaces of the probe constitute a conductive enclosure
  - Filter, or shield, or both all penetrations of the enclosure
  - Use the metallic sunshade and the conductive coating on window #4 to shield the optical aperture
  - Use filters at the top hat on all electrical penetrations
  - EMI filtration at vatterfly valves is TBD
- Prevent the components in the probe from interferring with one another
  - Shield the internal electrical cables between top hat and quartz block
  - Shield the SQUID packages, telescope detector packages, and gyros
  - Ensure that redundant components are in redundant shields

Primary Shielding Components

- Sunshade
- Window #4 coating
- Top hat
- Composite neck tube foil
- Probe Vacuum shell
- Internal electrical cable shields
- SQUID package cases
- Telescope detector package cases
- Gyro local shields

Optical System
EMI Filtration Requirement

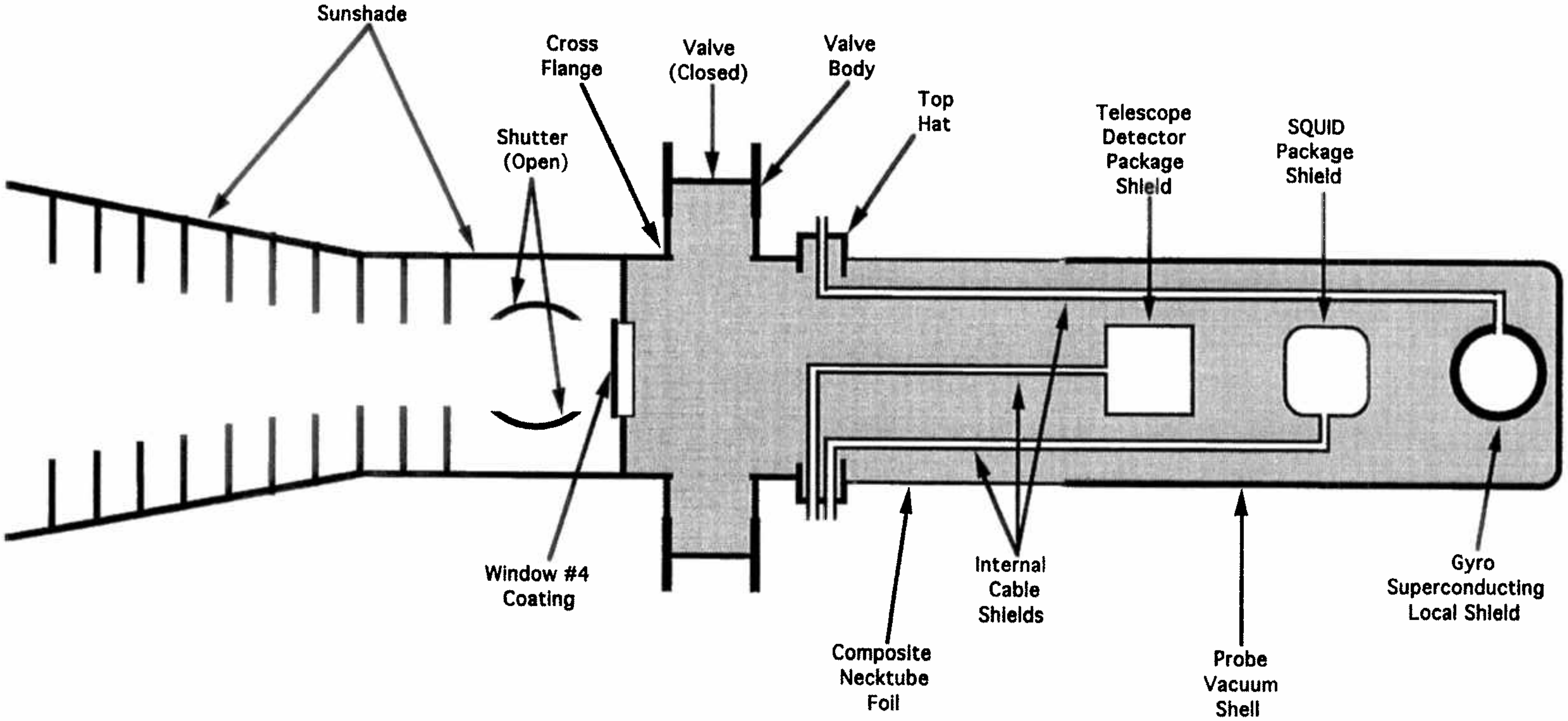
- Specified in section 3.7.3.2.7.5 of the payload specification

- This requirement applies from the sunshade aperture to the telescope corrector plate

- The attenuation requirement varries with frequency
  - 60 dB at 100 Hz increasing to 80 dB at 10 kHz
  - 80 dB from 10 kHz to 250 MHz
  - 80 dB at 250 MHz decreasing to 65 dB at 1 GHz
  - 40 dB from 1 GHz to 10 GHz

- The attenuation allocation between the sunshade and window #4 and the bore of the probe is TBD

Shielding Configuration



Sunshade

- The forward spacecraft omni antennas are located at the entrance aperture of the sunshade
- The entrance aperture of the sunshade can couple external environmental EMI into the sunshade
- The metallic sunshade will act as a “lossy” waveguide
  - For all but the highest frequencies, the sunshade will function as a waveguide below cutoff frequency
  - At the highest frequencies the baffles will help increase the attenuation
- The current specification of the EMI attenuation down the sunshade is TBD
- EMI attenuation down the flight sunshade will be predicted by attenuation measurements on a sheet-metal mock-up of the sunshade
- EMI attenuation of the flight sunshade will be measured when available

Window #4

- Window #4 will be metallized to attenuate EMI
- Window #4 will further attenuate EMI which has passed down the sunshade
- Window #4 will be most effective at the higher frequencies where the sunshade is least effective
- Window #4 attenuation allocation is <40 dB
- The better the Window #4 metallization attenuates EMI, the more it attenuates the starlight destined for the science telescope

EMI Tests

- Development tests
  - Detector sensitivity tests
    - » Science gyro readout detector tests
    - » Science telescope readout detector tests
    - » Suspension position-measuring bridge tests
  - Sunshade mockup component attenuation tests
  - Window #4 mockup component attenuation tests
  - Probe mockup component attenuation tests
  - Assembled sunshade, window #4, and probe mockup attenuation tests

- Flight component attenuation tests
  - Sunshade attenuation tests
  - Window #4 attenuation tests

- Payload-level tests of probe EMI susceptibility
  - Radiated EMI susceptibility (to environmental EMI)
  - Probe susceptibility to transmit antennas
  - Conducted EMI susceptibility

Top Hat External Electrical Cable EMI Filters

- External electrical cable EMI filters are used to prevent conduction of EMI into the probe
- EMI filters are used on **all** wires which penetrate the top hat
- For probe-B these EMI filters were a probe responsibility
- For probe-C these EMI filters are a **payload electronics responsibility**
- Attenuation characteristics of top hat EMI filters will be based on the results of measurements of probe-C conducted EMI susceptibility

Grounding

Rodger Cliff

Agenda

- Grounding Design Objectives
- Grounding Design Principles
- Special Proof-Mass and Gyro Grounding Considerations
- Grounding Schematic

Grounding Design Objectives — 1

- Prevent electrostatic charge build-up
  - Gyro housing metallization
    - Milli-Volt potential will cause torques on gyros
    - Milli-Volt potential will cause bias in drag-free system
  - Spinup gas inlet filter
    - Gas flow will charge filter
    - ESD could cause interference with electronics
  - All conductive objects
    - Charged particles will cause electrostatic charge build-up
    - ESD could cause interference with or damage to electronics
- Support EMI shielding
  - Window #4 metalization grounded
  - Shields of all cables entering probe grounded at top hat

Grounding Design Objectives — 2

- Prevent thermal emfs from causing current loops
  - Break conductive loops which have non-zero net thermal emf
  - Loops which have zero net thermal emf (balanced loops) are permissible
- Prevent differential ground voltages from corrupting data

Grounding Design Principles — 1

- The top hat is the single-point ground reference for the probe and the payload electronics
  - Signal grounding (a low-frequency regime) radiates from the top hat into the probe and into the payload electronics in tree topologies
  - All payload electronics have transformer isolation (dc/dc converters) from the spacecraft power system
    - All payload electronics secondary power returns are grounded to payload signal ground
    - All payload electronics primary power returns twisted with supply and returned to spacecraft PCU

- Grounding must support EMI shielding
  - The conductive outer surface of the probe acts as a grounded EMI shield around the components inside the probe
  - Shields of all electrical penetrations are grounded to the top hat at the point of entry
  - Conductors of all electrical penetrations will enter top hat through feedthrough EMI filters grounded at the point of entry
  - All non-electrical conductive penetrations (plumbing) grounded to top hat at the point of entry

Grounding Design Principles — 2

- All shields isolated from grounded structure except from at top hat
- all conductive plumbing isolated from grounded structure except from at top hat
- Balanced differential signals will be used to prevent differential ground potential interference with signals
  - Exception for suspension cables which are single-ended and coaxial
- Non-isothermal, non-balanced ground loops with $R < 20\ \Omega$ must be broken to prevent magnetic fields from currents due to thermal EMFs

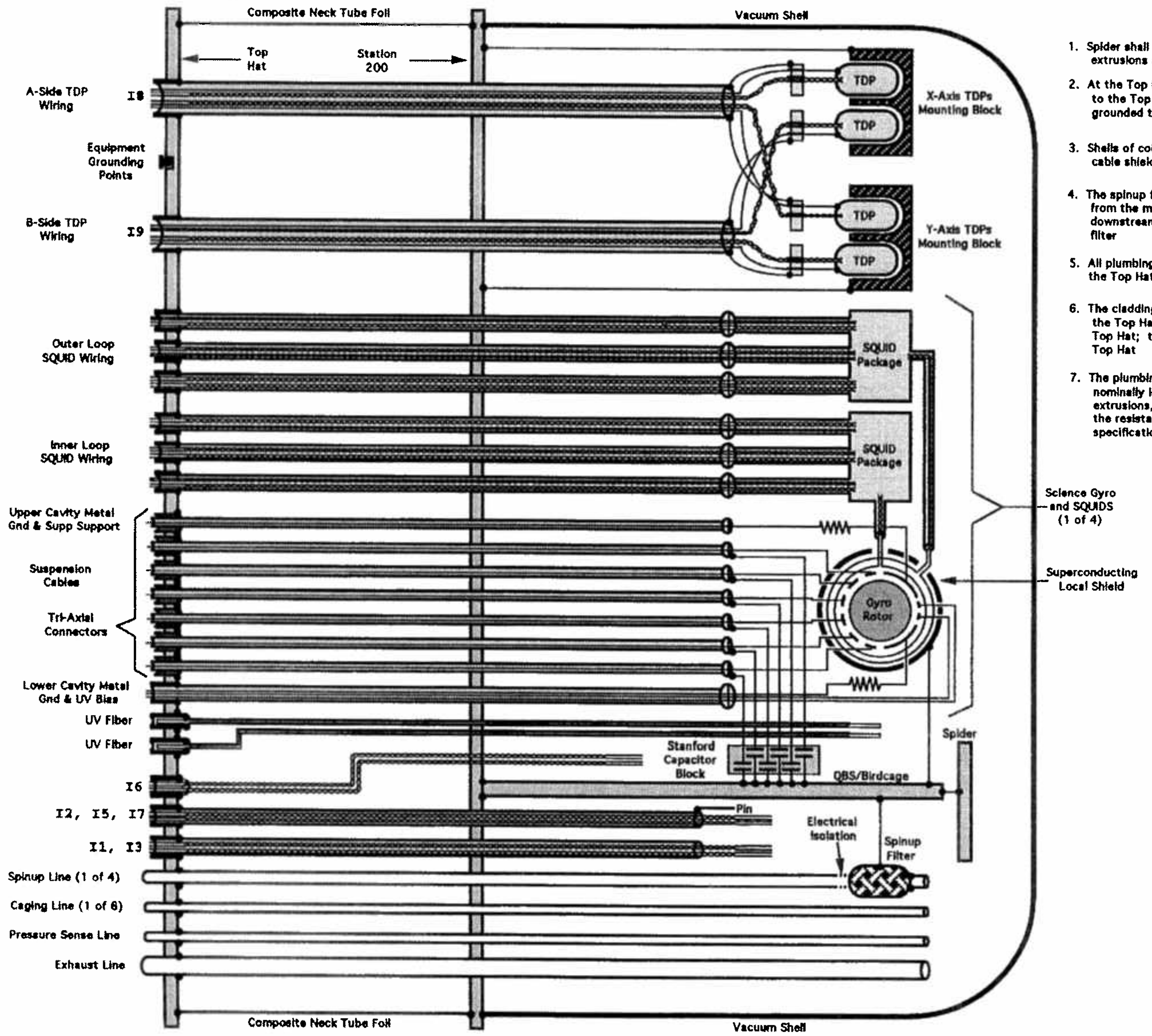
Special Proof-Mass and Gyro Grounding Considerations

- Proof mass and gyro cavity metallization
  - Required to be within 3 mV of suspension ground
    - » Must be grounded to ground of control electrode drivers inside suspension electronics
    - » Ground wiring must be made of same materials as control electrode wiring to prevent differential thermal EMFs from violating 3 mV requirement
  - Upper and lower cavity metallization require separate ground wiring
    - » Upper metallization used for supplemental support during ground test
      - Upper metallization coax ground cable must withstand ≥ 600 V dc
    - » Lower metallization always at ground (0 V) potential
      - Lower metallization ground conductors threaded through a common shield with UV charge control bias electrode wires to save space
- Driven shield of suspension coax cables
  - Capacitive ground to Stanford ground block
  - Experimentally shown to reduce suspension interference with SQUIDs

GPB-100417

Grounding Schematic

STANFORD
Lockheed
Probe-C CDR
29 March 95



Notes:

1. Spider shall be grounded to only one of the extrusions and isolated from all other structures
2. At the Top Hat, conector shells shall be grounded to the Top Hat and shields of cables shall be grounded to the connector shells
3. Shells of cold-end connectors shall be grounded to cable shields
4. The spinup filter shall be electrically isolated from the main spinup line; the short stub line downstream of the filter shall be grounded to the filter
5. All plumbing lines shall be electrically bonded to the Top Hat where they pass through it
6. The cladding of the UV fibers shall be grounded to the Top Hat where the fibers pass through the Top Hat; the cladding shall not pass through the Top Hat
7. The plumbing lines and the cable shields shall be nominally insulated from Station 200 and the extrusions, but they may make contact as long as the resistance is high enough to meet the specifications

Probe C Telescope

Optical Interface

Ken Triebes

Window Requirements

Operating temperature -	200, 100, 60, 25 K
Temperature gradient (radial #4, #3) -	< 0.275°, 0.798° C
Temperature gradient (linear #4) -	< 0.00069° C
Pressure differential (#4) -	14.7 psi
Transmitted wavefront (per window) -	< λ/10 p-v
Wedge angle -	2 to 5 arc sec
Net wedge angle -	< 0.5 arc sec
Surface roughness -	< 3 nm rms
Transmission band -	0.3 to 1.0 μm
Transmission efficiency (4 windows) -	Maximize
Reflectance (#4 @ 10.6 μm) -	> 95% (97%)
Interior surface emissivity -	< 5% (< 3%)
EMI shielding -	> 40 dB (> 60 dB)
Mounting angle -	2°

Values in ( ) indicate goals

Material Trade Study Results

- Sapphire selected for all four windows

Property	Temp. K	SiO_2	Al_2O_3	CaF_2
CTE	200 100	1.3E-7 -5.3E-7	3.3E-6 6.0E-7	1.62E-5 7.6E-6
Conductivity W/cm-°C	200 100 60 25	0.0114 0.0069 0.0041 0.0018	0.82 4.5 26.5 202.0	0.15 0.43 1.3 23.0
dn/dT	200 100	6.9E-6 4.0E-6	9.25E-6 2.29E-6	8.0E-6 4.3E-6
Fluoresence SNR		80,000	10,000	950

Transmitted Wavefront Quality

- Wave front errors degrade telescope Strehl ratio which degrades telescope tracking response.

- Strehl = $\text{Exp}(-(2 \times \pi \times \text{wfe})^2)$

- Balance total window wave front errors against expected errors in telescope optics.

- Get vendor feed-back for reality check on quality specification.

- Expected telescope wave front error = $\lambda/11$ rms

- Window transmitted wave front quality = $\lambda/10$ p-v, $\lambda/40$ rms

Thermal Analyses

- Radial thermal gradients create uncompensated “focus” errors in the guide star wave front which degrade tracking response in proportion to the Strehl ratio.
  - Assumed to have the same sign, cannot be rss’d together.
  - 4 window sum degrades Strehl < 5%
  - Maximum p-v wave front error per window = $\lambda/30$, 0.01873 μm
- Linear thermal gradients across Window #4 diameter, caused by off-axis solar radiation create a dynamic pointing error at the roll frequency.
  - Dynamic pointing error < 0.1 marc-s (0.485 nrad)
- Results to date indicate no problem with either radial gradients or rolling linear gradients in Window #4.

Thermal Requirements Summary

Radial thermal gradient $$\delta T = \frac{\text{opd}}{t \text{ x}(dn/dT + \alpha(n-1))} = 0.275 \text{ K}$$

opd = p-v optical path difference = 0.01873 μm
t = Sapphire window thickness = 0.275 inches
n = Sapphire refractive index = 1.769
α = Sapphire coefficient of thermal expansion = $3.3 \text{ x } 10^{-6}$
dn/dt = Sapphire refractive index temperature sensitivity = $7.2 \text{ x } 10^{-6}$

Linear temperature gradient $$\delta T = \frac{\text{Angle x Diam}}{t \text{ x } ((n-1) \text{ x } \alpha + n \text{ x } dn/dT)} = 6.9 \text{ x } 10^{-4} \text{ K}$$

Angle = maximum tracking error = 0.1 marc-s = 0.485 nrad
Diam = window clear aperture = 6.0 cm

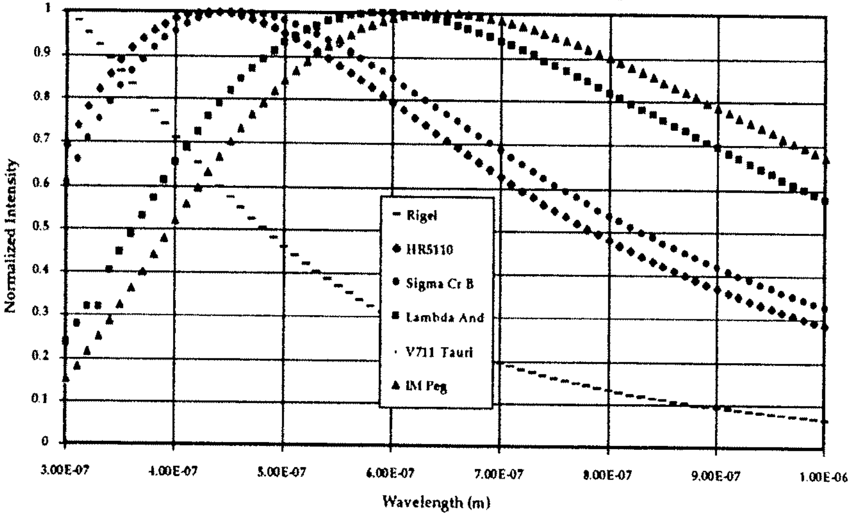
Low Emissivity Coatings

- Low emissivity coatings on interior windows degrade optical throughput efficiency.
- Substituting anti-reflection coatings for low-emissivity can improve optical efficiency by 50%.
- Elimination of low emissivity coatings increases thermal load on Science Payload as shown in table below.
- Thermal analyses currently in process to balance optical throughput efficiency against probe thermal requirements. Preliminary results in table below.

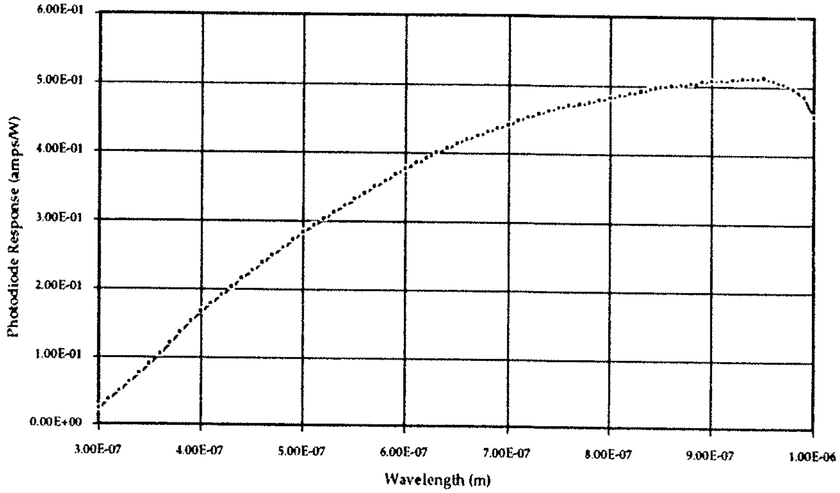
Parameter	Low E	A-R
Transported Energy	80 mw	322 mw
Corrector Plate Temp.	3.274 K	3.544 K
Quartz Block Temp.	2.519 K	2.644 K

Visible Coating Requirements Derivation

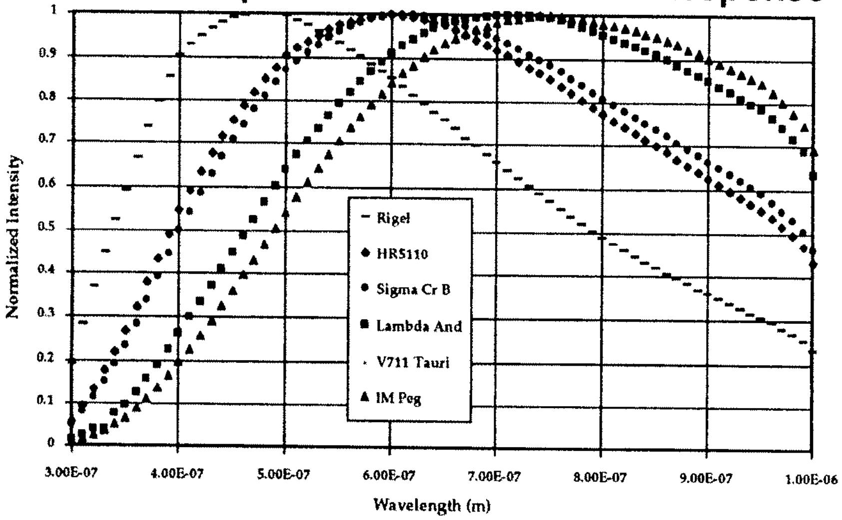
Normalized Guide Star Spectra



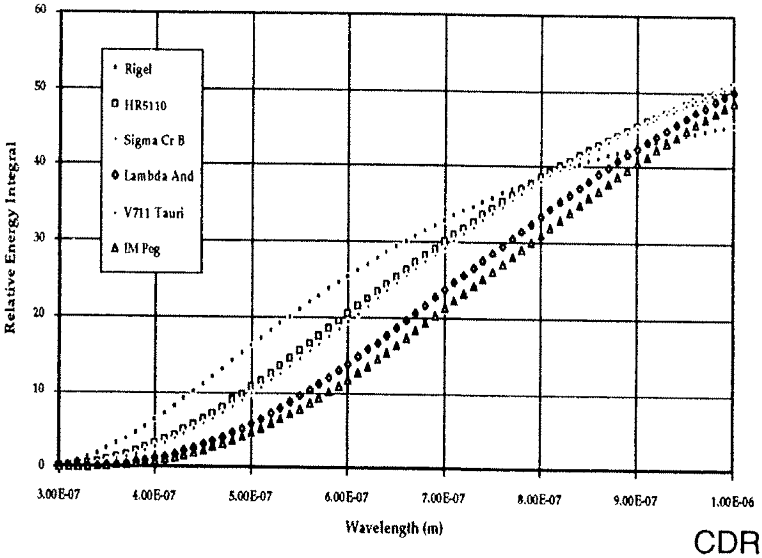
"Blue" Photodiode Response Curve



Normalized Spectra with Photodiode Response

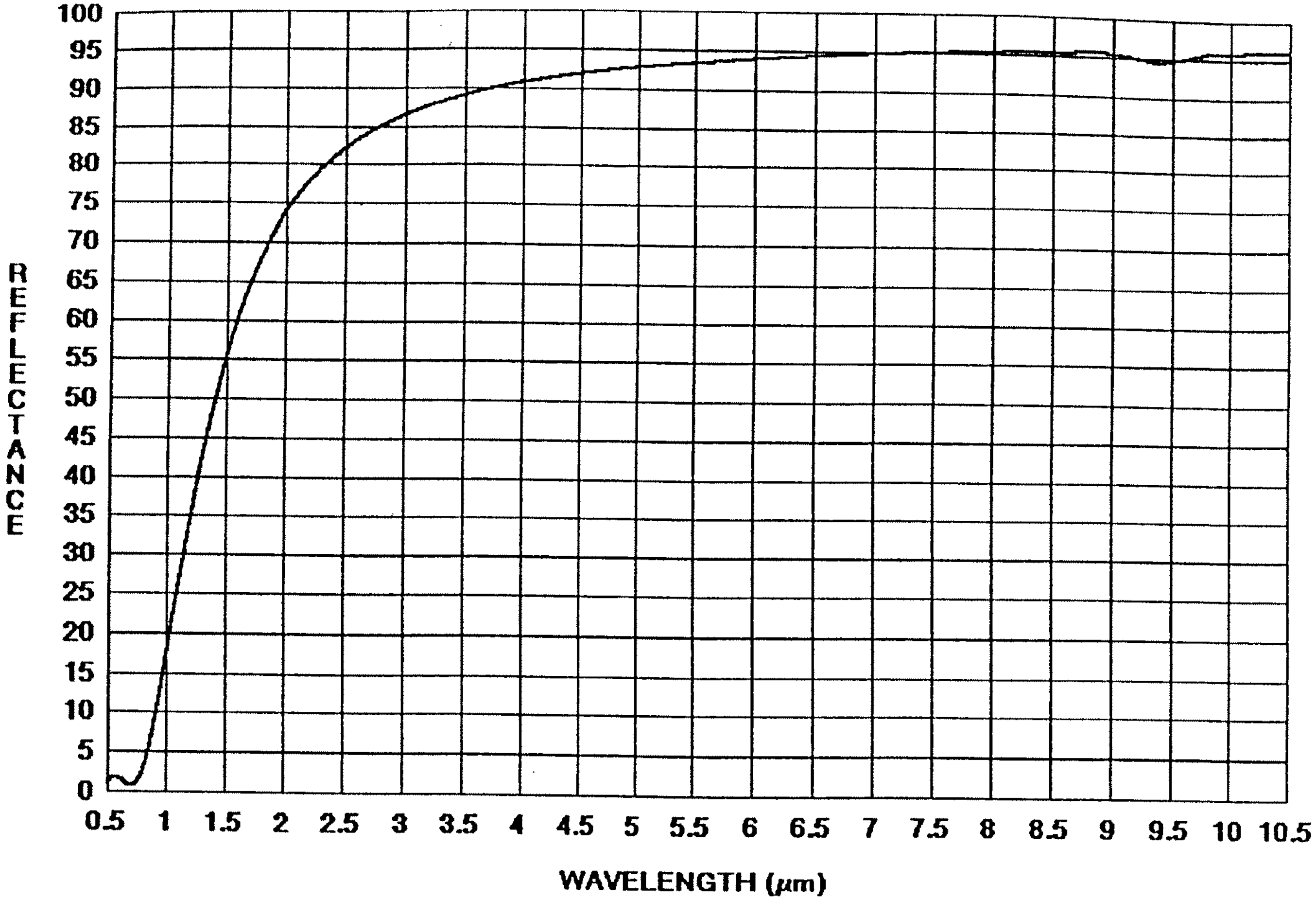


Integrated Spectra/PD Respones

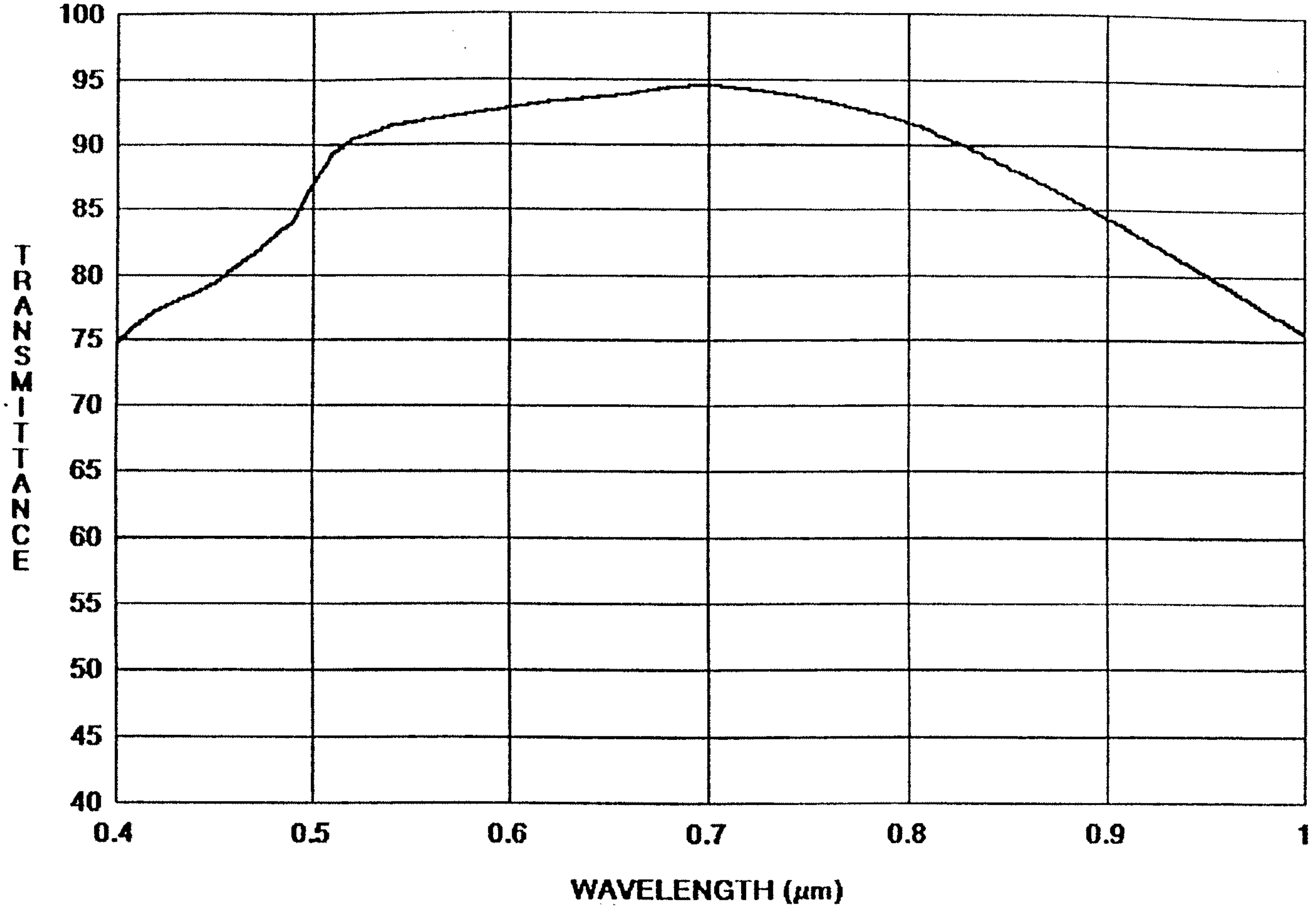


Itek Candidate Coating

Infrared Reflectivity vs Wavelength

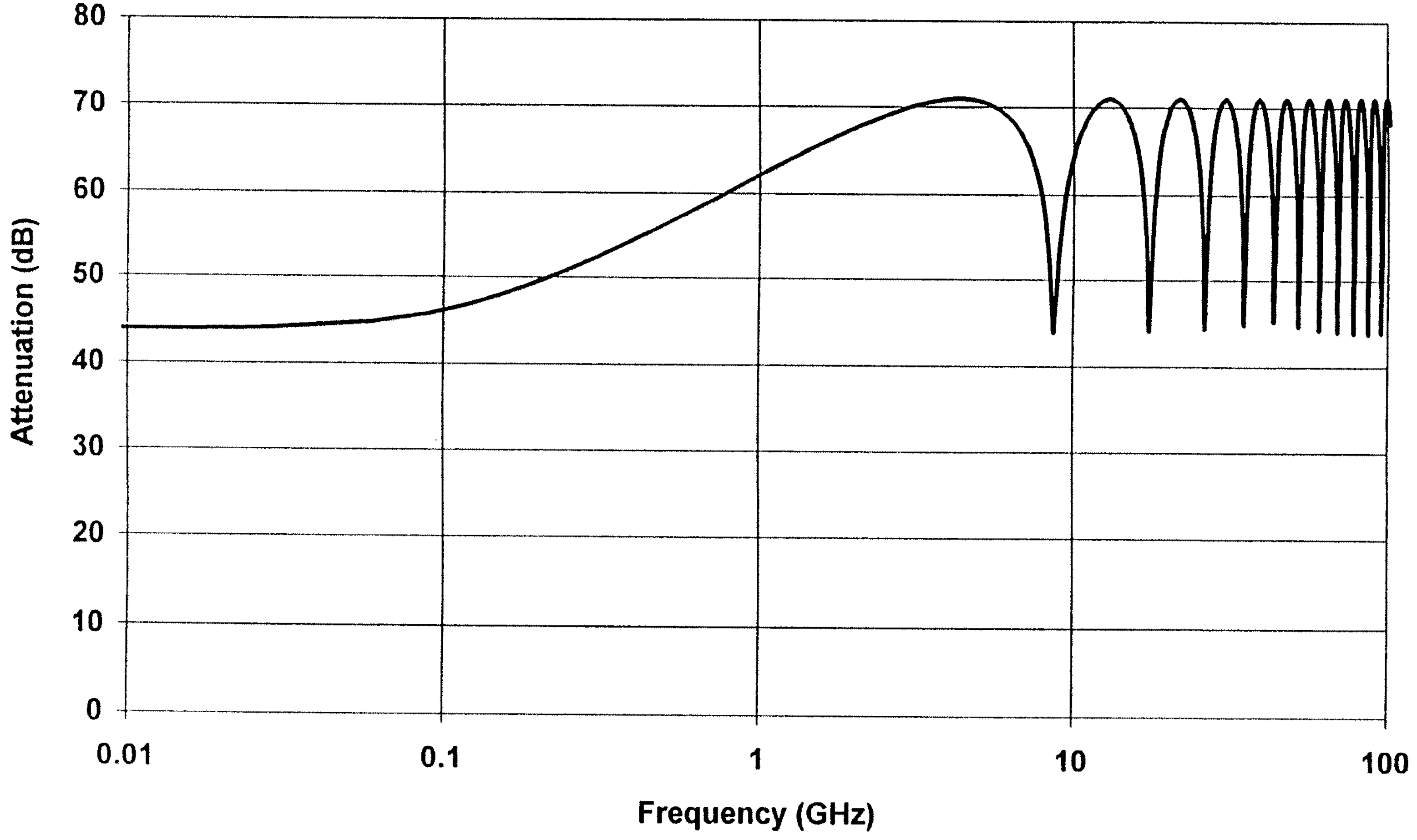


Visible Transmission Efficiency



Window #4 EMI Coating Predicted Performance

Theoretical attenuation of Itek Gravity Probe B coatings on sapphire



Sapphire Birefringence

- Birefringence creates two images with orthogonal polarizations.
- Birefringence coefficient is small, 0.008, so images are separated by 8.0 marc-s per arc-s of <u>net</u> wedge in windows.
- Net wedge is expected to be < 0.5 arc sec.
- If starlight is partially polarized, the intensity of the two images will be modulated which will modulate the apparent guide star centroid location at twice the roll frequency.
- No reliable information is available on the polarization of light from HR 5110, but it is believed to be in the range of 0.1% to 1.0%.

Image shifts back & forth. 2×roll
1% of 8 milliarcsec.

Ghost Images

- Inter-window ghost images from the guide star and nearby strong stars can cause tracking nonlinearities at the roll frequency.

- Internal window mounting precision uncertainty of <0.25° and window #4 dynamic thermal response eliminates zero-tilt window alignment.

- Ray trace results show no inter-window ghosts for stars outside 4.5°.

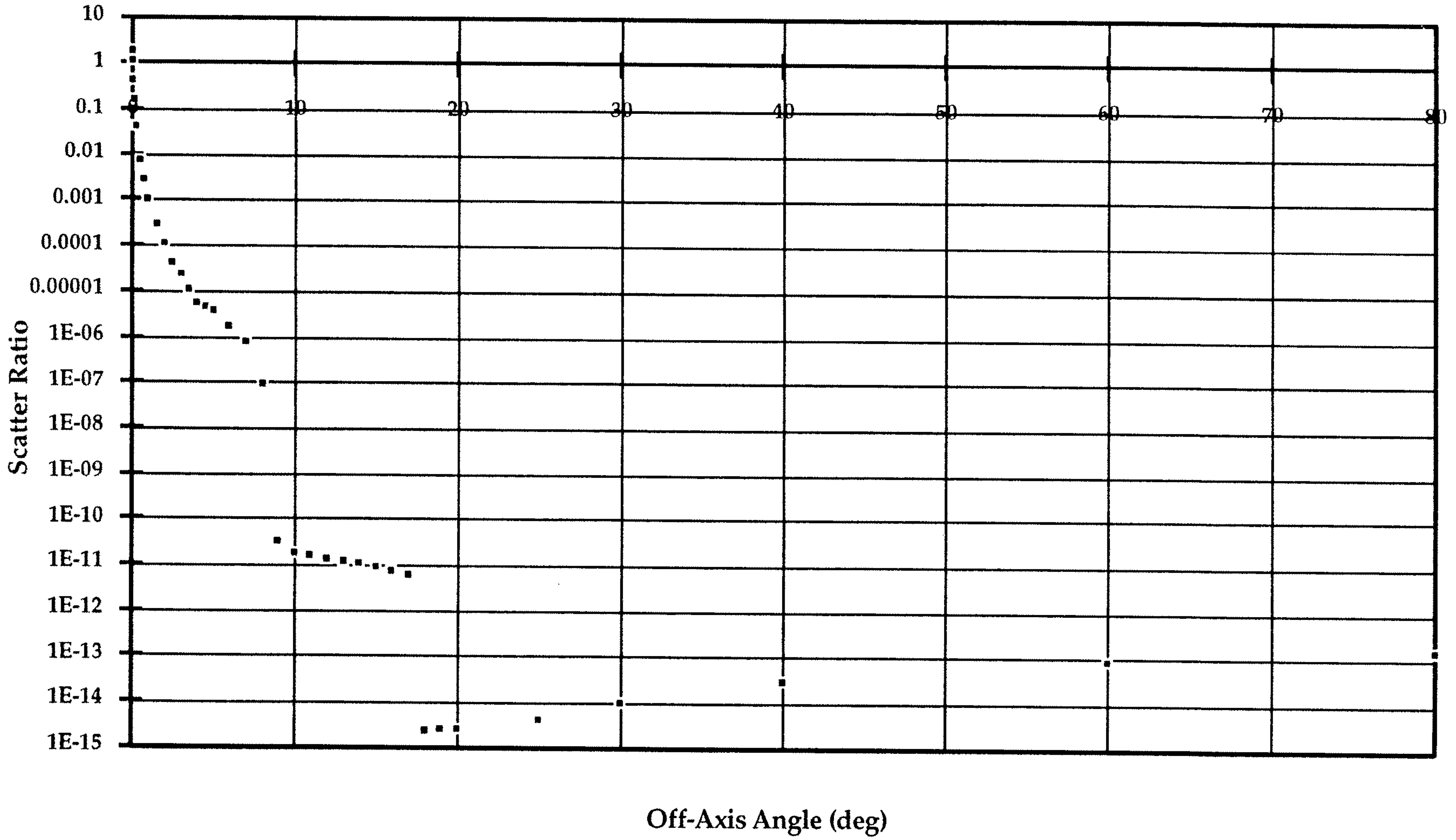
- Tilting all windows by 2° and clocking inter-window tilt axes by 90° eliminates formation of inter-window ghost problems from guide star or nearby stars.

- Window mount tilt angles are increased from the original 1° to 2°.

Stray Light Analysis (1)

- Stray light effects -
  - Reduced signal to noise in tracker
  - Dynamic tracking errors caused by non-uniform distribution with roll
- Sources -
  - Guide star
  - Nearby strong stars
  - Sun
- Factors -
  - Sunshade geometry & coatings
  - Windows materials, finish, contamination
  - Probe internal surfaces & coatings
- Results -
  - No problems with nearby stars or guide star
  - Preliminary results indicate possible problem with solar scatter at large angles. More detailed model shows greatly improved performance.

Stray Light Analysis (2)



Window Requirements vs Performance Predictions

Parameter	Requirement	Expectation
Temperature gradient (radial #4, #3) -	< 0.275°, 0.798° C	< 0.05° C
Temperature gradient (linear #4) -	< 0.00069° C	< 0.0005° C
Transmitted wavefront (per window) -	< λ/10 p-v	< λ/10 p-v
Net wedge angle -	< 0.5 arc sec	< 0.5 arc sec
Surface roughness -	< 3 nm rms	< 3 nm rms
Transmission band -	0.3 to 1.0 μm	0.3 to 1.0 μm
Transmission efficiency (4 windows) -	Maximize	> 37 %
Reflectance (#4 @ 10.6 μm) -	> 95 % (97 %)	> 96 %
Interior surface emissivity -	< 5 % (< 3 %)	< 5.0 %*
EMI shielding -	> 40 dB (> 60 dB)	> 40 dB *
Scattered light tracking errors -	< 0.07 marc-s	0.01 marc-s *

* Analyses still in process.

Structural Analysis of Probe-C

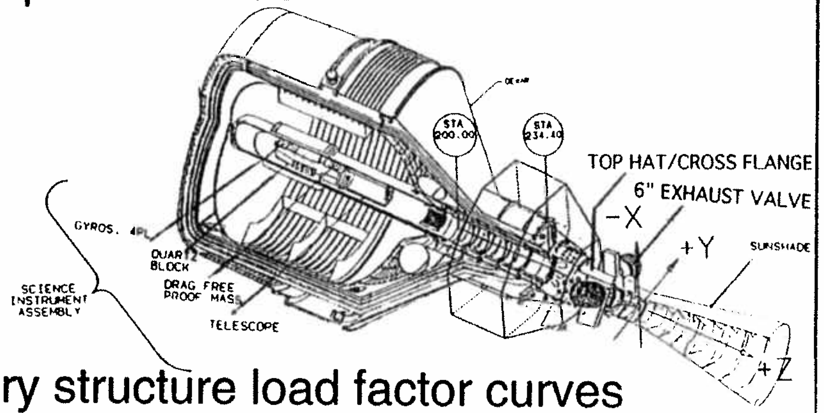
Anne Grover Vogel

Agenda

- Current launch loads
- Cross Flange analysis
- Review of Top Hat
- Window 4 analysis
- Cable analysis

Loads & Factors of Safety

- Launch loads - Ref. EM 310A (P030739A) updated 12/93
  - Inertial load factors:
    - » Sunshade: 28.2 g lateral, 9.8 g axial
    - » 6" Exhaust Valve: 10.6 g lateral, 9.8 g axial
    - » Tophat/Cross Flange: 8.9 g lateral, 9.8 g axial
    - » STA 200: 6.2 g lateral, 6.3 g axial
    - » QBS-SIA: 5.2 g lateral, 6.3 g axial
  - Lightweight components - use secondary structure load factor curves



- Internal & external pressure loads - Ref. F277277, v.3.0 updated 10/94
  - 0.13 MPA (19 psid) Normal working mode
  - x.xx MPA (xx psid) Failure mode

- Factors of safety - Ref. F277277, v.3.0 updated 10/94
  - Internal pressure: 4.0 for stress and buckling, 1.5 for proof pressure test
  - External pressure: 2.0 for stress and buckling
  - Mechanical loads (metallic): 1.25 for yield and test, 1.5 for ultimate
  - Mechanical loads (non-metallic): 2.0 for ultimate, 1.25 for test
  - Ground handling equipment: 3.0 for ultimate (5.0 for lifting)

Interface to SIA (1 of 3)

- Analysis from Probe-B is current - Ref. LMSC-P065974/EM367
- Quartz block analysis used 7.25 ksi ultimate tensile strength with safety factor of 10.0
- Predicted maximum tensile stress at quartz block flange with spacecraft launch loads is 450 psi
- Test of STU proved that the addition of Mo waffle pads under the QBS fingers would prevent chipping of the Quartz at the interface flange
- STU shake test
  - Tested to following levels:
    - » Lateral 3σ rms vibration levels -12.81 g (512 lb at QB flange)
    - » Axial 3σ rms vibration levels - 7.77 g (311 lb at QB flange)
  - QBS/SIA was undamaged by shake
- STU GTU shake test
  - Levels as above - 6 DB
  - Gyros spun-up successfully
  - Vacuum retained

Interface to SIA (2 of 3)

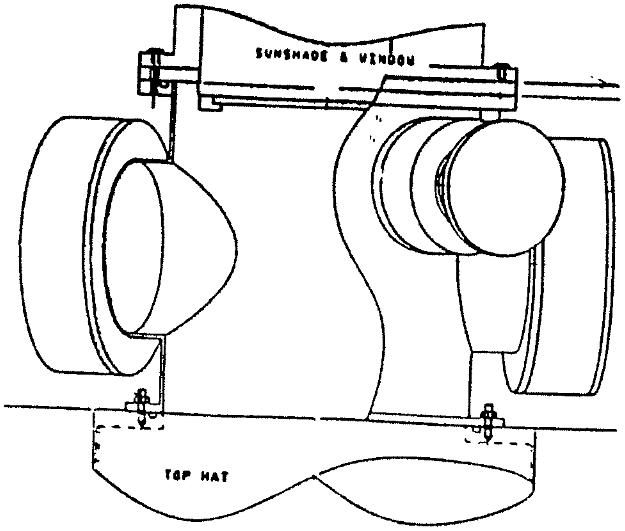
- Mock probe shake test
    - First test of telescope mechanical model
    - Sine vibration test 10-150 hz (reflects spacecraft level protoqual test and flight)
    - Test levels at QB flange
        - Lateral 5.5 g peak (525 lb at flange)
        - Axial 7.4 g peak (758 lb at QB flange)
    - Shake levels controlled with accels at QB flange, telescope and top of QB
    - Shake levels reduced from protoflight (1.25 * flight) to 1.06 * flight because of preexisting damage in mock probe QB

Interface to SIA (3 of 3)

- Probe-B protoflight shake test
  - Objectives:
    - Protoqual vibration of flight back-up
    - Verify test procedure for Probe-C
    - Workmanship test of Probe-B
  - Sine vibration test 10-150 hz (procedure verified in mock probe shake test)
  - Test levels at QB flange (full protoqual levels)
    - Lateral 6.5 g peak (525 lb at flange)
    - Axial 9.4 g peak (758 lb at QB flange)
  - Shake levels controlled with accels at QB flange, telescope and top of QB
  - LVDT's between fixture and probe vacuum shell to evaluate strain energy in venitian blinds

Cross Flange

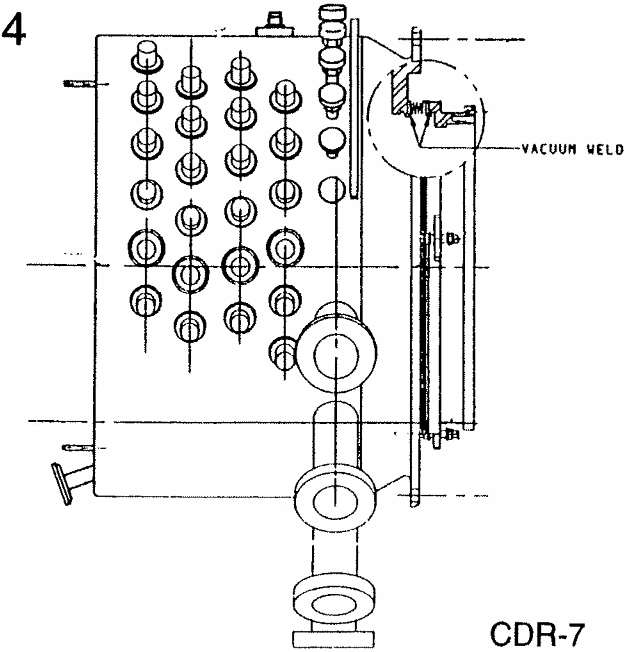
- Structural analysis documented in EM GPB-100434 dated 3/95
- Optimized structure for weight, considered 3 materials
  - Aluminum design - baseline
    - weight = 5.85 kg (12.9 lb)
    - Minimum margin of safety = +0.02
  - CRES design
    - weight = 13.89 kg (30.62 lb)
    - Minimum margin of safety = +0.02
  - Titanium design
    - weight = 7.84 kg (17.28 lb)
    - Minimum margin of safety = +0.14



- Aluminum design selected for Probe-C
  - Will be a CTE mismatch to the Top Hat
  - Successful test of large diameter helicoflex seals for a CRES/Aluminum joint at cold temperatures
  - Would be a CTE mismatch on at least one flange regardless of material choice

Top Hat

- Structural analysis documented in EM GPB-100435 dated 3/95
- Nostructural design changes required
- Results from Probe-B analysis were scaled up for current load conditions
  - Probe-B weight & axial CG calculations for components located beyond Station 234.4 was similar to (but higher than) current Probe-C weight & axial CG calculations
  - Minimum overall structural margin of safety = +0.18 in the flange
  - Minimum margin of safety in the cylinder = +0.34
- Current scaled analysis is conservative
  - Scaled up all components of the load when only lateral load was too low
  - Probe-B lateral CG location was far from the center (due to 80 lb gate valve).
- Welds require strength certification

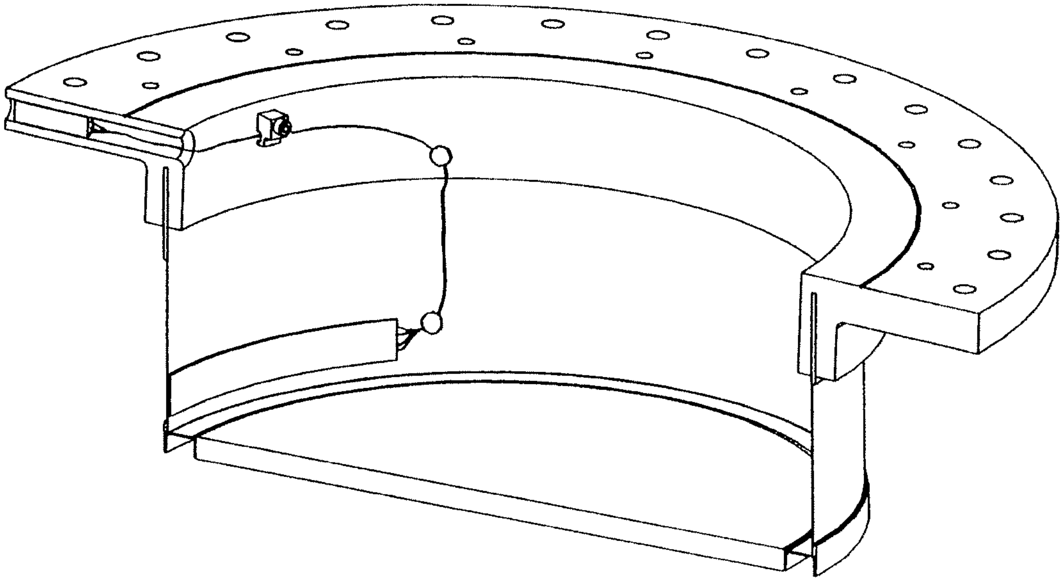


Window 4 (1 of 2)

- Loads: ΔT = -333 K from braze to operating temperatures; 15 psi external pressure; 4 psi internal pressure
- Results for the sapphire/kovar braze
  - Maximum σ shear = 1131 psi limit (FS=2, MS=+3.42)
  - Maximum σ compression = 2552 psi limit (FS=2, MS=+0.96)
  - Maximum σ tension = 130 psi limit (FS=2, MS=+High)
- Results for the sapphire window
  - $\sigma_{\Delta T}$ = 1783 psi limit (FS=10, MS=+2.37)
  - $\sigma_{ext.Pres}$ = 5200 psi limit (FS=10, MS=+0.15)
  - $\sigma_{Int.Pres}$ = 1385 psi limit (FS=10, MS=+3.33)
- Results for kovar ring, 304L tube, & bond joint: positive margin in all load cases

Window 4 (2 of 2)

- Future analyses
  - Optimize tube and Kovar ring ends
  - Optimize bond line at C-seal flange
  - Fracture analysis on weld and window substrate
- Testing planned
  - Sub-scale development test
  - Acceptance test



Cables

- Analysis references: GPB-100431 (2/95), GPB-100432 (2/95)
- Some new cables from Probe-B and old analysis revisited for updated loads
- Results:
  - Segment 1 D.C. SQUID cables must increase bend radius from 0.50" to 0.55" between heat stations (Increased loads from Probe-B analysis)
  - Cables with 'curved bellows' to be verified by development test (ie., Top Hat segments of the Instrumentation, Telescope, and UV bias cables)
  - Bracketry will be added in the Top Hat to prevent contact between the following cables during launch:
    - » D.C. SQUID, ground coax, suspension coax, Fiber-optic
    - » Instrumentation cables to be separated by kapton woven between them
  - All cables have positive Margins of Safety for stress

Summary

- All stress margins of safety are positive
- Some additional brackets added to cables in the Top Hat to prevent contact during launch
- Cross Flange to be made of Aluminum
- Thermal shoes analysis to be completed in July

Thermal Analysis of Probe-C

Jack Goodman

Agenda

- Thermal Requirements
- Temperatures at Selected Locations
- Orbital Heat Flows
- Summary

THERMAL REQUIREMENTS

DESCRIPTION	REQUIREMENT	CALCULATED VALUE
Cryogen Lifetime (with margin)	$\geq$16.5 mo.	18.02 months
QBS/QBF Thermal Resistance	$\leq$ 200 K/W	186.2 K/W @2.36K
Radiation to SIA (Ground hold)	$\leq$ 0.25 mW	TBD
(Orbit)		0.103 mW
QBS Finger Temperature	< 2.50 K	2.28 K
SQUID Attachment Point Temperature	$\leq$ 2.50 K	2.41 K, 2.40 K

TEMPERATURES AT SELECTED LOCATIONS

LOCATION	CALCULATED VALUE (K)
Heat Stations 1-4	28.26, 55.59, 92.73, 143.45
QBS/QBF Interface	2.28, 2.44
STA-200	2.05
Gyros	2.45, 2.45, 2.44, 2.44
Telescope	
– Corrector Plate	3.31
– Base	2.57
QB Average	2.54 ± 0.23 (sd)

ORBITAL HEAT FLOWS

HEAT FLOW PATH	PERCENT OF ~~PROBE~~ Payload TOTAL
Composite Necktube	8.7
Ti Liner	1.8
Cables	18.2
Spinup Supply Lines	0.9
Spinup Exhaust Lines	2.5
Caging Lines	0.0
SIA Support Tube	3.0
External Wires	5.9
	41.0% ~~Probe~~ Payload. Total

SUMMARY

- Thermal model is updated to incorporate Probe-C design features
- Analysis verifies that design meets requirements.

Hardware Cleanliness

Karl Mason

Agenda

- Approach
- Requirements
- Bakeout of hardware
- Operational controls
- Aqueous cleaning in place of Freon

Approach

- Primary focus of contamination control in Probe-B was particles
  - Particles that migrate into the science gyroscope housing may affect the operation of performance of the gyro
  - Magnetic particles that migrate into the region of the gyroscopes (outside the housing but within a few centimeters) may have sufficient magnetic field to affect the gyroscopes or SQUIDs
- Contamination control in probe-C will include molecular (NVR) contamination in addition to particulate.
  - Molecular contamination in the probe can degrade the optics and therefore the performance of the telescope

Cleanliness Requirements

- Cleanliness level
  - Probe-C interior   level 100
  - Windows   level 100A
  - Cross Flange & 6” valve interior surface   level 100A
  - Shutter surfaces   level 100A
  - Sunshade (interior)   level 300A
- Extensive bakeout of Probe-C hardware is required (same as probe-B)
- Material Selection (all materials)
  - Total mass loss (TML)   ≤ 1.0 %
  - Volatile condensable material (VCM)   ≤ 0.1 %

Bakeout of Hardware

- Bakeout (with or without vacuum) is used for multiple purposes
  - Removal of cleaning fluid after precision cleaning
    - Standard precision cleaning process calls for up to 12 hours at 300°F under vacuum
  - Removal of volatile components of nonmetallic materials
    - All nonmetallic components are baked out at highest practical temperature
    - Subassemblies are baked out again, typically at a reduced temperature
    - Bakeout of 12 hours under vacuum
  - Removal of water from hydroscopic materials
    - Dissipation performance of cables is degraded by absorption of water in ceramic insulators
    - Cables and complete probe are baked out in vacuum prior to cable testing
- Final bakeout of probe is nominally 2 weeks at 140°F
  - Probe is under internal vacuum with residual gas analyzer
  - Purpose is to remove all moisture and residual volatile components

Operation Controls

- Probe interior
  - Assembled in class 10,000 clean room
    - Typical operation in class 100-400 range during assembly operations
  - Probe assembly is covered at all times when not in work
- Windows
  - Cleaned and packaged by vendor to maintain cleanliness
  - Not installed during any probe bakeout
  - Installed at last possible time (at SIA integration at Stanford)
- Sunshade
  - Covered after cleaning
  - Cover remains on until payload fairing installation at launch pad
- Cleaning processes controlled or hardware tested to ensure compliance with applicable cleaning level requirement

Aqueous Cleaning Process

- LMSC is required by EPA to eliminate Freon TF from usage
- LMSC has evaluated numerous alternate cleaning processes and fluids and found that water is an acceptable cleaning fluid for most applications
  - Deionized (DI) water with surfactant and nitrogen boost
  - Water temperature of 120°F
  - Water removal by nitrogen purge and vacuum bakeout
    - Nitrogen purge immediately after cleaning
    - Bakeout within 8 hours
- GP-B cleaning equipment has been converted to water
  - Quadrex precision cleaning system
  - Ultrasonic bath
- Approximately 80% of Probe-C hardware will be cleaned by this process
- The rest of Probe-C hardware will be cleaned with Freon TF until LMSC develops new environment-friendly processes

Magnetic Control Procedures

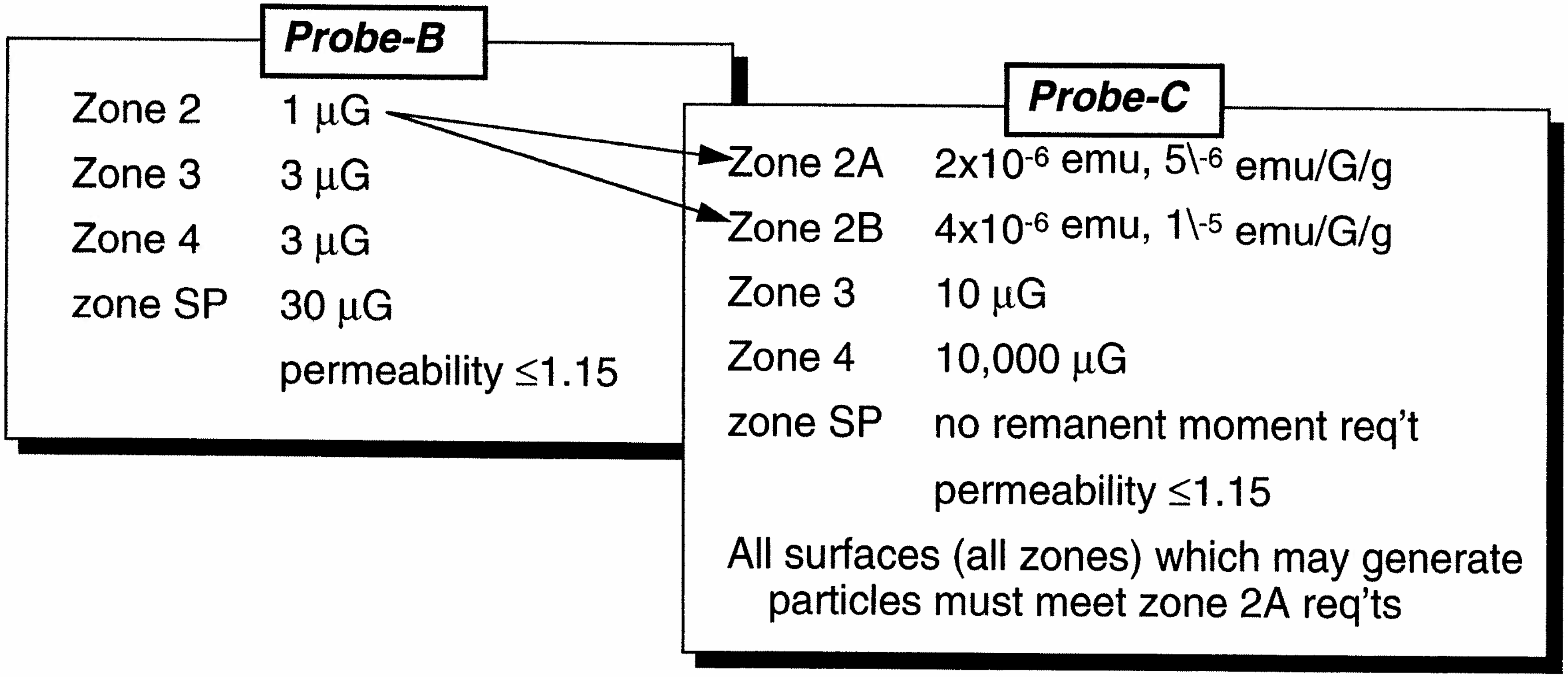
Graham Ross

Agenda

- New magnetic control zones and screening criteria
- New magnetic screening process
- Material development for zones 2A and 2B
- Plating development

Zones & Criteria

- New zones provide additional gradations of requirements in sensitive region
- Less sensitive zones have less stringent requirements
- Susceptibility now a formalized requirement (coupon test)
- Particle-generating surfaces now treated as critical materials



Probe-B

Zone 2	1 μG
Zone 3	3 μG
Zone 4	3 μG
zone SP	30 μG
	permeability ≤1.15

Probe-C

Zone 2A	2x10^{-6} emu, 5\\$^{-6}$ emu/G/g
Zone 2B	4x10^{-6} emu, 1\\$^{-5}$ emu/G/g
Zone 3	10 μG
Zone 4	10,000 μG
zone SP	no remanent moment req't
	permeability ≤1.15

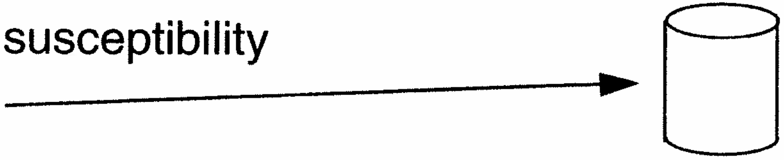
All surfaces (all zones) which may generate particles must meet zone 2A req'ts

Zone Location

- **Zone 2A** (within 9 cm of the center of any science gyroscope)
  - Affects parts on spider and direct connections to gyroscopes
    - Spider
    - GRTs, SDs
    - Instrumentation connector blocks, EMI shields, wire & insulation, shield tubes & bellows
    - Brackets & fasteners on spider
    - Aft caging assembly (tubing, junction blocks, ferrules)
    - Solder, epoxy, tie-down wire
    - Teflon tubes for spin-up inlet & exhaust lines
- **Zone 2B** (between 9 and 25 cm from the center of any science gyroscope)
  - New requirements beyond sensitivity of magnetometer
  - Affects most parts near SIA
    - Extrusions
    - Quartz block support, molybdenum pad, Teflon pads, QBA bolts, washers
    - Cable connectors, ceramic insulators, shield tubes & bellows
    - Cable mounting saddles
    - Spin-up inlet gas filter & heater, inlet & exhaust lines
    - Caging lines
    - Thermal straps

Screening Techniques

- Coupons required for zones 2A and 2B
  - Sample is at 2 K (fast cycle to insert part in cold test equipment)
  - Measure remanent moment and susceptibility
  - sample size is .25” dia x .25” tall



- Zone 2A components tested in large cryogenic screener at Stanford
  - Sample is at 2 K (slow process; entire tester must be temp cycled)
  - Measure remanent moment
  - Sensitive region is 4” dia x 10” long (sample may be longer)
- Zone 2B components tested with SQUID gradiometer
  - Sample is at room temperature
  - Instrument is cooled to 4 K
  - Measures differential magnetic field (near and far from sample)
  - Part may be of unlimited length, part is moved past sensor

Material Development

- Additional material development to achieve new requirements
  - Phosphor bronze was inconsistent in coupon testing; both remanent moment & susceptibility
  - Plating process (gold over rhodium) included magnetic contaminants at a level that is not acceptable for new requirements
  - Retesting of probe-B spares under new criteria shows that many items that passed in probe-B are no longer acceptable

- Phosphor Bronze
  - Custom-poured ingots produced to eliminate contaminants

- Aluminum
  - Stanford has had good experience buying based on chem analysis
  - “Cherry pick” lots: ≤ 0.01% total (iron, nickel, chromium, cobalt)

- Ceramic insulators (for coax cables)
  - Isostatic press blanks rather than injection mold
  - Procure ultrapure ceramic powder

Plating Development

- Gold (electrical connectors, ground contact surfaces)
  - Reduce usage of gold (soft gold is prone to particle generation)
  - Screening old plating solution with gradiometer showed high readings
  - New “clean” plating solution has much lower readings
  - A dedicated plating bath with the new solution is being tested with larger surface area cupouns to verify that process is now acceptable

- Rhodium (underplate for gold, particle barrier)
  - Will be anti-particle coating over stainless steel & other metals
  - Screening old plating solution also showed high readings
  - A new dedicated plating bath is being tested in parallel with gold

- Palladium (alternate for rhodium)
  - Evaluated and found acceptable for probe-C
  - Will not be used; was a backup if rhodium was not acceptable

- Silver (anti-galling & nonmagnetic particle coating for fasteners)
  - Preliminary screening of sample parts shows that process is acceptable

Interfaces

Lynne Sands

Agenda

- Probe-C / SIA ICD changes and issues
- Probe External Interfaces changes and issues

Probe-C / SIA ICD Changes

- Changes in cables for Probe-C
  - UV Bias Ground Cables
    - Addition of three cables
    - For Gyro 1&2 and 3&4, cable ends in a 6-pin connector and then a 'jumper' cable will go from the 6-pin connector to 6 single connection points (two minax and four instrumentation pins)
    - Proof Mass cable to end in 6 single connection points (two minax and four instrumentation pins)
  - Instrumentation Cables
    - Addition of two telescope cables each with 55 wires
  - DC SQUID Cables
    - All cables are now 4-pin cables to support 8 SQUIDS
  - UV Fiber Optics
    - Total of 12 UV fiber Optics lines (was four - one per gyro)
  - Coax Grounds
    - Elimination of three coax grounds (leaves one high-voltage coax ground per gyro & Proof Mass)
- Moved QB interface back to Station 148.24* (to compensate for addition of moly pads)

Probe-C / SIA ICD Changes

- Reidentified all DC SQUID connectors
- Removed SQUID thermal strap tie-down plugs
- Removed 10-pin Ground Block
- Several thermally grounded threaded ‘buttons’ added throughout extrusions in place of countersunk holes (similar design to BeCu plugs)
- Placement of BeCu ‘plugs’ modified to allow SU to add threaded plates on outside of extrusions
- UV fiber optic interfaces moved
- New, expanded telescope envelope (and stay-out zone)

Probe-C / SIA ICD Issues

- Flatness and perpendicularity requirements not reverified after addition of Moly Pads (and teflon interface pad) at QB interface (alignment of telescope to Probe is being revisited) (need by 7/1/95)
  - LMSC needs to look at the current design (the addition of the moly pads) and see what kind of flatness and perpendicularity can be achieved through proper tooling
- New telescope connectors (need by 7/1/95)
  - Grounding of telescope connectors not defined
  - Design of telescope connectors not complete
- Exact interface location of UV Bias Ground pins and minax connectors not verified (need by 5/1/95)
- Probe sensor locations not defined (need by 7/1/95)

Probe External Interface Changes

- Addition of one new instrumentation connector
- New location for UV Fiber Optics connectors
- Rearrangement and change of function for several coax connectors
- Two 6” Exhaust Valves in Tee-flange (was one 8” Exhaust Valve)
- New radial location of pressure sense valve

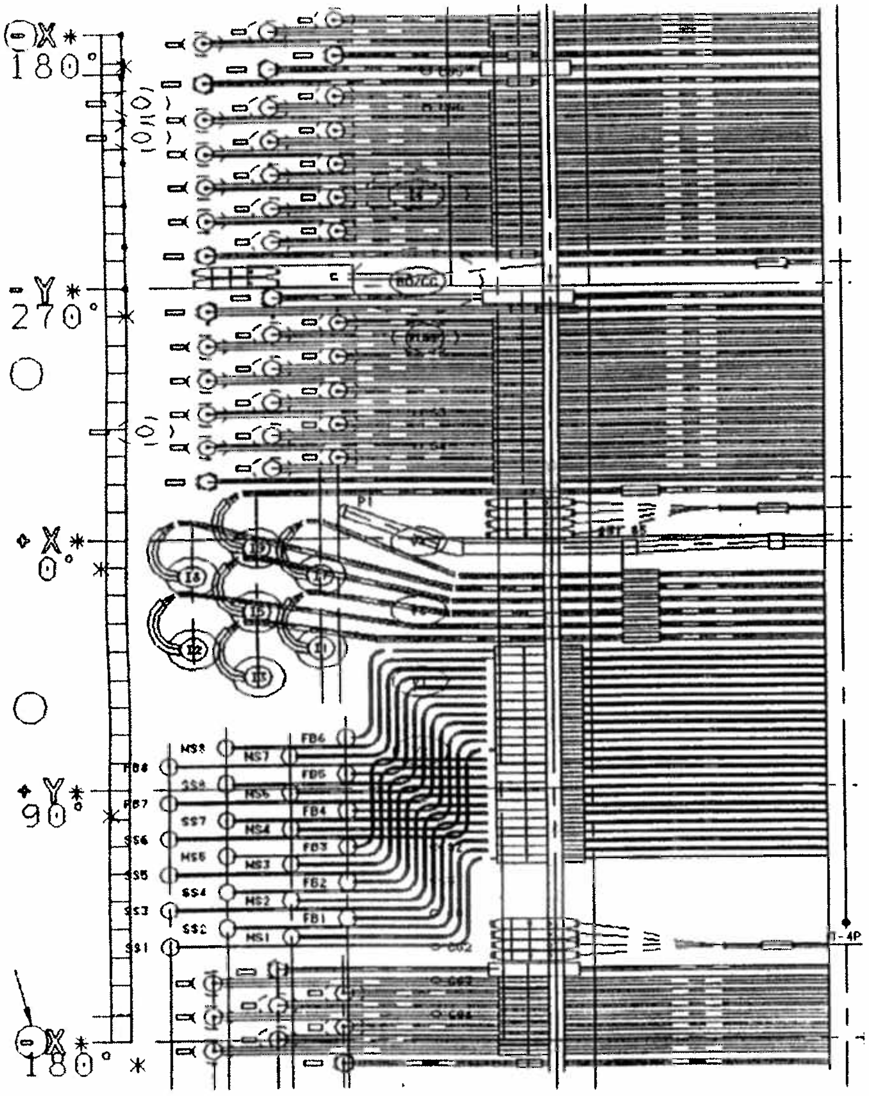
Probe External Interfaces Issues

- Radial and axial position of two 6” vatterfly valves not verified (need by 5/1/95)
- Radial and axial position of Probe Burst Disc and two Pressure Sense ports in Tee-flange not defined (need by 10/1/95)
- Radial and axial position of UV Fiber Optics feedthroughs still under investigation (need by 5/1/95)
- Possible change of radial position on some Spin-Up/Caging valves (need by 5/1/95)

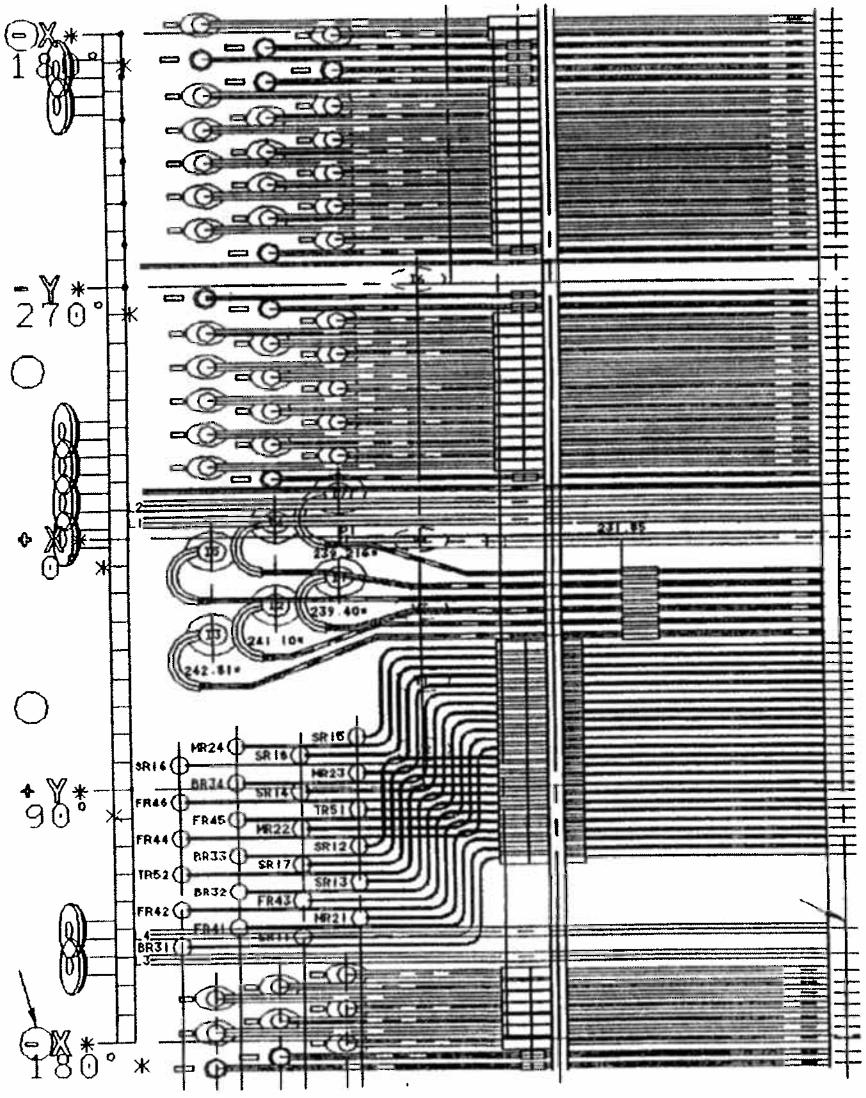
GPB-100417

Probe-C vs Probe-B
Top Hat Region

STANFORD
Lockheed
Probe-C CDR
29 March 95

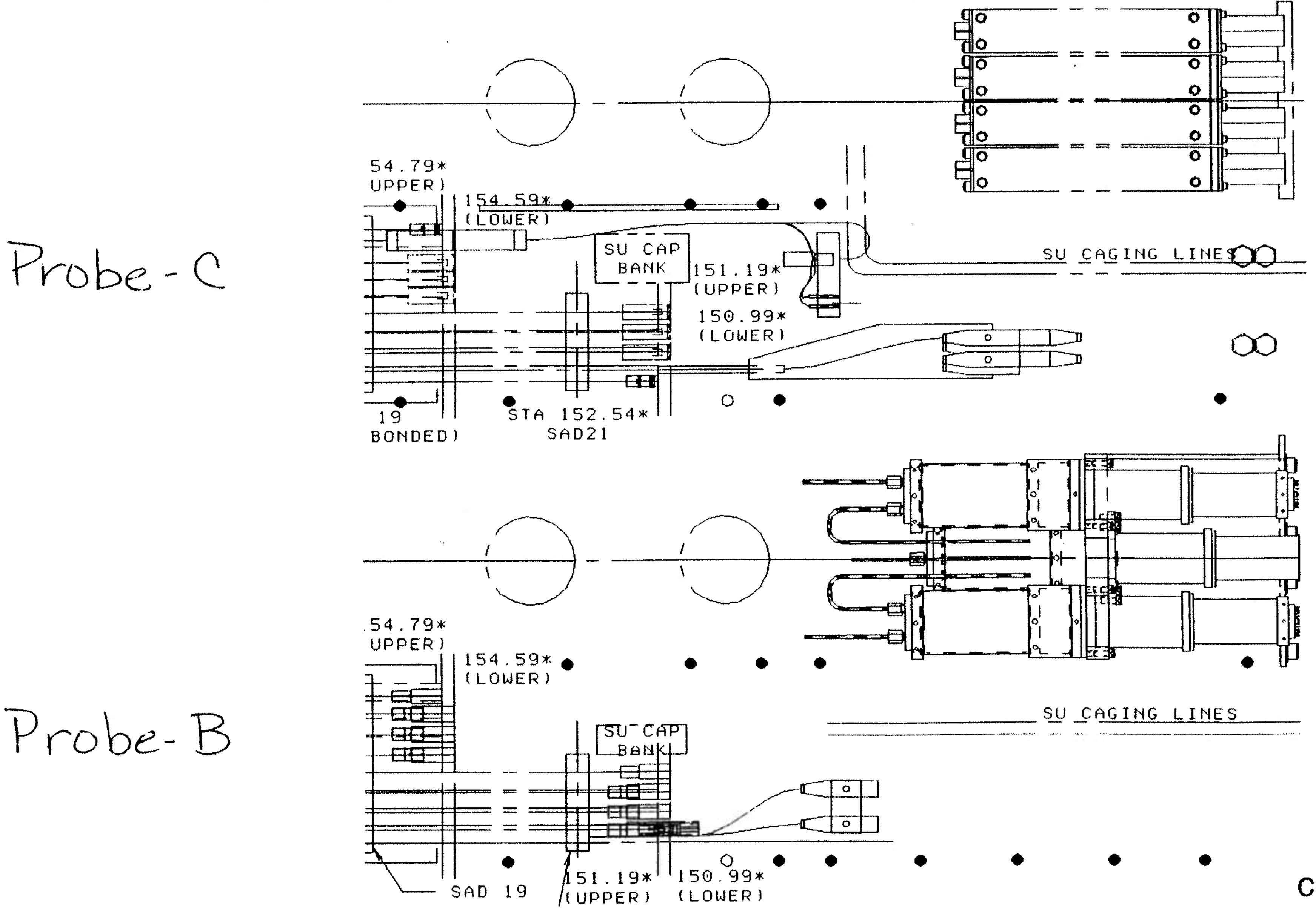


Probe-C



Probe-B

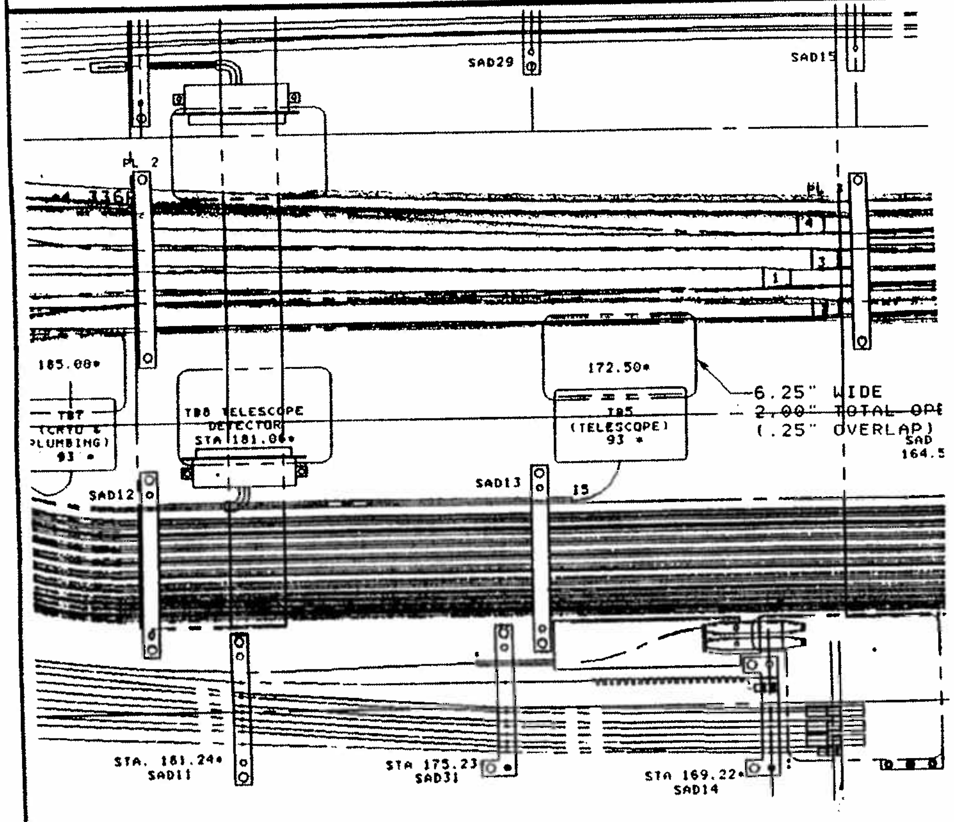
Probe-C vs Probe-B
Gyro 1&2 Region



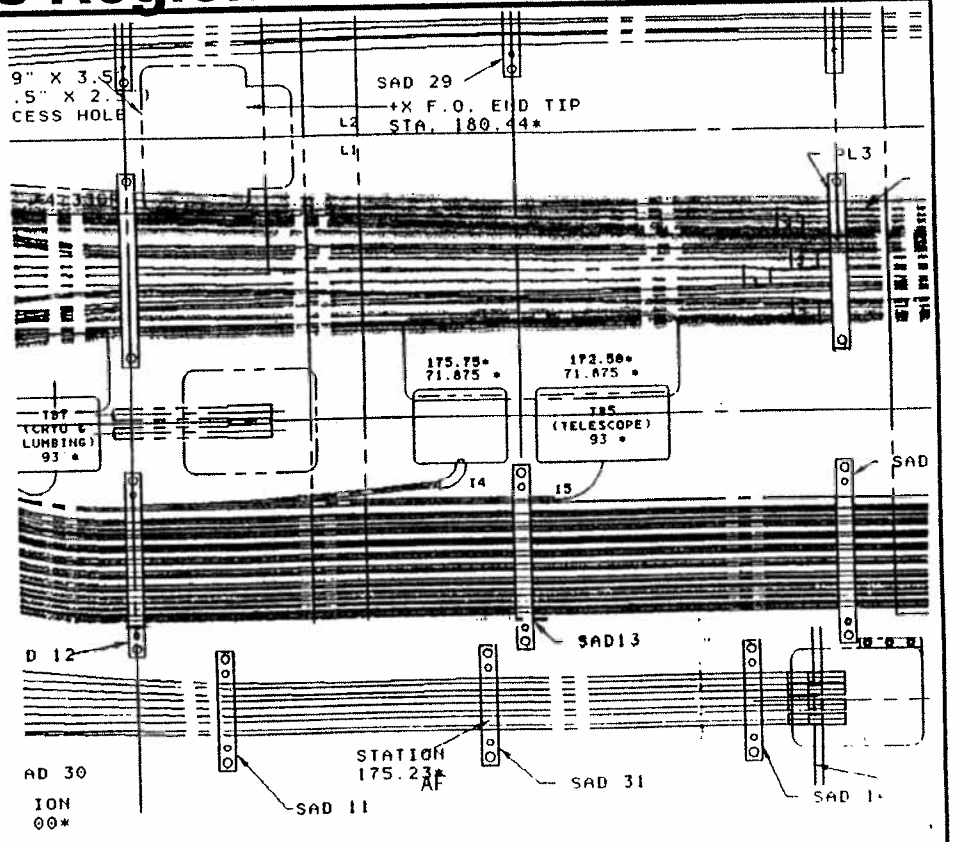
GPB-100417

Probe-C vs Probe-B
Proof Mass Region

STANFORD
Lockheed
Probe-C CDR
29 March 95



Probe-C



Probe-B

CDR-9

Probe-C Cables

Andy Dobrov

Agenda

- Summary of Cable Changes
- Fiber-optic Cables
- Telescope Cables
- Ground/UV Bias Cables
- DC SQUID Cables

PR-C Electrical Cable Changes

Probe-B	Probe-C
• Suspension coax cables	• No change, 35 cables
• Ground coax cables	• Reduced from 8 to 5 to provide 3 shields for low-voltage ground / uv bias cables (PCB 65)
• 24 SQUID cables	• 24 SQUID cables (PCB 45)
– 60 wires	– 96 wires to support 8 SQUIDs
• 6 Instrumentation cables	• 7 Instrumentation cables (PCB 62)
– 3 SIA region, 110 wires	– 3 SIA region, decreased to 102 wires (removal of SQUID switch wires)
– 2 Probe & SIA heater/temp sensors - 92 wires	– Same as Probe B
– 1 quad detector cable, 20 wires	– 2 Telescope detector cables, 110 wires **(Pending change reduces total to 80 wires)**
• No Low-voltage ground/UV bias cables	• 3 Low-voltage ground/UV bias cables, 18 wires (PCB 65)
Total wires: 325	Total wires: 458
Total shields/feedthrus: 73	Total shields/feedthrus: 74

Fiber-optic Cable Design

- Two-segment cables with feedthrough connector at top hat
  - Modular cables reduce risk of damage during assy and handling
  - Seg 1 cables rigidly mounted similar to electrical cables
  - Seg 2 cable replaceable/installed after top hat

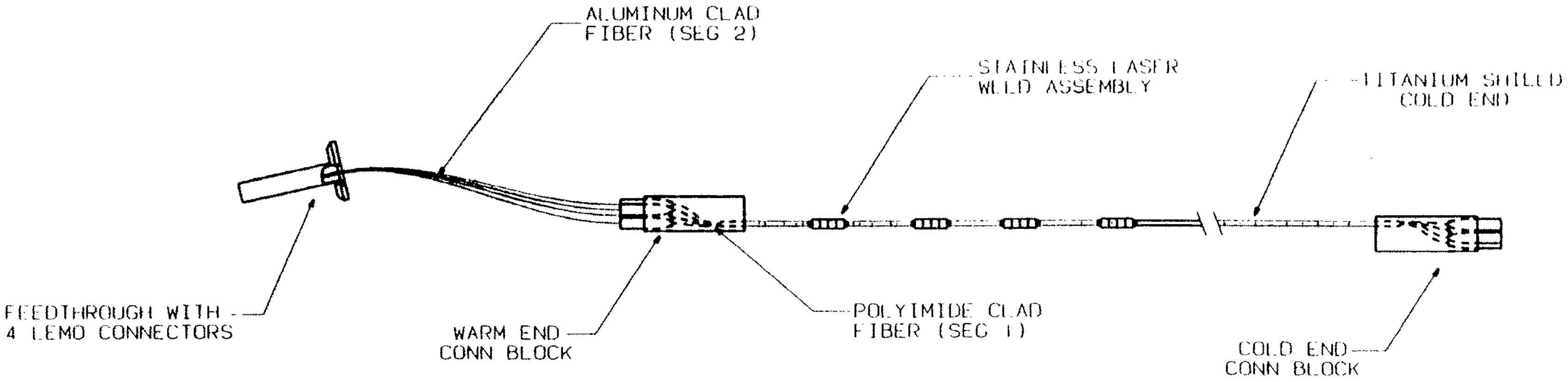
- Seg 1 fibers protected inside rigid shield assy
  - Similar to ground & instrumentation shield assys
  - Connectors and connector blocks integral part of shield assy
  - Polyimide jacket fiber used to minimize thermal impact
  - Titanium shield in cold end minimizes sag of fiber inside shield

- Seg 2 cables modular and replaceable (no shield assembly)
  - Aluminum jacket fiber better capable of handling bends

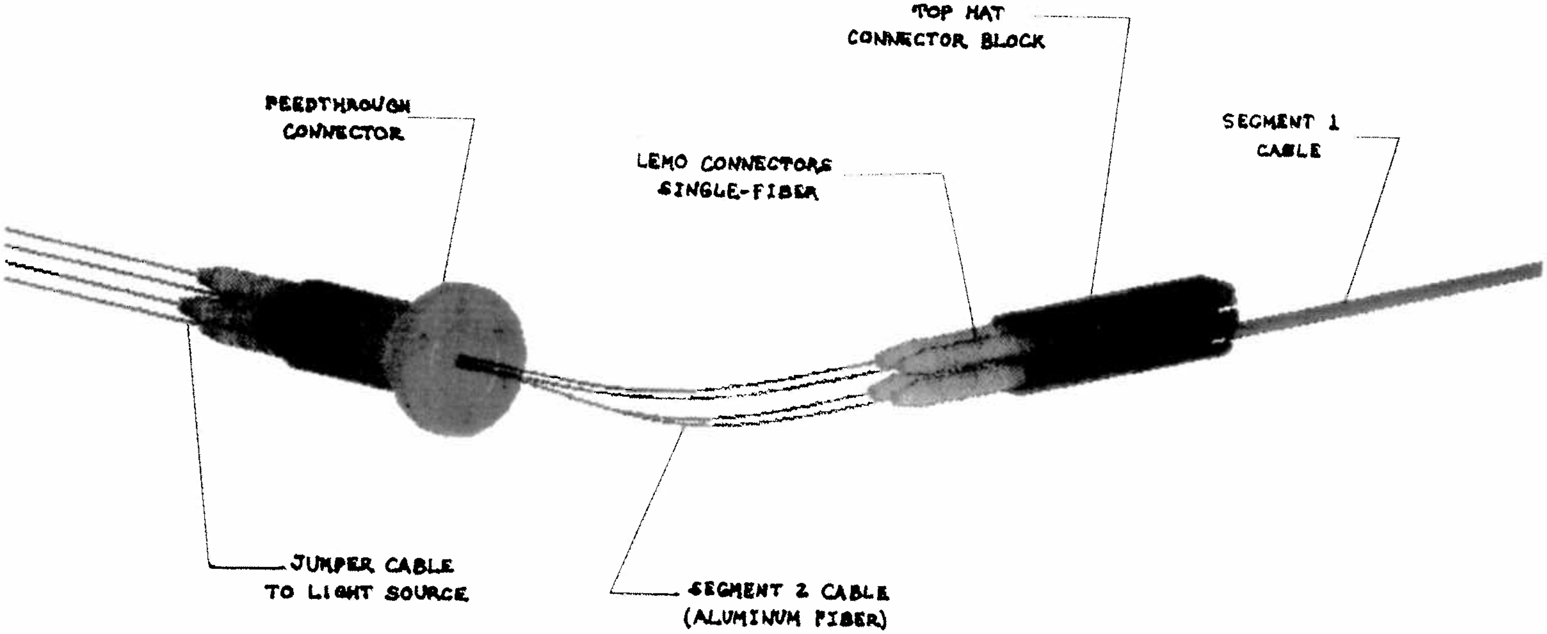
- Single-fiber Lemo connectors at all interfaces
  - Proven component on Probe-B and SVA
  - Small size and low attenuation

Fiberoptic Cable Layout

FIBER-OPTIC CABLE SCHEMATIC



Fiberoptic Cable Layout



LAYOUT OF CABLE IN TOP HAT REGION

Performance & Requirements

- Revised requirements (PCB in process)
  - Total attenuation at 254 nm and 5 μW input power level is ≤ 9 dB
  - Degradation required to be asymptotic and ≤ 2 dB after 200 hours
- Performance of fiber-optic components
  - Summary of expected losses in system components

» Entrance loss at Top Hat (1/2 connection)	0.5 - 1.2 dB (Lemo-Test)
» Coupling loss at segment 1/segment 2 connector	1.0 - 2.3 dB (Lemo-Test)
» Exit loss at cold–end connector (1/2 connection)	0.5 - 1.2 dB (Lemo-Test)
» Initial transmission loss in fiber	1.5 - 1.8 dB (Fiber-Test)
» Fiber degradation over 200 hours	1.0 - 1.5 dB (Fiber-Test)
Total expected loss in system	**4.5 - 8.0 dB**
	Requirement: ≤ 9 dB

- Measured values consistent with vendor specifications and meet system requirements

Analyses & Development Tests

- Analyses
  - Stress analysis of Seg 2 cable (GPB-100431)
    - » Unshielded aluminum fiber in Top Hat
    - » Results--Fiber can withstand stresses due to vibration and thermal excursions
      - Fiber must be restrained to reduce deflections due to vibration
  - Thermal analysis
    - » Analyze impact of using aluminum fiber for long seg 1cables
    - » Results: 3-week lifetime impact--too large
- Results of completed development tests
  - Transmission testing of Seg 1 and Seg 2 fiber
    - » Batches of aluminum and polyimide fibers tested at Stanford
    - » Aluminum fiber qualified and used by Stanford
    - » Results consistent with vendor specifications
    - » Fiber qualified for use in Probe-C

  - Attenuation test of Lemo connector pair
    - » Test cables assembled at Lockheed and tested at Stanford
    - » Connector attenuation ranges from 1.0 - 2.3 dB
    - » Consistent with vendor specifications
    - » Meets Probe-C component requirements

Development Tests Cont'd

- Optical test equipment
    - » Stanford to provide LMSC with Mercury light source and photodetector
    - » Allows qualification and acceptance testing to be done at LMSC
    - » Provides backup for Stanford test equipment

- Upcoming qualification testing
    - – Qual cable configuration
        - » Complete cable assy with full length Seg 2 and shortened Seg 1
        - » Cable mounted in fixture with representative saddles
    - – Qual cable testing
        - » Initial transmission and degradation over 200 hours
        - » Effects of shake test on transmission
        - » Effects of thermal cycling and bakeout on transmission
        - » Cold transmission test
        - » Qualify new aqueous cleaning process

Flight Hardware Verification Tests

- Acceptance testing
  - Input power level of 5 μW
  - Wavelength of concern is 254 nm
  - Degradation to be asymptotic over 200 hours and ≤ 2 dB
  - Total cable attenuation requirement ≤ 9 dB

  - Test sequence of complete assembly including Segment 2
    - » Initial transmission and degradation
    - » Precision clean and bakeout
    - » Thermal cycle
    - » Final transmission and degradation

Action Item Responses

- Requirements Review
  - AI#22: Impact of providing dedicated spare fiber for each gyro and PM
    - Resolution: Not feasible to provide dedicated spares; 2 spares total for gyros
  - AI#12: Identify location of interface connector for PM fibers
    - Resolution: Location specified on ICD 1C34103
- PDR
  - AI#5: Should cold–end Lemos be grounded?
    - Resolution: Cold-end connectors shall be isolated from ground and from each other
  - AI#20: Review vibration support of Probe-B fiber optics inside top hat
    - Resolution: Fibers adequately supported in Top Hat (GPB-100433)
- IDR
  - Should the aluminum fiber be grounded at the Top Hat feedthrough?
    - Resolution: The aluminum will be etched to break electrical continuity through the feedthrough

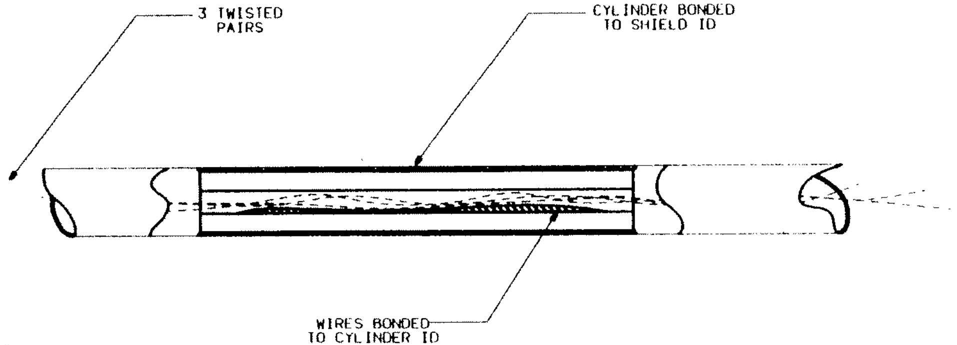
Fiber-optic Summary

- Fiber-optic cable design is based on successful electrical cable concept
  - Modular, robust construction
    - Replaceable seg 2 cable with rigid seg 1 construction
- Optical fibers tested for darkening, transmission and degradation
- All components meet performance requirements
- Thermal and structural analyses completed; acceptable results and margins
- Cable shake test will verify launch vibration survivability

Ground/UV Bias Cable Design

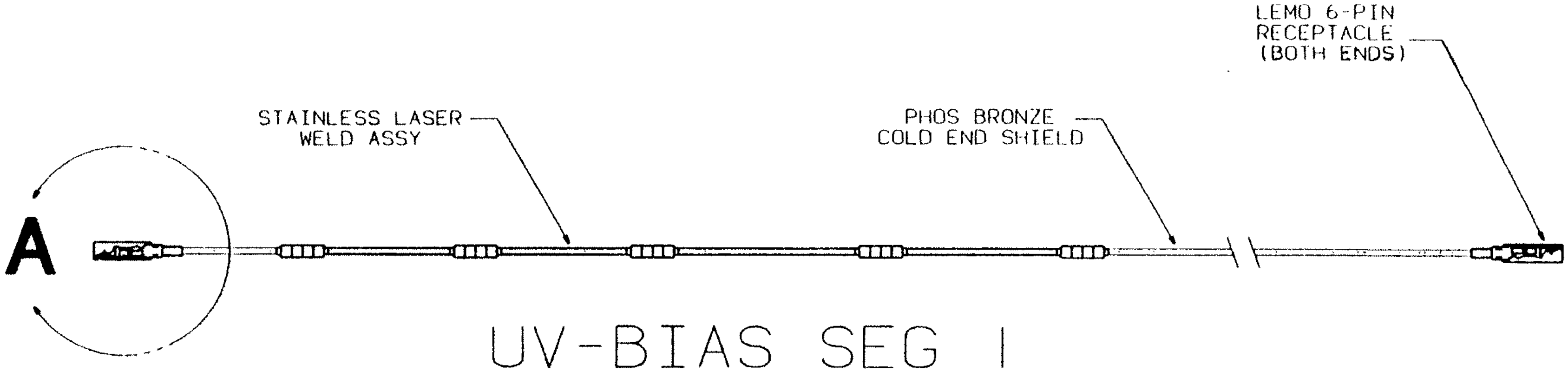
- Shield assy similar to PR-B Ground coax design
  - Segment 1 shield/bellows assy identical to PR-B Ground Coax
  - Segment 2 shield has single uncompressed bellows for 90° bend

- Wiring
  - Three twisted-pair wires, 5 mil PhBr (same as suspension cables)
  - Wires heat sunk at heat stations using aluminum cylinder

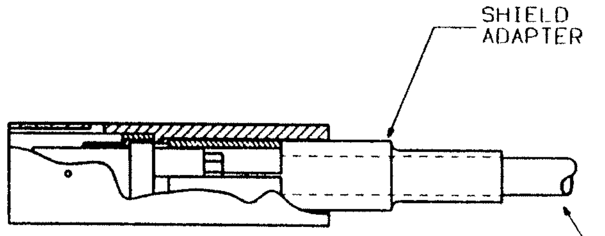


- Connector interfaces
  - » 6-pin Pacific Coast feedthru and mating connectors identical to Probe-B SQUID cable
  - » 6-pin Lemo connector in cold end similar to 4-pin Probe-B connectors
  - » Mating connector and jumper terminations provided by LMSC for easy interface
    - • 2 terminate with Lemo ground connectors and remainder with 4-pin connector block
  - » Warm-end seg 1 cable located forward of connector restraint collar
  - » Warm-end connector to be supported with saddle in top hat

Ground/UV Bias Cable Layout

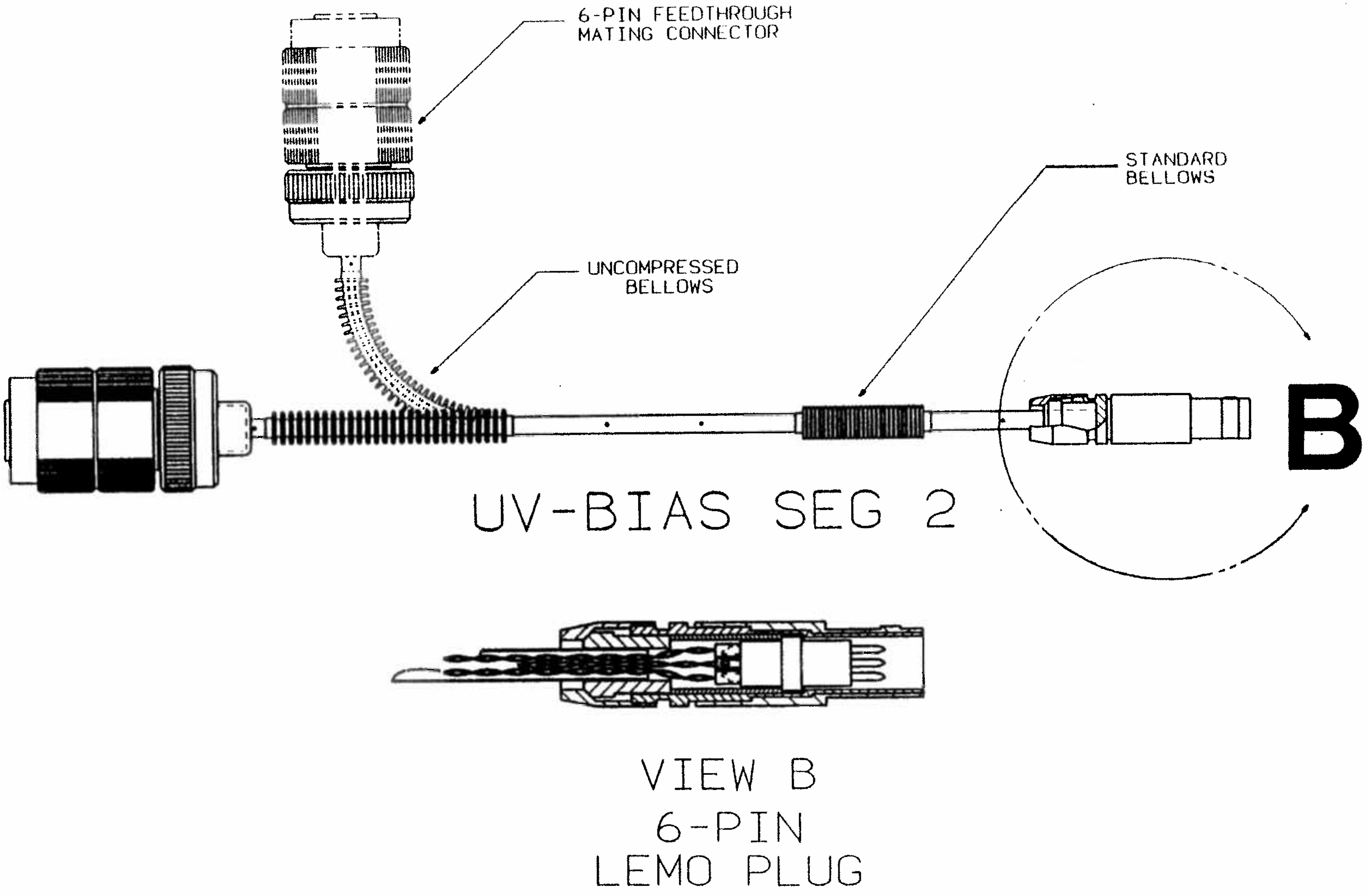


UV-BIAS SEG I

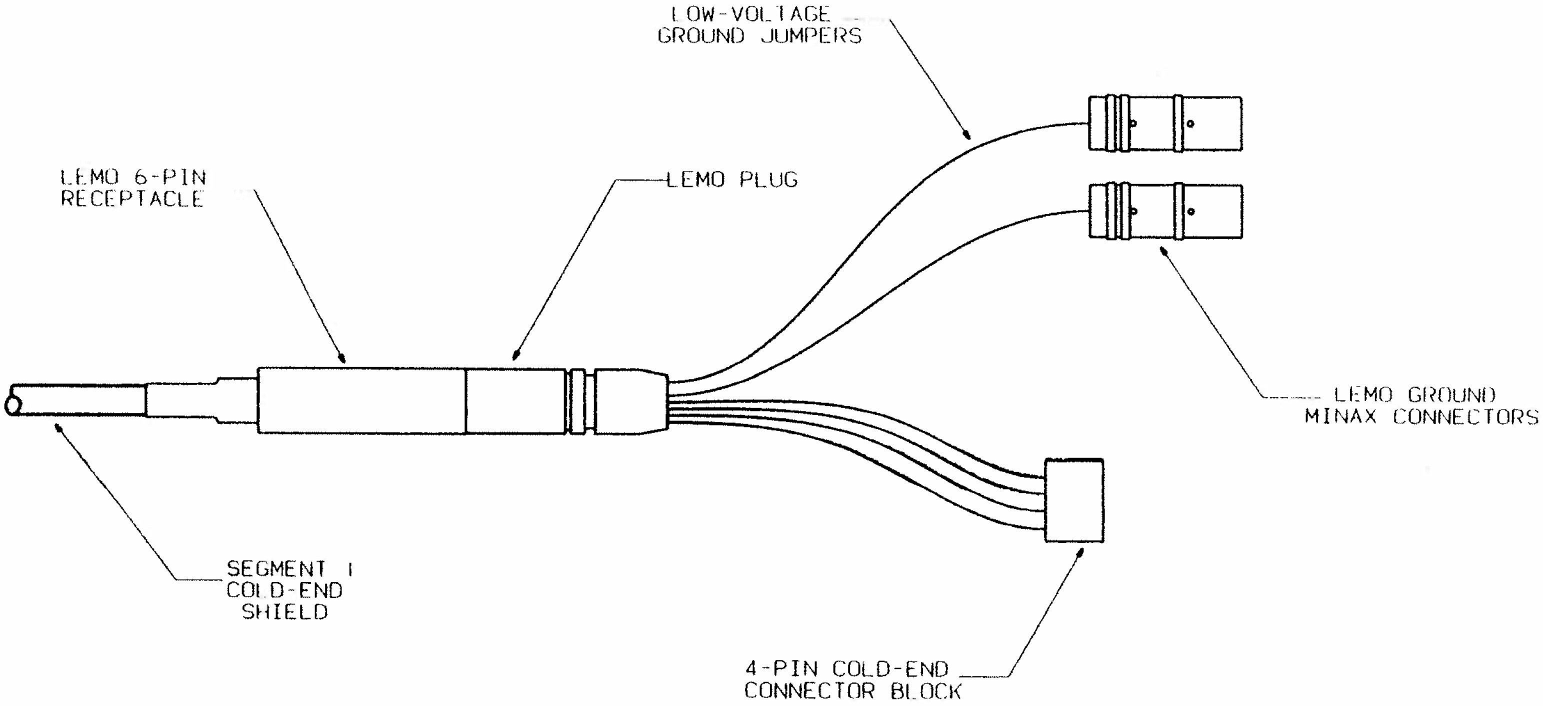


VIEW A
6-PIN LEMO
RECEPTACLE

Ground/UV Bias Cable Layout



Ground/UV Bias Cable Layout



UV-BIAS COLD-END TERMINATIONS

Performance & Requirements

- Shield assemblies and wire meet requirements by similarity to Probe-B
  - Laser welded assys identical to Probe-B grounds & instrumentations
  - PhBr wire identical to SQUIDS & instrumentation

- Lemo connectors meet requirements by similarity to Probe-B
  - 6-pin similar to 4-pin connector connector used on Probe-B
  - Cold end Lemo ground connectors identical to Probe-B coax grounds
  - All connectors to be made from LMSC-supplied non-magnetic material
    - » Phosphor bronze rod manufactured from special ingot
    - » Inserts machined from PEEK rod purchased by LMSC and screened in advance
      - Inserts machined instead of injection molded due to magnetics

- Top Hat bellows for 90° bend
  - Single uncompressed bellows fits in available space
  - Similar to Probe-B instrumentation bellows in Top Hat

Analyses & Development Tests

- Analyses
  - Thermal analysis of additional wires
    - » Negligible impact on lifetime with wires thermally grounded at heat stations
- Upcoming development tests
  - Seg 2 Top Hat bellows deflection development test
    - » Verify bellows ability to withstand .270 inches deflection
  - Develop assembly processes for heat station cylinder
    - » Proper thermal bond joint between cylinder and shield
- Upcoming qualification testing
  - Qual cable configuration
    - » Complete cable assy with full length Seg 2 and shortened Seg 1
    - » Cable mounted in fixture with representative saddles
  - Qual cable testing
    - » Shake test new shield/bellows assy
    - » Ability of Top Hat bellows to withstand thermal deflections

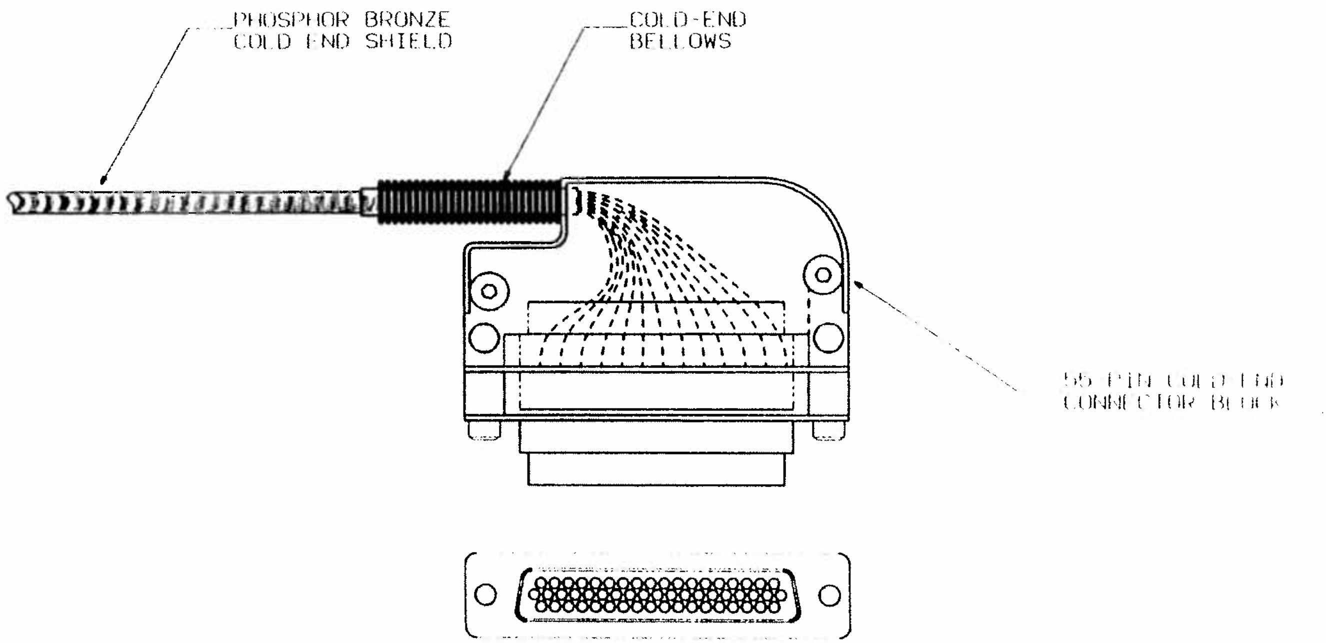
Summary

- Ground/UV Bias cable is similar to ground coax and instrumentation designs
  - Modular, robust shield/bellows assy
  - Wires heat sunk at heat stations similar to coaxes
- All components meet performance requirements; no risk issues
- Thermal and structural analyses completed; acceptable results and margins
- Cable shake test will verify launch vibration survival

Telescope Cable Design

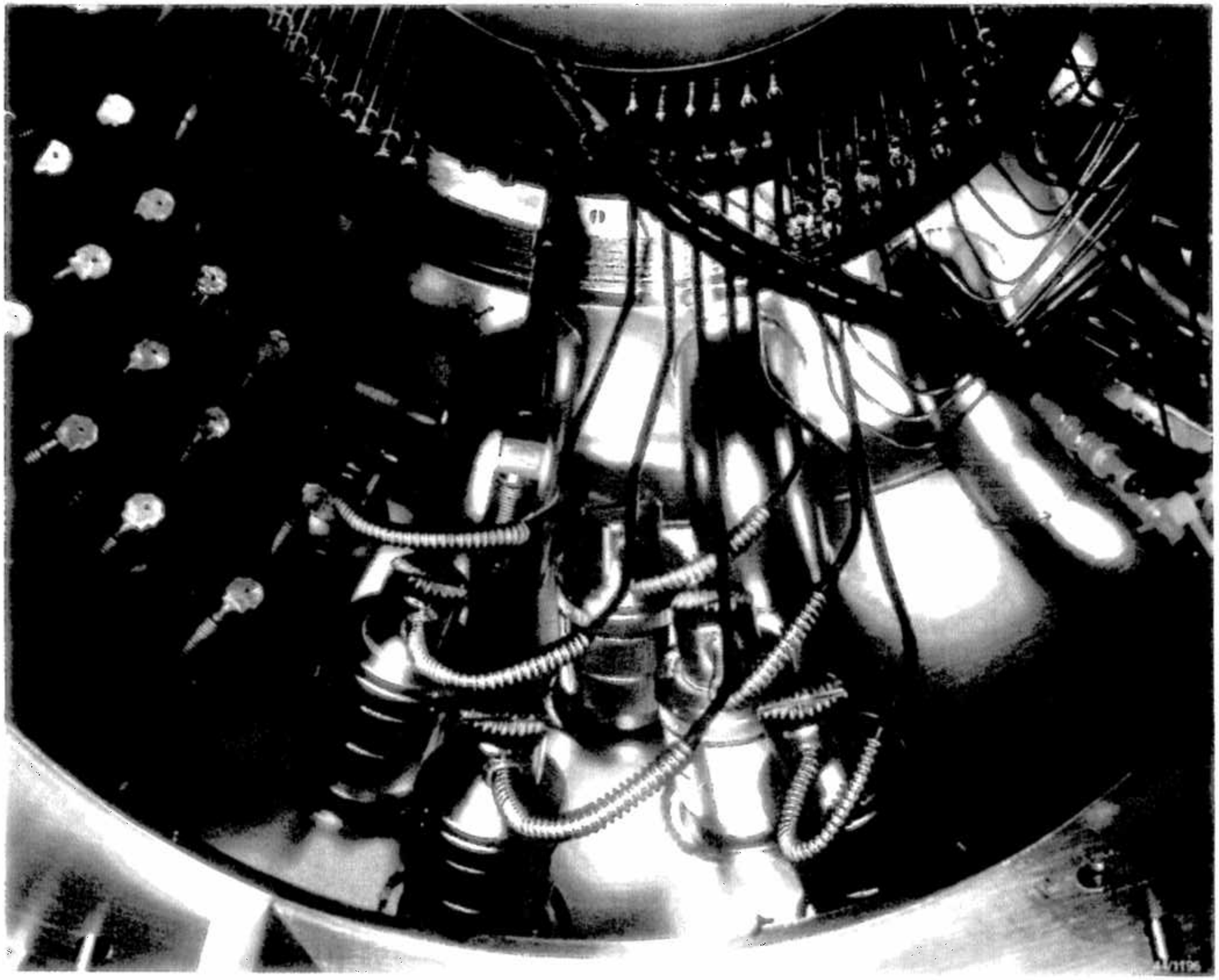
- Similar to Probe-B instrumentation cables
  - – Shield construction and internal wires
    - » 5 mil PhBr wires: 12 twisted pairs + 10 twisted triplets + 1 spare = 55 per cable
      - Pending PCB could reduce quantity to 40 per cable (Telescope meeting 2/9/95)
    - » Continuous PhBr shield/bellows assy baseline design
      - (Pending change has shield ending 2 inches before connector)
    - » All shield and connector joints accomplished by indium soldering
    - » Wires bonded in shield same as Probe-B instrumentation cables
    - » .120" diameter shield same as instrumentation
    - » Bellows same as instrumentation except made from PhBr
  - – Connector interfaces
    - » 55-pin top hat instrumentation feedthru same as Probe-B
    - » Baseline design
      - 55-pin cold-end connectors, similar to MIL-C-24308 "D" connector except as follows:
        - – Connector shell and pins shall be made from phosphor bronze
        - – Insert to be either alumina or PEEK
        - – Pins shall be bonded into insert using 2115 non-magnetic epoxy
    - » Pending change would have four 22-pin connectors
      - Each cable contains 40 wires and breaks out into two 22-pin connectors

Telescope Cable Layout



TELESCOPE CABLE COLD-END INTERFACE

Telescope Cable Layout



TELESCOPE CABLE TOP-HAT INTERFACE

Performance & Requirements

- Incorporating changes from Probe-B
  - Shielding
    - » Continuous PhBr shield provides maximum shielding
  - Packaging
    - » Larger wire bundle fits in standard instrumentation shield/bellows assy
  - Plating
    - » Special rhodium and gold baths in process for plating pins and connectors
      - Samples from Hammon have passed new magnetics requirements
    - » Threaded portions of connectors to be plated with rhodium only to prevent galling
  - Wire availability and screening
    - » All wire including new tri-twist configuration on order from MWS Wire Industries
    - » Coupons from MWS pass new magnetics requirements
  - Connector blocks and pins
    - » Coors 99.9% alumina to be used for fabricating connector block
    - » Connector pins to be made from LMSC-supplied PhBr foil (from special ingot)

Analyses & Development Tests

- Analyses
  - – Thermal impacts
    - » Continuous phosphor bronze shield has minimal impact on lifetime (0.1 month)
- Results of completed development tests
  - – Wire bundle fit-check
    - » Wire bundle installed in larger shield, wires pass all electrical tests after installation
- Upcoming qualification testing
  - – Qual cable configuration
    - » Complete cable assy with full-length Seg 2 and shortened Seg 1
    - » Cable mounted in fixture with representative saddles
  - – Qual cable testing
    - » Shake test new shield/bellows assy
    - » Ability of Top Hat bellows to withstand thermal deflections
    - » Qualify new aqueous cleaning process
    - » Thermal cycle and bakeout, then check wire continuity & isolation

Summary

- EMI shielding is maximized by continuous phosphor bronze shield assy
- Meet all performance requirements; no risk issues
- Thermal and structural analyses completed; acceptable results and margins
- Cable shake test will verify launch vibration survival

SQUID Signal Cable Design Change

- Changed signal wire material to meet round-trip resistance requirement of ≤ 2Ω with smaller diameter wire
  - Wire is .008” phosphor deoxidized copper wire, was .012” PhBr-E
    - » .008 “ Phosphor bronze-E wire does not meet requirement
    - » Using smaller wire creates room in shields for spares
      - Material switch postponed to Probe-C due to very long lead time
  - Development test conducted by Materials Research Incorporated
    - » Measured thermal and electrical conductivity of wire sample over entire temperature range down to 2K
    - » .008” dia. phos deox wire meets round trip resistance requirement
- Thermal analysis
  - Measured conductivity data used to analyze impact on lifetime
    - » 0.2 month lifetime impact
- Wire Status
  - Wire coated and twisted by MWS--In LMSC Stores
  - Should be screened by gradiometer ASAP
    - » Very long lead material

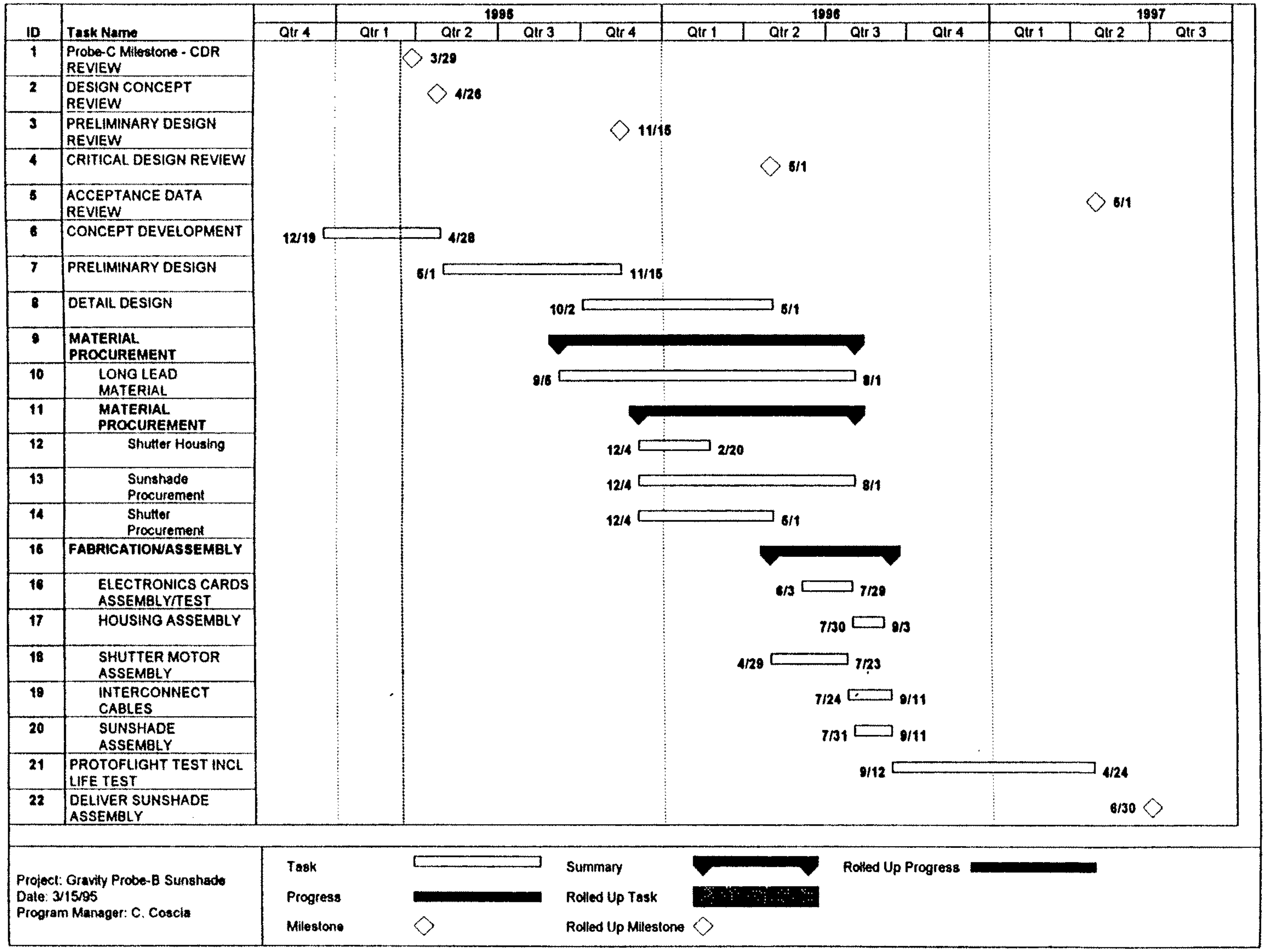
Sunshade

Richard Vassar

Agenda

- Schedule
- Requirements
- Mechanical design
- Stray light Analysis
- Testing
- RR & PDR action items

Schedule



Project: Gravity Probe-B Sunshade
Date: 3/15/95
Program Manager: C. Coscia

Performance & Requirements

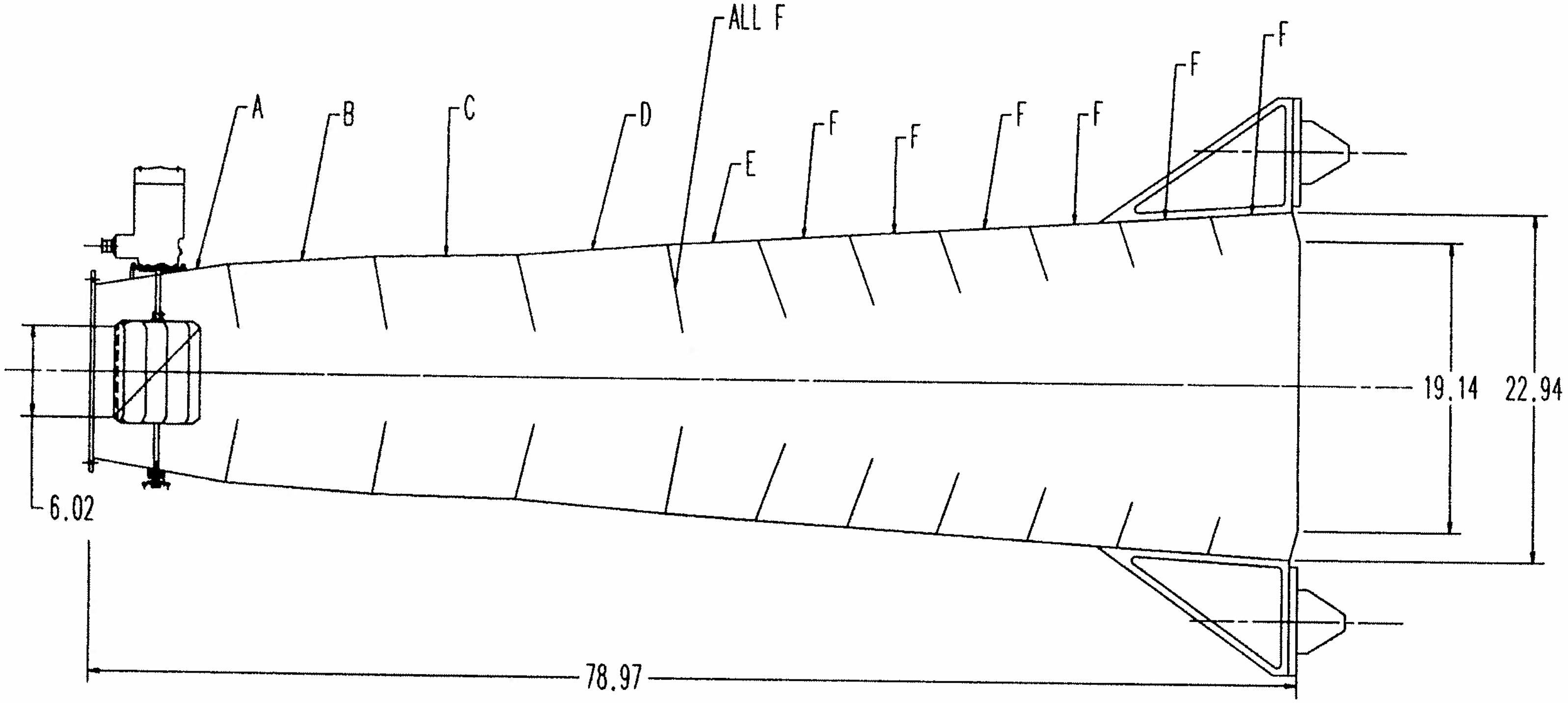
- Prevent light with rays greater than 18 deg from reaching window 4 before being reflected at least twice (attenuation $\geq 10^9$)
- Open and close each orbit (about 8,000 cycles in 16.5 months)
- Failsafe (fails to fully open position)
- Launch in closed position using motor power - no launch latch
- Optical attenuation > 100,000 along optical axis when shutter closed
- Provide mount for omni antennae & sun angle sensors
- Provide maximum level of EMI shielding without compromising optical requirements
- Minimize effects on spacecraft dynamics - low weight ($\leq$13 kg) and high stiffness / high vibration modes ($\geq$100 hz)
- Fit within Delta II composite fairing

MECHANICAL DESIGN

GPB-100417

Sunshade Mechanical Layout

STANFORD
Lockheed
Probe-C CDR
29 March 95



THICKNESS OF ALUMINUM
A - 0.107"
B - 0.066"
C - 0.044"
D - 0.028"
E - 0.018"
F - 0.016"

Sunshade Assembly Concept Design
Precedence of Requirements

- Dynamic Envelope
  - An optical design concept has been generated that fits within the allowable fairing envelope.
  - Sway space requirements must be reviewed at the vehicle level to ensure compliance.
- Attenuation
  - The optical design concept meets the required attenuation with manufacturing tolerance added.
- Shutter Fail Position
  - The existing GCS actuator can be rotated 90 degrees such that the fail position is open.
  - The test article currently under evaluation for torque disturbance has been assembled to return open.
- External Hardware.
  - A mount structure for the external sensors and antenna must be stiff and lightweight.
  - Current plans are to fabricate this structure using composite materials.
- Lowest Vibration Mode.
  - The requirement is >65 Hz. by analysis and >55 Hz. demonstrated.
  - The concept design was generated with a >75 Hz. design goal.
    - The concept design first mode is 75 Hz.

Sunshade Assembly Concept Design
Precedence of Requirements (Cont’d)

- ◆ Heat Conduction to mount surface.
  - The location of the thermal break will be determined by a trade study involving temperatures of the electronics and actuator bearings.
  - Two locations in study.
    - A break at the flange.
    - A break between the outer shade and housing.
- ◆ Mass properties.
  - The weight limit is ≤13.0 kg. (28.7 lbs).
  - There is very little design margin on weight.
  - The current design concept has allowance for manufacturing weight variation.
  - Proficient design effort is needed for the external equipment mount.
    - This mass is located at the very end of the shade.
    - Significant impact on natural frequency.
    - Significant impact on weight due to meeting natural frequency requirements.
    - Strong early control of design planned to mitigate this risk area.

Sunshade Assembly Concept Design Description

- The Sunshade consist of the following major components.
  - Housing.
    - Baseline is aluminum, casting or machined from billet.
  - Baffle assembly.
    - Aluminum sheet, riveted construction.
  - Shutter.
    - Baseline is fiberglass construction.
    - Graphite Epoxy under consideration for reduction of torque disturbance.
  - Shutter Actuator.
    - Existing design, qualified on an existing GCS program.
  - Actuator control electronics.
    - Basic control function, simplicity is key driver for reliability.
  - External hardware mount.
    - Lightweight composite construction, graphite epoxy baseline for rigidity and weight.

Sunshade Assembly Concept Design
Design of Shade

- ◆ A suite of computer aided engineering tools is being utilized for this design.
  - Quantity and delivery requires tight and robust control of the entire design and fabrication.
  - Solid modeling and tightly coupled analysis tools are being used to generate the design.
- ◆ A concept design has been made using a powerful optimization analysis program.
  - Mechanica version 7.0 from RASNA Corporation was used.
  - The mass of the external equipment (1.264 kg) was included in the model.
  - Mass was minimized for a designed first mode 10 Hz. above specification.
    - – 75 Hz. was chosen to provide design margin for fabrication methods and materials.
    - – The model does not represent the riveted joints between sheet metal thickness changes.
      - A loss in stiffness is expected due to these joints.
- ◆ Optimization using analysis tools will be used throughout the design activity to meet the weight and frequency requirements.

Sunshade Assembly Concept Design
Design of Shade (Cont'd)

- ♦ A NASTRAN model was made using the IGES geometry from the optimized concept model.
- ♦ Preliminary stress and buckling analyses were performed on the optimized design concept using NASTRAN Version 68.
    - The stresses and natural frequency results agree with the those obtained using the Mechanica software.
    - The stresses due to launch loads show sufficient margin to proceed with this concept.
    - The buckling mode shows a margin greater than 5 for this concept design.
        - This margin will allow for manufacturing tolerance and stress concentrations due to actual joint construction.
        - Buckling will not be a critical weight driver.
- ♦ A non-linear buckling analysis will be performed during the detail design phase.
- ♦ This design technique will be continued through the detail design activities.
    - Design Engineer generates and optimizes design using CAE tools.
    - Structural analyst verifies design using advanced solution tools and modeling expertise.

Characterization of existing actuator.

- ◆ The existing actuator is currently being set up in a lab for torque disturbance measurements.
  - The existing design and balancing during assembly nearly eliminates the need to measure force.
  - Measurement capability is being evaluated for possibility that analysis cannot demonstrate sufficient margin for the forces.
- ◆ Torque vs. time measurements of the standard operation will be made by the end of March.
- ◆ After establishing a baseline, testing will proceed with pulse shape control of the actuator.
- ◆ Current analysis based on motor torque and actuation times reveal:
  - The torque output must be reduced approximately 50% or the opening time must be increased from ~0.75 seconds to ~2 seconds to meet the available thruster mass flow rate.
  - The torque can be reduced by reducing the motor current.
    - Careful evaluation will be made to ensure proper operation.
  - The time can be increased with pulse shaping.

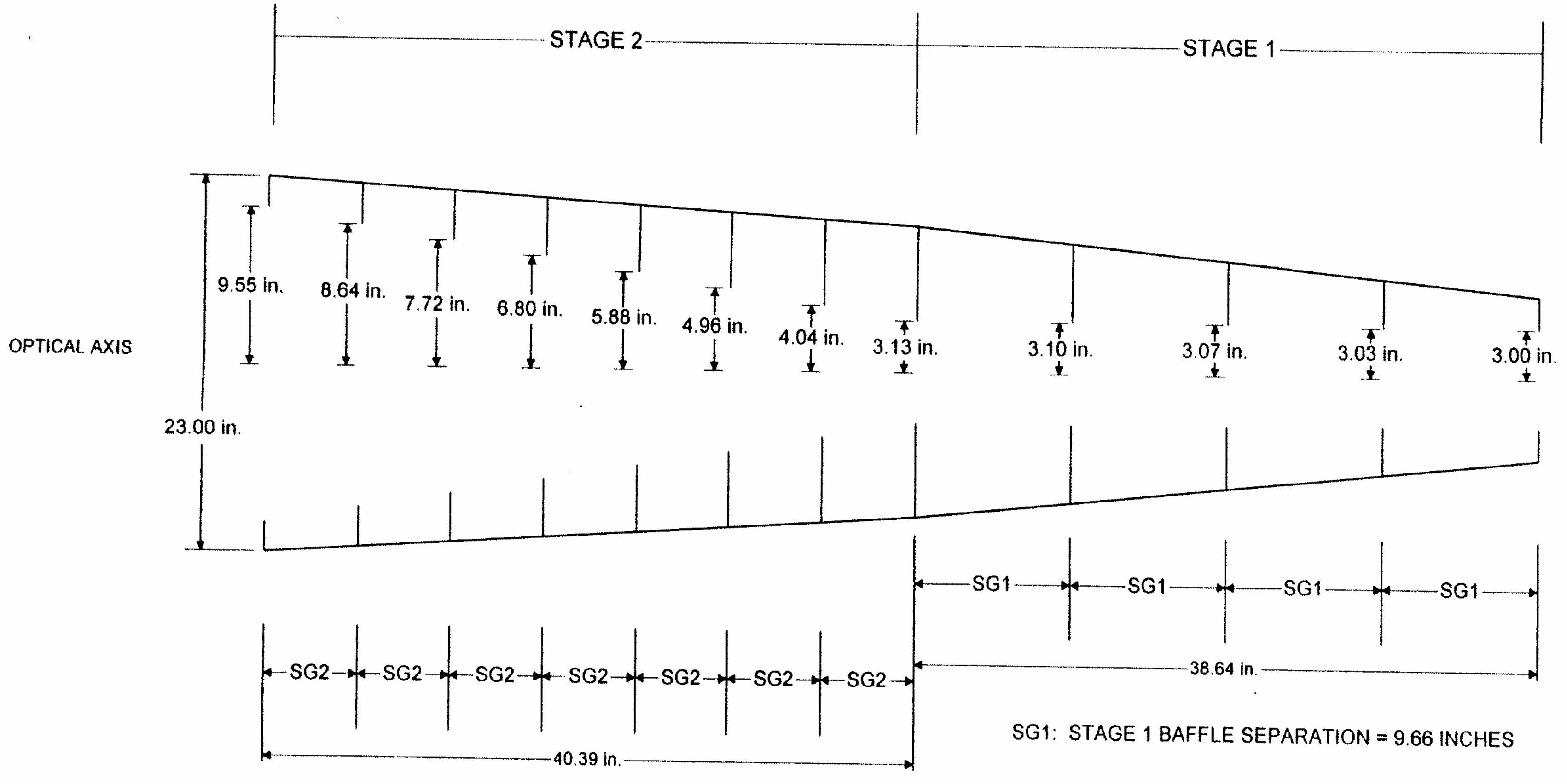
Characterization of existing actuator. (Cont'd)

- ♦ Some form of feedback control may be possible.
  - • Testing will evaluate the feasibility of using back-emf of motor as control feedback.
    - – Signal may be too small due to low rate.
    - – Signal may have too much variability over temperature.
- ♦ There is confidence that the engineering, lab testing, and trade studies will result in meeting the requirements.

Sunshade Assembly

Preliminary Stray Light Analysis Results

Sunshade Layout



SG1: STAGE 1 BAFFLE SEPARATION = 9.66 INCHES

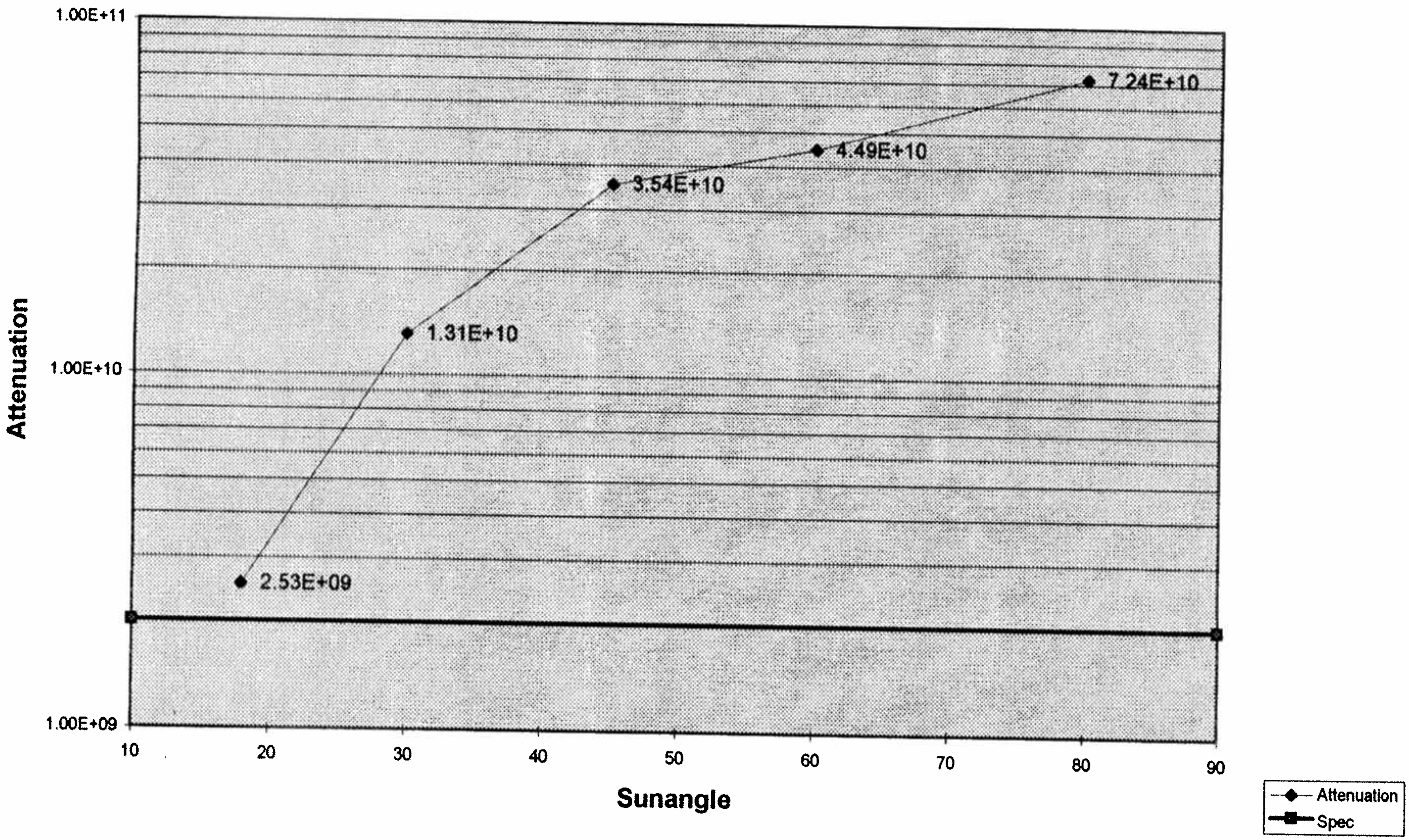
SG2: STAGE 2 BAFFLE SEPARATION = 5.77 INCHES

SCALE: 1 inch = 10 inches

DESIGN PARAMETERS

- Overall Length: 78.97 inches
- Entrance Port Radius: 9.545 inches
- Exit Port Radius: 3.000 inches
- Critical Baffle Radius: 3.134 inches
- Field of View (Half Angle):
  - Specified FOV: 2 arcminutes
  - Boresite error allowance: 10 arcminutes
  - FOV used in design: 12 arcminutes or 0.2 degrees
- Edge Radius: 0.005 inches
- Paint: Flat Black, Z306
- Critical Sunangle: 18 degrees
- Wavelength Range: 0.44 microns to 5.0 microns

Sunshade Attenuation vs. Sunangle



Planned Activities

- BRDF, ESDF Measurements for wavelengths up to 5 microns
  - Submit RFQ to vendor
  - Manufacture sample coupons
    - Edge scatter
      - Bare aluminum
      - Painted edge using flat black Z306
    - Surface scatter of flat black Z306
  - Scatter measurements performed
  - Update APART program with scatter measurement data
- Perform Stray Light Analysis using measured scatter data to obtain final results

Flight Hardware Verification Tests

- Sunshade tests (protoqual levels on flight unit)
  - Thermal cycle completed sunshade in thermal vac chamber
  - Vacuum bakeout
- Shutter
  - Flight unit gets 160,000 cycle life test, refurbishment, then 10,000 cycle burn-in test in thermal-vac chamber
  - Thermal cycle during burn-in test
  - Vacuum bakeout during burn-in test
- Sunshade Assembly
  - Modal test (0.5g sine sweep)
  - Vibration test (protoflight level, 11.2g RMS at shutter flange)
  - Mass properties test
  - EMI attenuation test

RR & PDR Action Items & Issues

- Requirement Review Action Items & Issues
  - AI35: Must add shutter power consumption to budget - Added
  - AI62: Define EMI requirements -- Process ongoing, covered in EMI section
  - AI70: Define allowable shock & torque of shutter -- (analysis results incorporated into Sunshade Assembly specification 5835073)
- Preliminary Design Review Action Items & Issues
  - AI02: Assess feasibility of having separate sunshade and shutter so sunshade could be lengthened or shortened if req'd -- Complete, units are separable but are being procured as an assembly
  - AI21: Verify EMI performance of sunshade -- Covered in EMI section

Summary

- Design is based on existing flight-qualified hardware
- Design utilizes available length within Delta II composite fairing
- Design provides excellent mechanical and optical performance
- AlliedSignal is currently performing additional analyses and development tests
- Conceptual Design Review 26 April 1995

Windows

Frank Chilese

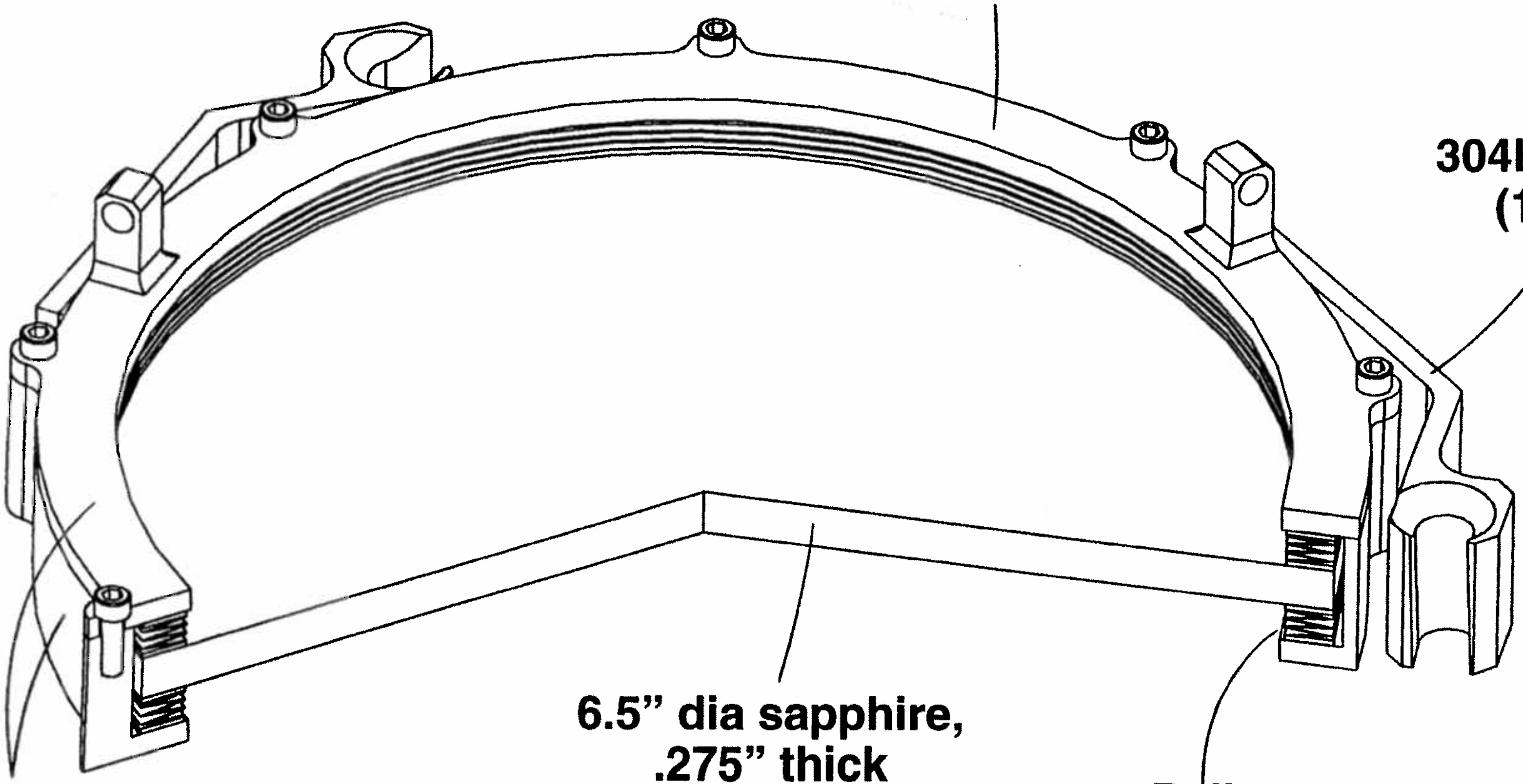
Agenda

- Design description - Windows 1-3
- Design description - Window 4
- Performance & requirements
- Analyses and development tests
- RR & PDR action items
- Flight hardware verification tests

Design Description -- Windows 1- 3

- Tilt angle increased from 1° to 2° for ghost image reduction
  - Sunshade critical baffle shadows any stars which could cause problem ghost images
- Substrate changed from calcium fluoride to sapphire
  - Need even number of sapphire windows to compensate for birefringence effects
  - All four window substrates cut from single crystal
  - Substrates polished in groups of four
  - Wedge angles mounted in opposition to minimize effect
- Substrate retained by low-force springs within copper ring
- Substrate located by two annular springs and one circumferential spring
- Stainless steel flexures between ring and heat station ring for compliance and thermal standoff
- New coatings are required to accommodate all candidate guide stars & substrate material

Design Layout -- Windows 1-3



Heater & sensor mount here

304L flexure (1 of 3)

6.5” dia sapphire, .275” thick

Bellows (1 of 2)

Copper rings, gold plated

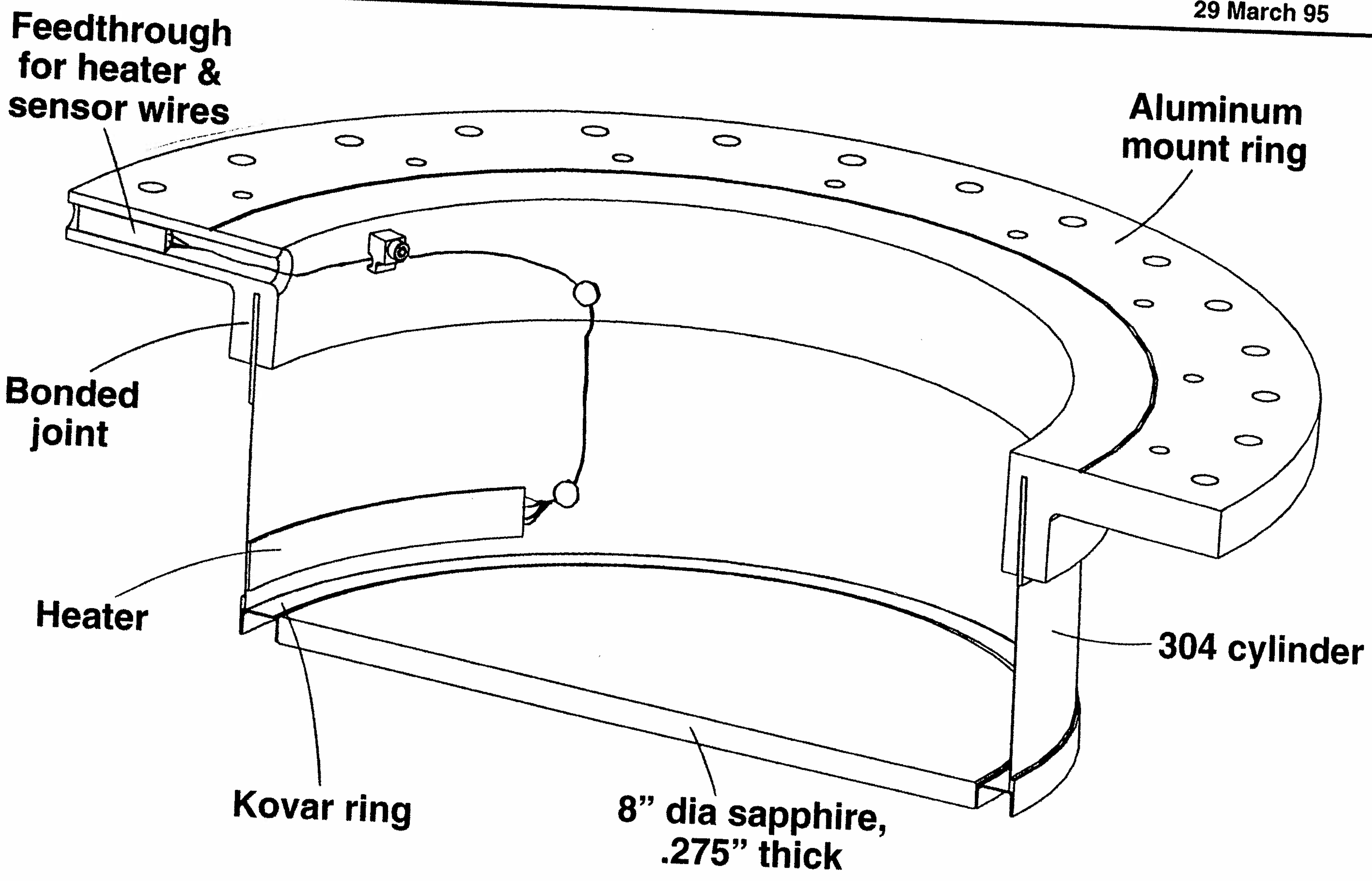
Design Description -- Window 4

- Window 4 not produced for Probe-B
- Design updated as further analysis & test performed
  - Earlier concept using calcium fluoride proved unproducible
  - Sapphire reduces fluorescence by a factor of 10 (S/N ratio now 10,000)
  - Sapphire substrate meets thermal gradient-induced pointing error rqmt (CaF_2 may not have)
- Sapphire substrate brazed to an kovar ring
- Kovar ring welded to stainless steel cylinder for thermal & structural compliance
- Substrate tilted 2° for ghost image reduction
- Mechanical factors of safety
  - Substrate: FS > 10
  - Mount: FS > 4
- Heater added to cylinder to heat substrate to reduce condensation

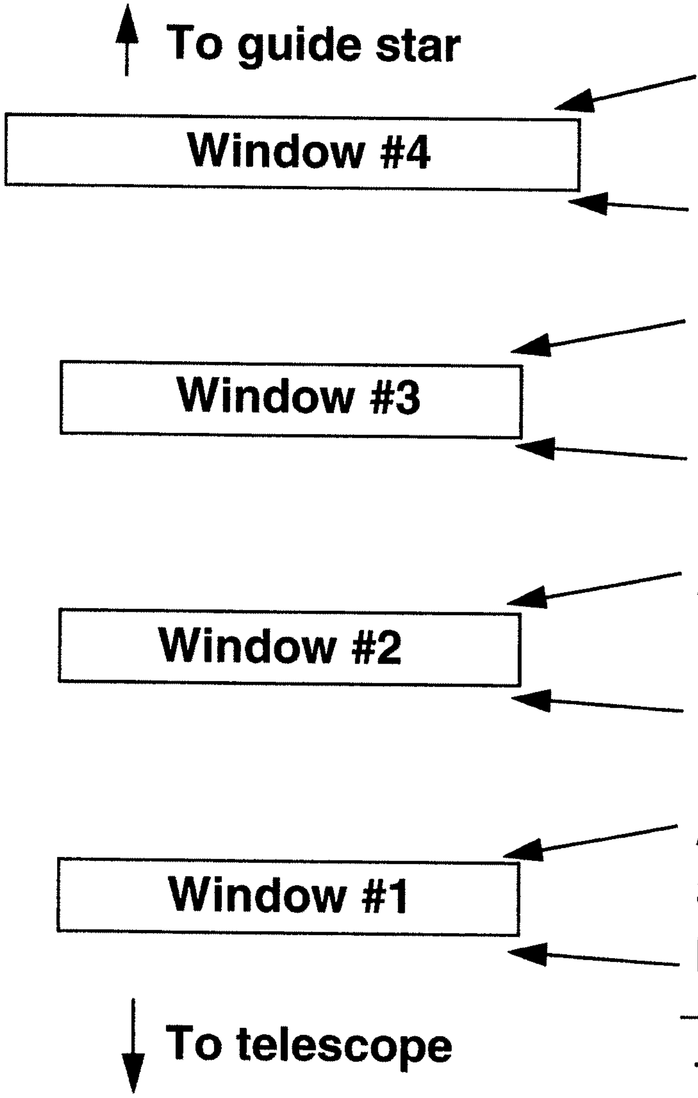
GPB-100417

Design Layout -- Window 4

STANFORD
Lockheed
Probe-C CDR
29 March 95



Window 1-4 Transmission Budget



AR	.97	
Sapphire	.99	(W#4 = .67)
EMI / IR rejection	.70	
AR	.97	
Sapphire	.99	(W#3 = .82)
Low-e	.85	
AR	.97	
Sapphire	.99	(W#2 = .82)
Low-e	.85	
AR	.97	
Sapphire	.99	(W#1 = .82)
Low-e	.85	
Total	.37	

Window Analyses & Development Tests

- Analyses

		date or ECD
– Window 1-3 launch loads	EM421	4/21/95
– Window 1-3 thermal gradients	EM422	4/28/95
– Window 1-3 thermo-optical errors	EM423	5/25/95
– Window 4 launch loads	EM426	4/14/95
– Window 4 thermal gradient analysis	EM424	4/5/95
– Window 4 thermo-optical errors	EM425	4/21/95

- Development Tests
  - Window 1-3 optical & vibration
  - Window 4 subscale build, shake, leak
  - Window 4 Probe-B qualification tests

Window 4 Development Testing

- Primary open issues are method of sealing substrate and optical effects of sealing method
- Five half-scale sapphire substrates have been ordered
- Half-scale windows will be built using three different sealing methods:
  - Brazing to a kovar ring
  - Bonding using special ceramic adhesives
  - Clamped between two metal seals
- Each half-scale window will be
  - thermally cycled
  - leak tested
  - vibrated to launch loads (warm)
- Flight window design will be finalized after developement tests are complete

Window RR & PDR Action Items & Issues

- Requirement Review Action Items & Issues
  - #41: Fluorescence of window 4 may overwhelm guide star -- Change to sapphire increases S/N ratio to > 10,000 over SAA (EM420)
  - #42: Window 4 vacuum seal may not be producible -- Changed to more conventional approach, demonstrate with development testing
  - #44: Grounding requirements for window 4 not consistent with EMI requirements -- Grounding requirement being deleted; only EMI filtration is critical, spec change is ongoing

- Preliminary Design Review Action Items & Issues
  - #13: Condensibles on window 4 may cause optical problems -- Heater added to window 4 mount ring, CCB meeting is required
  - #14: Has coating life been analyzed? -- Life tests added to substrate coating subcontract, previous test data being analyzed
  - #19: Ensure vacuum seal possible on outside of window 4 to allow star simulator attachment -- New design for mount is compatible with external vacuum seal

Flight Window Verification Tests

- Windows 1-3
  - Thermal cycle each window to LN2 temperature (10 cycles)
  - Optical throughput of coated substrate
  - Wavefront error (each surface and transmission)
  - Heater and thermal sensors' performance verification

- Window 4
  - Thermal cycle to operating temperature (10 cycles)
  - Optical throughput of coated substrate
  - Wavefront error (each surface and transmission)
  - Heater and thermal sensors' performance verification
  - Leak test to verify seal integrity
  - Proof pressure test to 4 atm pressure difference

Window Summary

- Windows 1-3 are similar to those in probe-B except
  - substrate is now sapphire
  - mount ring tilts substrate slightly more
  - different coatings due to different guide star
- Window 4 design based on more conventional sealing techniques
- Development testing will validate Window 4 design prior to build of flight window

Overall Temperature Sensors and Heaters

Paul Dineen

Temperature Sensors and Heaters

- Probe-C versus Probe-B highlights
  - New functions
    - » Add heaters and temperature sensors to window 4 design
    - » Increase windows 1,2 and 3 bakeout temperatures
  - Analysis
    - » Compare results of Probe-B GTU-1 testing with analytical model
    - » Determine window 4 heater power
    - » Update windows 1,2 and 3 heater analysis
    - » Review spin-up heater power for increased gas flow rate of 2.8mg/s
  - Design and construction
    - » Optimize layout of heater element to reduce generation of EMI
    - » Replace epoxy which strain relieves the germanium resistance thermometer and silicon diode wires with non-magnetic epoxy
  - Qualification testing
    - » Qualification shake test of heaters and temperatures sensors during window shake test
  - Vendor calibration and acceptance testing, LMSC acceptance testing, installation and post-installation testing
    - » Same as Probe-B

Thermal Control Functions

- New Probe-C functions
  - – Window 4 temperature control (PCB 160 pending)
    - » Heat window 4 to 270 K within 20 minutes
- Revised Probe-C functions
  - – Window 1,2 and 3 bakeout temperatures increased (PCB 160 pending)
    - » Heat window 1 to 60 K within 20 minutes (was 40K) 60
    - » Heat window 2 to 95 K within 20 minutes (was 90K) 100
    - » Heat window 3 to 220 K within 20 minutes (was 170K) 200
- Unchanged functions from Probe-B
  - – Temperature control of the quartz block interface
    - » Temperature of QBS fingers shall be stable to ±0.001 K rms when interface temperature is under active control
  - – Flux flushing
    - » Raise temperature of SIA to ≥ 16K in ≤ 4 hrs by heating QBS without raising lead bag temperature above 6.5K. Then cool SIA down over a period of ≤ 8 hrs
  - – Low temperature bakeout
    - » Heat ≥ 90 percent of internal surfaces which operate at < 6k to temperature ≥ 6K

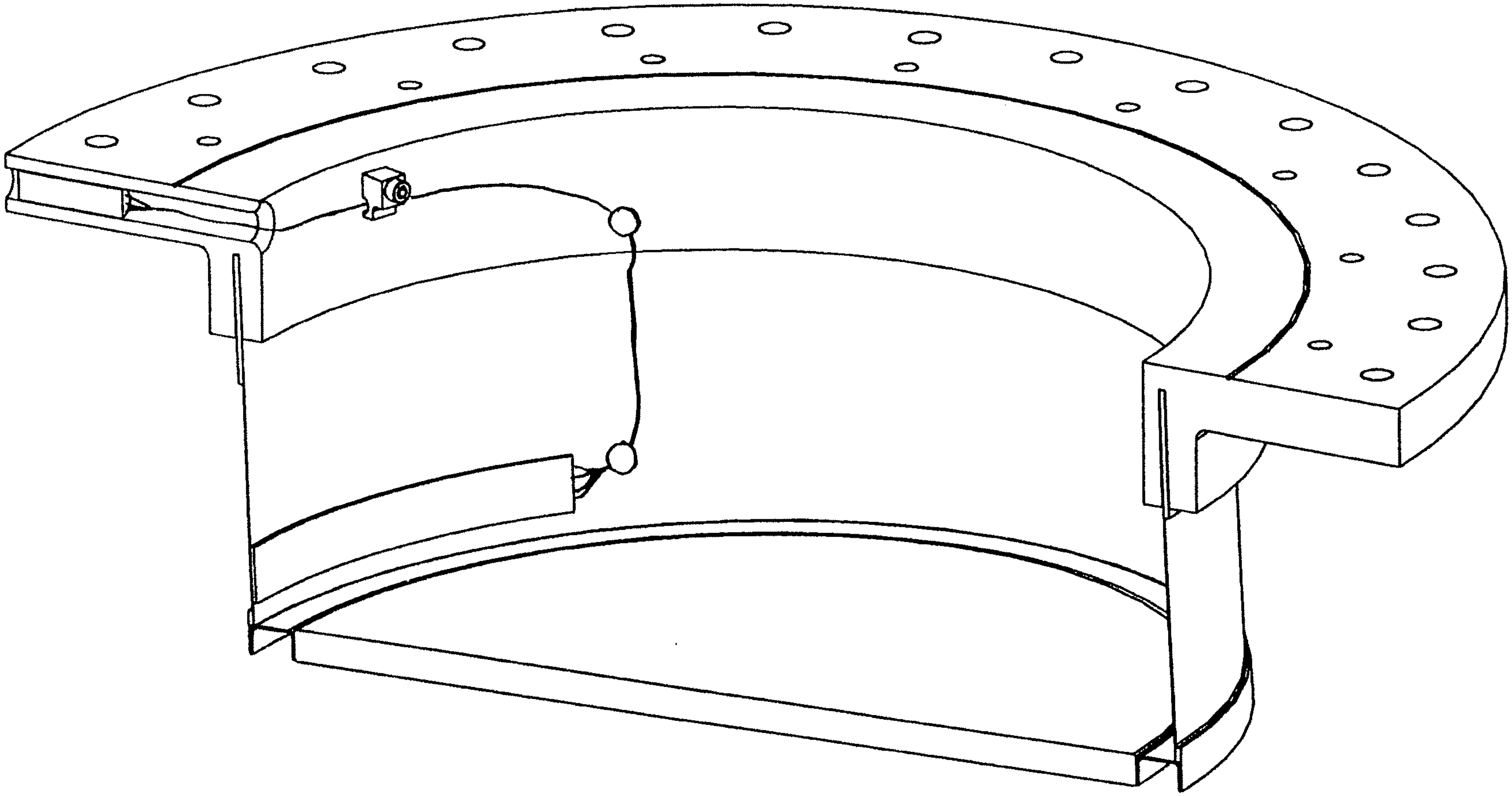
Thermal Control Functions

- Unchanged functions from Probe-B cont.
  - Gyro spin-up
    - » Heat spin-up filters to ≥ 10K
    - » Temperature of spin-up gas at inlet interface shall be adjustable over the range of 5-12K and stable to +/- 0.25K
    - » Heat spin-up exhaust lines to ≥6K
  - Monitor critical thermal links to Dewar
    - » Science payload shall have an orbital operating lifetime of ≥ 16.5 months after initiation of launch
  - Heat pressure sense line
    - » Heat entire length of pressure sense line to ≥ 6K under all operating condition
  - Monitor cooldown of Probe/SIA during insertion into Dewar
  - Monitor probe top hat position during probe insertion into Dewar to prevent damage to neck tube

- Science Instrument Assembly functions
  - Monitor telescope and quartz block temperatures
  - Temperature control of the SQUID mounting platform
  - SQUID loop heaters

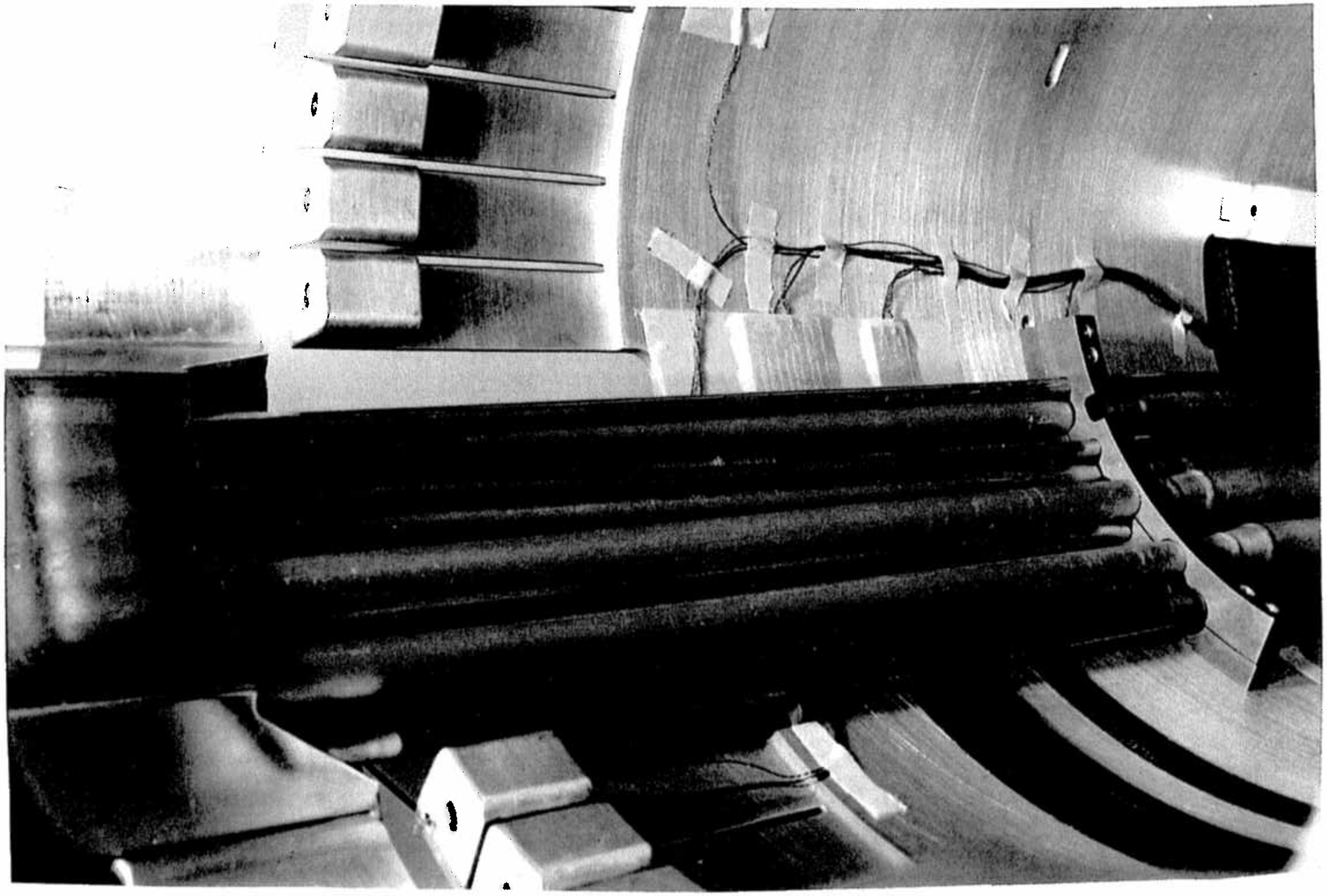
Window 4 Mounting Locations

- Heater mounting concept



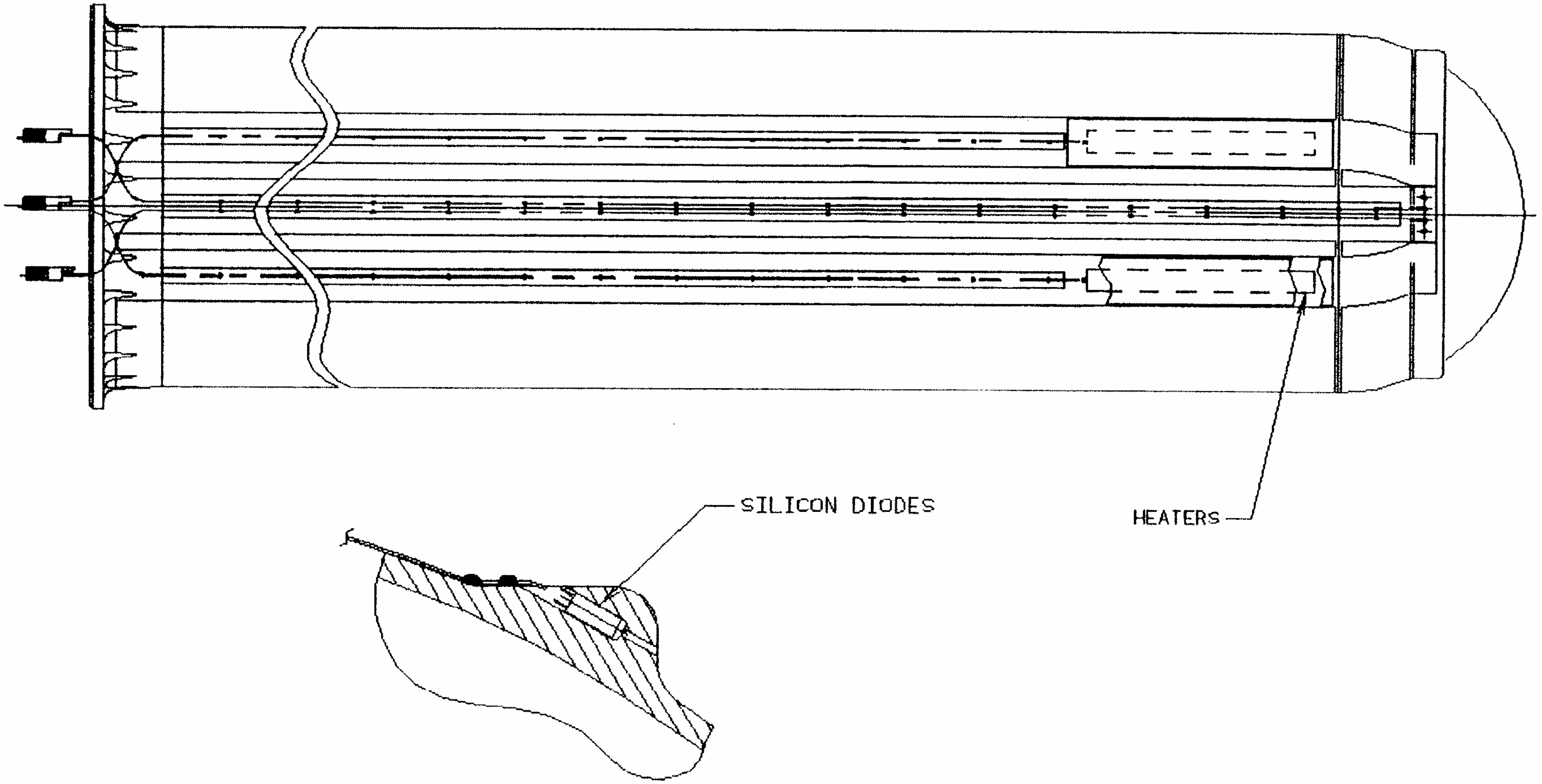
Quartz Block Support Mounting Locations

- Heater and temperature sensor wire routing



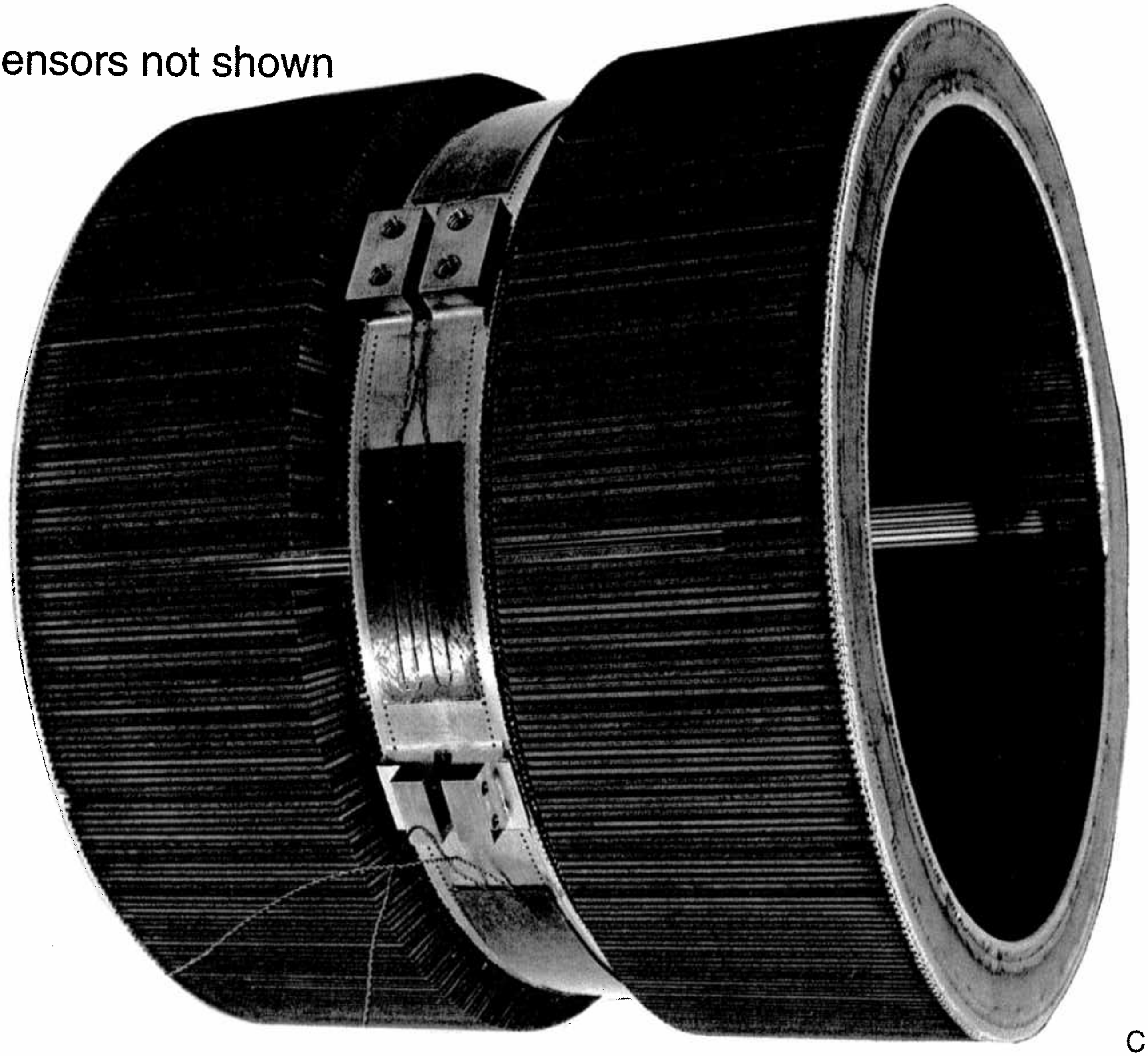
Vacuum Shell Mounting Locations

- Vacuum shell assembly drawing sketch



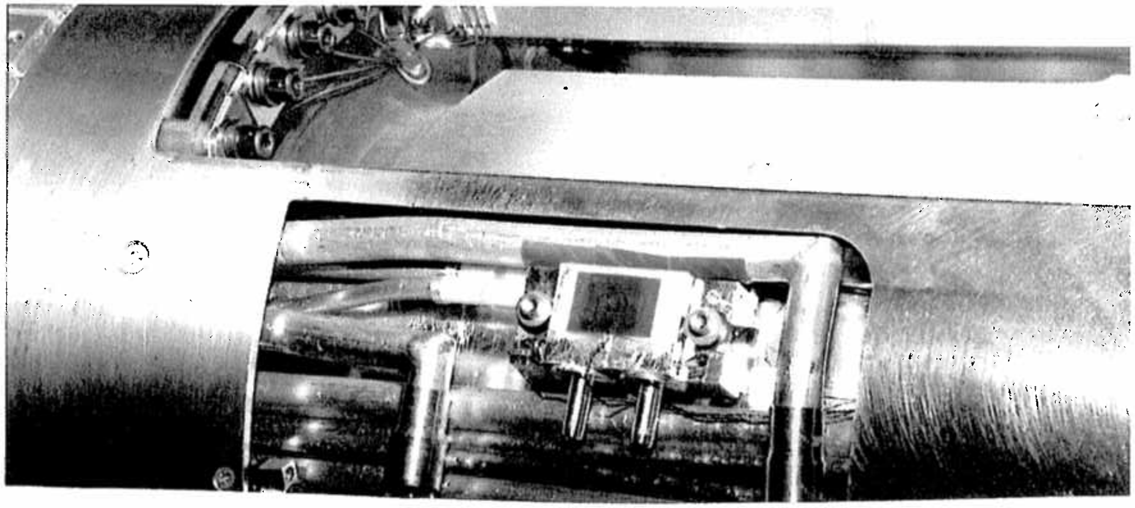
Cryopump Mounting Locations

- Temperature sensors not shown



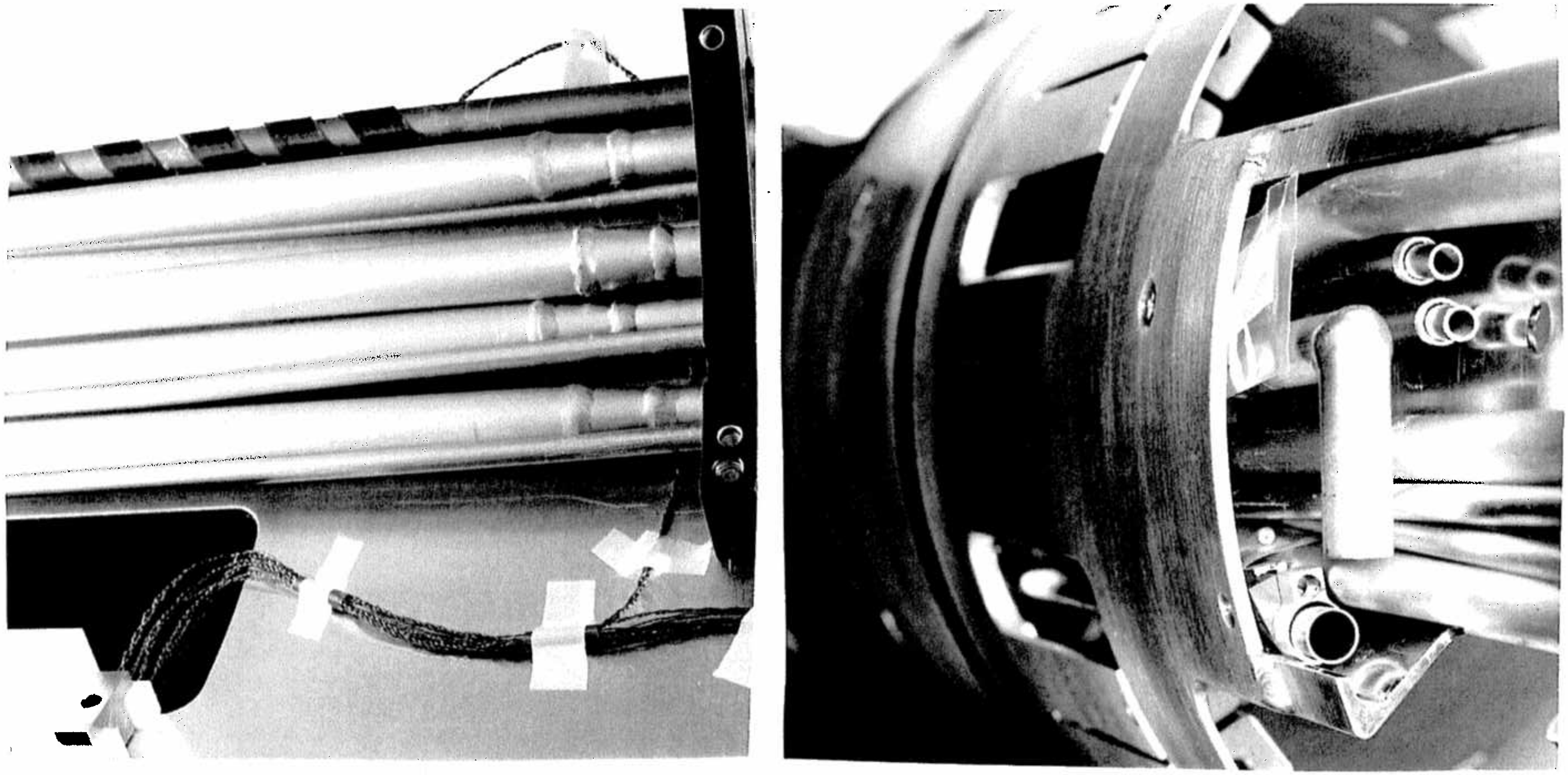
Spin-up Filter Mounting Locations

- Photo of installed spin-up filter assembly



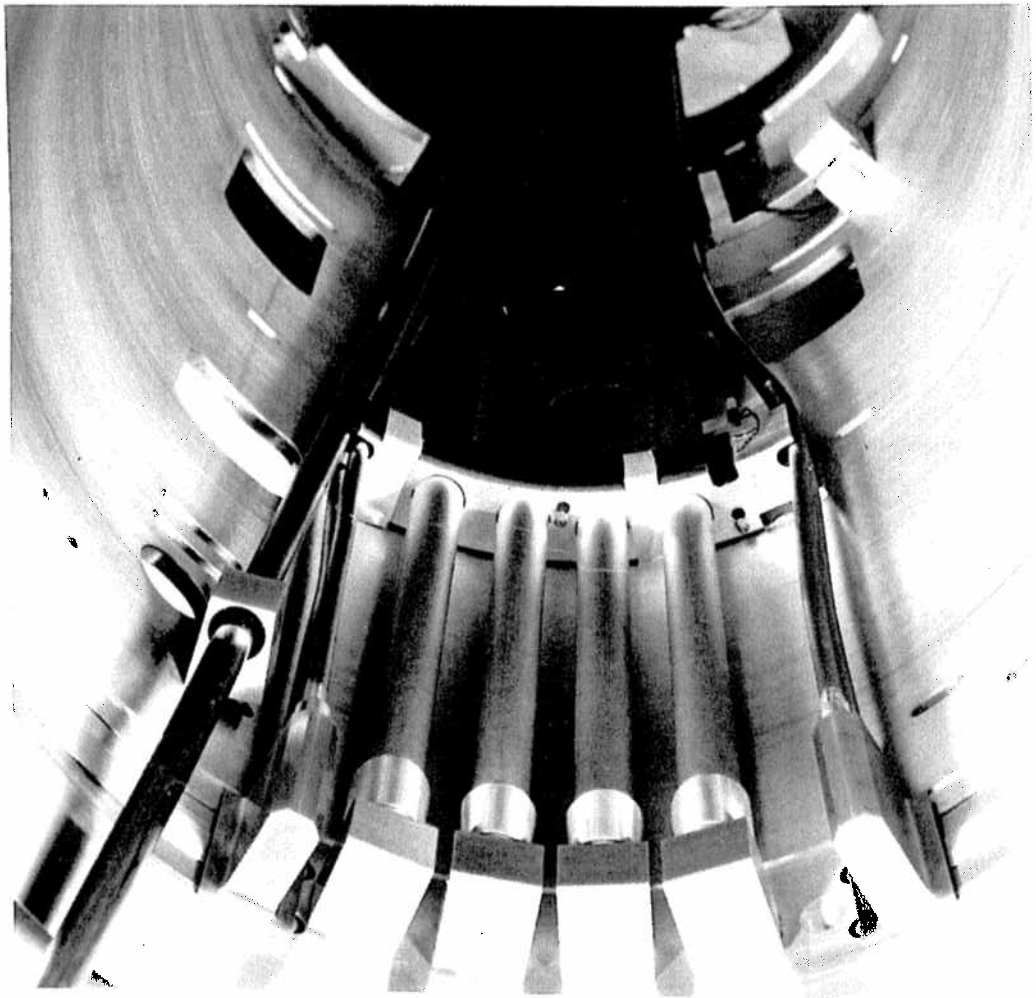
Pressure Sense Line Mounting Locations

- Heater and silicon diode wire routing



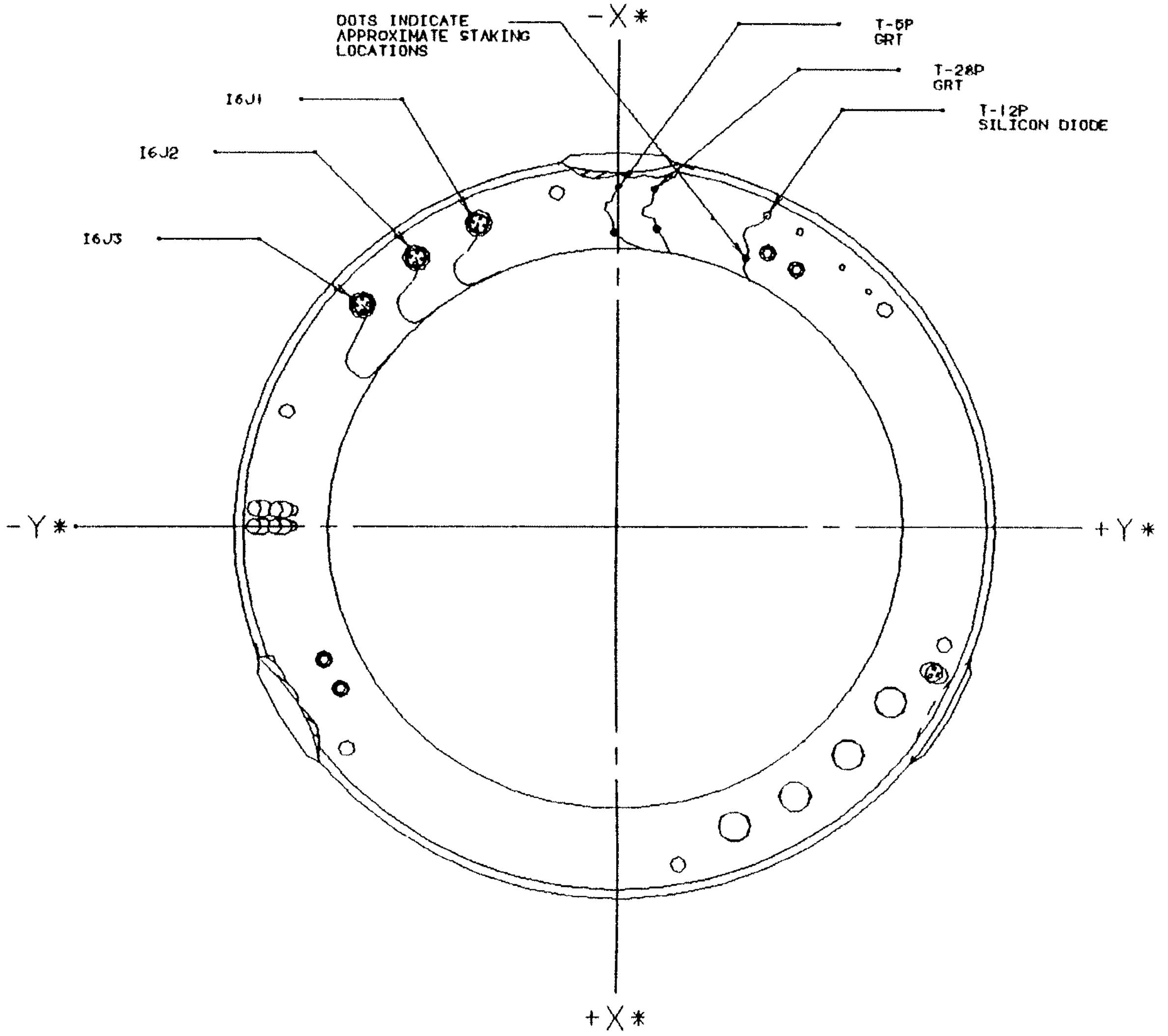
Plumbing Saddle Mounting Locations

- Heater and silicon diode wire routing



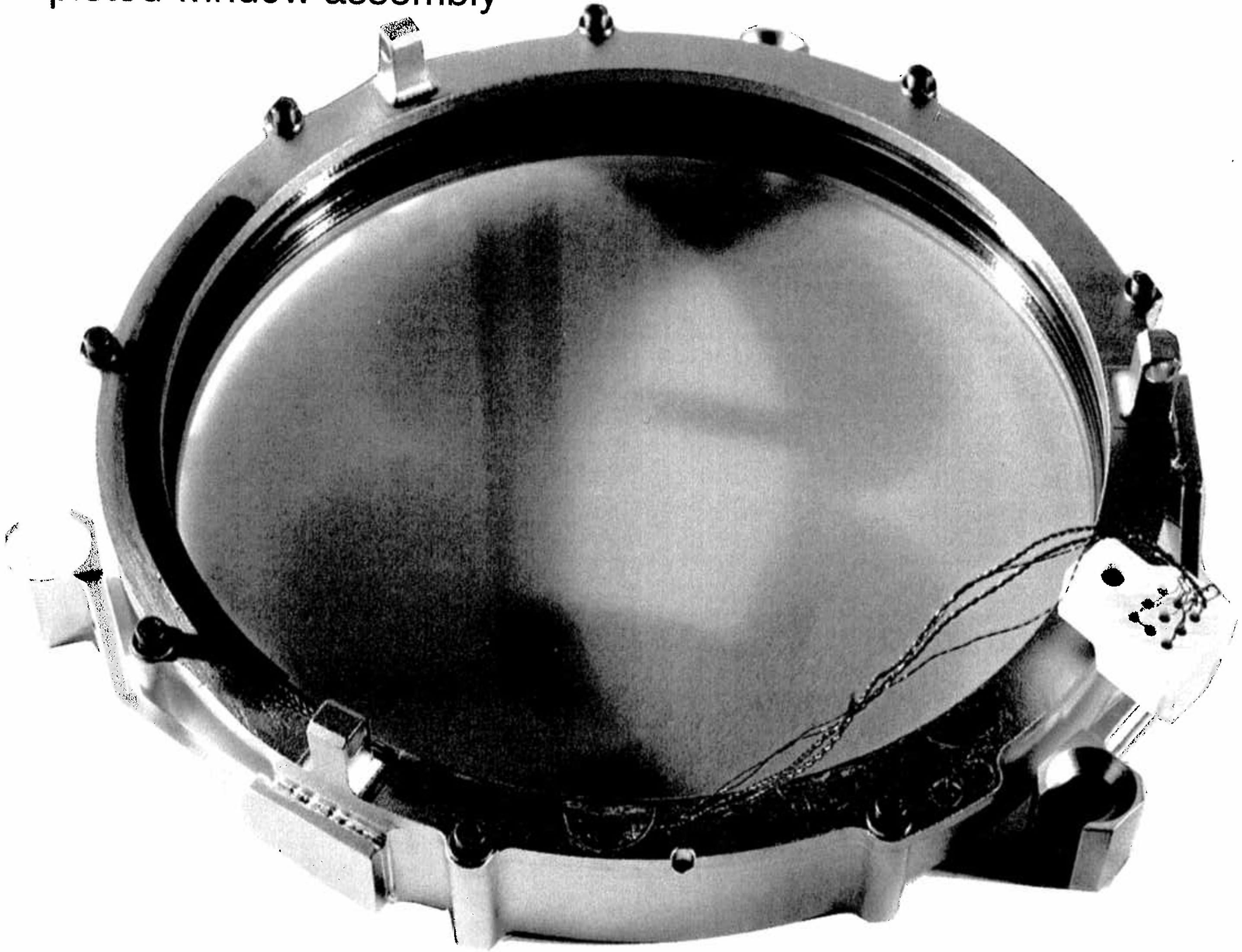
Sta 200* Mounting Locations

- Installation drawing section view



Window 1-3 Mounting Locations

- Completed window assembly



Design and Construction

- Silicon diodes and germanium resistance thermometers
  - Sensors fail zone 2B remanent moment magnetic requirements
    - Replace epoxy that strain reliefs wire with Stycast 1266
    - Change was made on Stanford's GTU-1 temperature sensors
    - Probe C drawing updated to reflect new epoxy

- Heaters
  - Heaters generate EMI when operated
    - Bifilar layout of heater elements on Probe B did not completely cancel EMI
    - Heater element is .0015" diameter coated platinum tungsten coiled wire
    - Usage of coiled wire required to obtain high thermal impedance and reduce current
    - Difficult to cancel field using coiled wire
    - Development tests in process to identify problem areas and minimize EMI.
    - Probe C heater drawings to be revised to effect necessary changes

Summary

- Heater and temperature sensor design changes to existing Probe-B design identified
- Probe-C design changes do not impact Probe-C fabrication and assembly

External Plumbing

Eric Will

Agenda

- Design description
- Design Improvements
- Analyses and development tests
- Flight hardware verification tests
- Summary

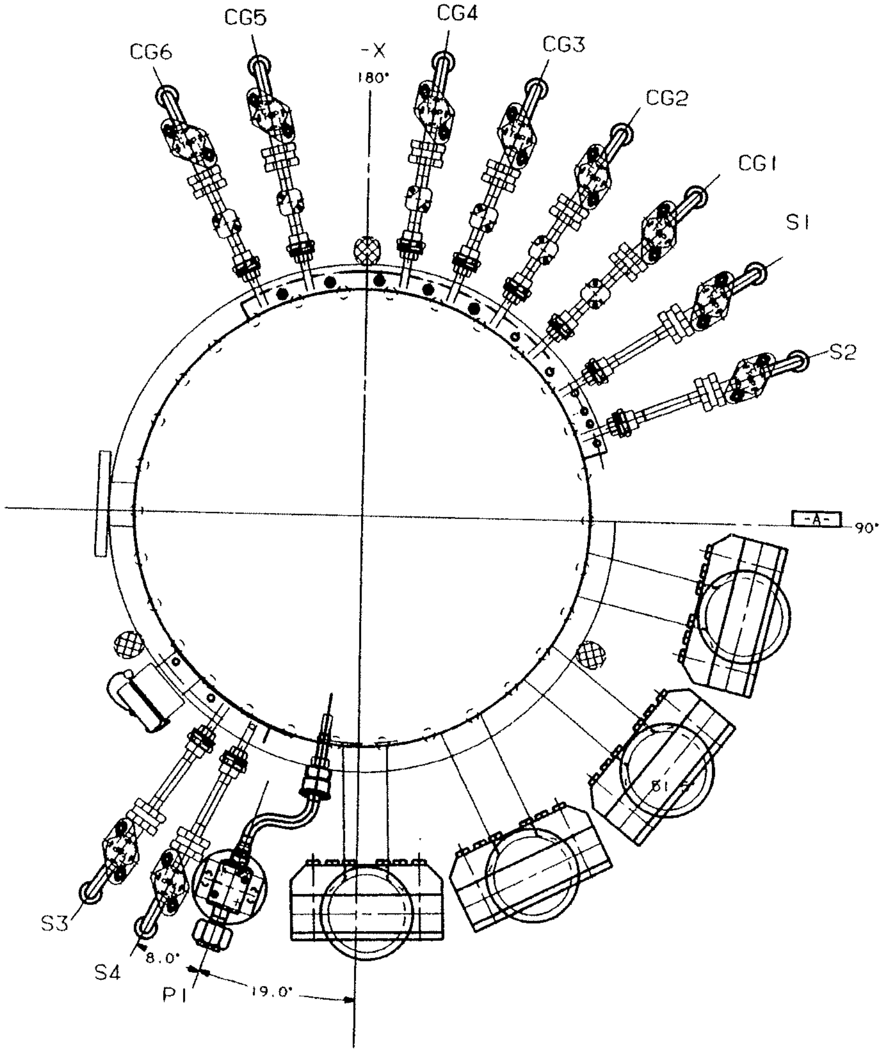
Plumbing Design Description

- Primary function is to provide plumbing connections external to the Probe at the Top Hat.
  - Includes spin-up, caging and pressure sense plumbing.
  - Provides manual shutoff valves and external connections to the GMA.

- Individual valve assemblies extend radially outward from the Top Hat portion of Probe
  - Caging assembly contains pressure relief for safety.
  - Standard off-the-shelf shut-off valves and connections are used.
  - Caging assembly provides 2 micron filter.

- Leak tight shutoff capabilities to 5 E-9 scc/s He.
- Clear access for GMA connection.
- Positive verification of open valve condition prior to launch.

Plumbing Layout



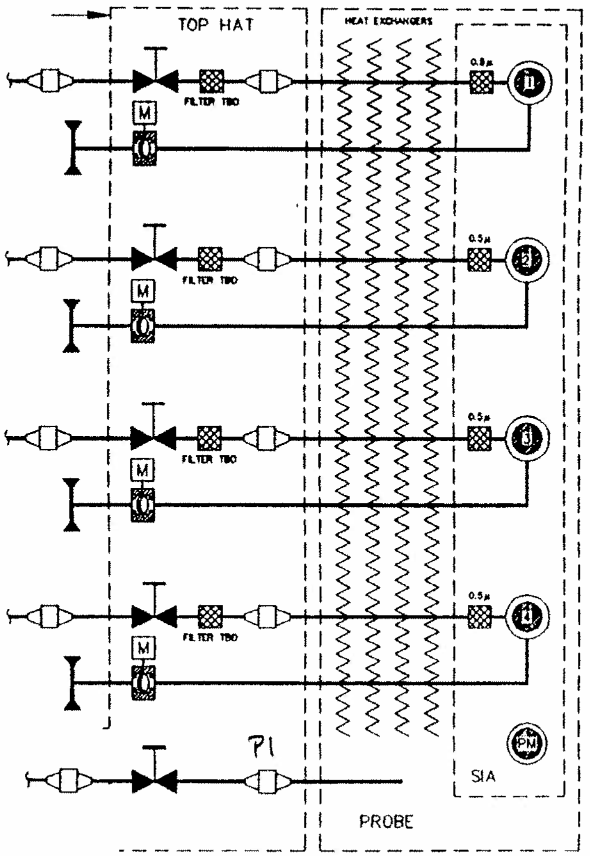
GPB-100417

External Plumbing Schematic

STANFORD
Lockheed
Probe-C CDR
29 March 95

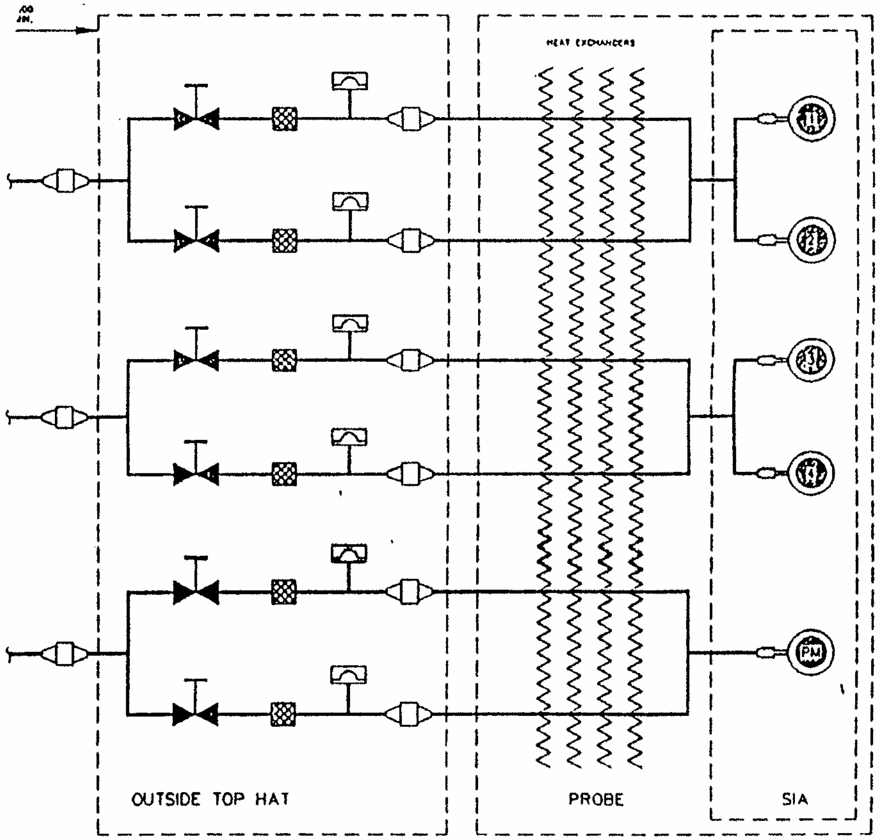
Spin-up Plumbing

External / Internal



Caging Plumbing

External / Internal



Plumbing Improvements for Probe-C

- Refined mounting supports.
  - Goal is to reduce weight and size with minimum changes, while maintaining structural integrity.
  - Accomodate misalignments and provide ease of access during dewar integration activities.
- Redesign caging pressure relief protection to allow easier replacement and proof testing.
- Improve verification of burst disk set point.
- Changed from brass body valve to more durable SS valve with stellite seat (PCB 95).

Plumbing Improvements for Probe-C

- Develop special weld fixturing to maintain consistent alignment of external plumbing components.
- Other changes for Probe-C. These changes affect GMA interface locations for Probe-B retrofit.
  - Interface location rerouted toward dewar to ease plumbing line connections from GMA.
- Other changes for Probe-C. These changes affect GMA interface locations for Probe-B retrofit.
  - Interface location rerouted toward dewar to ease plumbing line connections from GMA.

Plumbing Analysis

- Structural Analysis

  - Perform structural analysis to optimize mounting support. Goal is to improve accessibility and reduce weight and size of existing support plate.

Plumbing
Flight Verification Tests

- Probe-B vibration tests will proto-qualify by similarity to Probe-B design.
- The plumbing will be shaken as an installed assembly during Probe-C vibration test.
- The plumbing will undergo the following tests as acceptance tests:
  - Leak test - verifies ability to meet overall vacuum requirement.
  - Vacuum bakeout - improves ability to meet overall vacuum requirement.
  - Proof pressure test (caging only) - verifies weld and design integrity.

Plumbing Summary

- Minor changes from Probe-B.
- Provides easier GMA plumbing connection and routing.
- Improved access and structural support.

RR & PDR Action Items & Issues

- PDR
  - AI#105: Add backfill line to spinup system.
    - » Resolution: Stanford to provide spin-down capability by including by utilizing existing pressure sense plumbing.
- RR
  - AI#80: Define specification of acceptable pinhole size in CNT foil liner.
    - » Resolution: Aggregate pinhole size shall be ≤ .150 diameter to meet permeation goal of 1EE-9 scc/s He outgassing from neck tube region. Recommend a workmanship requirement of 10 pinholes of .015 diameter. Impact on EMI shielding is ?
  - AI#67: Evaluate need for a sunshade on each 6” exhaust valve.
    - » Resolution: Sunshade needed to keep excess light from reaching telescope if valve fails open. Unresolved issue whether valve failure is considered probable. (EM # xx)

Cross Flange

Eric Will

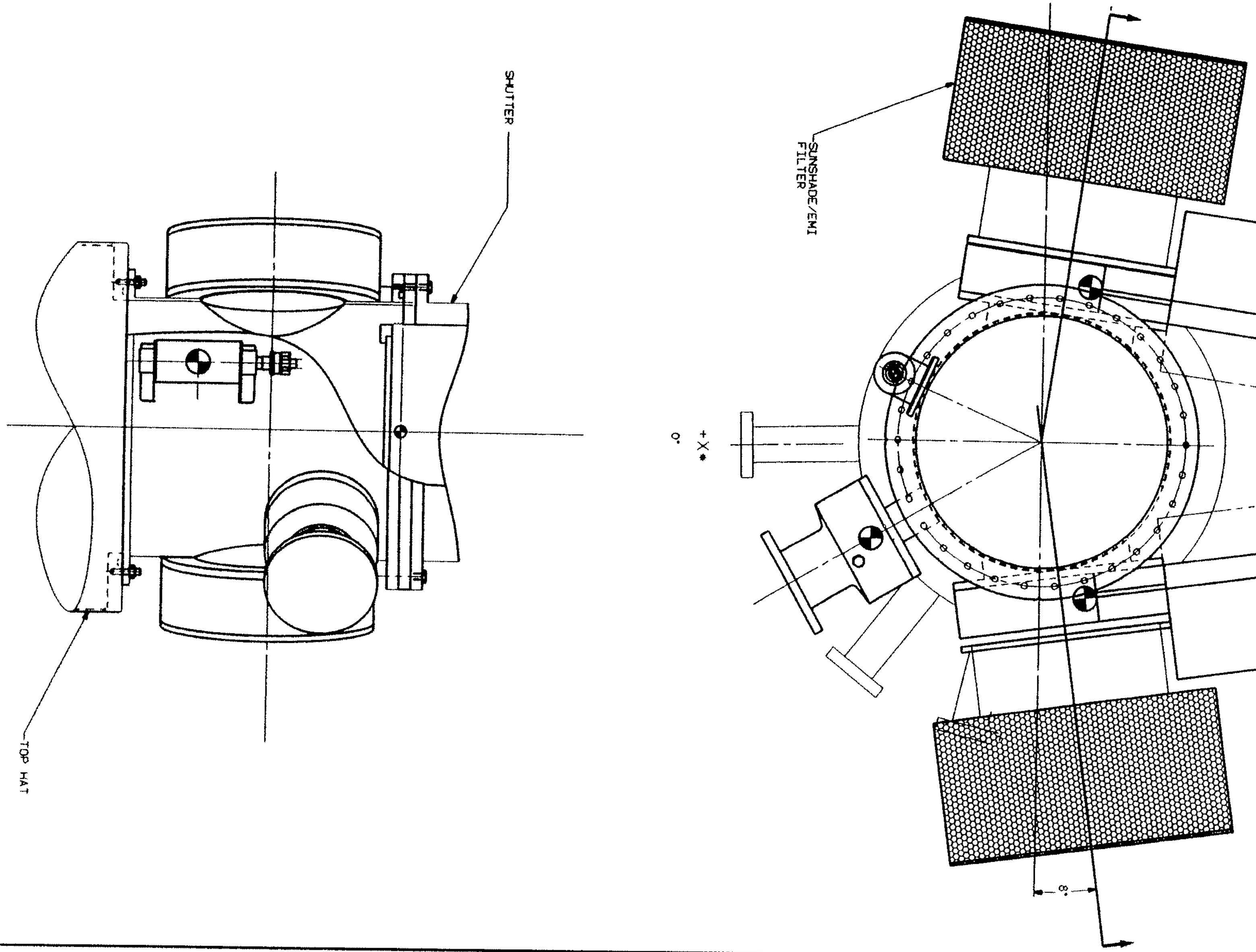
Agenda

- Design function
- Functional Requirements
- Analyses
- Flight hardware verification tests
- RR & PDR action items

Cross Flange
Design Description

- Vacuum chamber extending beyond Top Hat portion of Probe
  - Provides structural support for probe exhaust valves, burst disk, window 4, sunshade and shutter.
- Provides clear aperture opening for telescope.
- Twin 6” Vatterfly valves provide flow conductance path to vent probe (PCB 151).
- A special shield will protect the interior of the probe in case an exhaust valve fails open.
  - Stray light protection to avoid blinding the telescope.
  - EMI shielding to prevent interfence with Squid readout data.
  - Debris filtering during launch.

Cross Flange Layout



Cross Flange
Functional Requirements

- New requirement to provide mounting for twin 6” gate valves (PCB 151).
  - Adds redundancy to prevent single point failure.
  - A single valve able to provide sufficient flow conductance.
- New mounting configuration for vacuum sensors.
  - Change standard conflat connections to ones compatible with alumimun welding.
  - Provide custom mounting support for “P8 and P9” pressure sensors.
- New requirement to provide shielding from EMI, light, and debris.
- Existing requirement for window 4 mounting support.
  - Must maintain accurate window alignment within .1° degrees.
- Existing requirement to hold sunshade in alignment with the Top Hat.

Cross Flange Analyses

- Structural Analysis
  - Perform structural analysis using CRES as baseline material.
  - Use latest secondary launch loads.
- Weight reduction trade study. (EM GPB-100434)
  - Weight savings of 18 lbs. by using aluminum. No loss in structural performance.
  - No manufacturing or packaging limitations from using aluminum.
  - Detailed results presented in Structural Analysis section.
- Flow conductance analysis.
  - Results show a single 6” exhaust valve meets overall pressure drop requirement. System is fully redundant. (GPB-100244)

Cross Flange
Flight Verification Tests

- The cross flange will undergo the following acceptance tests:
    - Leak test - verifies ability to meet overall vacuum requirement.
    - Vacuum bakeout - improves ability to meet overall vacuum requirement.
    - Proof pressure test - verifies weld and design integrity.
- It will be shaken as an installed assembly during Probe-C vibration test.

Cross Flange Summary

- Structural analyses completed.
- Overall design is optimized for structural performance and weight savings.
- Overall weight reduced 18 lbs. by using aluminum instead of CRES.
- Provides mounting for twin side-mounted 6” exhaust valves.
- Provides mounting for all required pressure sense connections.
- Provides mounting for probe burst disc/relief valve.

Safety

Jim Regimbal

Environmental Safety

- No uncontrolled environmental risk is posed by Probe-C development.
- All Probe-C effort is being conducted under LMSC rules and regulations, which are in compliance with applicable OSHA and EPA rules.
- Environmental safety awareness is carried over to Probe-C development through continuity of Probe-B/C personnel (REE, designers, analysts, technicians) and operations.

Personnel Safety

- Personnel hazard categories for Probe-C development are the same as those for Probe-B.
  - Collision during hardware handling operations
  - Exposure/contact during operations involving liquid helium
  - Electrical shock/burn during test operations
  - Release of hazardous/toxic materials
  - Impact as a consequence of inadvertent overpressure events
  - Compression/crushing resulting from inadvertent mechanisn actuation
- Safety evaluation is conducted to establish that identified personnel injury hazards are controlled by Probe-C design, auxilliary features or planned procedures. Use of preferred order of precedence (e.g. design vs. procedures) is reviewed.
- Personnel safety adequacy of Probe-C design/operating procedures also will be developed and verified through Probe-B testing and implementation of “lessons learned” at Stanford (GTU-1, GTU-2).
- Probe-C personnel risks (estimated to be low) are reduced by carry-over of experience from Probe-B design and operations.

Probe-C Design Safety

- A Probe-C Critical-Design-level hazard matrix (hazard categories vs. design elements) has been established.
- The Probe-C Safety Assessment Report (SAR) has been updated to a Critical Design level.
  - Structures, mechanisms, pressurized systems, relief systems
  - Thermal control systems, temperature conditioning equipment, materials
  - Electrical subsystems, power supplies, instm / control systems
  - Tooling, assembly, ground support equipment
  - Handling, transportation equipment
- Probe-B “lessons-learned” have been incorporated into Probe-C SAR updates.
- No uncontrolled Probe-C design hazards have been identified.

Operations Safety

- Probe-B operations at Stanford (GTU-1, GTU-2) qualify Probe-B as a backup flight unit (Probe-B “lessons learned” validly apply to the Probe-C flight unit operations).
  - Probe-B design qualification (configuration control, released drawings)
  - Probe-B integration / operations qualification (released procedures)
- Documented basis for Probe-C flight unit integration/operation safety certification is contained in applicable qualified (released) procedures.
- Probe-C operations/procedures reflect incremental changes to Probe-C and GSE design, and ongoing operations “lessons learned”.
  - Phased safety evaluation and qualification of procedures for Probe-C operations
  - Procedures carry-over from current Probe-B operations (GTU-1)
  - Carry-over from released procedures for Probe-B operations with flight dewar (GTU-2)
- Provisions for safety assurance (including safety monitoring) are mandatory in procedures for handling, transportation, assembly, integration and testing of Probe-C high-value hardware.

Reliability

Dick Maxwell

Agenda

- Reliability Approach
- Risk Evaluation Methodology
- Risk Evaluation Worst Case Examples

Reliability Approach

- Probe-C was divided into its major functional assemblies.
    - See the FMECA for the assembly list.
- Functional assembly failure modes were delineated.
- Worst possible effects were determined for each failure mode.
- Mil-Std-1629A was used as the FMECA model.

Risk Evaluation Methodology

- Assumed Probe-C passed assembly verifications and that qualification and thermal and vibration integration tests were successful.
- Component failure modes evaluated for relative probability of occurrence P(M).
  - A = 0.2; B = 0.1; C = 0.05; D = 0.005; E = 0.001
- Conditional probability (ß) was evaluated that worst postulated effect would happen, given the failure mode had occurred.
  - 1 = Actual loss (1.0) 2 = Probable loss (0,5);
  - 3 = Possible loss (0.005); 4 = No effect (0.0)

Risk Evaluation Methodology

- Failure modes evaluated for Mission Severity.
  - Sev 1 (1000) = Catastrophic: Loss of mission.
  - Sev 2 (100) = Critical: Major system damage prevents completion of experiment or invalidates science data.
  - Sev 3 (10) = Minor: Minor system damage.
  - Sev 4 (1) = Other: No system damage, but may result in unscheduled repair or maintenance.

Risk Evaluation Methodology

- Risk measured by Criticality (Cr) value, where Cr = P(M) x Beta x Sev.
  - Cr values normalized to $1 \leq Cr \leq 24$. See the Cr table in the FMECA.
  - $Cr \leq 7$ is unacceptable; $8 \leq Cr \leq 12$ is undesirable; $13 \leq Cr \leq 18$ is acceptable with a review; $Cr > 18$ is acceptable without a review.

- Based on the Mil-Std-1629A risk evaluation scheme, Probe-C failure mode Cr frequencies were as follows at this time:

• Unacceptable	0
• Undesirable	38
• Acceptable / review	51
• Acceptable / no review	9

Risk - Worst Case Examples

- $8 \leq Cr \leq 12$ examples.
  - Sunshade Assembly - on-orbit shutter position fails closed or partially open - damaged or inoperative mechanism.
  - Cross Flange Assembly - both valves fail closed - no power to actuator, actuator fails in closed position, or linkage jammed.
- Failure mode Cr values are expected to increase when ground tests are completed and evaluated.

Probe-C Critical Items

TOP 3 ON-ORBIT RISKS

			CRIT
Sunshade	Shutter fails closed or partially closed due to damaged or stuck mechanism	Probable loss of mission	10
Composite Neck Tube	Rupture or buckling during launch,	Loss of vacuum, loss of structural integrity, probable loss of mission	11
Spin-up exhaust valve	Fails closed, due to loss of power, failed motor, or jammed linkage	One gyro cannot be spun up.	11

TOP 3 GROUND, TEST, INTEGRATION RISKS

Burst Disc, Probe	Fails to burst when required	Possible facility damage or personnel injury.	10
Burst Disc, Dewar	Fails to burst when required	Possible facility damage or personnel injury.	10
Pump-out Port	Leak thru O-ring due to repeated removals and insertions	Air could condense in well, causing a thermal short, preventing removal of probe, possible over-pressurizing the tank.	11

Mass Properties

Rich Whelan

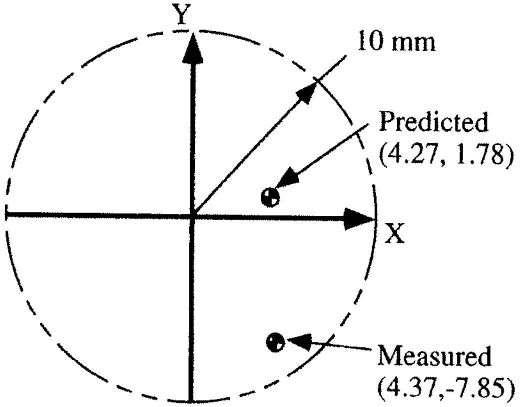
Agenda

- Probe-B actuals vs mass properties model
- Changes from Probe–B to Probe–C
- Plan for measuring and tracking Probe-C weights

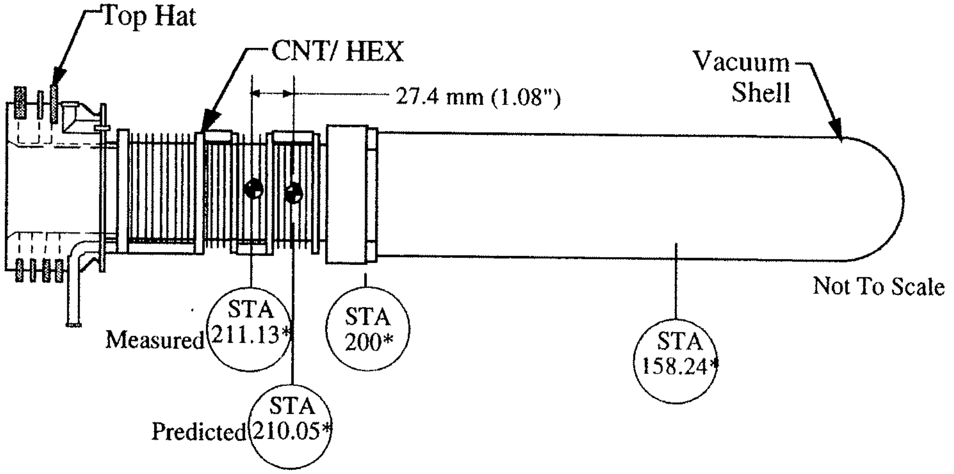
Mass Properties
Probe-B Actuals vs. Predicted

- Mass Measured: 105.0 kg
- Analytical Model: 105.3 kg
  - Model updated from build records, revised drawings, and analyses.

Axial Center of Gravity



Longitudinal Center of Gravity



- Delta (measured - analytical model):

  Δx: 0.10 mm (0.004”) Δy: -9.63 mm (-0.379”) Δz: 27.60 mm (1.087”)
- See supplemental mass properties data for further detail.

Mass Properties
Changes from Probe-B to Probe-C

- Probe Internal
  - Thermal Shoes
    - » Design to be reviewed for weight reduction, April 95
  - Minor changes
    - » Additional cabling, fiberoptics, QB interface

- Forward Probe Equipment
  - Top Hat
    - » Additional connector (telescope I9)
    - » Cable Brackets (Internal/ Segment 2 at Top Hat)
    - » Valve Stack Support Plates revised
    - » Connector Filters moved to Electronics (previously reported as probe components)
  - Window 4
    - » New design / materials
    - » Revised weight estimate per solid model analysis
  - Cross Flange
    - » Design modified for (2) 6” Vatterfly Exhaust Valves
    - » Thermal, Stress, Weight optimization complete
  - Improved Sunshade/ Shutter definition

Mass Properties
Plan for Tracking and Measuring Probe-C Weights

- Build upon Probe-B knowledge
  - Probe-B weight correlated to analytical model
    - » Model required extensive rework to achieve a modest level of correlation
    - » Discrepancies for Y & Z CG still unacceptable
    - » Probe-B Weight and CG not tracked as Flight / Flight Back-up hardware
  - Need improved correlation for Probe-C.
  - Build upon techniques used for Probe-B tracking
    - » Weights Log Book tracks flight hardware.
    - » Standardize Operations Orders for weighing hardware prior to installation.
    - » Large items and sub-assemlies will be tested for weight and center of gravity (CG as achievable within other constraints - schedule, hardware safety, cleanliness, etc.).
      - QBS
      - CNT
      - HEX
      - Top Hat
      - Vacuum Shell
      - Windows
      - Cross Flange
      - SunShade/ Shutter
      - SIA
      - Thermal Shoes
- Construct analytical model based upon new drawing tree
  - Apply test deltas for measured Probe-C weights.
  - Drawing Tree will flush out Probe-B Model discrepancies.

Probe-C
Mass Properties Summary

CATEGORY	Mass [kg]	Contingency [%]
Top Hat Weldment & Probe Internals [includes Vacuum Shell, CNT/HEX, QBS and all cables and shields]	106.87	1.2%
Top Hat Plumbing [includes Spin Up & Caging, Dewar Well Burst Disk, and Supports]	19.88	9.2%
Cross Flange Assembly [includes Cross Flange, 6" Exhaust Valves, Debris Filters, and Probe Burst Disk]	28.90	16.8%
Window 4 Assembly [revised to Sapphire substrate design with Aluminum mounting flange]	5.74	15.0%
Sunshade Assembly [includes Shutter]	15.60	20.0%
Science Instrument Assembly [includes telescope, SQUIDs, and gyroscopes]	38.95	6.4%
Probe-C Total Mass:	215.94	6.7%

Reference Mass Properties Report #15 (Feb 95) plus approved changes documented in the supplemental handout.

Note: “Top Plate Weldment & Probe Internals” is equivalent to Probe-B configuration during weight and CG test.

PROBE C CDR

MASS PROPERTIES STATUS REPORT

-SUPPLEMENTAL-

29 March 1995

Prepared by: Richard A Whelan
Richard A. Whelan
Science Payload Mass Properties Engineer

Scope: The scope of this supplemental mass properties status report is limited to Probe C only, including the Science Instrument Assembly, Top Hat External Plumbing, Cross Flange (and attached hardware), and the Sunshade/ Shutter Assembly.

Reference: Mass Properties Status Report, LMSC/ P024612-15

Mass Properties Management: The changes incorporated into this supplemental report have been approved by the Science Payload Mass Properties Control Board. Changes reflected herein will be incorporated into the next Mass Properties Status Report, LMSC/ P024612-16. Additional changes will be incorporated, as appropriate.

Report Terminology:

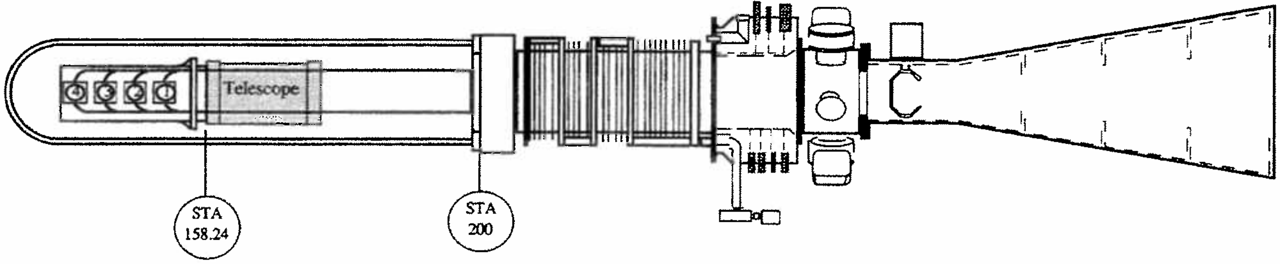
Basic weights are estimated, calculated, or measured values.

Current weights are basic weights increased by a contingency which accounts for a lack of design maturity.

Contingency: a tool based upon weight growth profiles from several flight programs. Percentage increases depend upon type of hardware and design maturity status. A table containing the contingency values used on GP-B is given in the referenced report.

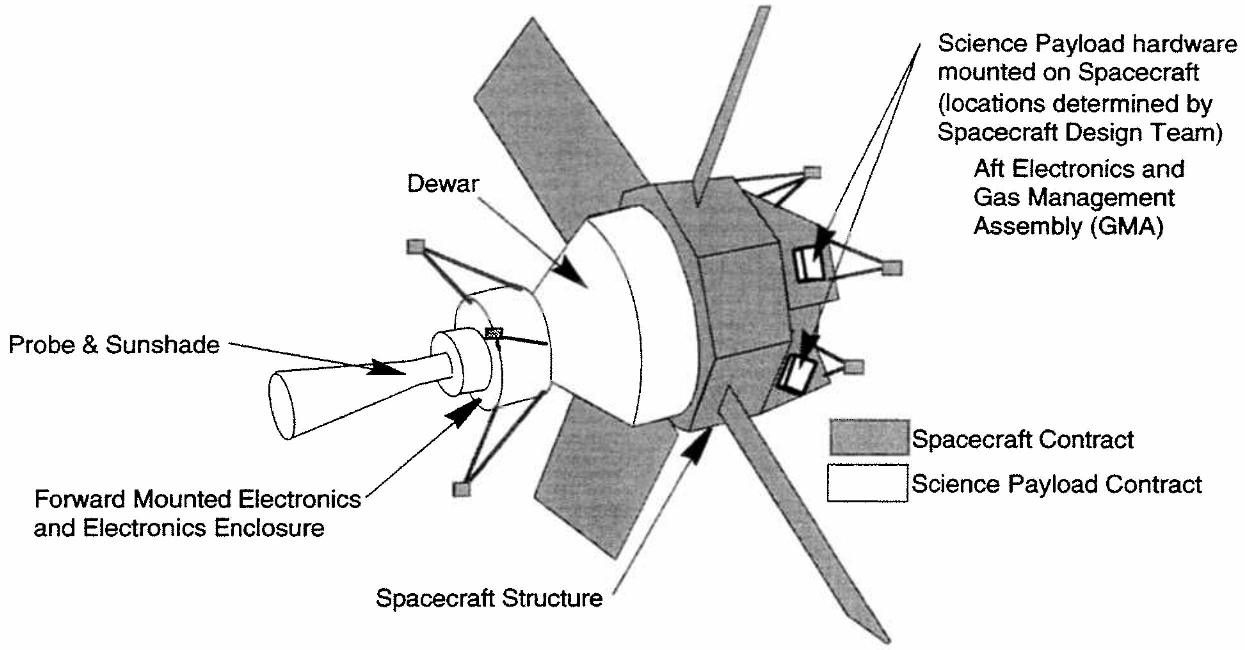
STA: Station Numbers (as shown below) represent Z axis positions and CG locations. Station values are equivalent to 'inches' with Station 200 being a main interface between the Probe and Dewar.

Probe Diagram and Contents Summary:



SIA & Telescope inside Probe Vacuum Shell supported by Quartz Block Support structure. Includes cryopump, Saddles, Segment 1 of Instrumentation Lines and Coaxial Cables.	CNT/ HEX, Composite Neck Tube & Heat Exchanger. Includes Thermal Shoes, Windows 1 - 3, and stop rings.	Top Hat includes bellows, conn.'s, and fwd valves.	Cross Flange includes Vat valves	Sunshade and Shutter Window 4 between Sunshade and Cross Flange.

Spacecraft/ Science Payload Contract division:



Science Payload Hardware:

Probe-C represents 15.18% of the total Science Payload contract when the Lockheed and Stanford portions shown in the table below are conmbined.

Percent of Total	Major Groups	Basic Weight (kg)	Cont. (%)	Current Weight (kg)	Basic Weight (lb)	Current Weight (lb)
45.90%	Dewar	805.53	4.35%	840.61	1775.88	1853.22
8.61%	Probe, Lockheed	151.12	4.87%	158.48	333.17	349.39
6.57%	Probe, Stanford (SIA, GMA, Valves)	115.33	14.57%	132.13	254.25	291.29
18.50%	Electronics	324.68	23.07%	399.58	715.79	880.93
20.42%	Cryogen	358.37	0.00%	358.37	790.08	790.08
100.00%	Total	1755.03	7.64%	1889.17	3869.17	4164.91

Detailed Probe Mass Properties

800 - Probe, Top Hat&Int.

F/C	P/N	Description	QTY	ECA	Weight -Kilograms--	Contngncy -Percent--	Xbar	Ybar	Zbar	Rxx	Ryy	Rzz
							---------Millimeters	----------		---------Millimeters	----------	
	5834133-	Top Hat Assy			29.388	1.00	-1.14	-1.62	6085.65	166.38	165.98	200.16
	260 -	CNT Assy			30.440	1.00	0.00	0.00	5496.48	216.51	216.51	125.80
	5834135-	Quartz block support			16.721	1.00	0.00	0.00	4634.75	436.17	436.17	128.35
	5834142-	Cryopump assy			2.869	1.00	1.24	2.21	4945.49	151.03	150.63	150.51
	290 -	Saddles			1.282	1.00	-14.89	2.25	4619.19	416.61	416.84	107.88
	380 -	Instr. cables			2.734	1.00	84.88	7.02	5450.90	1001.21	1003.90	114.06
	400 -	SQUID cables			2.329	1.00	22.13	104.57	5789.38	586.08	587.48	63.18
	410 -	Grnd coax cables,S1			0.240	1.00	-42.10	-61.82	4930.25	599.40	602.77	88.14
	420 -	Suspension cables,S1			2.276	1.00	-14.45	-72.39	4890.21	620.21	624.22	88.96
	430 -	Susp&grndCoaxCbl,S2			1.418	1.00	-46.69	-88.41	6109.09	88.03	133.74	140.34
	440 -	Spin-up lines			2.128	1.00	98.32	49.15	4736.06	678.09	677.82	46.37
	450 -	Caging lines (CL)			1.100	1.00	50.67	38.62	4221.74	812.37	812.22	127.25
	460 -	Pressure sense line			0.222	1.00	103.23	41.42	4952.56	749.30	747.94	45.19
	470 -	UV FibrOptCbl Int.			1.379	15.00	-1.66	-47.08	5399.75	948.04	952.96	137.05
	5834124-	Vacuum Shell			11.270	1.00	0.00	0.00	4259.07	496.06	496.06	124.97
K199	5834119-XXX	Phase I HW (@CG)	1	X	0.073	1.00	3.88	0.10	5334.77	752.05	752.32	151.90
K299	5834118-XXX	Phase II HW (@CG)	1	X	0.036	1.00	3.88	0.10	5334.77	752.05	752.32	151.90
K399	5834117-XXX	Phase III HW (@CG)	1	X	0.028	1.00	3.88	0.10	5334.77	752.05	752.32	151.90
K499	-	Probe B Test Corr.	1	X	-0.311	1.00	3.88	0.10	5334.77	752.05	752.32	151.90

```
                                ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For:                                          Xbar =      3.88    Ixx =         59.7  Pxy =     0.03
 P/N:   800    -                W =     105.621     Ybar =      0.10    Iyy =         59.8  Pxz =     0.01
 Title: Probe, Top Hat&Int.                         Zbar =   5334.77    Izz =          2.4  Pyz =    -0.05

                                ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For (with contingency):                       Xbar =      3.87    Ixx =         60.5  Pxy =     0.03
 P/N:   800    -                W =     106.871     Ybar =      0.02    Iyy =         60.6  Pxz =     0.01
 Title: Probe, Top Hat&Int.                         Zbar =   5334.88    Izz =          2.5  Pyz =    -0.05
 Weight Maturity Status: Unknown =   0.01%    X =  99.99%
```

240 - Top Hat Plumbing

F/C	P/N	Description	QTY	ECA	Weight -Kilograms--	Contngncy -Percent--	Xbar	Ybar	Zbar	Rxx	Ryy	Rzz
							---------Millimeters	----------		---------Millimeters	----------	
K603	-	SpinUp Valve Stack1	1	X	0.368	1.00	-162.56	251.46	6018.53	76.20	76.20	76.20
K603	-	SpinUp Valve Stack2	1	X	0.368	1.00	-106.68	279.40	6018.53	76.20	76.20	76.20
K603	-	SpinUp Valve Stack3	1	X	0.368	1.00	213.36	-213.36	6018.53	76.20	76.20	76.20
K603	-	SpinUp Valve Stack4	1	X	0.368	1.00	251.46	-162.56	6018.53	76.20	76.20	76.20
K803	-	SpinUpExhaustValve1	1	L	2.000	15.00	81.28	340.36	6026.91	76.20	76.20	76.20
K803	-	SpinUpExhaustValve2	1	L	2.000	15.00	218.44	274.32	6026.91	76.20	76.20	76.20
K803	-	SpinUpExhaustValve3	1	L	2.000	15.00	312.42	154.94	6026.91	76.20	76.20	76.20
K803	-	SpinUpExhaustValve4	1	L	2.000	15.00	350.52	10.16	6026.91	76.20	76.20	76.20
K603	-	Caging Valve Stack1	1	X	0.368	1.00	-213.36	213.36	6018.53	76.20	76.20	76.20
K603	-	Caging Valve Stack2	1	X	0.368	1.00	-251.46	162.56	6018.53	76.20	76.20	76.20
K603	-	Caging Valve Stack3	1	X	0.368	1.00	-279.40	106.68	6018.53	76.20	76.20	76.20
K603	-	Caging Valve Stack4	1	X	0.368	1.00	-297.18	48.26	6018.53	76.20	76.20	76.20
K603	-	Caging Valve Stack5	1	X	0.368	1.00	-292.10	-73.66	6018.53	76.20	76.20	76.20
K603	-	Caging Valve Stack6	1	X	0.368	1.00	-269.24	-132.08	6018.53	76.20	76.20	76.20
K603	-	PressSenseVlv stack	1	X	0.368	1.00	-127.00	-271.78	6032.50	76.20	76.20	76.20
K603	1C34289-101	Lrg Plmbng Sprt Brkt	1	L	1.361	15.00	-228.60	76.20	5969.00	152.40	152.40	152.40
K603	1C34289-102	Sml Plmbng Sprt Brkt	1	L	0.680	15.00	127.00	-177.80	5969.00	152.40	152.40	152.40
K603	1C34293-001	BrKt-spin-up exh.vlv	4	E	0.120	20.00	241.30	195.58	6026.91	76.20	76.20	76.20
K603	1C34183-001	Dewar BD/ CV	1	X	2.644	1.00	-7.62	-254.00	6026.91	76.20	76.20	76.20
K303	1C34284-001	Pumpout port DWwell	1	E	0.250	20.00	-167.64	-190.50	6027.42	50.80	50.80	50.80
K603	1C34120-101	Rad.Bffl -heat sta.5	1	R	1.098	3.00	0.00	0.00	6070.60	127.00	127.00	177.80

```
                                ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For:                                          Xbar =     60.59    Ixx =          0.9  Pxy =     0.13
 P/N:   240    -                W =      18.201     Ybar =     50.73    Iyy =          1.0  Pxz =     0.02
 Title: Top Hat Plumbing                            Zbar =   6021.48    Izz =          1.7  Pyz =     0.00

                                ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For (with contingency):                       Xbar =     67.88    Ixx =          1.0  Pxy =     0.15
 P/N:   240    -                W =      19.881     Ybar =     57.54    Iyy =          1.0  Pxz =     0.03
 Title: Top Hat Plumbing                            Zbar =   6021.11    Izz =          1.9  Pyz =     0.01
 Weight Maturity Status:  E =   2.03% L =  55.17%  R =   6.03%  X =  36.77%
```

Probe-C Supplemental Mass Properties Report

Detailed Probe Mass Properties (cont.)

230 - Cross Flange Assy

F/C	P/N	Description	QTY	ECA	Weight -Kilograms--	Contngncy -Percent--	Xbar (Millimeters)	Ybar (Millimeters)	Zbar (Millimeters)	Rxx (Millimeters)	Ryy (Millimeters)	Rzz (Millimeters)
K602	-	ProbeC CROSS-FLANGE	1	L	5.670	15.00	0.00	0.00	6398.26	381.00	381.00	177.80
K802	-	6"Exhaust Valve #1	1	E	6.804	20.00	5.08	-231.39	6385.56	177.80	177.80	177.80
K802	-	6"Exhaust Valve #2	1	E	6.804	20.00	-113.03	201.93	6385.56	177.80	177.80	177.80
K802	-	Filter, Valve #1	1	E	0.907	20.00	5.08	-231.39	6385.56	76.20	76.20	76.20
K802	-	Filter, Valve #2	1	E	0.907	20.00	-113.03	201.93	6385.56	76.20	76.20	76.20
K602	-	Bracket, Exh.Vlvs	1	E	0.500	20.00	5.08	-231.39	6385.56	127.00	127.00	127.00
K602	-	Bracket, Exh.Vlvs	1	E	0.500	20.00	-113.03	201.93	6385.56	127.00	127.00	127.00
K602	1C34183-001	Probe BD/ CV	1	X	2.644	1.00	218.44	132.08	6418.07	76.20	76.20	76.20

```
                                  ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For:                                            Xbar =    -12.48    Ixx =         2.1  Pxy =    -0.12
 P/N:   230    -                  W =      24.736     Ybar =      4.34    Iyy =         1.5  Pxz =     0.02
 Title: Cross Flange Assy                             Zbar =   6391.95    Izz =         1.7  Pyz =     0.01

                                  ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For (with contingency):                         Xbar =    -16.62    Ixx =         2.5  Pxy =    -0.16
 P/N:   230    -                  W =      28.897     Ybar =      2.16    Iyy =         1.8  Pxz =     0.02
 Title: Cross Flange Assy                             Zbar =   6391.43    Izz =         2.0  Pyz =     0.01
 Weight Maturity Status:  E =  66.39%  L =  22.92%  X =  10.69%
```

5834160- Window 4 Assy

F/C	P/N	Description	QTY	ECA	Weight -Kilograms--	Contngncy -Percent--	Xbar (Millimeters)	Ybar (Millimeters)	Zbar (Millimeters)	Rxx (Millimeters)	Ryy (Millimeters)	Rzz (Millimeters)
K701	-	Window 4	1	L	4.990	15.00	0.00	0.00	6553.20	88.90	88.90	127.00

```
                                  ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For:                                            Xbar =      0.00    Ixx =         0.0  Pxy =     0.00
 P/N:   5834160-                  W =       4.990     Ybar =      0.00    Iyy =         0.0  Pxz =     0.00
 Title: Window 4 Assy                                 Zbar =   6553.20    Izz =         0.1  Pyz =     0.00

                                  ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For (with contingency):                         Xbar =      0.00    Ixx =         0.0  Pxy =     0.00
 P/N:   5834160-                  W =       5.738     Ybar =      0.00    Iyy =         0.0  Pxz =     0.00
 Title: Window 4 Assy                                 Zbar =   6553.20    Izz =         0.1  Pyz =     0.00
 Weight Maturity Status:  L = 100.00%
```

900 - PROBE ASSEMBLY

F/C	P/N	Description	QTY	ECA	Weight -Kilograms--	Contngncy -Percent--	Xbar (Millimeters)	Ybar (Millimeters)	Zbar (Millimeters)	Rxx (Millimeters)	Ryy (Millimeters)	Rzz (Millimeters)
	800 -	PROBE, Top Hat & Int			105.621	1.18	3.88	0.10	5334.77	752.05	752.32	151.90
	240 -	Top Hat Ext. Plumbin			18.201	9.23	60.59	50.73	6021.48	222.77	229.50	306.50
	230 -	Cross Flange Assembl			24.736	16.82	-12.48	4.34	6391.95	292.62	248.33	262.08
	5834160-	Window 4 Assy			4.990	15.00	0.00	0.00	6553.20	88.90	88.90	127.00
V701	-	Sunshade/ShutterAssy	1	E	13.000	20.00	-4.88	0.00	7211.57	412.24	413.00	215.90
U801	-	SIA	1	P	36.600	6.43	-0.76	-0.25	3980.00	250.44	250.70	64.52

```
                                  ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For:                                            Xbar =      5.48    Ixx =       222.1  Pxy =     0.09
 P/N:   900    -                  W =     203.148     Ybar =      5.08    Iyy =       221.6  Pxz =     0.34
 Title: PROBE ASSEMBLY                                Zbar =   5430.96    Izz =         6.8  Pyz =     0.62

                                  ----Kilograms-----  ---Millimeters----  ------Kg-M^2------  ------Kg-M^2------
Total For (with contingency):                         Xbar =      5.45    Ixx =       242.2  Pxy =     0.09
 P/N:   900    -                  W =     215.941     Ybar =      5.55    Iyy =       241.7  Pxz =     0.27
 Title: PROBE ASSEMBLY                                Zbar =   5462.99    Izz =         7.4  Pyz =     0.67
 Weight Maturity Status: Unknown =   0.00%    E =  14.67%  L =  10.19%  P =  18.02%  R =   0.54%  X =  56.59%
```

Change Summary

The following changes have been incorporated since the release of LMSC/ P024612-15.

			Weight Change (kg)	
Dwg Number	Part Description	Weight Change (from->to)	Basic Wt	Subtotal
	Fiber Optics			+0.522
1.	UV Fiber Optics	(0.448 kg ->1.380 kg)	0.932	
	Update to new layout with 3 fiber optic cables, each containing 4 fibers. Weight of connectors from Probe-B surplus and, weight of connector block from solid model analysis. Top Hat Feedthru weight estimated; 15% group contingency assigned.			
2.	Telescope Fiber Optics	(0.606 kg ->0.000 kg)	-0.606	
	Telescope cables and connectors added in previous report but Probe-B Telescope Fiber Optics are not used on Probe-C			
3.	Contingency Change		+0.196	
	Window 4			-4.694
1.	Window 4	(9.072 kg ->4.990 kg)	-4.082	
	Previous weight reflected the new sapphire substrate design but maintained adequate margin for a steel mounting flange. Thermal analysis has concluded that the material of the mounting flange (and the Cross Flange to which it is attached) have little affect on the thermal gradients that may have varied with roll-rate. The mounting flange has been changed to aluminum and bellows and substrate mounting flange changes have also contributed to the reduction in weight.			
2.	Contingency Change		-0.612	
	Cross Flange			-8.263
1.	Cross Flange	(12.855 kg ->5.670 kg)	-7.185	
	Stress and thermal analyses have concluded that aluminum is the preferred material for this application.			
2.	Contingency Change		-1.078	
	Science Instrument Assembly			0.000
1.	SIA	(no weight change)	0.000	
	The recent report published by Stanford University has indicated that the Z CG of the SIA previously reported was incorrect at 151.65. The corrected Z CG is 156.69 which increases the Main Payload CG by 0.13 (3.3 mm)			
2.	Contingency Change		0.000	

Net Change -12.435 kg

Conclusion:

The Probe C Mass Properties (Lockheed portion as shown on page 2) has a 4.87% overall contingency. The majority of this contingency is for forward plumbing on the Top Hat, which, although somewhat less mature, does not represent a great design or weight growth risk. The Stanford portions are similar, with the SIA having a high level of design maturity, and the lower risk plumbing at a lower maturity level.

The weight and center of gravity test of Probe-B revealed some inaccuracies of the previous mass properties model, which was developed for engineering information and not with the diligence associated with tracking and analyses of flight hardware. Contractual changes which have made the Probe-B unit a flight backup to Probe-C have lead to greater interest in the discrepancies between the Probe-B test and the model predictions, both for weight and center of gravity. However, the Probe-B test serves as a great tool in gaining better predictions of the Probe-C weight despite the inaccuracies previously seen.

Quality Assurance

Jim Lepetich

Agenda

- Procurement
- Assembly
- Test
- Discrepancies
- DPRO Involvement

Quality Assurance Objectives

- Magnetic traceability on components and assemblies
- Dimensional verification of components and assemblies
- Re-use of qualified vendors
- Hardware traceability
- Incorporating knowledge gained from Probe-B build into Probe-C

Procurement

- Procurements are processed in FASTBUY, an R&DD - developed, computerized procurement system
- Quality Engineer (QE) is responsible for adding quality requirements to all procurements
- Quality requirements are driven by program R&DD policy, Relativity Mission Quality Assurance plan, drawing notes, engineering requirements and hardware - based special requirements
- Suppliers are required to be approved by the R&DD Product Assurance management
- R&DD Receiving Inspection requirements are established at the same time as the supplier quality requirements, and are added to procurement records for Inspection's use when hardware arrives
- Hardware is not accepted for use until all Quality Assurance requirements have been satisfied

Assembly

- All flight hardware is assembled using paperwork that is generated by the responsible engineer and then approved by the QE
  - Paperwork was developed on Probe-B, and will be used as a baseline for Probe-C
  - Paperwork performs kitting, assembly, and lower level acceptance testing of sub-assemblies
  - Paperwork documents the as-built condition of the hardware
    - » part number and revision
    - » records personnel who performed the work
    - » records discrepancies and resolutions during build and test
    - » Inspections performed
  - Critical process steps are witnessed or inspected by Inspection personnel; i.e. soldering, safety wiring and fastener torquing
  - Inspection verifies assembly is complete per paperwork requirements
- The QE performs the final review to assure that paperwork is complete with no issues left unresolved

Test

- All AcceptanceTesting is performed to paperwork generated by the responsible engineer and approved by the QE
  - Included in acceptance testing paperwork are: test instructions, accept/reject criteria, test equipment used and its calibration status, record of personnel performing testing
  - Quality personnel witness all Acceptance Testing
- Controlled interface dimensions are considered part of acceptance requirements
  - Dimensions may be checked at a supplier (Source Inspection), in LMSC Receiving Inspection, in-process or at the final acceptance level depending on which stage of hardware assembly provides the least amount of risk to the hardware
- Deliverable data package will contain the results of all Acceptance Testing and dimensional verifications

Discrepancies

- Probe-B discrepancies are being evaluated and used to eliminate problems on Probe-C hardware
- Discrepancy Logs (D-Logs) are used to record 'anomalies'
  - D-Logs are attached to build paper and become part of build history
  - Anomalies are investigated by responsible engineer, who provides written response
  - Responsible Equipment Engineer and QE approve or disapprove resolution before any action is taken
  - Response may perform minor rework which is subject to existing requirements or may escalate issue to a Discrepancy Report (DR)
  - D-Logs are also used to record parts shortages
- DRs are generated by Quality personnel
  - Hardware is tagged with DR and impounded as appropriate
  - QE is responsible for maintaining all DRs and statusing those that remain open
  - QE conducts Material Review Board

Discrepancies cont.

- Closed DRs are attached to build paperwork
- Discrepancies that violate controlled interfaces or affect Payload Specification performance requirements are escalated to a “Top Level” DR and routed to Stanford for their review and concurrence

DPRO

- Government representative has provided a “Mandatory Inspections” letter to R&DD that identifies areas of their participation in the Relativity Mission program

- Relativity Mission program incorporates DPRO into program activities
  - Program reviews
  - Procurements
  - Hardware assembly
  - Hardware AcceptanceTesting
  - Hardware shipments
  - Dispositioning of discrepant hardware

Probe–C Verification and Test

Art Nakashima

Agenda

- Verification Objectives
- Verification and Test Philosophy
- Test Plan
- Verification Analyses
- Verification Documentation

Verification Objectives

- Verify compliance to applicable requirements in Payload Specification F277277
  - Probe Specification, Section 3.7.3
  - Design and Construction, Section 3.3
  - SIA to Probe Interface, Section 3.7.2
  - Probe to Dewar Interface, Section 3.7.4
  - Probe/Dewar to Science Payload Assemblies, Section 3.7.6
- Verify compliance to Interface Control Drawings
  - Probe to SIA ICD, 1C34103
  - Probe External Interface ICD, 1C34102
  - Probe to Dewar ICD, 1C34159
  - Payload to Spacecraft ICD, 1C33115
- Follow guidelines of MIL-STD-1540B for environmental tests
- Validate the structural, thermal, and mass properties models

Verification and Test Philosophy

- Development tests for new designs or build processes from Probe-B
- Updated structural, thermal, optical, and flow analyses where applicable
- Qualification testing of mechanical devices
- Rigorous component-level environmental acceptance testing
- Probe-C acceptance tests at LMSC include all tests possible before integration of SIA and dewar.
  - Incorporates lessons learned from Probe-B acceptance tests
- Probe-C warm vibration using same test fixture used for Probe-B vibration
- Verification of SIA integration and SMD integration performed at Stanford
  - Incorporates lessons learned from GTU-1
- Verification of performance at He I and He II temperatures performed at Stanford

Probe-C Test Plan

DEVELOPMENT/ QUALIFICATION

- UV Fiber OpticsCables
  Transmission, Degradation, Attenuation of Lemos, Effects of shake, thermal cycling, bakeout on transmission
- Ground/UV Bias Cables
  Seg 2 Bellows deflection, Assembly processes, Vibrate, Thermal deflections
- Telescope Detector Cables
  Shake test shield, bellows; Thermal deflections, Thermal cycle, bakeout
- SQUID Signal Cables
  Thermal and electrical conductivity down to 2K.
  Round trip resistance
- Thermal Shoes
  Load, vibrate
- Window 1 Assembly (Pr-B spare)
  Mount induced distortions, vibrate, instrumentation test
- Window 4 Assembly (Pr-B window quals Pr-C)
  Mount induced distortions, vibrate, leak, thermal cycle, coating life test
- Cryopump
  Subscale adsorption, bakeout
- Shutter
  Life test in thermal vac
- Composite Neck Tube
  (SMD CNT quals Pr-C)
  load tests- lateral and axial

COMPONENT ACCEPTANCE

Thermal Cycle
- all components and subassemblies subject to temperature cycling

Magnetic Screen
- according to Magnetic Control Plan

Contamination Control
- according to Contamination Control Plan

Vacuum Bakeout
- according to Probe Bakeout Plan

Leak Check
- all vacuum and flow enclosures

Proof Pressure
- all pressurized components and subassemblies

Vibrate
- Sunshade & Shutter
- Vatterfly Valves
- Window Assemblies
- Burst Discs

Window Measurements
- Wavefront
- Spectral Transmission
- EMI Attenuation & Emissivity

PROBE-C ACCEPTANCE

At LMSC

- Interface Control Drawings Dimensions
- Alignments
- Grounding Resistances
- UV Cables Transmission
- Instrumentation Cables and Connectors
- Probe Assembly Magnetic Test
- Probe Assembly Weight and CG
- High Temperature Bakeout and Vacuum
- Leak, Permeation, and Outgassing
- Coax, SQUID, and Detector Cable Functionals
- Probe Vibration with SIA Mass Model

At Stanford

- Probe to SIA Integration and Alignment
- Post SIA Integration Cables and Instrumentation Functionals
- Pressure Drop, Cleanliness of Spin-up Exhaust Lines
- Probe to Science Mission Dewar Integration
- Leak and Vacuum Measurements
- Optical Performance - warm and cold
- Flux Flushing
- EMI Attenuation
- Thermal Radiation Down the Neck
- Window Bakeout
- Low Temperature Bakeout
- Spinup Gas Temperatures and SIA Pressure

Updated Verification Analyses

- Structural Analyses
  - Stress Analysis of Probe-C Electrical Cables, GPB-100431
  - Deflection Analysis of Probe-C Cables, GPB-100432
  - Analysis of UV Fiber Optic Cables in the Probe-B Top Hat, GPB-100433
  - Structural Analysis and Weight Optimization of the Probe-C Cross Flange, GPB-100434
  - Stress Analysis of the Probe-C Top Hat, GPB-100435
  - Structural Analysis of the Probe-C Window 4 Assembly, GPB-100436
- Thermal Analyses
  - Thermal Analysis of the Telescope Corrector Plate, GPB-100453
  - Calculation of Window 4 Temperatures and Gradients, GPB-100454
  - Sensitivity of Cryogen Lifetime and Radiation at the SIA to Window Coatings, GPB-100455
  - GPB Thermal Model for lifetime impacts of probe design changes
- Optical Analyses
  - Probe-C Window Requirements Analysis, GPB-100465
  - Stray Light Analysis, GPB-100466
  - Integrated Optical Analysis, GPB-100467
  - Ghost Images Analysis, GPB-100468

Verification Documentation

- Probe-C Verification and Test Plan, Version 2 (PLIT-01), GPB-100268
  - Verification Matrix, including plan for complying with each requirement
  - Verification Test Flow and Test Plan
  - Components and Subassemblies Test Matrix
  - Update prior to probe assembly tests
- Probe-C Verification Requirements Compliance Document, Version 2 (PLIT-03), GPB- 100269
  - Provides compliance/non-compliance document numbers and explanations
  - Final at Acceptance Data Review
- Probe-C Acceptance Test Procedure
  - Provides data results for requirements verified by test or measurement

Probe-C Components Test Matrix
(1 of 2)

item	functional	therm cycle	proof press	vac bake	leak	vibration	life test	load	optical trans	wavefront error	emissivity
PROBE-C				A	A	P					
VACUUM SHELL		A		A	A						
SUNSHADE ASSEMBLY		A		A		P					
SHUTTER ASSEMBLY	D, A	A		A		P	D				
CROSS-FLANGE/TOP HAT SUBASSEMBLY			A								
CROSS-FLANGE			A	A	A						
TOP HAT ASSEMBLY		A	A	A	A						
X-FLANGE FILTER		A		A							
LEAKAGE VATTERFLY VALVES*	Q, A	Q, A	Q, A	Q, A	Q, A	Q, A	Q				
SPIN-UP EXHAUST VALVES*	Q, A	Q, A	Q, A	Q, A	Q, A	Q, A	Q				
ELECTRICAL FEEDTHROUGHS	A	A			A						
TOP HAT BELLOWS		Q, A	Q, A	A	Q, A		Q	Q			
COMPOSITE NECK TUBE		A	A	A	A			sim to SMD			
HEAT EXCHANGERS		A	A	A	A						
THERMAL SHOES	D	D, A		A		D	D	D			
FALSE WALLS / HEAT STATION RINGS		A		A							
WINDOW 4 (SUBSTRATE & COATING)							coating life test		A	A	A
WINDOW 4 ASSEMBLY	D, A	D,A	D,A	D,A	D,A	D,A				D, A	

Q: Qualification Unit; A: Acceptance Unit; D: Development Sub-unit: P: Protoqual levels

* Stanford provides and tests

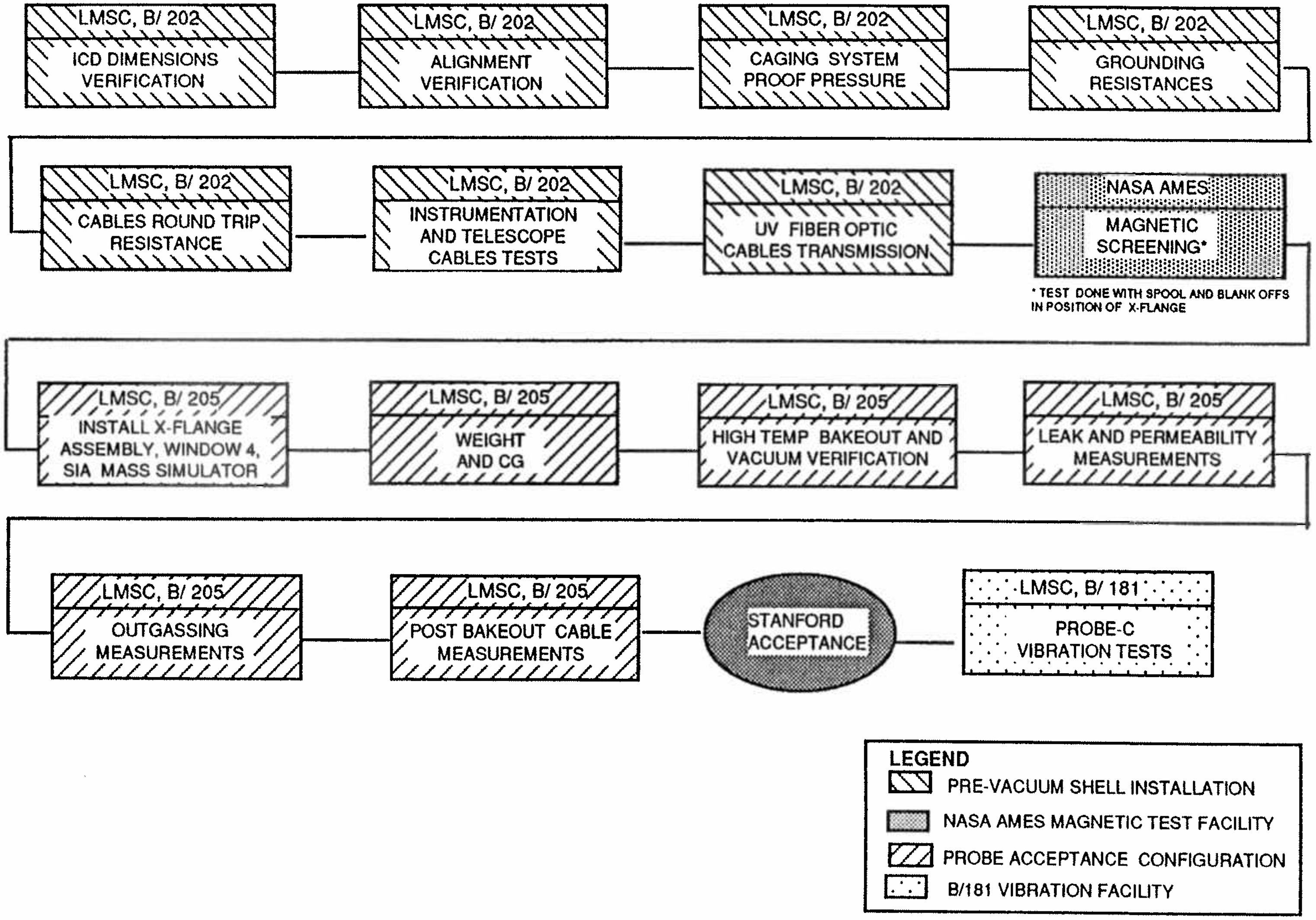
Probe-C Components Test Matrix
(2 of 2)

item	functional	therm cycle	proof press	vac bake	leak	vibration	life test	load	optical trans	wavefront error	emissivity
WINDOWS 1,2,3 (SUBSTRATE & COATING)									A	A	A
WINDOWS 1,2,3 ASSEMBLIES	D, A	D, A		D, A		D, A				D, A	
HEATERS	Q, A	Q, A		Q, A		w/window assemblies					
GRTS	Q, A	Q, A		Q, A							
SI DIODES	Q, A	Q, A		Q, A		w/window assemblies					
CRYOPUMP	D	A		D, A		P					
MANUAL VALVES		A	A	A	A						
BURST DISCS (8)	Q, A	Q, A		A	Q, A	Q, A					
CAGING LINE ASSEMBLY			A	A	A						
SPINUP INLET LINES ASSEMBLY				A	A						
SPINUP EXHAUST LINES				A	A						
QBS ASSEMBLY		A		A	A						
COAXIAL CABLES	D, A	D, A		A		D					
SQUID CABLES	D, A	D, A		A							
UV FIBER OPTIC CABLES	D, A	D, A		A		D			D, A		
TELESCOPE DETECTOR CABLES	D, A	D, A		A		D					
GROUND & UV BIAS CABLES	D, A	D, A		A		D					
INSTRUMENTATION CABLES	A	A		A							
PRESSURE SENSE LINE				A							

Q: Qualification Unit; A: Acceptance Unit; D: Development Sub-unit: P: Protoqual levels

* Stanford provides and tests

Probe-C Acceptance Test Flow at LMSC

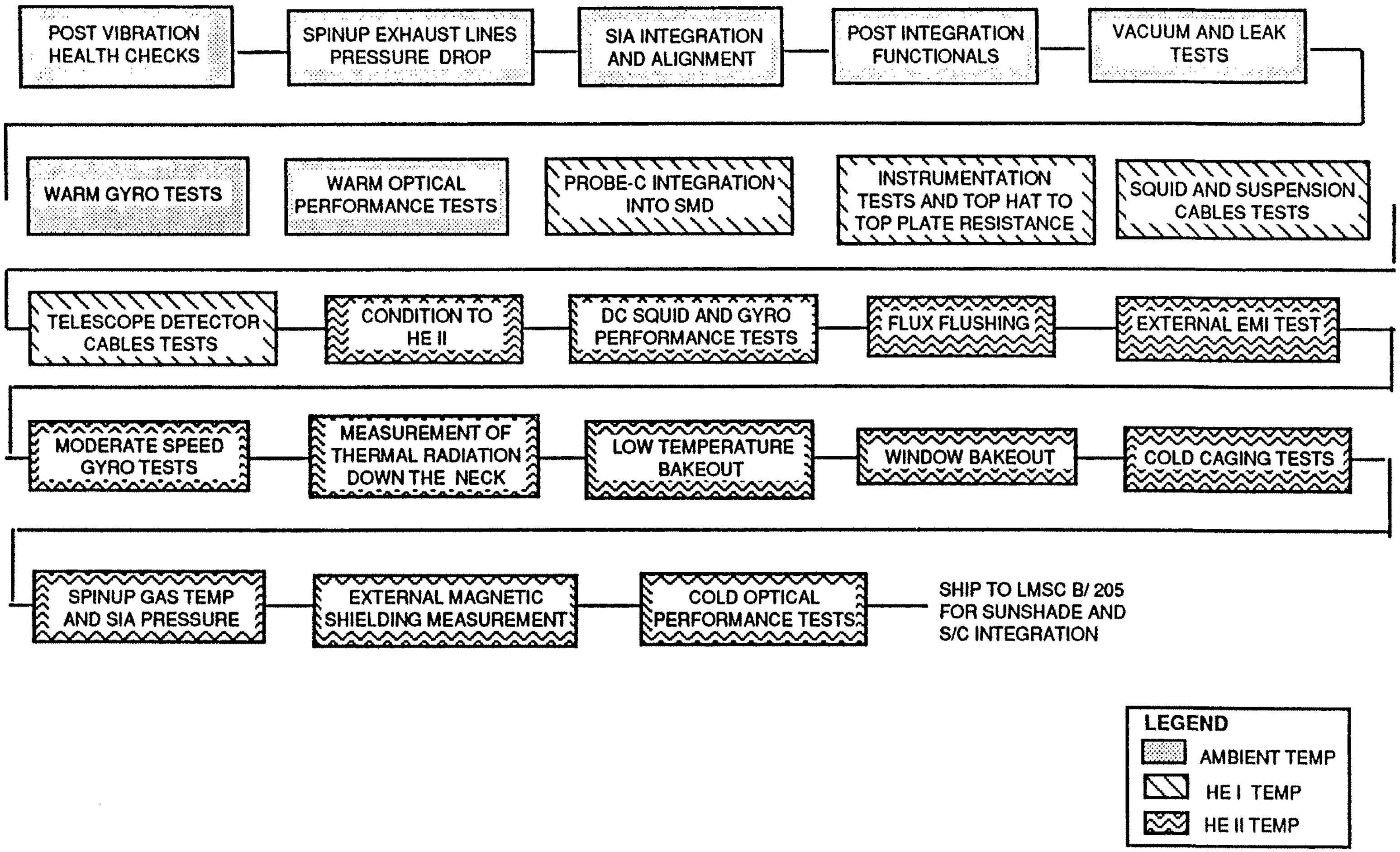


LMSC, B/ 202 — ICD DIMENSIONS VERIFICATION
LMSC, B/ 202 — ALIGNMENT VERIFICATION
LMSC, B/ 202 — CAGING SYSTEM PROOF PRESSURE
LMSC, B/ 202 — GROUNDING RESISTANCES
LMSC, B/ 202 — CABLES ROUND TRIP RESISTANCE
LMSC, B/ 202 — INSTRUMENTATION AND TELESCOPE CABLES TESTS
LMSC, B/ 202 — UV FIBER OPTIC CABLES TRANSMISSION
NASA AMES — MAGNETIC SCREENING*
LMSC, B/ 205 — INSTALL X-FLANGE ASSEMBLY, WINDOW 4, SIA MASS SIMULATOR
LMSC, B/ 205 — WEIGHT AND CG
LMSC, B/ 205 — HIGH TEMP BAKEOUT AND VACUUM VERIFICATION
LMSC, B/ 205 — LEAK AND PERMEABILITY MEASUREMENTS
LMSC, B/ 205 — OUTGASSING MEASUREMENTS
LMSC, B/ 205 — POST BAKEOUT CABLE MEASUREMENTS
STANFORD ACCEPTANCE
LMSC, B/ 181 — PROBE-C VIBRATION TESTS

* TEST DONE WITH SPOOL AND BLANK OFFS IN POSITION OF X-FLANGE

LEGEND
▧ PRE-VACUUM SHELL INSTALLATION
▒ NASA AMES MAGNETIC TEST FACILITY
▨ PROBE ACCEPTANCE CONFIGURATION
⁘ B/181 VIBRATION FACILITY

Probe-C Acceptance Test Flow at Stanford



March 20, 1995

Subject: PROBE C PDR

Action Item #21

Assignee: Paul Dineen

Action: Investigate parylene.

Response: Parylene C will be retested along with other alternate isolation materials for use on Probe C.

Background: Parylene is a vacuum deposited conformal coat. There are three parylene coatings C,N and D. At this time, parylene is being investigated for use as an electrical insulator on the outside of the Probe C caging lines. For this application, Parylene C which has the highest percent elongation prior to breaking is recommended. See attached sheet for additional parylene material properties.

Parlyene C was tried at Stanford by Barry Muhlfelder with poor results. The samples done for Barry had poor adhesion and delaminated and flaked when bent. Barry felt that proper precleaning and abrading of substrate would provide better adhesion but this coating still should be limited to areas of low abrasion.

Recommendation: I am recommending that parylene C, teflon tubing and teflon coatings be evaluated for use on the Probe C caging lines. See below for details:

Parylene C

- Apply parylene C to spare caging tubing. LMSC to prepare the surface of the tubing prior to delivery for coating. After coating, bend tubing 90° then twist tubing 90° and verify adhesion.

Teflon Coating

- Apply teflon coating (EM Corp System No. 6219), which was used on quartz block bolts, to spare caging tubing. LMSC to prepare the surface of the tubing prior to delivery for coating. After coating, bend tubing 90° then twist tubing 90° and verify adhesion.

Teflon Heat Shrink Tubing

- Verify that teflon shrink tubing, which was used by Stanford on the DC SQUID jumper cables, can be installed over the solder joint on development caging line assemblies. After installation and shrinkage, bend tubing 90° then twist tubing 90° and verify teflon doesn't crack.

Paul M Dineen
Written : Paul Dineen

Gary
Checked: Gary Reynolds

A J Calhoon 3/20/95
Approved: LMSC

Approved: Stanford University

VIKING TECHNOLOGY, INC.

VIKING TECHNOLOGY, INC. was established in January of 1981 to provide coating solutions to industries utilizing our Parylene deposition services. We added E. Coating services in 1986 to broaden our coating problem solving capabilities. Our experience with coatings has allowed us to provide other specific manufacturing services that our customers have requested. These services include consulting, inspection, and cleaning of coated and uncoated substrates.

WHAT IS PARYLENE?

Parylene is a unique vacuum deposited polymer which is used for conformal coating of a variety of substrates. Parylene has several characteristics which make it stand out from other conformal coatings. They include:

- Totally conformal
- Inert/biocompatible
- Pin hole free
- Exceptional chemical and solvent resistance
- Good electrical insulator
- Low coefficient of friction (no stiction)

VIKING TECHNOLOGY, INC. has 5 Parylene coating systems, as well as other associated equipment, and a staff that is competent in providing the highly technical capability required for quality Parylene applications.

TYPICAL PARYLENE ELECTRICAL PROPERTIES*

	Parylene N	Parylene C	Parylene D
Dielectric Strength, Short Time, volts/mil at 1 mil	7,000	5,600	5,500
Volume Resistivity, 23°C, 50% RH, ohms-cm	1x10^{17}	6x10^{16}	2x10^{16}
Surface Resistivity, 23°C, 50% RH, ohms	10^{13}	10^{14}	5x10^{16}
Dielectric Constant			
60 HZ	2.65	3.15	2.84
10^{3} HZ	2.65	3.10	2.82
10^{6} HZ	2.65	2.95	2.80
Dissipation Factor			
60 HZ	0.0002	0.020	0.004
10^{3} HZ	0.0002	0.019	0.003
10^{6} HZ	0.0006	0.013	0.002

TYPICAL PARYLENE PHYSICAL AND MECHANICAL PROPERTIES*

	Parylene N	Parylene C ✓	Parylene D
Tensile Strength, psi	6,500	10,000	11,000
Yield Strength, psi	6,100	8,000	9,000
Elongation To Break, %	30	200	10
Yield Elongation, %	2.5	2.9	3
Density, g/cm^3	1.11	1.289	1.418
Coefficient of Friction			
Static	0.25	0.29	0.33
Dynamic	0.25	0.29	0.31
Water Absorption, 24 hours	0.06 (0.029")	0.01 (0.019")	--
Index of Refraction, N_D 23°C	1.661	1.639	1.669
Melting Temperature	405°C	280°C	380°C

*Information courtesy of Union Carbide Corporation (Data recorded following appropriate ASTM method)

Schedule for Probe–C

Gary Reynolds

Agenda

- Long-lead procurements
- Drawing status
- Schedule from CDR to delivery
- Program risks

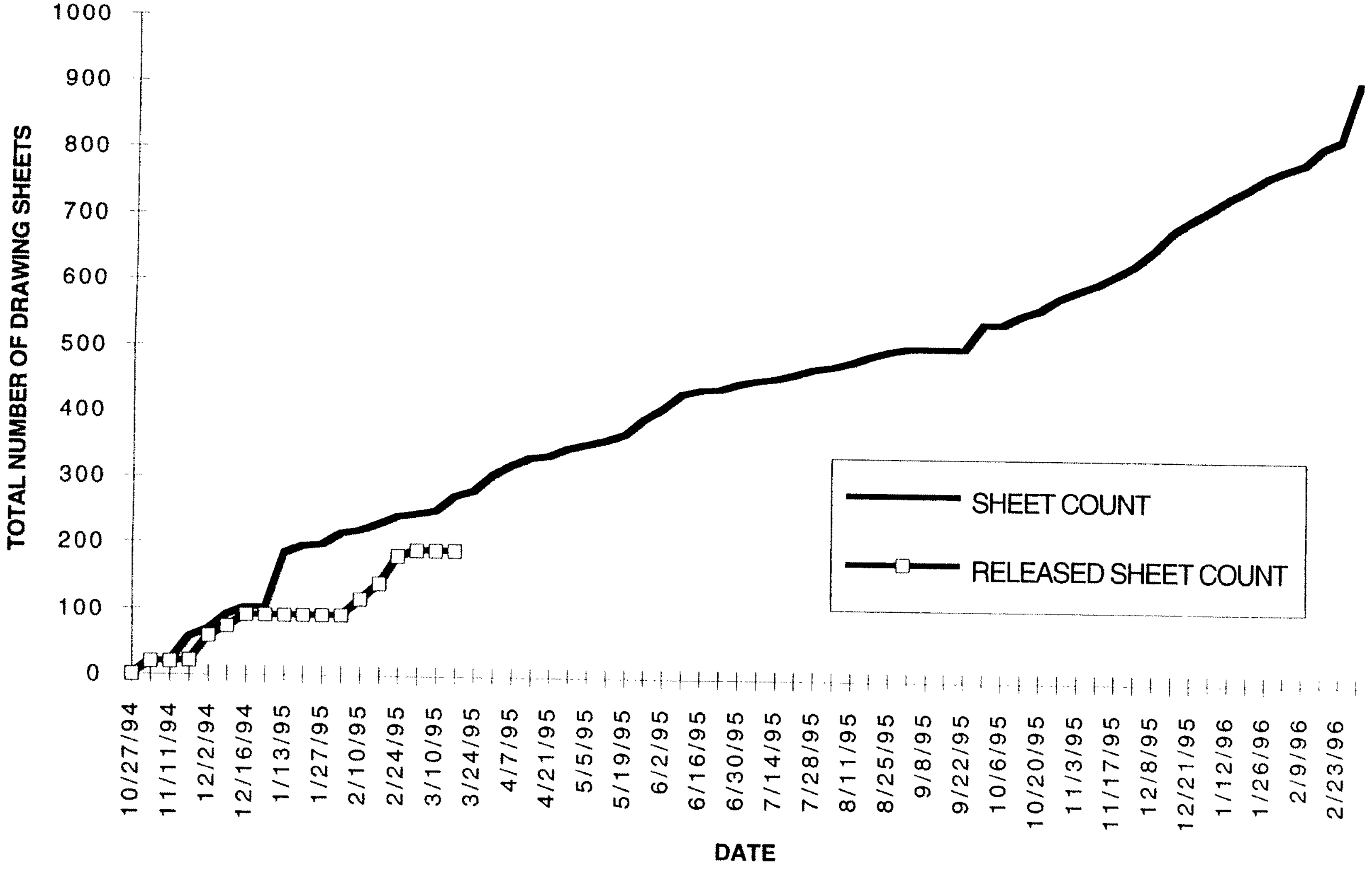
Long Lead Raw Materials

- High purity materials (for critical magnetic zones)
  - Phosphor Bronze (for shield tubing and connectors)
    - » Ingots supplied by Iowa State Materials Preparation Center
    - » Reworked at Lockheed B/204 metals lab, at Iowa State and at Accumetrics into rod, tube, and plate
    - » All material passes magnetic testing to Zone 2B reqt's
  - PEEK (for Lemo connector insulators)
    - » Solid rod passes Zone 2B
  - Boron Nitride (for ground cable insulators)
    - » Special run by Carborundum passes Zone 2B reqt's
- Other materials
  - Alumina (for suspension and proof mass cable insulators)
    - » Coors isopress material same as Probe-B

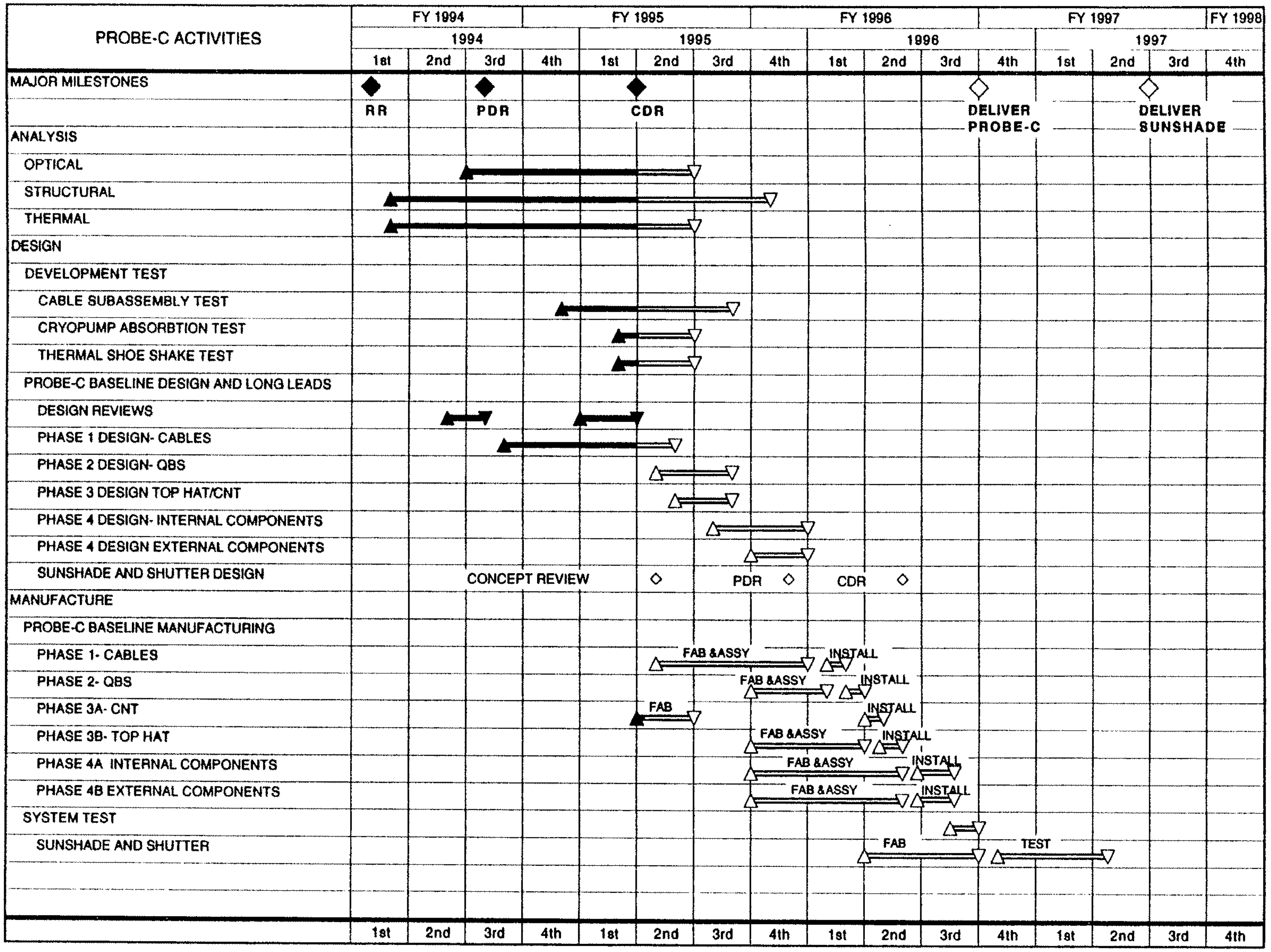
Long Leads Ordered

- Phase 1
  - All suspension insulator bead machining (Kadco)
  - All cable connectors (Lemo, Pacific Coast)
  - All shield tubing, bellows and wire (Accumetrics, Miniflex, MWS)
  - Optical fiber (FiberGuide)
- Phase 2
  - Aluminum material ordered for saddles
  - Forging and tube for QBS
  - Extrusions from Probe-B in magnetic test
- Phase 3
  - Composite Neck Tube (SCI)

Drawing Status

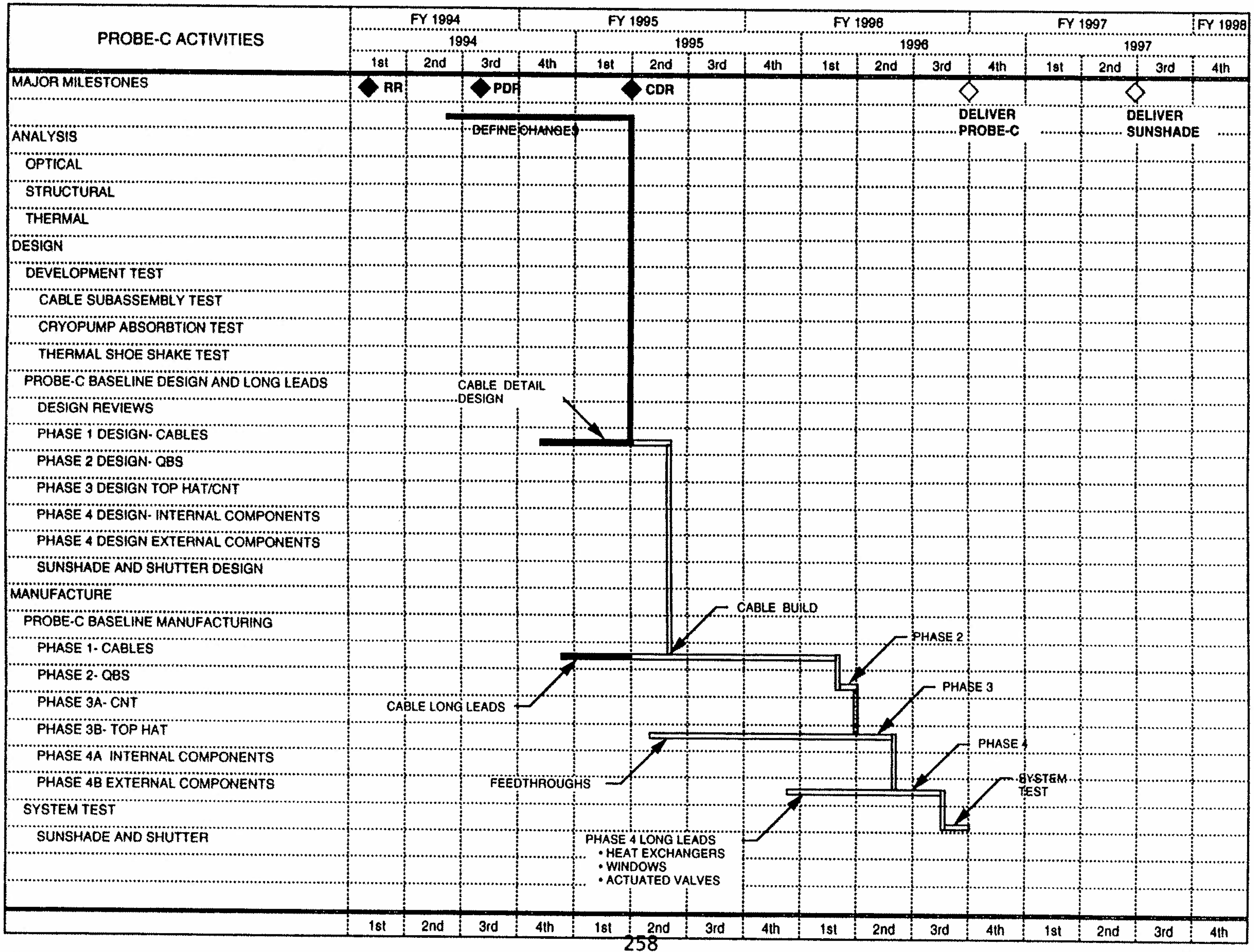


Schedule


PROBE-C ACTIVITIES
FY 1994
FY 1995
FY 1996
FY 1997
FY 1998
1994
1995
1996
1997
1st
2nd
3rd
4th
MAJOR MILESTONES
RR
PDR
CDR
DELIVER PROBE-C
DELIVER SUNSHADE
ANALYSIS
OPTICAL
STRUCTURAL
THERMAL
DESIGN
DEVELOPMENT TEST
CABLE SUBASSEMBLY TEST
CRYOPUMP ABSORBTION TEST
THERMAL SHOE SHAKE TEST
PROBE-C BASELINE DESIGN AND LONG LEADS
DESIGN REVIEWS
PHASE 1 DESIGN- CABLES
PHASE 2 DESIGN- QBS
PHASE 3 DESIGN TOP HAT/CNT
PHASE 4 DESIGN- INTERNAL COMPONENTS
PHASE 4 DESIGN EXTERNAL COMPONENTS
SUNSHADE AND SHUTTER DESIGN
CONCEPT REVIEW
PDR
CDR
MANUFACTURE
PROBE-C BASELINE MANUFACTURING
PHASE 1- CABLES
FAB &ASSY
INSTALL
PHASE 2- QBS
FAB &ASSY
INSTALL
PHASE 3A- CNT
FAB
INSTALL
PHASE 3B- TOP HAT
FAB &ASSY
INSTALL
PHASE 4A INTERNAL COMPONENTS
FAB &ASSY
INSTALL
PHASE 4B EXTERNAL COMPONENTS
FAB &ASSY
INSTALL
SYSTEM TEST
SUNSHADE AND SHUTTER
FAB
TEST

Critical Path

STANFORD
Lockheed
Probe-C CDR
29 March 95



Program Risks

Risk	Approach
• Schedule has little slack	
– Magnetics problems cause delays	- Early detection, efficient screening
– Cables built in short time frame	- Shift work, efficient use of clean room
– Water cleaning	- Development of good methods
• Technical	
– Window 4 development	- Choosing most reliable mounting
– Fiber optic cable developments	- Parallel development
• Cost	
– PCB items and ICD driven changes	- Evaluating changes vs cost
– Magnetics	- Gradiometer on order for LMSC, magnetics lead technician

Action Items

Graham Ross

Agenda

- Requirements Review Action Items
- PDR Action Items
- Closure plan for Action Items

Open Req'ts Review Action Items

Action item	Status
45 Determine whether electronic filters in external cables are located in boxes or at Top Hat.	Filter responsibility has been moved from probe to electronics; probable that every cable will have some filter at Top Hat.
55 Review limits on ground loops and thermomagnetic sources.	Requirements under review by Stanford with respect to specific probe design details.
24 Review vacuum & cleanliness requirements with respect to recent gyro operations.	Revised Vacuum and Cleanliness Requirements Document about to be released by Stanford; have been working on draft revision with Stanford and foresee no problems.
64 Determine need to coat inside of probe vacuum shell with superconducting metal to shield SIA from Johnson noise in aluminum shell.	Reviewing options and related cost/ schedule impacts with Stanford; will be resolved prior to vacuum shell design release.

PDR Action Items

Action item	Status
10 Identify window coating life tests.	Sensitivity of coatings to expected orbital environment is being discussed with coating vendors.
15B After mock probe shake test, review data with respect to plans for shaking Probe-B and Probe-C.	Mock probe shake completed on 16 Mar 95.

Closure Plan for Action Items

- Open action items from previous reviews will be tracked to closure along with new action items from this CDR.
- Closure of Action Items require approval by Lockheed payload CSE (Stuart Calhoon) and Stanford Hardware Manager (John Turneaure).
- Action Item status is tracked by Stanford at Monthly Reviews.
- Action Item status is tracked by Lockheed payload management at weekly milestone meeting.

AI#	ASSIGNEE	SUBJECT
1	Bardas	Determine if the SIA-to-Probe ICD needs to be changed to accommodate a larger capacitor bank.
2	Bardas	Possible new mounting holes on spider for additional SQUIDs
3	Bardas, Ross	Provide information on new type of seals to be considered as alternates for C-seals.
4	Calhoon	Identify the person responsible for the overall grounding and EMI shielding for the payload probe, dewar and electronics.
5	Calhoon	Review the gap and profile for the QBS/vacuum shell bumpers at the bird cage to address concerns about differential shrinkage during cooldown, vibration performance and ease of integration.
6	Dobrov	Prepare PCB Change Request for recommended changes to spec; include addition of 70 kHz operating frequency, rewriting capacitance stability requirement at 1 kHz, requirements to be at roll frequency, as well as changes shown on chart.
7	Kasdin	Determine whether QBS needs to be shortened to move the gyros back to the location specified on the ICD.
8	Kasdin	Determine the requirements on the orientation reference surfaces and marks (fiducials) for the SIA position and orientation.
9	Parmley	Is there a potential for significant thermal grounding between the QBS and vacuum shell at the bumpers due to high contact forces?
10	Reynolds	Evaluate benefits and cost of performing acceptance tests on probe electrical cable cross-talk by running a signal through one cable while monitoring the other sensitive cables. Review with EMI committee.
11	Bardas	Define valve telemetry.
12	Bardas	Identify location of interface connector for proof mass fiber optics.
13	Buchman	Define the requirement on bias between the gyro ground plane and the suspension electronics ground reference; this will determine number of ground coax cables required in probe-C.
14	Buchman	Define requirements for bias voltage signal for UV charge control system. Are additional wires or cables required?
15	Buchman	Will proof mass cables be identical to gyro cables? Are ground cables required for proof mass?
16	Cliff	Define the overall grounding plan for the payload. Have plan reviewed by Stanford EMI committee.
17	Lockhart	Determine the criteria for approving stainless steel for use in zone SP; define usage restrictions (ex: circlips in Gamah connectors)

AI#	ASSIGNEE	SUBJECT
18	Nakashima Reynolds	Define requirements for GMA-to-top hat plumbing line to introduce spin-down gas into the probe.
19	Ross	Convene a Working Group meeting to review the thermal interface between the SIA and probe. Evaluate location of GRT used for SIA temperature control.
20	Ross	Prepare PCB to eliminate 77 K detector provisions.
21	Turneaure	Current spec requires ≤ 250 µW radiation into SIA during normal operation; possibly should be 250 µW on ground, 100 µW on orbit.
22	Buchman	Evaluate impact of providing only 2 fibers per gyro, 2 fibers to the proof mass, and 2 total spares at spider (12 total fibers) as compared to 2 fibers plus a spare for each gyro and the proof mass (15 total fibers).
23	Buchman Turneaure	Possible change in flow rate from 2.0 to 2.8 mg/sec.
24	Keiser	Review the vacuum requirements and the cleanliness requirements in light of recent experience with gyro operations.
25	Lockhart	CNT titanium foil resistance is too high
26	Lockhart	Specify limitations on use and location of superconducting metals (indium, etc.).
27	Bardas	Are the current access holes adequate for integration activity?
28	Bardas	Need to verify integration method for mounting SIA to QBS at room temperature.
29	Bardas	Valve actuators have not been developed for flight. Define valve type and redundancy.
30	Bardas	Is a filter required to prevent a small magnetic particle from migrating into bellows?
31	Bardas	New SQUID cable configuration and pin assignments for probe-C. Requires new layout for Stanford jumper cables on spider.
32	Bardas Reynolds, Taber, Keiser	Prepare bakeout plan for assembly and integration of probe and SIA. Address condensation of outgassing material on optics.
33	Buchman	Possible change in insulator material to provide higher breakdown capability. Ref: number of cables action items 14,15)
34	Calhoon	Review the level of proof pressure; trade off manufacturing quality assurance vs risk of failure on launch
35	Calhoon	Must add shutter power consumption to budget.
36	Chilese	Evaluate adhesion and flaking of Paralyne coating; concerns expressed by Mike Taber based on their experience.
37	Chilese	How can interior of 0.005 ID lines be cleaned?

AI#	ASSIGNEE	SUBJECT
38	Chilese	Will He3 or He4 be used to pressurize the system?
39	Chilese	Perform end-to-end optical system analysis
40	Chilese	Perform stray light analysis
41	Chilese	Evaluate effect of fluorescence in window 4 for guide star of magnitude 6 or greater.
42	Chilese	Window 4 vacuum seal may not be producible.
43	Chilese	Possible change in material to reduce flourescence.
44	Chilese	Grounding requirements for window is not consistent with EMI requirement.
45	Cliff	Can filter connectors be moved to electronics boxes. If not, define temperature control requirements (if any).
46	Dineen	Evaluate performance of spin-up filter heaters with higher gas flow rate (2.8 mg/s). Ref: gas flow rate action item 23.
47	Dineen	Interface location for I8 and I9 needs to be defined.
48	Ernie	Prepare magnetic req'ts compliance matrix for zone 2
49	everyone	Reduce mass of probe where feasible and cost effective.
50	Goodman	Verfiy pressure drops in spin-up system and probe body during spin-up.
51	Goodman	Perform transient thermal analysis for motion of tophat relative to dewar as the vacuum shell shrinks on orbit
52	Goodman	Perform transient thermal analysis for temperature distribution (subcooling) after liftoff
53	Goodman	Verify capability of heaters to selectively heat portions of probe to desired temperatures
54	Goodman	Need to analyze additional heat leak down larger cables.
55	Iufer	Review limits on ground loops and thermomagnetic sources
56	Keiser	Possible change in operational frequency.
57	Lockhart	review adequacy of test methodology for zone 2 parts; new zones and req'ts
58	Lockhart	SQUID filter connectors may not meet no–resonance requirements.
59	Lockhart	Thermal stability of SQUID filter connectors to achieve requirements has not been established.
60	Lockhart	Possible change in SQUID operating frequency and source and load impendances.
61	Lockhart	Grounding issues: multiple contact point between plumbing and caging lines in extrusion, do bond joints break conductive paths, grounding of plumbing at top hat and STA 200.
62	Lockhart Cliff	Define EMI attenuation requirements for sunshade.
63	Lockhart Dineen	Define capacitance stability of SQUID filters at roll frequency; specify temperature for filter tests.

AI#	ASSIGNEE	SUBJECT
64	Muhlfelder	Potential need to coat inside of vacuum shell with a superconducting metal to shield the instrument from Johnson noise in normal metal.
65	Nakashima	Define reliability requirements for valves and electronics. Ref: valve action item 29.
66	Reynolds	Review helicoflex tests from dewar and cleaning requirements when replacing a seal
67	Reynolds Vassar	Evaluate the impact of solar radiation directly into the probe through open side-mounted gate valves during spin-up and low temperature bakeout.
68	Ross	Determine how to document different requirements for probe-B and probe-C after probe-B in completed.
69	Ross	Create an EMI section in specification to consolidate all EMI requirements.
70	Ross	Define allowable shock and torque applied to spacecraft by shutter.
71	Sands	Bird cage bumper must be integrated into design.
72	Sands	STA 167 plumbing saddle protrudes into stayout zone for telescope
73	Sands	Add saddles in plumbing extrusion to prevent lines from touching extrusion. Ref: grounding action item 61.
74	Sands, Bardas	Modify clearances for cables. Tighten up tolerances on cable interface location in x-y plane.
75	Sokolsky	Ensure that transportation and handling loads are evaluated in structural analysis.
76	Sokolsky	Reanalyze loads due to sunshade weight increase (if required with latest PCB change to a fixed sunshade).
77	Sokolsky Parmley	Does the addition of the bumpers allow the thickness of the QBS to be reduced to save weight?
78	Turneaure Chilese	Burst disks may not protect bellows from failure due to poor flow conductance of tubes.
79	Will	Reevaluate bellows design and material to eliminate welding problems.
80	Will, Keiser	Define specification on acceptable pinhole size.
81	Reynolds Lepetich	Verify bumper design, cable structure and support, and fastener adequacy during vibration test.
82	Taber	Report performance of probe-B in GTU-1 tests: thermal perfomance,temperatures in SIA, effectiveness of flux-flushing and low-temp bakeout, electrical cable performance.
83	Iufer	Verify total magnetic performance of probe at Ames.

	Assignee	Author	Full Action Statement
1	Ross	Ingraham	Establish list of all actions necessary for probe-B to be flown instead of probe-C. Make 1 person responsible for list. Solicit input from everyone. Divide into necessary vs desired actions. Provide system for individuals to add to list until launch.
2	Vassar	Richards	Assess the feasibility/desirability of making the shutter and sunshade such that they can be separated so that the sunshade can be added later with the maximum length.
3	Dineen	Bardas	Reevaluate caging solder. SVA experience shows Indalloy#9 is very difficult to work with, The ???? Stanford paste works much better but had some questionable metallurgy. This was marginal in the last analysis several years ago.
4	Nakashima	Bardas, Calhoon	Should the bakeout be done before or after SIA mass model is installed at LMSC? Would it affect the bakeout? Does it degrade the wt & CG measurements? Installing it early saves 1 open/close/bakeout cycle.
5	Cliff	Buchman	Cold–end fiber optic Lemos need to be isolated from ground. Should shields be isolated?
6	Buchman	Buchman	Determine grounding limits on cavity metalization; 15 mV or 3 mV.
7	Calhoon	Calhoon	Submit Data Items that were not available at the PDR. CIL, LLIL, drawing tree, ICDs 112, 115, 116,4159
8	Cliff	Cliff	Determine whether the final (cold) spinup gas filter should be electrically grounded or floating.
9	Triebes	Green	Relook at window #4 to ensure all condensables on Earth will not cause problems on orbit.
10	Nakashima	Green	Identify window coating life tests.
11	Whelan	Parkinson	Disucss and coordinate the probe-B measured weight and CG discrepancies with spacecraft people.
12	Calhoon	Sullivan	Expand the LMSC Approved Material & Process List, LSE–03, to include materials and processes approved for zone 1. If it cannot be modified, develop a similar independent document.
13	Calhoon	Sullivan	Implement a materials database which would list quantities of materials in stock with magnetic and contamination zone assigned. This could be two lists, but both groups should have access such that material emergencies can be better dealt with.
14	Lipa	Turneaure	Need to establish TBD interface to window #4 flange to allow the possibility of attaching star simulator with vacuum seal to allow test of telescope system in PL configuration.
15A	Sokolsky	Turneaure	A-Review adequacy of instr. planned for mock probe test.
15B	Sokolsky	Turneaure	B- After "Mock probe shake test" convene working group to review data and plans for shaking probe-B and C. The concern is that the sine dwell at 5g and 3g can excite hi Q modes to very high levels.
16	Green	Turneaure	What is the schedule for experimentally verifying the 40dB EMI attenuation of window #4? Carry out an analysis of the EM field from antennas reaching window #4. (TBD-Define and carry out development test with antenna, sunshade, and window #4).
17	Nakashima	Turneaure	Prior to CDR, coordinate probe-C verification test flow at Stanford with Mike Taber.
18	Nakashima	Turneaure	Stanford review of probe-C components test matrix. Include issues of cost, schedule, and technical risks. How many are needed. Can qual unit be used as flight unit or flight spare? What components should be shaken prior to the probe-B shake?

	Assignee	Author	Full Action Statement
19	Turneaure	Turneaure	Stanford to give a full review of probe-B specification as given in PL spec version 3.0. Should be completed in about 1 month.
20	Dineen	Turneaure	Fiber optical cables inside of top hat of probe-B do not look well supported during shake. Has an analysis been done? What ar the results?
21	Dineen	Turneaure	Investigate Parylene.
22	Ross	Vassar	Update document tree in Science Payload Spec v3.0 (p.11) to reflect current program document tree (titles, numbers, heirarchy, separate electronics documents, etc.) Richard has one from NA Review.

ACTION ITEM 4

Identify the person responsible for the overall grounding and EMI shielding for the payload probe, dewar and electronics.

RESPONSE SUMMARY

Rodger Cliff is the Lockheed payload engineer responsible for the overall grounding and EMI shielding.

Stuart J Calhoon

Stuart Calhoon

approved:

John Turneaure, Stanford

Stuart J Calhoon

Stuart Calhoon, LMSC

Probe-C Requirements Review Action Item # 5.

Assignee: Stuart Calhoon and Larry Sokolsky

Action Item: Review the gap and profile for the QBS / vacuum shell bumpers at the birdcage to address concerns about differential shrinkage during cool-down, vibration performance, and ease of integration.

Response: The bumpers in question are the eight bumpers added at the cold end of Probe-B, near the spider. Their purpose is to limit the travel of the birdcage before it strikes the vacuum shell, to prevent high-energy impacts from occurring during launch. They are similar to the bumper located near the QBA mounting fingers, with two primary differences:

- first, the ~~QBA~~ QBS bumper is a solid ring, designed to contact another solid ring -- the vacuum shell. The birdcage bumper is eight discrete pads mounted on the birdcage extrusions, which then are designed to contact a ring bonded into the vacuum shell.
- second, the ~~QBA~~ QBS bumper is designed to have a nominal radial gap of 0.004 in. The birdcage bumper is designed to have a nominal radial gap of 0.008 in.

Differential Shrinkage -

When the cool-down occurs, the vacuum shell and the birdcage both shrink by 0.0186 in on radius. The concern is that the vacuum shell cools more quickly than the birdcage, causing contact and potentially high forces to be generated before the shrinkages equalize.

Tests were done on Probe-A back in September 1992 to measure the differential temperatures during cool-down. The worst-case result between the vacuum shell and the QBS (5" in the +z direction from the QB/QBS finger flange) was 63 K. This occurred when the vacuum shell reached ~ 75 K while the QBS was still at ~ 138 K. Differential contraction at this point is equal to .005" on radius.

Larry Sokolsky previously analyzed this issue for the ~~QBA~~ QBS bumper, which is a worse case, since the contact consists of a full ring contacting a full ring. Larry calculated that the stress generated in this case was 24.5 ksi for the vacuum shell and 8.8 ksi for the QBS. This analysis assumed a 0.010" overlap, which is conservative. A 63 K delta-T should cause only a .001" overlap under nominal conditions.

The stress generated at the new bumpers will be less. Since there are eight discrete bumpers, when contact is made, the birdcage and the vacuum shell will tend to distort elastically by bending, rather than trying to expand circularly. In addition, since the nominal gap is larger, the amount of interference will be less, if it interferes at all. Note that the predicted differential shrinkage is .005", vs. a nominal gap of .008". Also, not taken into account, if interference does occur, the heat transfer path between the two structures would be ~~greatly~~ increased, tending to ~~eliminate~~ reduce the delta-T. ~~quickly.~~

Vibration Performance -

The current design for these bumpers consists of magnaplated aluminum bumpers contacting an aluminum ring. This is the same approach as the QBS bumper. Magnaplate is a Teflon-impregnated anodize and gives a hard, durable surface. The Teflon is impregnated in the porous anodize surface -- it is not a separate layer on the surface. The contact forces have been minimized by keeping the gaps small -- the QBS / birdcage assembly cannot develop significant speed or energy in the small amount of travel it is allowed. Therefore, the force of impact will be low, and the impacting surface has a protective coating to minimize the chance of particulation.

There is a small risk of particulation occurring. Further analysis would be of limited value in this area. This issue could only be fully resolved by test. The planned shake test of Probe-B should provide confirmation.

Integration -

When the vacuum shell is installed over the QBS/birdcage assembly, these bumpers act as a centering device during the last 1" of travel. The bumpers have tapered leading edges with Teflon anodize to facilitate smooth operation. The bumpers have a half-inch long, 5°-sloped leading edge, and the edge of the ring inside the vacuum shell is rounded, so no difficulty installing the vacuum shell is expected. The final positioning is determined by the base of the vacuum shell where it slips into a groove on the Station 200 ring.

PREPARED:

S J Calhoon 6/9/94
Stuart Calhoon Date

6/9/94
Larry Sokolsky Date

APPROVED:

S J Calhoon
Stuart Calhoon, LMSC

J P Turnea
John Turneaure, Stanford

STANFORD   Lockheed

Program Control Board Change Request

page 1 of 2

PCB number 77
Class I / II to NASA II

Action Item # 6

Screening Committee Disposition:

Approved for implementation ( )
Submit to full PCB for decision ( )
date of approval
Screening Chairman

PCB disposition:

Rejected ( )
Approved ( )
date of approval
PCB Chairman

Concurrence:

SU Hardware Manager
SU Spacecraft Manager
PL Program Manager
PL CSE
SC Program Manager

Description of Proposed Change:

- Revise the dissipation factor requirement for the suspension coax cables to become a product of dissipation and capacitance. Change 2 kHz requirement from .002 to .300 pF (150 pF x .002) and change 1 MHz requirement from .025 to 3.75 pF (150 pF x .002).

- Change the 1 MHz suspension cable operating frequency to 70 kHz. The electrical requirements would stay the same but now apply at 70 kHz.

Reason for the Proposed Change:

- The impact of dissipation on performance is proportional to the product of dissipation and capacitance. Therefore, dissipation factor is not an independent requirement and should be specified as a function of total cable capacitance. The current requirement assumes a cable capacitance of 150 pF, the maximum allowable per the spec. If the cables can be designed to be under 150 pF, the dissipation could proportionally exceed .002 without impacting performance. Probe-B coax cables use up less than half of their capacitance budget while they barely meet the current dissipation requirement.

- The 70 kHz frequency substitution will reduce the noise in the squid circuit

Technical Impact of Proposed Change:

- 70 kHz change: Unknown cable capacitance and dissipation at 70 kHz. Capacitance is not very frequency dependent and dissipation should be reduced by going from 1 MHz to 70 kHz.

Impact if not approved:

- Dissipation change: Difficult to meet dissipation requirement under current specification.

Reviewed with the following Stanford screening committees (list the individual) and individuals:

Contamination & Vacuum Committee ( )
EMI Committee ( ) none
Magnetics Committee ( )

Originator Dobrov
Date of submittal 4 May 94

STANFORD   Lockheed

PCB # 77 **Cost & Schedule Impact of Change Request** page 2 of 2

Cost of Implementing Proposed Change:

none

Schedule Impact of Implementing Proposed Change:

none

Note: These cost and schedule impact estimates are not automatically incorporated into the contract. Actual dollar amount added to contract and any change in program milestones will be defined in a contract amendment.

Effect of Implementing Proposed Change on Controlled Budgets and Documents:

Weight: none

Electrical Power: none

Lifetime: none

Documents and Drawings Affected: Payload specification F277277

Recommendation to PCB:

Approve change.

PCB Disposition (to be completed at the PCB meeting):

MEMORANDUM

FROM: N. Jeremy Kasdin
SUBJECT: Probe C Requirements Review AI #7
CC:
DATE: 5/24/94

This memo is in response to Probe C Requirements Review Action Item #7, "Determine whether the QBS needs to be shortened to move the gyros back to the location specified in the ICD."

The source of the AI is the new "egg crate" between the probe fingers and the QBS flange. This results in a QB location approximately 30 mils to the rear of the defined location specified in the Probe to Quartz Block ICD.

The only impact of the change is that the proof mass and gyroscope center are moved rearward relative to the vehicle center-of-mass. This has some influence on the gravity gradient force acting on the drag free controller and the possibility of using gyroscope #2 as a drag free sensor.

However, the amount the QB position has changed is exceedingly small compared to the capability of the translational control system and differences in location between the various drag free sensor options. The extra cost and effort involved in redesigning the QBS is not warranted.

Conclusion: The QBS does not need to be shortened to move the gyros back to the location specified. The ICD should be updated to reflect the new QB position.

Submitted:

N. Jeremy Kasdin

Approved:

5/28/94
John Turneaure

SJ Calhoon 6/9/94

ACTION ITEM REPORT

REVIEW/MEETING: Probe C Requirements Review

Action Item #: 8

Status: Closed

Date: May 27, 1994

Assignee: Jeremy Kasdin

Action: Determine the requirements on the orientation reference surfaces and marks (fiducials) for the SIA position and orientation.

Response:

There are many issues and requirements regarding alignment of the SIA and mounting to the probe. I am currently studying all the alignment requirements (gyros to QB, telescope to QB, proof mass, pick-up loops, SIA to Probe, etc.) and plan a report that will also satisfy the NASA Marshall requirement for an Instrument Alignment Plan. However, this action item specifically addresses the requirements for fiducials on the outside of the Dewar marking the location and orientation of the SIA. I will not, therefore, discuss here the larger question of alignment requirements within the SIA and allocations to various parts of the payload. I will only address the question of reference marks on the dewar.

There are three areas impacted by proper fiducials on the dewar: cryogenic operations in FIST Ops, mounting and alignment of spacecraft hardware (star trackers, control gyros, thrusters, antennas, etc.), and mass balancing the vehicle after integration (spin table alignment, mass trim mechanism adjustment, ballast, etc.). The current requirement for alignment fiducials on the dewar is stated in section 3.7.4.3 of the Science Payload Specification:

> **3.7.4.3 External Alignment Reference**
> A reference surface that is on the top exterior of the dewar shall be aligned to ± 0.25 degrees, to the QBA mounting flange. This surface shall be controlled by LMSC ICD drawing 5833116.
>
> *FIST provided reference surfaces that were accurate to ±1.0° for roll about the z* axis and ±0.25° relative to the QBA/Science Telescope interface. This section requires that Stanford further clarify the probe position reference marks so that the information can be incorporated into the ICD drawing.*

This requirement was derived primarily by considering cryogenic operations at Stanford. The original rationale is still valid and this requirement is still in force, that is, ±1 deg in roll and ±0.25 deg in pitch/yaw.

Spacecraft equipment mounting and mass balancing require more accurate reference surfaces (primarily driven by mass balancing requirements).

Orientation

The reference surface marks for SIA orientation are provided by the star tracker platform mounts. The current requirement for roll orientation of these mounts is stated in T003:

> *20.2 QB Roll Reference*
>
> *The uncertainty (electrical and mechanical) of the roll angle reference system with respect to a quartz block reference shall not exceed 1 deg at the beginning of Science Data measurement. Total random changes in this number shall not exceed 10 arcsec/year.*

This implies that the star tracker platform mount must be stable and marked such that the fiducial provides roll angle knowledge relative to the readout loop plane better than 1 degree. This fiducial accuracy is adequate for test operations, for spacecraft alignment, and for mass balancing. No further PCB action is required for the roll angle fiducial.

The pitch/yaw accuracy for the star tracker platform mounts is less critical and is driven only by manufacturing requirements of the star tracker platform and mounting of the star trackers. As the platform itself is provided by the spacecraft contractor, the payload contractor only supplies a bolt hole pattern on the dewar. There is no requirement on orientation of this bolt hole pattern beyond the circumferential position implied by the roll angle requirement above. Final alignment of the star tracker platforms will be provided by referencing to an optical flat with cross hairs located on the telescope corrector plate just behind the tertiary mirror, directly bypassing any dewar fiducials. The spacecraft contractor plans to align an optical cube on the star tracker platform relative to the telescope optical flat and then mount their equipment using an optical alignment system. This system should align the trackers to better than 30 arcsec, good enough for star acquisition. It will also be used for mounting and aligning the control gyros, thrusters, and mass trim mechanisms. Ground based mass trim will be done using the optical flat directly while on the spin table.

This does imply tight requirements on the alignment and characteristics of the telescope optical alignment fixture that are still TBD (the current plan is to align the optical flat to the telescope boresight and quartz block axis to better than 5 arcsec). These will be submitted as a separate PCB item.

There are no additional requirements for orientation fiducials on the dewar. The tracker mount locations in roll, combined with the optical flat on the SIA, and the current fiducials for ground test are adequate.

Position

The required knowledge of SIA position is driven by mass properties adjustments, which is performed using the cross hairs on the optical flat on the telescope. The radial (x-y) position of the center of the proof mass cavity is determined by the center of the cross hair on the telescope optical flat. The position alignment of the flat cross hairs is

TBD (but is currently planned to better than 0.1 mm). <u>There is no requirement for fiducials on the outside of the dewar marking the x-y position of the SIA.</u>

The axial (z) position of the SIA is not determined by the optical flat. However, manufacturing tolerances relative to station 200 are such that any fiducial at station 200 is adequate. There is much less sensitivity to axial position error in both spacecraft alignment and mass properties. Therefore, a reference mark at station 200 with an accuracy of 1 mm is more than adequate.

Prepared by:

N. Jeremy Kasdin

Approved by:

Doron Bardas

Doron Bardas

Approved by:

John P. Turneaure

John Turneaure

Approved by:

Bill Reeve, LMSC SSD

Approved by:

S J Calhoon

Stuart Calhoon, LMSC RDD

5/9/94

RESPONSE TO PROBE C RR ACTION ITEM NO. 9

ACTION ITEM:

Is there a potential for significant thermal grounding between the QBS and vacuum shell at the bumpers due to high contact forces?

Response:

If the QBS and the vacuum shell touch at the bumpers in orbit at Sta 162.84 and Sta 142.16, the following effects will occur. The SIA will run colder than predicted and an asymmetric temperature gradient will be established at these two stations (if both are touching). More heater power will be required for gyro spinup, flux flushing and low temperature bakeout.

The radial gap was investigated and is as follows if all tolerances are maintained. (Fig. 1)

Sta 162.84	.004 ± .002 in.
Sta 142.16	.007 ± .001 in.

If the gaps are not maintained and there is interference, the force generated at Sta 162.84 is shown in Fig. 2. The conductance at this interference point as a function of force and temperature is shown in Fig. 3. Since the force due to potential interference will not be known until final assembly and testing of the probes, the magnitude of the forces can only be handled on a parametric basis as shown in Figs. 2 and 3. However, let's assume the worst case interference at Sta. 162.84 is six mils. From Fig. 2 the force is ~ 150 lb_f . The resulting conductance from Fig. 3 is 3.5 mW/K at 2.5 K. Since the heater power required in mW is:

	Spinup	Low Temp Bakeout	Flux Flushing
Vacuum Shell	--	180	--
QBS Finger	270	175	490
Spinup Gas Filter	90	--	--
Plumbing Saddle	--	110	--
Cryopump	--	5	--

and the design margin is a factor of two, no changes in the specified heater sizing is required.

Conclusions

Touching of the bumpers in orbit probably is not a problem if interference is less than six mils. The SIA will run colder (desirable), an axisymmetric temperature gradient will be established around the fingers and/or bird cage (requires test data to assess the impact) and the heater sizing can handle the additional thermal short to Sta 200. Particle generation at the bumpers during vibration is a potential problem whether the bumpers touch or not.

Prepared by

R. T. Parmley

R. T. Parmley

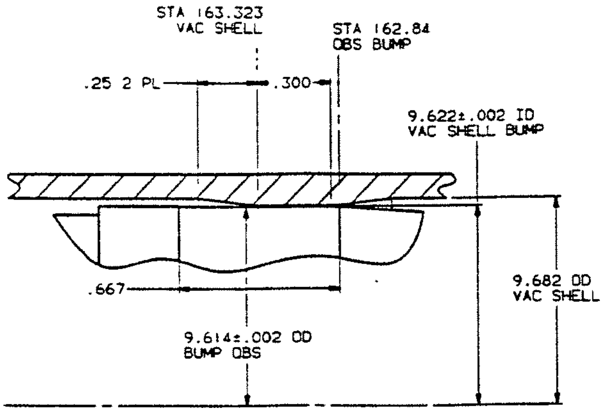
Approved by

S J Calhoon

S. Calhoon, LMSC

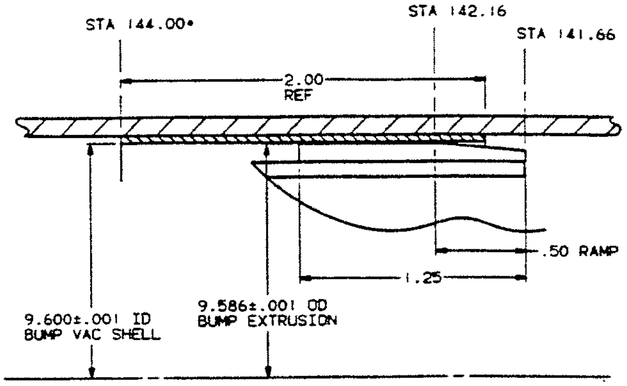
John P. Turne

J. Turneaure, Stanford



RADIAL GAP

MIN	NOM.	MAX
9.620	9.622	9.624
− 9.616	− 9.614	9.612
2⟌.004	2⟌.008	2⟌.012
.002	.004	.006



BIRD CAGE BUMP

MATERIALS: VAC SHELL - 6061 ALUM
VAC SHELL BUMP - 6061 ALUM
BIRD CAGE BUMP - 6061 ALUM
BIRD CAGE BUMP IS MAGNAPLATED

RADIAL GAP

MIN	NOM.	MAX
9.599	9.600	9.601
9.587	9.586	9.585
2⟌.012	2⟌.014	2⟌.016
.006	.007	.008

FOR DWG REVISION STATUS
SEE STATUS BLOCK ON SHEET 1

FIG 1 CLEARANCES BETWEEN QBS AND VACUUM SHELL AT BUMPERS

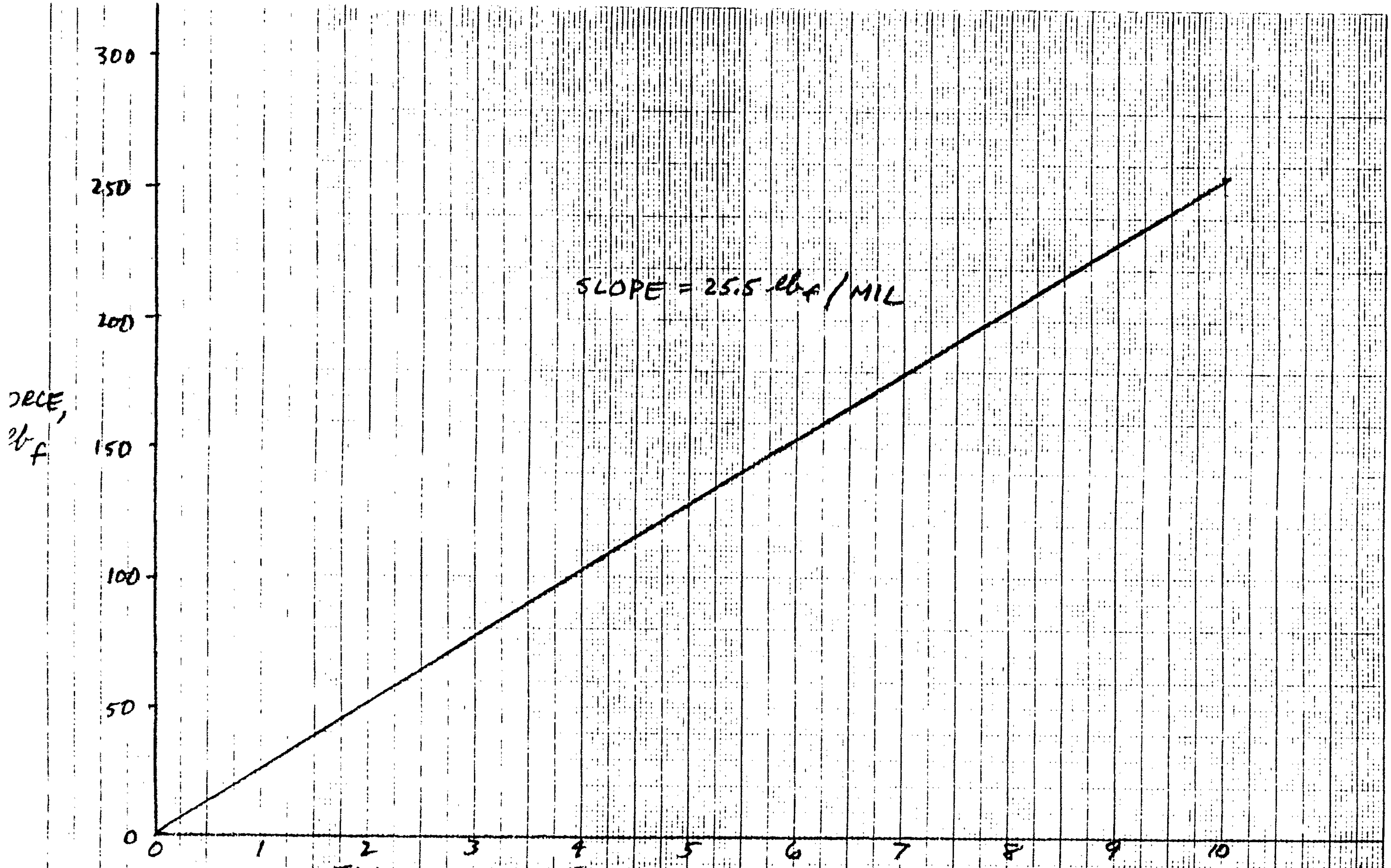
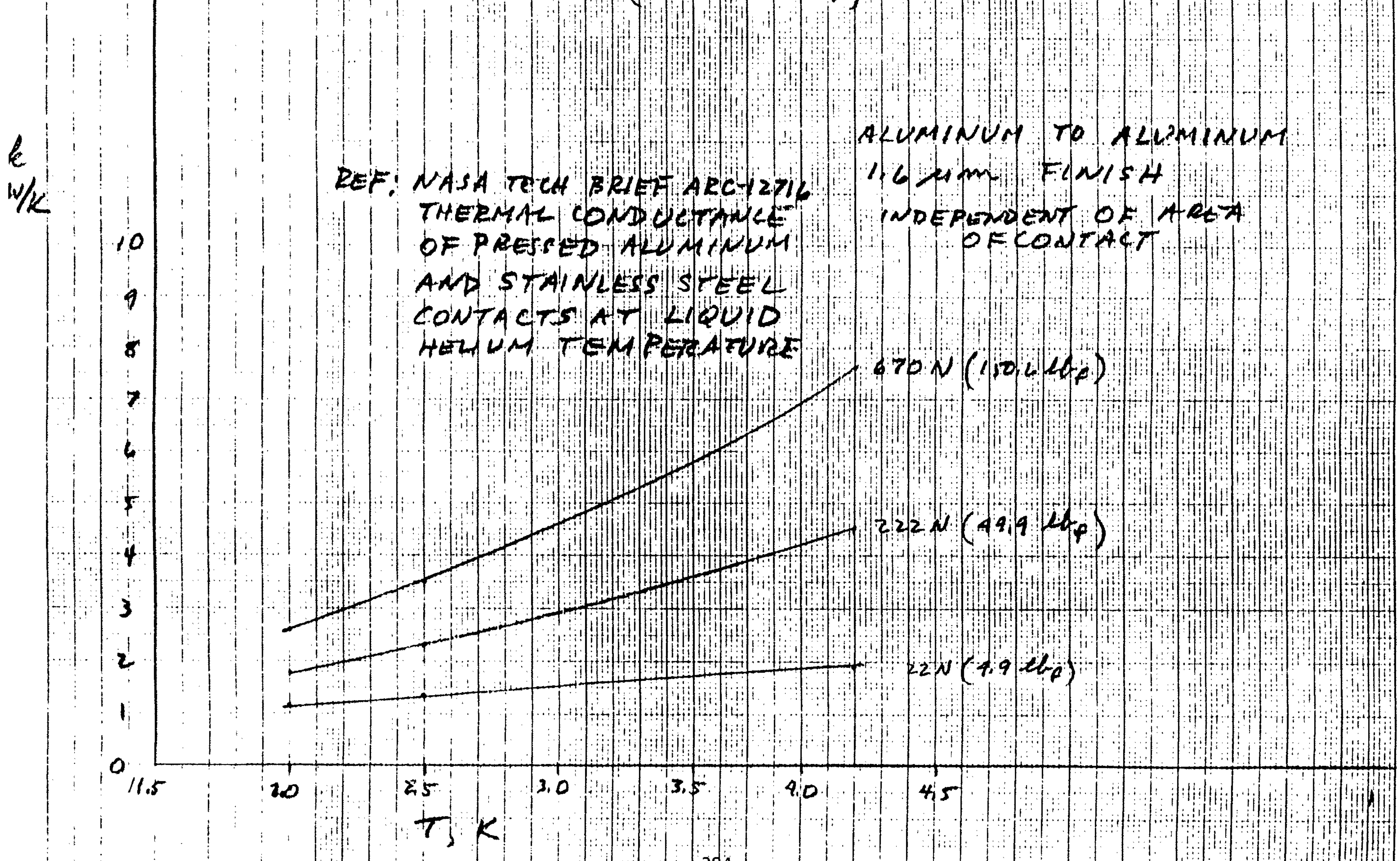


FIG 2 INTERFERENCE AT STA 162.84 BETWEEN QBS AND PROBE VACUUM SHELL, MILS

FIG 3 CONDUCTANCE ACROSS QBS TO VACUUM SHELL AT BUMP (STA 162.84)



2 June 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 10

STATUS: **Closed**

ASSIGNEES: **G. Reynolds** **J.M. Lockhart** **M. Taber**

SIGNATURES:

Action: Evaluate benefits and cost of performing acceptance tests on probe electrical cable cross-talk by running a signal through one cable while monitoring the other sensitive cables. Review with EMI Committee.

Resolution:

Such tests will be performed on Probe B at Stanford. Similar tests on Probe C will be performed only if cable construction or routing is changed significantly . Cost impact of such tests, if required, would be that corresponding to a half day of engineer time per set of tests.

Probe-C Requirements Review Action Item Response

ACTION ITEM #: 11 ASSIGNEE(s): D. Bardas STATUS: Closed

Define valve telemetry
[I assume that what is needed here is a description of how the valves are controlled ands communicate with the ECU. Also, I assume this topic s covers the Leakage gas exhaust valves, the spinup exhaust valves and the GMA valves]

RESPONSE SUMMARY:

See also the attached comments from the PDI electrical engineer on the subject.
The **Leakage gas exhaust valves and the Spinup exhaust valves** have been baselined (pending approval) as 2 ea. 6 inch motorized Vatterfly valves for the former, and 4 ea. 2 inch motorized Vatterfly valves for the latter. The design will follow that of the flight-qualified motorized 4 inch Vatterfly valve, developed in joint effort between Stanford and PDI. One difference is that the present plan is to centralize the electronic controls for the 6 valves in a redundantly configured electronic module located remotely from the valves. This saves on weight and power. [The possibility of placing this module within the ECU can also be investigated]. The basic functions of the PDI motorized Vatterfly valves follows:

- The motor has two redundant windings on one common shaft (MW1 & MW2)
- Associated with each winding are 2 ea. optical switches, one for valve closed and one for open. Thus there are redundant valve closed and open switches.
- It takes *no power* to secure the valve open or closed. It is effectively latched.
- When the 28 ± 4 V power is turned on, the electronics returns a 5 DC signal on different wires [output discrete transistors inactive], identifying the open or closed positions respectively. If the valve seal plate is somewhere in between, the output discrete transistors are active and the signal out is 0 VDC.
- A trigger pulse, ~ 100 ms is needed to activate the motor in either direction. It takes about 13 secs [4 in. valve] to go from closed to open and vice versa. The end of travel is determined by a signal from the respective optical switch.
- The electronics stops the motor upon detection of the AC transition of the light signal from the leading edge of an occulting shutter. For this reason it was necessary to offset the optical switches for MW1 and MW2 by approximately .030 in. so that the go signal to the other motor would not result in the valve shaft pushing into a physical end-stop.
- While the shaft is capable of handling the load this will not happen except for a failure of an optical switch depending on the DEP logic. The sequence is: OPEN: MW1 first, then MW2; CLOSED: MW2 first, then MW1. This ensures no hitting the end-stops. The valve is essentially fully open after running either winding and *is* fully closed after running either winding.

PR-C RR AI#11.061394

Probe-C Requirements Review Action Item Response

The **GMA valves** (Garrett Fluid Systems) are electric solenoid latching valves. They therefore do not require any power to seal or remain open and require only a 28 ± 4 V pulse of ~ 100 ms to change state. In addition, the valve has a micro switch which senses the position of the solenoid actuator rod. This switch can be wired normally open or closed as is suitable for the ECU electronics.

There are many more details on valve operation [particularly PDI] and plans for investigation of temperature performance of electronics and valve components. Please see me for further details before proceeding with designs in this area.

Doron Bardas

Doron Bardas, Stanford

Ron Sharbaugh, LMSC

Approved:

John Turneaure, Stanford

S J Calhoon 7/1/94

Stuart Calhoon, LMSC

Probe-C Requirements Review Action Item Response

B. MEREDITH

Doron:

Perhaps a general note of explanation will help you w/ the details.

Both (Redundant) controllers are designed to detect the leading edge of the command pulse (either extend/open or retract/close). When the edge is detected the following events take place in the controller:

(I.) (1.) A general reset clears previous command and sets the new command.

(2.) A Direction latch is set (open or close)

(3.) A 60 sec time out counter is started.

(4.) The stepper motor is enabled to drive in the direction commanded.

(5.) The valve $\left(\frac{\text{open}}{\text{closed}}\right)$ output transistor switches 'ON' as the valve closes. stop.

(II.) It takes ≈ 15 sec to traverse from open to close (etc.) at which time the following events occur:

(1.) The limit detector senses the leading edge of the shutter vane causing:

(a.) a 1ms Reset pulse to clear the previous command and shut down the motor.

(b.) the valve $\left(\frac{\text{open}}{\text{closed}}\right)$ output transistor to switch 'OFF'

Probe-C Requirements Review Action Item Response

Due to the very short distance set for the secondary limit detector in either the open or closed position - (Remember, this was a mechanical overtravel we set to allow a small amount of additional travel in the VAT actuation mechanism) - The command pulse can effectively over lap the limit detector action. If this occurs the controller will run until the 60 sec. timer clears.

Normal operation of the Redundant command:

III - Repeat of step I

(a) Input command pulse: S/B 75 ms to 2 sec for the 1st command

(b) Input command pulse width cannot exceed (TBD.) pulse width for the 2nd (redundant) command

~ 100 ms

IV Output Discrete Transistor(s) State Diagram —

	M1	M2	M2	M1
Value Position	M1 Open Discrete	M2 - Open Discrete	M2 Closed Discrete	M1 Closed Discrete
M1 - Open Limit	OFF	OFF	Active	Active
M2 - Open Limit	Active	OFF	Active	Active
M2 - Closed Limit	Active	Active	OFF	OFF
M1 - Closed Limit	Active	Active	Active	OFF
M1 - (No Limit)	Active	Active	Active	Active
M2 - (No Limit)	Active	Active	Active	Active

Active = Transistor is ON, current limited to ≤ 20 ma

OFF = Transistor OFF open ckt.

PR-C RR AI#12.061594

Probe-C Requirements Review Action Item Response

ACTION ITEM #: 12 ASSIGNEE(s): D. Bardas/Buchman STATUS: Closed

Identify location of interface connector for proof mass fiber optics.

RESPONSE SUMMARY:

The two proof mass fiber optic connectors shall be located within the same QBS access hole as the coax cables for the proof mass. They shall be disposed either, one on each side of the coax cables, within the access hole, (with the interface at the same station number as the outer row of coaxs), or next to each other on either side of the coaxs with care taken to ensure the greatest possible access for integration. If the latter cases are chosen then the interface locations should be staggered just like those of the large coaxs to provide better access to adjacent connectors.

We would like to study the new flat wrap, or other appropriate pictorial representation of Probe-C, as soon as a preliminary version is available, in order to verify the location of all interfaces and access ports.

Please note that our experience with fiber optic Lemos has been less than ideal. Problems have been encountered with the back nut [breaks easily, delicate], inadequate designs for strain relief of the fiber as it exits the inner tube and back nut, and wedging [design or assembly problem] of the Stanford -side connector in the LMSC-side. In the SVA at least one pair seemed so tightly wedged, once pushed closed, that it is doubtful if we shall be able to disconnect the pair after SimfFight.

Doron Bardas

Doron Bardas, Stanford

Sasha Buchman.

Sasha Buchman, Stanford

Approved:

John Turneaure, Stanford

S J Calhoon 6/28/94

Stuart Calhoon, LMSC

SUBJECT: **Probe C. Requirements Review**

Action item #: **13**

STATUS: **Closed**

DATE: **23 May, 1994**

ASSIGNEES: **J. Turneaure** **S. Buchman** **M. Keiser** **R. Cliff**

Signatures: J.P. Turneaure S. Buchman M Keiser
SJ Calhoon

Action: Define the requirement on bias between the gyro ground plane and the suspension electronics ground reference; this will determine number of ground coax cables required in probe-C.

Resolution:

1) The bias between the gyro housing ground plane (cavity coating) and the suspension system ground reference to be less than (or equal to) $\leq$ **3 mV** as measured at the cold gyroscope. This will add less than 20% to the 15 mV bias given by the limit on the gyro charging. The implication is that ground cables are required and that the inner conductor of these cables should be identical to the suspension cable inner conductors.
2) Two ground cables are required per gyroscope to allow ground suspension testing with supplementary support.
3) The total number of ground cables (and spares) is also the subject of PCB #65 (Roger Cliff, S. Buchman), as a function of total space available at top hat for other additional connectors.

Tel: (415) 725-4110 Fax: (415) 725-8312 Email: sasha@relgyro.stanford.edu

SUBJECT: **Probe C. Requirements Review**

Action item #: **14**

STATUS: **Closed**

DATE: **23 May, 1994**

ASSIGNEES: **J. Turneaure** **S. Buchman** **R. Brumley**

Signatures: S. Buchman R Brumley SJ Calhoon

Action: Define requirements for bias voltage signal for UV charge control system. Are additional wires or cables required?

Resolution:

1) The UV bias voltages available should be **0 V, +4 V, and -4 V**.

2) One UV bias cable should be provided per UV fiber, for a total of 12 cables (4 gyroscopes, proof mass, and 2 cable spares).

3) The bias between the suspension electronics ground cable and the UV bias nominal 0 V should be less than 50 mV at the cold gyroscope.

4) The bias cables should be shielded and filtered, to avoid introducing noise in the read-out; as per **Jim Lockhart TBD**. Consider also the requirements for cable isolation and termination to be able to withstand arcing from the gyroscope (the distance to the gyroscope is 10m").

5) The total number of UV bias cables is also subject to PCB #65 (Roger Cliff, S. Buchman), as a function of total space available at top hat for other additional connectors.

Tel: (415) 725-4110 Fax: (415) 725-8312 Email: sasha@relgyro.stanford.edu

SUBJECT: **Probe C. Requirements Review**

Action item #: **15**

STATUS: **Closed**

DATE: **23 May, 1994**

ASSIGNEES: **J. Turneaure** **S. Buchman** **M. Keiser** **R. Cliff**

Signatures: John P. Turneaure S. Buchman JM Keiser Robert D. Cliff
J. Calhoon

Action: Will proof mass cables be identical to gyro cables? Are ground cables required for proof mass?

Resolution:

1) Proof Mass suspension cables will be identical to gyroscope suspension cables. This will allow suspension and pendulation verification of the Proof Mass in the cold probe.
2) Ground cables are required for Proof Mass.
3) The bias between the Proof Mass housing ground plane (cavity coating) and the suspension system ground reference to be less than (or equal to) $\leq$ **3 mV** as measured at the cold Proof Mass. This will add less than 20% to the 15 mV bias given by the limit on the Proof Mass charging. The implication is that ground cables are required and that the inner conductor of these cables should be identical to the suspension cable inner conductors.
4) Two ground cables are required for the Proof Mass to allow ground suspension testing with supplementary support.
5) The total number of Proof Mass cables (and spares) is also subject to PCB #65 (Roger Cliff, S. Buchman), as a function of total space available at top hat for other additional connectors.

27 May 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 17

STATUS: **Closed**

ASSIGNEES: **J.M. Lockhart**

SIGNATURES: J. M. Lockhart

Action: Determine the criteria for approving stainless steel for use in zone SP; define usage restrictions (e.g. circlips in Gamah connectors).

Resolution:

Two restrictions are to be applied to the use of stainless steel in Magnetics Zone SP.

1. No stainless steel should be used in zone SP in any case where mechanical rubbing or abrasion of the steel could take place, unless the stainless steel is totally contained within a sealed sub-system such that any particles generated could not possibly migrate into the lead bag region of the Dewar. Stainless steel plated or coated with other (magnetically acceptable) materials may be used in applications where abrasion is encountered if testing establishes that the thickness and strength of the coating is sufficient to guarantee that no migration of steel particles could take place. Threaded stainless steel fasteners may be used if the use is permanent (i.e., no motion of the fastener during installation of the probe in Dewar or during probe operation).

2. The total amount of stainless steel used in the probe must be such that the remnant magnetization resulting from exposure of the probe to a 100 Gauss magnetic field will produce a field at the top of the Cryoperm shield no larger than 0.1 Gauss. In practical terms, this requirement restricts the stainless steel used to the austenitic type, with 304- and 316- series stainless steels recommended and 310- series acceptable.

Approved
John P. Turneaure 5/28/94
John P. Turneaure
SJ Calhoon 6/9/94

Gravity Probe-B FAX

TO John Turneaure
FAX 415/725-8312
DATE May 20, 1994
TEL 415/725-4118

FROM Graham Ross
FAX 415/424-3315
TEL 415/424-3488

CC Stuart Calhoon
Don Hitzl, probe-C RR action item closure

PAGES SENT (INCLUDING COVER) 3

SUBJECT PCB #83

The following pages are PCB #83 to delete the provisions to mount 77K telescope detectors up on heat station ring #2. This closes action item #20 from the probe-C Requirements Review; this FAX serves as the written closure for this action item.

In Mae's absence, I have assumed that the appropriate number for this PCB request is #83, but please have Mae confirm this.

STANFORD

Lockheed

Program Control Board Change Request

page 1 of 2

PCB number 83
Class I / II to NASA II

SCREENING COMMITTEE DISPOSITION:

Approved for implementation ( )
Submit to full PCB for decision ( )
date of approval ______
Screening Chairman ______

PCB DISPOSITION:

Rejected ( )
Approved ( )
date of approval ______
PCB Chairman ______

CONCURRENCE:

SU Hardware Manager ______
SU Spacecraft Manager ______
SU CSE ______
PL Program Manager ______
PL CSE ______
SC Program Manager ______

Description of Proposed Change:

Delete the requirement for probe-C to provide the capability to mount 77K photodetectors in the probe on heat station ring 2.

Reason for the Proposed Change:

Detectors are now mounted directly on the science telescope.
(Ref: probe-C requirements review action item #20)

Technical Impact of Proposed Change:

Simpler machining.

Impact if not approved:

Slight additional effort to machine components and assemble probe.

Reviewed with the following Stanford screening committees (list the individual) and individuals:

Contamination & Vacuum Committee ( ) ______
EMI Committee ( ) ______
Magnetics Committee ( ) ______

Originator G. Ross
Date of submittal 20May94

STANFORD

Lockheed

PCB # 83 **Cost & Schedule Impact of Change Request** page 2 of 2

Cost of Implementing Proposed Change:

none

Schedule Impact of Implementing Proposed Change:

none

Note: These cost and schedule impact estimates are not automatically incorporated into the contract. Actual dollar amount added to contract and any change in program milestones will be defined in a contract amendment.

Effect of Implementing Proposed Change on Controlled Budgets and Documents:

Weight: none

Electrical Power: none

Lifetime: none

Documents and Drawings Affected: probe-to-SIA ICD 5833112
heat station ring drawing, STA 200 drawing

Recommendation to PCB:

Approve change.

PCB Disposition (to be completed at the PCB meeting):

sm/probe_c/rr_ai21.doc

Probe-C Requirements Review Action Item Response

ACTION ITEM #: 21 ASSIGNEE(s): John Turneaure STATUS: Closed

Current specification requires < 0.25 mW thermal radiation into the SIA during normal operation. Should this possibly be < 0.25 mW on the ground, and < 0.10 mW on orbit?

RESPONSE SUMMARY:

The requirement stated in the Payload Specification, Version 2.6 is incomplete. The Stanford response to Probe B PDR Action Item #4 on 9/19/90 states the following:

> "The thermal radiation heat power input into the SIA shall be ≤ 0.25 mW when the outside of the probe and dewar are at 300 K."

The 300 K condition for the outside of the probe and dewar is missing in Version 2.6 of the Payload Specification, and it should be added to the Payload Specification. This requirement was verified in both FIST-B and GTU-0 when the outside of the probe and dewar were at about 300 K. In FIST-B, the measured value is 0.18 mW with metal baffles in place of Windows #1-3. In GTU-0, the measured value is 0.13 mW with windows coated with Au to mimic the emissivity of the multi-layered coatings of Windows #1-3.

Some time before 1990, an analysis was done by LMSC to estimate the thermal radiation passing through Station 200 for both ground conditions (300 K) and orbital conditions (220 K). Unfortunately, I am unable to find this analysis in my records. To first order I would expect that the thermal radiation on orbit (220 K) would be reduced by roughly a factor of $(220/300)^4 = 0.29$, but the actual situation is probably more complicated. Applying this factor to 0.25 mW, yields a thermal radiation level of 0.073 mW.

Although a lower level of thermal radiation heat power input into the SIA is expected on orbit when the outside of the dewar and probe are ~ 220 K, there is no identified need for the value to be less than 0.25 mW. Therefore, I suggest the following requirement:

> "The thermal radiation heat power input into the SIA shall be ≤ 0.25 mW when the outside of the probe and dewar are ≤ 300 K. An estimate of the on-orbit thermal radiation heat power input into the SIA shall be made by analysis when the dewar is at its nominal temperature during the SM data taking phase (~ 220 K)"

S J Calhoon 7/1/94

John P. Turneaure, Stanford

Stuart Calhoon, LMSC

Tel: (415) 725-4110 Fax: (415) 725-8312 Email: sasha@relgyro.stanford.edu

SUBJECT: **Probe C. Requirements Review**

Action item #: **22**

STATUS: **Closed**

DATE: **23 May, 1994**

ASSIGNEES: **J. Turneaure** **S. Buchman** **R. Brumley**

Signatures: S. Buchman R Brumley & J Calhoon

Action: Evaluate impact of providing only 2 fibers per gyro, 2 fibers to the proof mass, and 2 total spares at spider (12 total fibers) as compared to 2 fibers plus a spare for each gyro and the proof mass (15 total fibers).

Resolution:

1) The necessary UV fibers to be provided: 2 per gyroscope, 2 for Proof Mass, 2 spares at spider. Total of 12.
2) Subject to PCB #65, the solution with 15 UV fibers (2 plus 1 spare per gyro and Proof Mass) is preferable but not necessary.
3) The UV fibers (aluminum clad) to be protected with coating or sleeve for avoiding nicks in aluminum coating. Smallest nick causes fiber break.
4) The total number of UV bias cables is also subject to PCB #65 (Roger Cliff, S. Buchman), as a function of total space available at top hat for other additional connectors.

SUBJECT: **Probe C. Requirements Review**

Action item #: **23**

STATUS: **Closed**

DATE: **24 May, 1994**

ASSIGNEES: **J. Turneaure** **S. Buchman**

Signatures: J P. Turn— S. Buchman. SJ Calhoon

Action: Possible change in flow rate from 2.0 to 2.8mg/sec.

Resolution:

1) The maximum flow rate for spin-up to be increased from 2.0 mg/sec to 2.8 mg/sec (950 sccm).

2) No physical changes to probe, plumbing, and ground support equipment.

3) The allowable probe pressure at gyroscope, leakage flow rate, and spin-up exhaust line pressure to be increased accordingly. Initiate **PCB # 84** to incorporate these changes:

   a) Increase spin-up flow rate from 2.0 to 2.8mg/sec.
   b) Increase leakage flow rate accordingly.
   c) Increased allowed probe pressure at gyroscope.
   d) Increase allowed exhaust line pressure.

31 May 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 25

STATUS: **Closed**

ASSIGNEES: **J.M. Lockhart**

SIGNATURES: J M Lockhart

<u>Action:</u> CNT titanium foil resistance is too high.

Resolution:

Section 3.7.2.2.3.3 of the Science Payload Specification shall be changed as follows:

> The resistance of the primary ground path between the top hat and the z* station 200* ring shall be $\leq$ ~~0.5~~ 0.8 Ω.

Lockheed (Reynolds/Dineen) will initiate a PCB request for this specification change.

<u>Approved</u>
J P. Turne 6/4/94
John P. Turneaure
SJ Calhoon 6/9/94

25 May 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 26

STATUS: **Closed**

ASSIGNEES: **J.M. Lockhart**

SIGNATURES:

Approved
J P Turneaure 5/28/94
John P. Turneaure
S J Calhoon 6/9/94

Action: Specify limitations on use and location of superconducting metals (indium, etc).

Resolution: The use of superconducting materials in GP-B probes must be controlled in order to avoid the possibility that significant amounts of magnetic flux become trapped in superconducting circuits during insertion of a probe into a cold Dewar. This trapped flux could then radiate to the gyroscopes and lead to unacceptable trapped flux levels in the gyros.

This problem is of particular concern in the case of superconducting materials which form closed loops of significant area and low inductance.

A second area of concern is the use of superconducitng materials with transition temperatures which fall in the range of temperatures which might be experienced by the probe during the flight mission. Were such materials to fluctuate in and out of the superconducting state during science data gathering, the resulting field noise pickup could impair such data.

The following guidelines for use of superconductors have been established:

1) No superconductors other than the rotor, pickup loop & cable, and local magnetic shield shall be used in Magnetic Zone 1.

2) No superconducting loops of diameter larger than 1.0" shall be formed in Magnetic Zone 2A (within 12 cm of any gyro).

3) No superconducitng loops of diameter larger than 2" shall be formed in Magnetic Zone 2B.

4) No materials having superconducting transitions temperatures in the range 1.8 K - 2.4 K shall be used in Magnetic Zones 1 or 2.

PR-C RR AI#27.070394

Probe-C Requirements Review Action Item Response

ACTION ITEM #: 27 **ASSIGNEE(s):** Bardas **STATUS:** ~~Closed~~ Open

Expected Completion 10/94

Are the current access holes adequate for integration activity?

RESPONSE SUMMARY:

Assuming the reference is to holes in the QBS for Probe-C, I feel that it is somewhat premature to give a definitive answer to this question. Holes in the QBS between the fingers and STA200 were not relevant to Probe-A. Also, although I was involved with the location of holes on the layout and interface drawings of Probe-B, we have yet to see if these choices need modification, especially in the Telescope and Proof Mass connector areas. There will be significant changes in the connector arrangement on the main part of the QBS mostly concerning the large number of extra wires for the Telescope detector. I have not yet seen any drawings of this area and was informed that the Probe-C flat wrap had just been started.

It is therefore prudent to decline full approval of the access holes on the basis that:

% [for Probe-B] they have not been dealt with under integration conditions,

% the Probe-C designs have not yet been available for study.

I believe that access holes similar to those in Probe-B are likely to be workable.

I suggest that a good time for final approval will be when we can study the appropriate Probe-C drawings *after* we have the experience of integrating Probe-B. This should be well timed for Lockheed and Stanford by the end of September, 1994.

Additional Comment re Spider region of QBS:

I am concerned with the bellows arrangement through which the instrumentation wires pass to the Spider. This delicate arrangement is very prone to damage during QB installation into the QBS. This should be carefully studied for Probe-C. Other areas of concern are the caging lines [bending them out of the way] and soldering them. Fiber optics routing is of great concern due to their fragility.. We also have many readout wires from the SQUIDs. I believe the whole Spider area should be thoroughly reviewed after Probe-B integration. prior to approval for Probe-C.

Doron Bardas

Doron Bardas, Stanford

Approved:

John Turneaure, Stanford

Stuart Calhoon, LMSC

PR-C RR AI#28.070394

Probe-C Requirements Review Action Item Response

ACTION ITEM #: 28 **ASSIGNEE(s):** Bardas **STATUS:** Closed

Need to verify integration method for mounting SIA to QBS at room temperature.

RESPONSE SUMMARY:

Based on past experience with the SVA integrations and assisting G. Reynolds and S. Calhoon during trial with a quartz slice to the Probe-B QBS, I feel quite confident that the process is well understood even with the Molybdenum shoes in place.

A Finger Assembly Tool has been developed to precisely control the pushing in of the shoes ~ 4 mils to allow the finger holes to line up with those of the QB flanges. The expectation is that this will go well. We are planning a simulation of the method using the Mock QBS and an Aluminum slice with 4 mil radially offset bolt pattern. This will take place in July 1994. Following that, final verification will be in late August with Probe-B.

One concern that may yield the need for QBS [internal] changes is the fact that, for the first time, we will be inserting the telescope through the birdcage, fingers and saddles in the QBS behind the fingers. Although there are no significant encroachments on the stay-out envelope of 7.7 inches dia., it may prove hard to prevent the telescope from bumping into a QBS feature. Lessons may need to be learned here for Probe-C. Every effort should be made to stay well outside the 7.7 inch envelope. *In fact, from the SVA experience the stayout zone in the region from the QB flange to the forward end of the QB should be 7.9 inches*, which Probe-B already complies with. SGC 7/6/94

Doron Bardas

Doron Bardas, Stanford

Approved:

Jn P. Turnea

John Turneaure, Stanford

Stuart G Calhoon 7/6/94

Stuart Calhoon, LMSC

PR-C RR AI#29.070394

Probe-C Requirements Review Action Item Response

ACTION ITEM #: 29 ASSIGNEE(s): Bardas STATUS: Closed

Valve actuators have not been developed for flight. Define valve type and redundancy.

RESPONSE SUMMARY:

The statement above is simply not true. All actuated valves proposed for use in the SM GMA and for the Spinup Exhaust valves and Leakage Gas Exhaust Valves will be variations of very similar valves developed for the STU EPA. The STU valves were fully developed and qualified for flight; they were shaken to Shuttle launch levels and subjected to wide temperature extremes during operation.

GMA Valves

In the case of the GMA valves the actuator is a latching solenoid mechanism. There is no redundancy in the solenoid valve actuator itself, however, should it fail to open OR close, the redundancy is satisfactorily taken care of by the redundancy in the way the rest of the valves are laid out. Micro switches and the surrounding pressure sensors indicate valve condition. See attached schematics of the SM GMA.

Exhaust Valves

These will be variations on the 4" Vatterfly valve built for STU. The main drive shaft which operates the seal plate is driven by two redundant windings on a common motor shaft. The electronics controlling the motors is redundant, one per winding. In typical operation the winding 1 is activated to open the valve followed by winding 2. The opposite sequence applies to closing the valve. See also AI 11.

In addition, the GMA & Exhaust Valve Working Group has recommended two valves for the critical job of evacuating the probe during spinup. The importance of at least one valve opening [calculations show adequate pumping speed with only one valve] is paramount to GP-B, and thus this additional redundancy was built in.

Doron Bardas

Doron Bardas, Stanford

Approved:

John P. Turneaure

John Turneaure, Stanford

SJ Calhoon 7/6/94

Stuart Calhoon, LMSC

Probe-C Requirements Review Action Item Response

ACTION ITEM #: ~~30~~ 31 ASSIGNEE(s): Bardas STATUS: ~~Closed~~ Open
Expected Completion: 10/94

New SQUID cable configuration and pin assignments for probe-C. Requires new layout for Stanford jumper cables on spider.

RESPONSE SUMMARY:

The routing for the Stanford SQUID jumper cables is now being worked out using the Mock QBS. Our intention is to route the cables for Probe-B as a subset of those for Probe-C. A tentative layout was produced by Tom Meunch [LMSC] when he did the drawings for the "stockades" which will be used with the Mock QBS. Examination of the situation using the Mock QBS's spider has shown that we need to do another iteration of the routing between connectors and the "warm" end of the SQUID packages as well as a modification to the design of the "stockades" themselves.

The final requirements for this layout will be forthcoming by September, 1994, after Probe-B is integrated. Please note, however, that the pin assignments are likely to remain unaffected, and all this will require is routing variations for the cables.

Doron Bardas
Doron Bardas, Stanford

~~Barry Muhlfelder, Stanford~~

Approved:

John Turneaure, Stanford

Stuart Calhoon, LMSC

Interdepartmental Communication **GPB-100396**

To: G. Ross **Org:** 92-10 **Bldg:** 253 **Fac:** 2 **Date:** 30 November 1994

From: L. Sokolsky **Org:** 92-10 **Bldg:** 253 **Fac:** 2 **Ext:** 45973
S. Calhoon

Subject: Response to Probe-C Requirements Review Action Item 34

cc: A. Nakashima

Action Item: Review the level of proof pressure; trade off manufacturing quality assurance vs. risk of failure on launch.

Discussion: Proof pressure testing for Probe-C components is done per the payload specification; this is derived from Mil-Std-1522. For internal pressure, this corresponds to a proof pressure of 1.5x the maximum design pressure (MDP), and for external pressure to 1.0x the MDP. The only exception to this is for the CNT, where the tube is proof-pressure tested for external pressure to 1.5x internal and external pressure. This is done as a quality assurance precaution because of the composite construction.

Because all proof testing is done at or above the levels of the recognized design guidelines, risk of failure on launch is minimized. The proof test levels are adequate for all design regimes.

L. Sokolsky

S J Calhoon
S. Calhoon

12/30/94
John Turneaure

July 25, 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 49

STATUS: **Closed (On going activity during design & analysis phases for Probe C)**

ASSIGNEE: **All (response by R. Whelan, GPB Mass Properties Engineer)**

Action: Reduce Probe weight where feasible and cost effective.

Resolution:

The following areas have been identified for weight reduction:

- Top Hat Nupro Valve Supports
  - -material change from CRES to aluminum
- Top Hat Nupro Valve Support Spacers
  - -material change from CRES to aluminum
  - -redesign to remove material from center
- Telescope weight reduction (8 kg -> 5 kg per telescope PDR)
  - -need detailed analysis or measured weight if a flight-like unit is available.
- Thermal Shoe
  - -redesign for smaller cross-sectional area
- Cross Flange
  - -material change from CRES to aluminum
  - -redesign for lower offset moments due to leakage valve change

Additional areas will be identified as the Probe C design matures. The Probe C design team and analysts will maintain an awareness to consider weight impacts during all change deliberations.

Approval:

S J Calhoon

S. J. Calhoon, LMSC

J. Turneaure, Stanford

11 July 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 57

STATUS: **Closed (Review and Zone Redefinition complete; Magnetic Control Plan to be updated)**

ASSIGNEES: **J.M. Lockhart**

SIGNATURES: JM Lockhart

Action: Review adequacy of test methodology for [Magnetics] Zone 2 parts; new Zones and req'ts

Resolution:

Magnetic Control Zone 2 was sub-divided into Zones 2A and 2B in PCB #87. The LMSC Magnetic Control Plan is being updated (under the auspices of the Stanford/LMSC Magnetics Committee) to reflect the requirements and test methods appropriate to Zones 2A and 2B. The updated Magnetic Control Plans (LMSC + SU) are expected to be written and approved by the end of August 1994.

Approved

John P. Turneaure 7/14/94
John Turneaure

S J Calhoon 7/27/94
Stuart Calhoon, LMSC

22 February 1995

PROBE-C PDR
ACTION ITEM RESPONSE

ACTION ITEM 20: Fiber optic cables inside of top hat inside of probe-B do not look well supported during shake. Has an analysis been done? What are the results?

RESPONSE: An analysis has been completed (see attached IDC GPB–100433 dated 16 Feb 1995, from Anne Grover Vogel to Frank Chilese, "Analysis of UV Fiber Optic Cables in the Probe-B Top Hat").

This analysis indicates that the fiber optics are supported well enough to survive shake. The fibers are predicted to move a substantial amount, but that the predicted stress levels exhibit positive margin.

Frank Chilese 2/22/95

Frank Chilese, LMSC

John Turneaure, Stanford

ACTION ITEM 22

Update document tree in Science Payload Spec v3.0 (p.11) to reflect current program document tree (titles, numbers, heirarchy, separate electronics documents, etc.) Richard has one from NA Review.

RESPONSE SUMMARY

Document tree in version 3.1 has been updated.

15 Nov 94

Actionee's name

approved:

J.P. Turneaure 12/30/94

John Turneaure, Stanford

S J Calhoon

Stuart Calhoon, LMSC 11/15/94

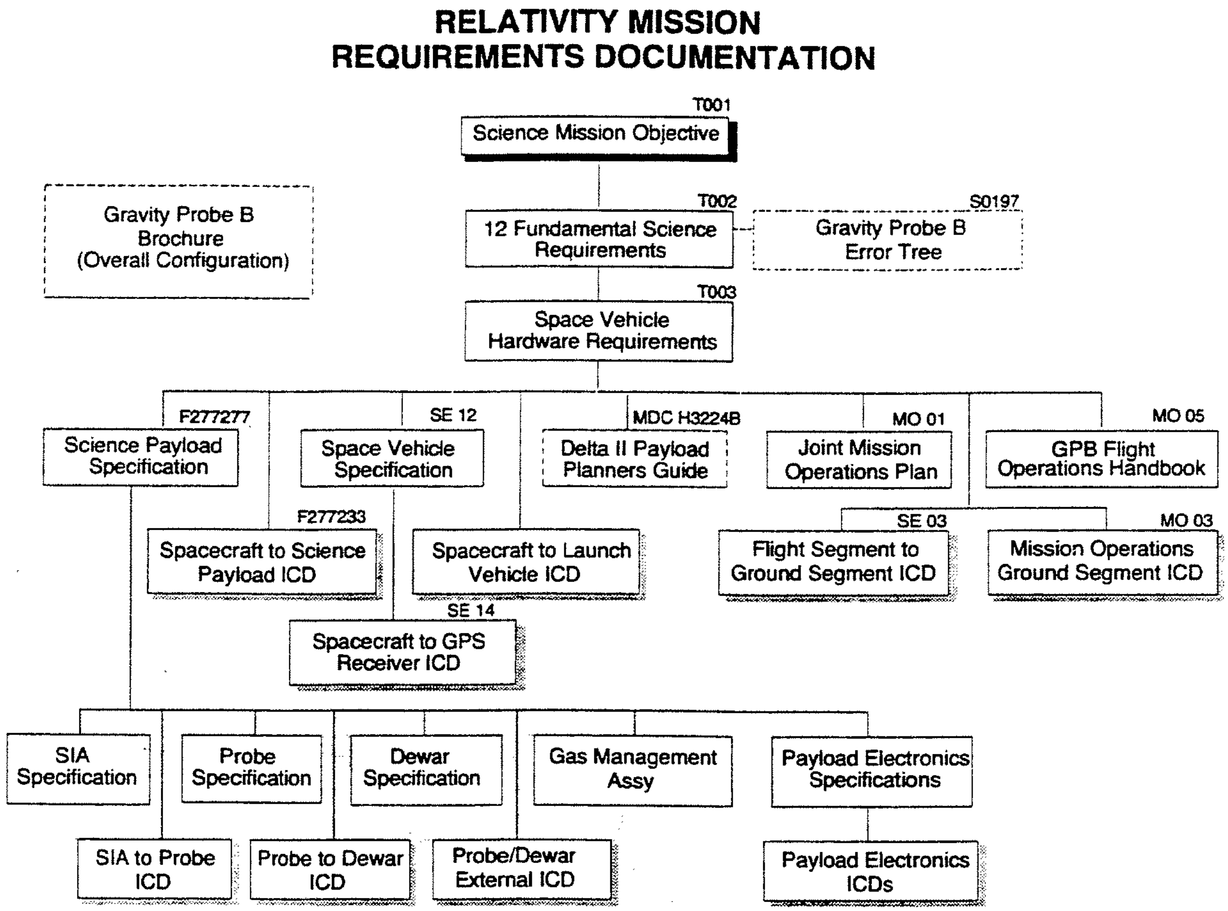


Figure 2.1-1 **Relativity Mission Document Tree**

NFPA 493	National Fire Prevention Association Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1 Hazardous Locations
NFPA 496	National Fire Prevention Association Standard for Purged and Pressurized Enclosures for Electrical Equipment in Hazardous (Classified) Locations
MSFC-HDBK-527 / JSC 09604	*Material Selection List for Spacel Hardware Systems*
MSFC-SPEC-521A	Electromagnetic Compatibility (EMC) Requirements on Spacelab Payload Equipment
TM 4527	NASA Technical Memo, Orbital Environments

2.2 Stanford

The following Stanford documents are referenced within the italicized commentary for traceability purposes only.

T003 rev A	*GP-B Space Vehicle Hardware Requirements, dated 15 Apr 93*

Approval

J.P. Turneaure 7/14/94

John Turneaure

S.J. Calhoon 8/1/94

Stuart Calhoon, LMSC

11 July 1994

SUBJECT: **Probe C Requirements Review**

ACTION ITEM # 60

STATUS: **Closed**

ASSIGNEES: **J.M. Lockhart**

SIGNATURES: J. M Lockhart

Action: [Describe] possible changes in SQUID operating frequency and source and load impedances

Resolution: The anticipated SQUID parameters for Science Mission are:

Operating (modulation) frequency: 420 kHz

"Load" Impedances (looking into the SQUID; not including cable impedance):

Bias current circuit	220 Ohms
Modulation Circuit	220 Ohms
Feedback Circuit	220 Ohms
Signal Circuit	150 Ohms
Loop Switch Circuit	220 Ohms

"Source" Impedances (from SQUID electronics; total per circuit, half stated value in each leg)

Bias current circuit	200 kOhms
Modulation Circuit	2000 kOhms
Feedback Circuit	40 kOhms
Signal Circuit	100 kOhms
Loop Switch Circuit	40 kOhms

Probe-C PDR Action Item Response

ACTION ITEM 1

Establish list of all actions necessary for probe-B to be flown instead of probe-C. Make 1 person responsible for list. Solicit input from everyone. Divide into necessary vs desired actions. Provide system for individuals to add to list until launch.

RESPONSE SUMMARY

Graham Ross will maintain a list of all identified actions required for probe-B to be upgraded to a flight unit. This list will be a computer file on his machine that is accessible throught the Lockheed Macintosh network:

zone:	RDD_Phase_2
server:	Graham's mac
volume:	see but don't touch
file:	flight upgrade of probe-B

Email has been distributed to the Lockheed program and the Stanford lead engineers and scientist to solicit their input on this issue. Any ideas, concerns and comments can be sent to Graham via Email to:

ross@lmsc.lockheed.com

All inputs will be incorporated into the upgrade document.

Actionee's name

approved:

Jn P. Turnea 12/30/94
John Turneaure, Stanford

S J Calhoon
Stuart Calhoon, LMSC

February 8, 1995

SUBJECT: PROBE C PDR

ACTION ITEM #3

ASSIGNEE: Paul Dineen

ACTION: Reevaluate caging solder. SVA experience shows Indalloy #9 is very difficult to work with. The Stanford paste SN96 works much better but had some questionable metallurgy. This was marginal in the last analysis several years ago.

RESOLUTION: Part 1: Initial Probe B Decision:

Indalloy #9 was used at LMSC because 100µm CuSn intermetallics were found in the SN96 solder joints after initial soldering. Indalloy #9 was free of these larger intermetallics after the initial soldering. Because large intermetallics are potentially brittle, Indalloy #9 was recommended. No other difference was noted between the two solders. Reference the following two supporting engineering memos:

EM No. 308 Caging and Spinup Heat Source and Solder Tests
EM No. 311 Caging Line Solder Joint Metallurgical Evaluation

Part 2: Probe C Recommendation:

Use Indalloy #9 on Probe C. See technical investigation on attached sheet. If an alternate is desired investigate SN63 .

February 8, 1995

Probe C Technical Investigation:

The material composition of Indalloy #9 and SN96 was reviewed to see if the differences in soldering performance could be explained.

Indalloy #9 : Chemical Composition: 70% Sn, 18Pb, 12In
Melting Temp: 324°F
Form: Wire

SN 96: Chemical Composition: 95-96% Sn, 0.1% Pb, 3.6-4.4 Ag, .2% Cu max, .005 Zn max and .005 Cadmium max.
Melting Temp: 430°F
Form: Solder cream

Chemical composition:

As can be seen by EM No. 311, Caging Line Solder Joint Metallurgical Evaluation the chief intermetallic formed during soldering is CuSn. The high concentration of tin (95-96% in SN96) results in the rapid formation of intermetallics. This makes soldering easier but can lead to brittle joints.

SN96 contains trace elements of cadmium and zinc. I've done a preliminary literature search and have been found that cadmium and zinc are not recommended for space applications because they release metal vapors which will deposit on optical and thermal control surfaces. Reference excerpt from SSD Design handbook.

Indalloy No.9 contains 70% Sn which allows CuSn to form but not at the same rate as SN96. Indalloy #9 has indium as a component, which tends to oxidize rather rapidly. An oxidized indium coating can make soldering very difficult if not impossible. Indium tinning must be kept free oxides or be recleaned using flux. The flux should then be removed.

Melting Temp:

Not an issue.

Form:

It appears using paste which contains flux is the more desirable application of solder.

Conclusion:

Use Indalloy #9 for Probe C.
Do not use SN96 because of the larger CuSn intermetallics formed and the traces of cadmium found.
If an alternate is desired, evaluate SN63. SN63 has never been evaluated for use on Probe cables, but will be used in the assembly of the Dewar. Also SN63 has been used on previous Dewar programs. SN63 is easy to solder like SN96 but it has a lower percentage of tin (63% for SN63, 70% for Indalloy #9). It also does not contain any cadmium. The evaluation process would repeat the mechanical, metallurgical and magnetic tests previously performed on SN 96 and Indalloy #9. While LMSC has found Indalloy #9 to be satisfactory, SN63 might be a viable

alternative. However evaluation of it for use on Probe C would require Stanford University authorization.

Paul M Dineen
Written : Paul Dineen

Gary M Reynolds
Checked: Gary Reynolds

S J Calhoon
Approved: LMSC

Approved: Stanford University

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

ENGINEERING MEMORANDUM

TITLE Caging and Spinup heat source and solder tests

PREPARED BY: Jay Nauss
CHECKED BY: G. Reynolds/S. Calhoon

EM NO. 308
REF: PO30733
DATE: 10/06/92
APPROVAL:

SUMMARY

Solder tests for caging and spin up joints were conducted for selecting the most suitable heat source and solder for cleanroom applications.

The Ultratorch was shown to be the best heat source for this soldering process. The Indium alloy#9 solder was shown to be the best solder for this process.

DISCUSSION

The tests were conducted to determine which heat source would produce the least amount of particulation during this clean room soldering operation and which solder, Indium alloy #9 or Multicore, Sn96 PRAB3 Paste, had the best workability and flow characteristics.

Four joint specimens were tested, two pretinned with indium alloy #9 solder and two pretinned with Multicore solder, Sn96 PRAB3 Paste. One of each of the joint specimens of the two solder types were mated and demated with the Ultrasonic soldering iron. The remaining two joint specimens of the two solder types were mated and demated with the Ultratorch.

The joints were first mated and the cleanliness of the outside diameter and inside diameter were checked and the level of cleanliness recorded. The joints were then leak tested and recertified. Next, the joints were demated and the cleanliness of the mating ferrule was checked for contamination and the level of cleanliness recorded.

Samples of mated joints pretinned with both the Indium alloy #9 solder and the Multicore solder(Sn96 PRAB3 Paste) were load tested to 20Lbs. and sectioned by the Metallurgist in Bldg 205.

319

CONCLUSION:

The level of cleanliness checks on both the inside and outside diameters of the solder joint specimens show conclusively that the Ultratorch is the superior heat source. The level of cleanliness after mating and demating with the ultratorch in every instance was still within level 100, were as the joints assembled with the Ultrasonic soldering iron always exceeded level 100 cleanliness. This was due to the tip of the Ultrasonic soldering iron oxidizing by the time it heats up for use, therefore causing large particulates. It was also noted that the Ultrasonic soldering iron caused particulation by splattering the solder. Furthermore, the iron also drove solder in some instances down to the interior of the sleeve due to the Ultrasonic vibration effect. These problems were not evident when using the Ultratorch.

Some leak were present in joints. The joints made with the ultrasonic soldering iron produced unacceptable leaks. One very small leak at 10-09 cc/sec @ STP of He was detected when using the Ultratorch. Adequate pretinning of the parts and leak check of the joints at assembly will ensure the integrity of the connection.

The applied load to the joint when the system is caged is less than one pound. The specimens were loaded to 20lbs each at LMSC with no failures for either solder type.

Sectioning of the joint specimens by the metallurgist in bldg 205 showed that the solder joints had minimal voids. The sectioning also showed that the Multicore solder (Sn96 PRAB3 Paste) formed more intermetalics with the phosphor bronze, causing more erosion of the components than would be present when using the indium alloy #9 solder. There were no marked differences in the workability or flow characteristics of the two solders.

LOCKHEED MISSILES & SPACE COMPANY, INC.

ENGINEERING MEMORANDUM

TITLE:	Caging Line Solder Joint Metallurgical Eval.	EM NO.	311
		REF:	LMSC-P030742
PREPARED BY:	D. Yaney	DATE:	9/23/92
CHECKED BY:	J. Nauss	APPROVAL:	S. Calhoon

PURPOSE

The purpose of this investigation is to evaluate the integrity of Indium #9/phosphor bronze A and Multicore/phosphor bronze A solder joints in both the as-fabricated and re-worked conditions.

SUMMARY

This report documents the results of metallographic and scanning electron microscopy (SEM) examinations as well as mechanical testing of five different tube/ferrule/sleeve solder joints. The history of the five joints is summarized in Table 1 below.

TABLE 1. Tube/Ferrule/Sleeve Joints Examined as Part of this Investigation

Sample No.	Tube, Ferrule and Sleeve Mat'l.	Tube/Ferrule Braze Alloy	Ferrule/Sleeve Solder	Thermal History
1005921	Phosphor Bronze A	Ag-28 wt.%Cu	Indium #9*	As-fabricated
1005922	Phosphor Bronze A	Ag-28 wt.%Cu	Indium #9*	Re-worked
1005923	Phosphor Bronze A	Ag-28 wt.%Cu	Multicore**	As-fabricated
1005924	Phosphor Bronze A	Ag-28 wt.%Cu	Multicore**	Re-worked
1005925	Phosphor Bronze A	Ag-28 wt.%Cu	Multicore**	Over-temp.

*Sn-18 wt.%Pb-12 wt.%In
**Sn-3.7 wt.%Ag

All samples were successfully loaded to 20 lbs. in tension without failure. Porosity was frequently observed in both the Ag-28 wt.%Cu braze joints (between the ferrule and tube) as well as in the Indium #9 and Multicore solder joints (between the sleeve and ferrule). Small Cu-Sn intermetallic particles, identified by energy dispersive x-ray analysis as the η phase containing 43.5 to 45.5 at.%Sn, were observed at all Indium #9/Phosphor bronze A and Multicore/Phosphor bronze A interfaces. In addition, the re-worked Indium #9 joints, as well as all of the Multicore solder joints, contained large needle like η phase particles within the solder fillet regions. Apparently the higher tin content of the Multicore solder, in comparison with the Indium #9 solder, leads to more aggressive attack of the phosphor bronze A and thus to more extensive η phase formation during the initial soldering process. Given the large size (100 µm in some cases) and potentially brittle nature of these particles, use of the Indium #9 solder with its reduced tendency for η phase formation is preferred.

DISCUSSION

The five different tube/ferrule/sleeve joints examined as part of this investigation were described previously in Table 1. Fabrication of these joints occurred in two steps. First the ferrule was brazed to the tube with the Ag-Cu alloy . After this joint had cooled, the sleeve was then added by soldering with either the Indium #9 or Multicore solder. In order to provide a preliminary assessment of joint integrity, all samples were loaded in tension to 20 pounds and then unloaded. No failures were observed, so all samples were then cross-sectioned, cold mounted and polished

Prepared by:
D. Yaney
23 Nov. 92

Checked by:
J. Nauss
Date

Approved by:
S. J. Calhoon
Date

Caging Line Solder Joint Metallurgical Evaluation

Model
EM 311

Report No.
LMSC-P030742

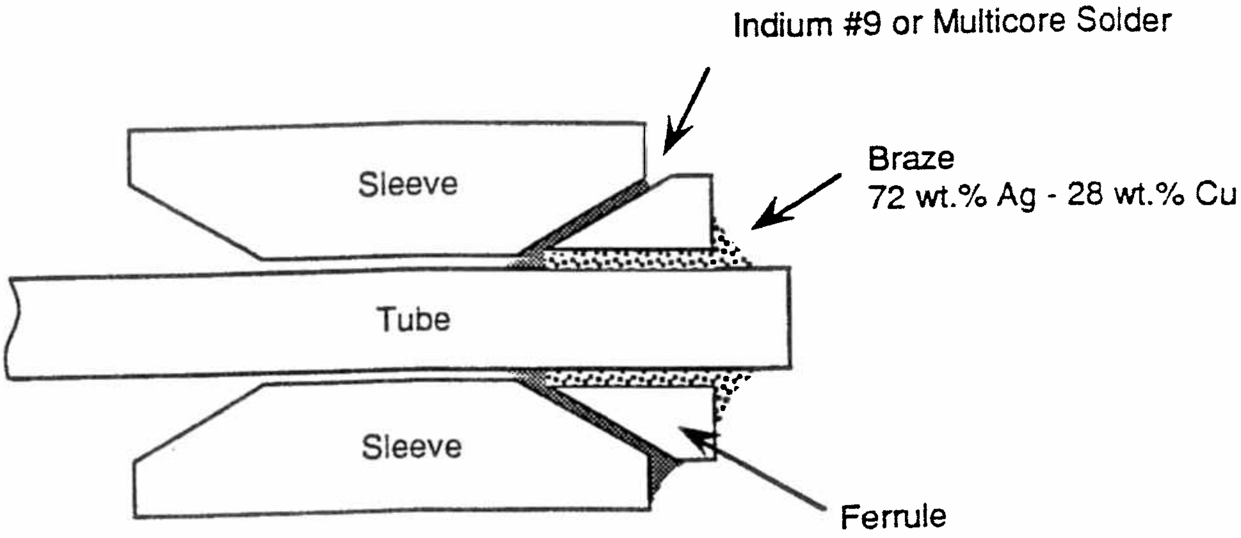


Figure 1. Schematic illustration of tube/ferrule/sleeve joint.

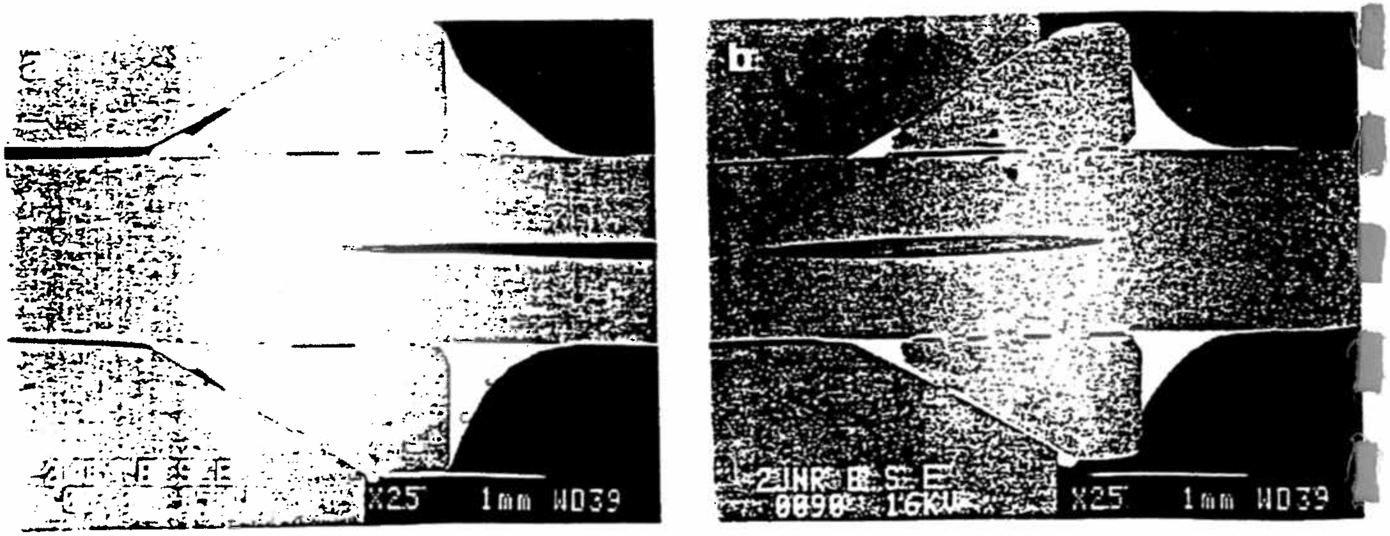


Figure 2. Low magnification SEM micrographs of the (a) as fabricated and (b) re-worked Indium #9 tube/ferrule/sleeve joints.

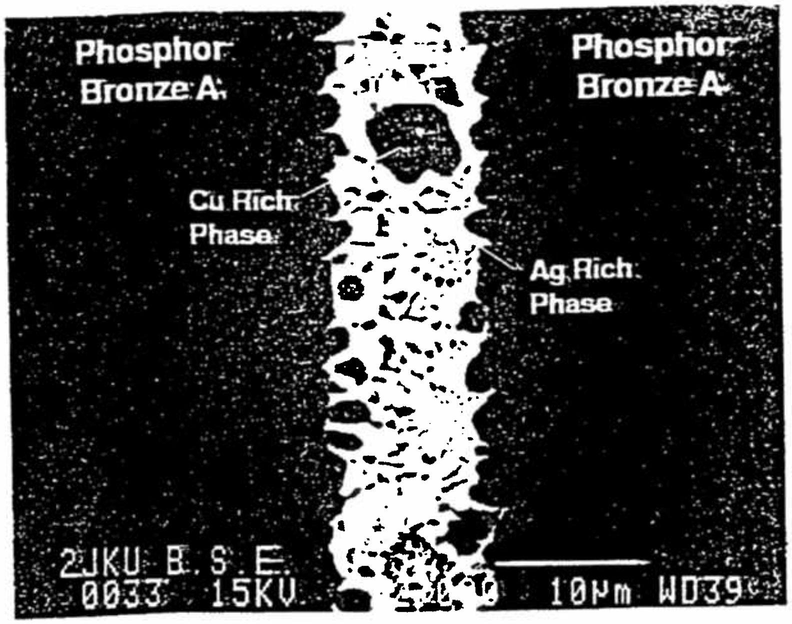


Figure 3. SEM micrograph of Ag-28 wt.%Cu braze joint in the as-fabricated condition.

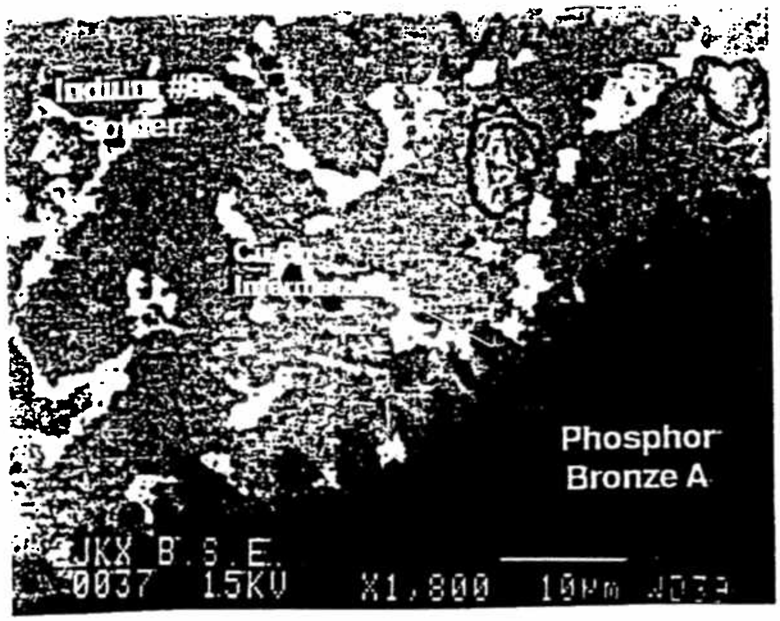


Figure 4. SEM micrograph of Cu-Sn, η phase intermetallic particles at the phosphor bronze A/Indium #9 solder interface. As-fabricated condition.

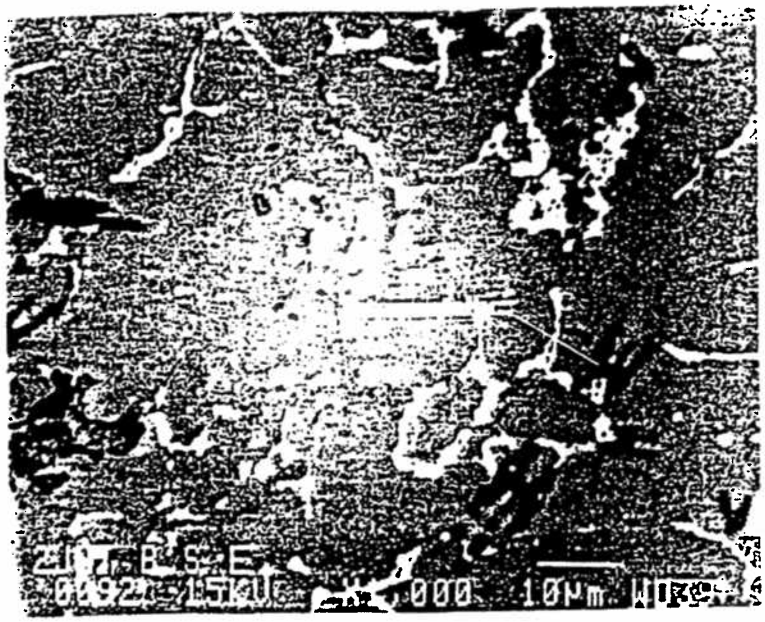


Figure 5. SEM micrograph of Cu-Sn, η phase intermetallic particles in Indium #9 solder filler following re-work.

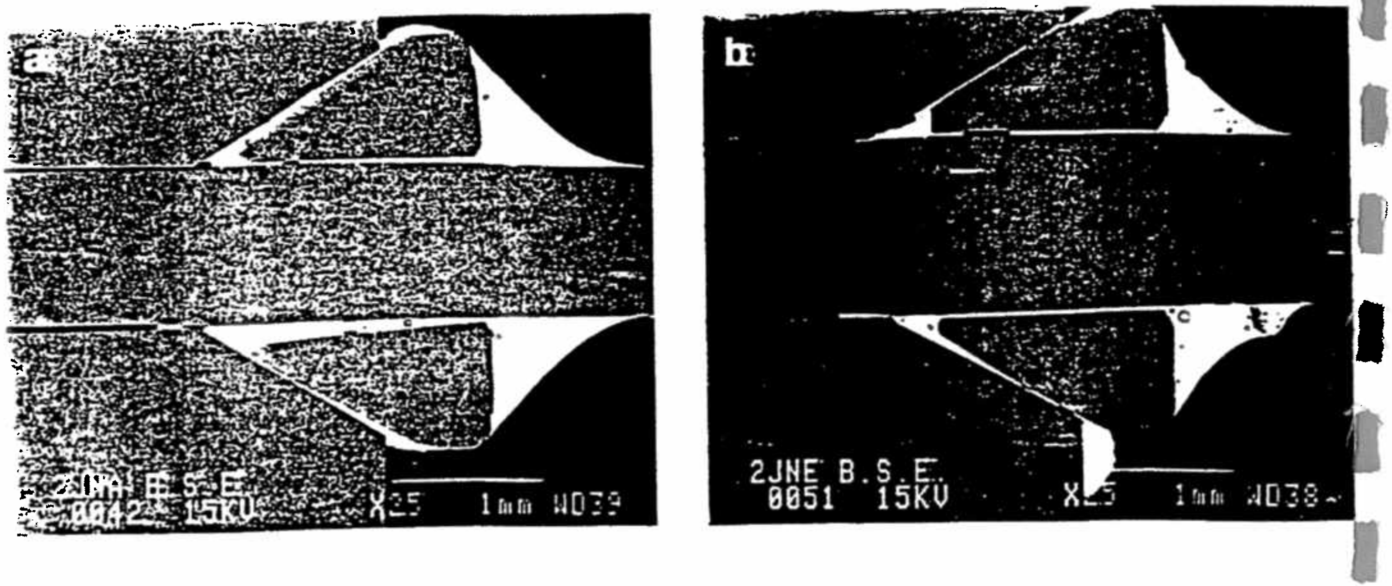


Figure 6. Low magnification SEM micrographs of the (a) as-fabricated and (b) re-worked Multicore tube/ferrule/sleeve joints.

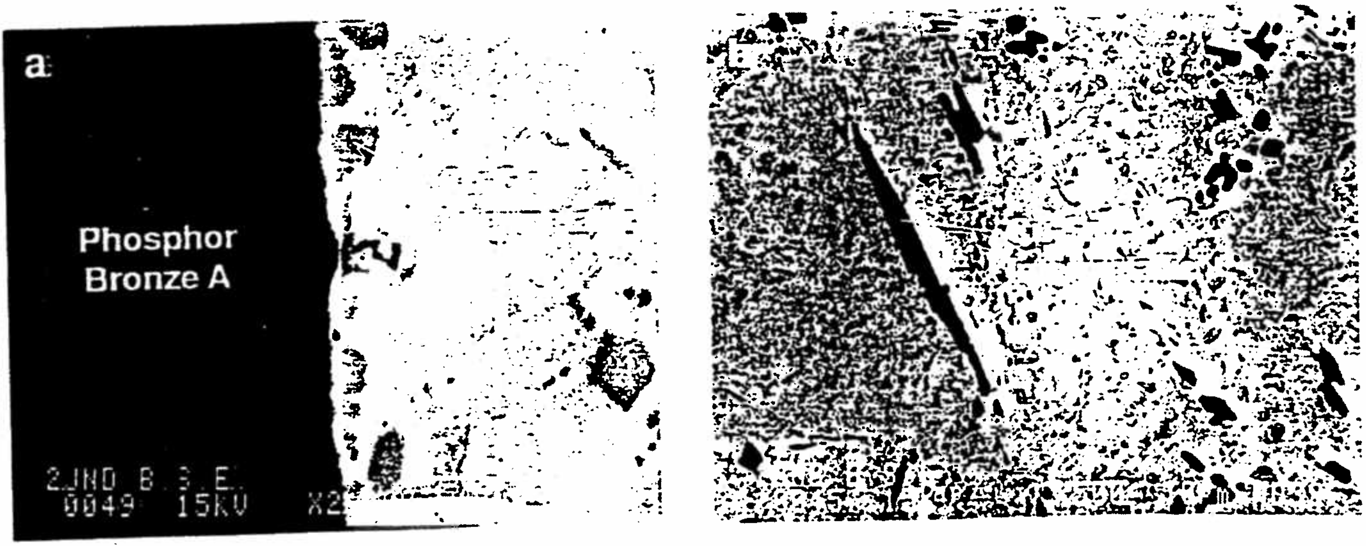


Figure 7. SEM micrographs of Cu-Sn, η phase intermetallic particles (a) at the Multicore/Phosphor bronze A interface and (b) in the Multicore solder fillet region following initial fabrication.

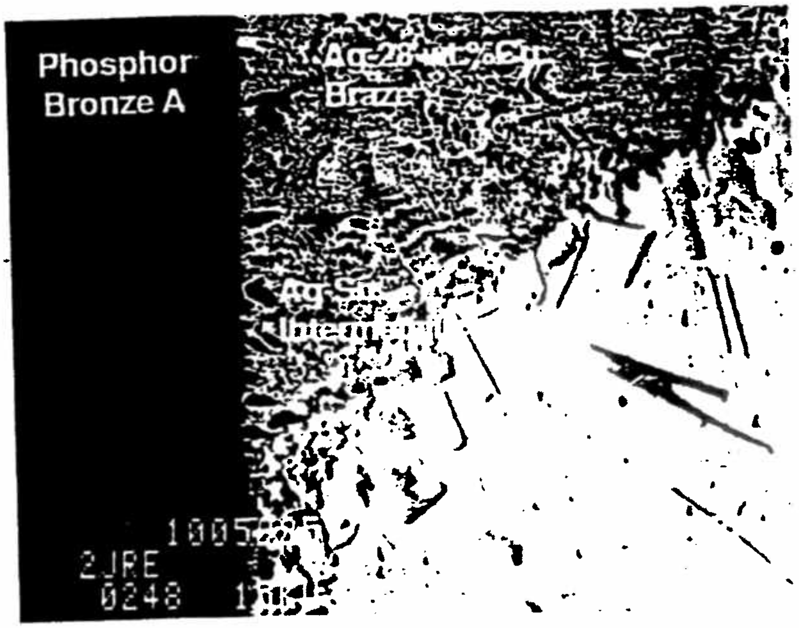


Figure 8. SEM micrograph of interface between Ag-28 wt.%Cu braze and Sn-3.7 wt.%Ag (Multicore) solder. Over-temperature sample. Note the presence of Ag_3Sn and Cu-Sn η phase particles.

4. FASTENER SELECTION CONSIDERATIONS (Continued)

Cadmium and zinc must not be used on any space systems flight item because of the detrimental effect possible on optical and thermal control surfaces due to thermal decomposition/volatilization and condensation. This restriction is applicable throughout the flight vehicle. Included are such items as nuts, bolts, washers, and plated electrical connectors. However, this restriction does not apply to AGE and separable booster hardware.

5. DESIGN CHECK LIST

In the design application of mechanical fasteners, the following list of considerations may provide a convenience in design.

- Are standard fasteners used? Can the number of different types be reduced?
- Has the most economical fastening method been selected?
- Is proper fastener edge distance provided for all parts?
- Is additional fastener edge distance provided on parts requiring fitting on installation?
- Are minimum spacing requirements met for nonflush, countersunk, and dimpled hole patterns?
- Is standard tool clearance provided?
- Are standard spotfaces and counterbores provided where required?
    - Is clearance sufficient for wrenching?
    - Is clearance adequate for back spotfacing?
- Is selection of hole sizes compatible with function, assembly, and interchangeability requirements?
- Are adequate fastener instructions called out?
- Is bolt torque specified if nonstandard?
- Are shear type bolts not loaded in bending?
- Are washers provided under bolts, nuts, and nonflush screws that bear on thin (0.032 inch and under) aluminum sheet, magnesium, plywood, or plastics?
- Are safetying requirements for fasteners met?
- Are self-locking bolts or nuts, as appropriate, used wherever possible?
- Can rivets be used in lieu of more expensive fasteners?
- Are flush fasteners used only where necessary?
- Are fastener materials compatible with material being joined?
- When riveting castings, does drawing require manufactured head to be on casting side of joint?
- Does design accomodate automatic fastener installation wherever practicable?
    - Can fastener pitch be constant?
    - Can fastener patterns be straight and parallel or perpendicular to each other?

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Probe-C PDR Action Item 4

Should the bakeout be done before or after the SIA mass model is installed at LMSC? Would it affect the bakeout? Does it degrade the weight and CG measurements? Installing it early saves one open/close bakeout cycle.

RESPONSE

The Probe-C Acceptance Test Flow presented at PDR is shown in the accompanying figure. Probe-C will be vibrated with a mass model of the SIA, probably made of aluminum, after Stanford Acceptance and prior to shipment to Stanford. The question is whether the SIA mass model should be installed prior to the high temperature bakeout, as shown in the figure, or after Stanford acceptance, just prior to vibration.

Magnetic screening must be done with a spool in place of the cross-flange, in order to rotate the probe during magnetic testing. After the magnetic test, the probe cross-flange with valves, and window 4 are installed in B20~~5~~2. It would be convenient to install the SIA mass simulator at this time.

The mass simulator will not degrade the probe weight and CG measurement, and in fact should be more informative if the mass model weight and CG are representative of the SIA. The mass simulator will be weighed and its CG measured separately and the probe sans SIA can be derived analytically.

During Probe-C high temperature bakeout, the SIA mass simulator will also be baked-out. This should present no negative impacts to the probe bakeout. It would be best to bake-out the mass model alone prior to integration with the probe.

Prepared

AK Nakashima 12/7/94

A. K. Nakashima

Approved

Gary M Reynolds 3/2/95

G. M. Reynolds

Approved

S J Calhoon 2/26/95

S. Calhoon, LMSC

Approved

J. Turneaure, Stanford

Tel: (415) 725-4110 Fax: (415) 725-8312 Email: sasha@relgyro.stanford.edu

SUBJECT: **PROBE C**

Action item #: PDR AI#6

STATUS: **Closed**

DATE: **27 February, 1995**

ASSIGNEES: **S. Buchman**

Signatures: S. Buchman

APPROVED: **J. Turneaure**

Signature:

Action: Determine permissible thermoelectric differential potential on suspension ground plane and UV bias cables for the gyroscopes in Probe C.

Resolution: The maximum variation (highest to lowest) in thermoelectric induced potential differences between all suspension ground plane and UV bias cables in probe C should be less than 5mV.

December 1, 1994

PROBE-C PDR
ACTION ITEM RESPONSE

ACTION ITEM 7: Submit data items that were not available at the review: CIL, LLIL, drawing tree, ICD's 3112, 3115, 3116, and 4159.

RESPONSE: These documents have all been updated and transmitted to Stanford now, except for the Limited Life Items List. Referral to the Statement of Work reveals that the LLIL is not due until the CDR and was on the original list in error.

SJ Calhoon 12/1/94
Stuart Calhoon, LMSC

12/30/94
John Turneaure, Stanford

November 3, 1994

SUBJECT: Probe C PDR Action Item No. 11

ASSIGNEE: R. Whelan

STATUS: Closed (ongoing activity required to identify extent of potential problem and determine appropriate courses of action)

Action: Discuss and coordinate the Probe-B measured weight and CG discrepancies with spacecraft people. (assigned by B. Parkinson)

On October 10, 1994, Richard Whelan of GP-B Science Payload Mass Properties met with Bob Schultz of GP-B Spacecraft Systems Engineering to discuss Z CG status and requirements. Following the measurement of Probe B weight and center of gravity, where a large discrepancy between the model prediction and measured value was revealed, an action item was assigned to determine possible courses of actions that the Lockheed Teams would take to meet the overall Z CG requirement.

The results of the Probe B measurement, when incorporated into the present model and combined with several other changes occurring at the forward end of the Main Payload, reveal a strong likelihood that the Main Payload Z CG will not fall between the required values of 4260 mm and 4500 mm.

The decision was made to fully assess the problem and determine solutions after the release of the next Science Payload report (November 15) which will incorporate the change to a fixed Sunshade (reducing the predicted Z CG from approximately 4550 mm to 4525 mm). The Spacecraft Team will use the new input to evaluate ballast requirements due to the high Main Payload Z CG. At that point, alternatives to the required additional ballast (if any) will be determined, including: changing the trunnion interfaces between Main Payload and Spacecraft by shimming, changing aft box locations, or identifying other hardware that might be moved to change the Z CG. Feasible solutions will be presented at future Interface Control Working Group meetings and discussions will continue in that forum until all concerns are addressed and a solution is reached.

Prepared by:
R. Whelan
R. Whelan

Approval:
S J Calhoon
S. J. Calhoon, LMSC
11/3/94

Approval:
J. P. Turneaure
J. Turneaure, Stanford
12/30/94

December 1, 1994

PROBE-C PDR
ACTION ITEM RESPONSE

ACTION ITEM 12:	Expand the LMSC Approved Material & Process List, LSE-03, to include materials and processes approved for Zone 1. If it cannot be modified, develop a similar independent document. (Sullivan)
RESPONSE:	After due consideration, we are requesting that this Action Item be withdrawn. Two separate groups of people use each of these lists, and there is no apparent value added in combining them. If a Zone 1 list needs to be created, that should more logically be done by Stanford.

SJ Calhoon 12/1/94
Stuart Calhoon, LMSC

12/30/94
John Turneaure, Stanford

December 1, 1994

PROBE-C PDR
ACTION ITEM RESPONSE

ACTION ITEM 13: Implement a materials data base which would list quantities of materials in stock with magnetic and contamination zone assigned. This could be two lists, but both groups should have access, such that material emergencies can be better dealt with. (Sullivan)

RESPONSE: After due consideration, we are requesting that this Action Item be withdrawn. To create such a data base would entail a significant amount of work, and frequent updates would be required. A good portion of the raw material in our Stores is designated for a specific purpose, and determining how much of it is unallocated would also be tedious.

As far as dealing with emergency situations, these would best be handled on an ad hoc basis. We can quickly determine the quantity of an individual material in Stores, and condition and availability could then be determined.

I don't believe these emergencies come up frequently enough to justify establishing a full-blown tracking system as requested.

S J Calhoon 12/1/94
Stuart Calhoon, LMSC

12/30/94
John Turneaure, Stanford

Probe-C PDR Action Item 17

Prior to CDR, coordinate Probe-C verification test flow at Stanford with Mike Taber

RESPONSE

The attached Probe-C verification test flow was reviewed with Mike Taber. The test flow at Stanford utilizes the experience gained from planning GTU-1. The major differences between Probe-C and GTU-1 are the optical tests and the Science Mission Dewar replacing the EDD. It is anticipated that further updates to the test flow will occur as we gain more knowledge and experience with the SMD, optical test equipment, etc. For example, the tests which are more amenable to a vertical vs horizontal orientation of the dewar will affect the test flow.

Prepared

AK Nakashima

A. K. Nakashima

Approved

M. Taber

M. Taber, Stanford

Approved

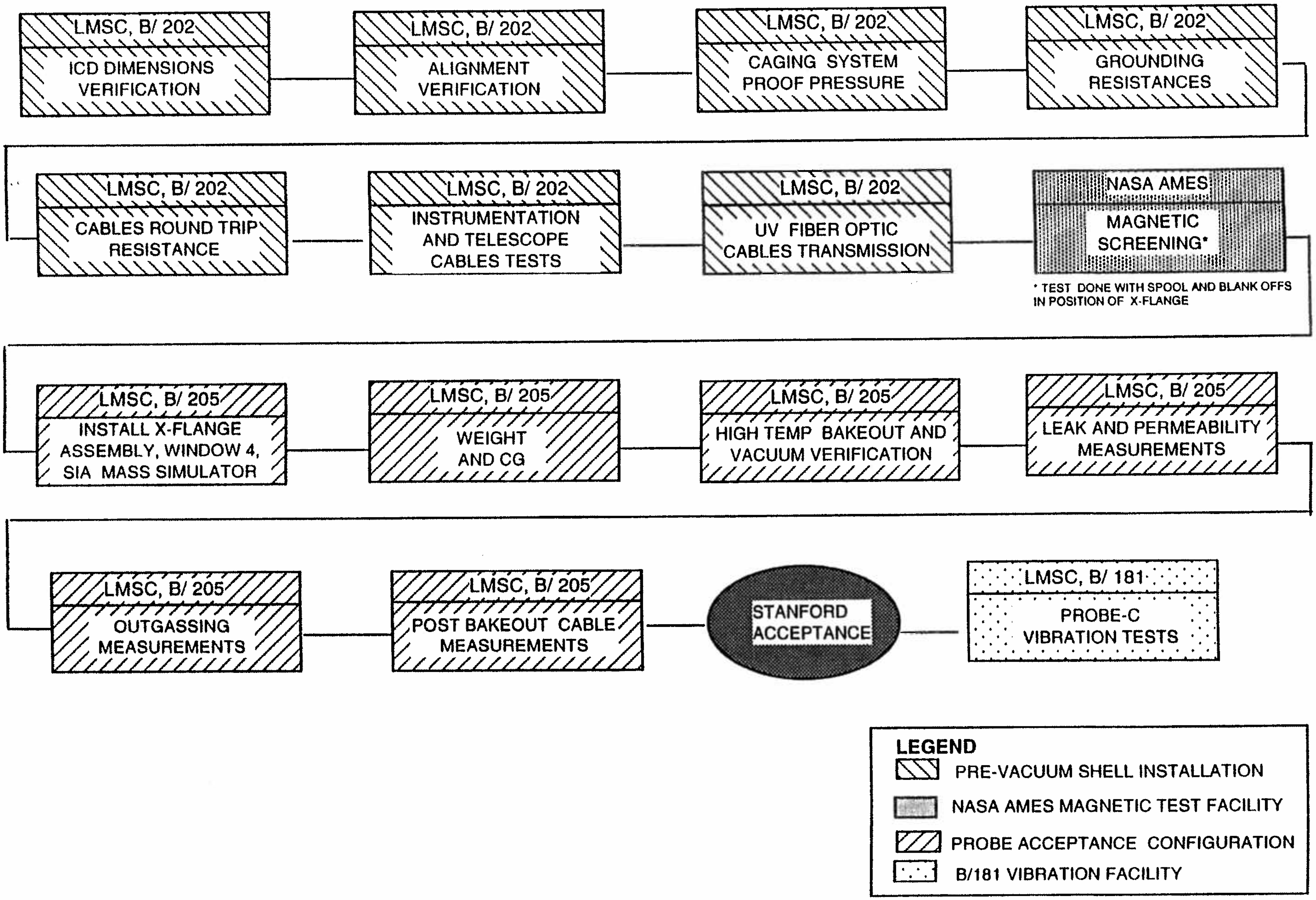
S J Calhoon

S. Calhoon, LMSC

Approved

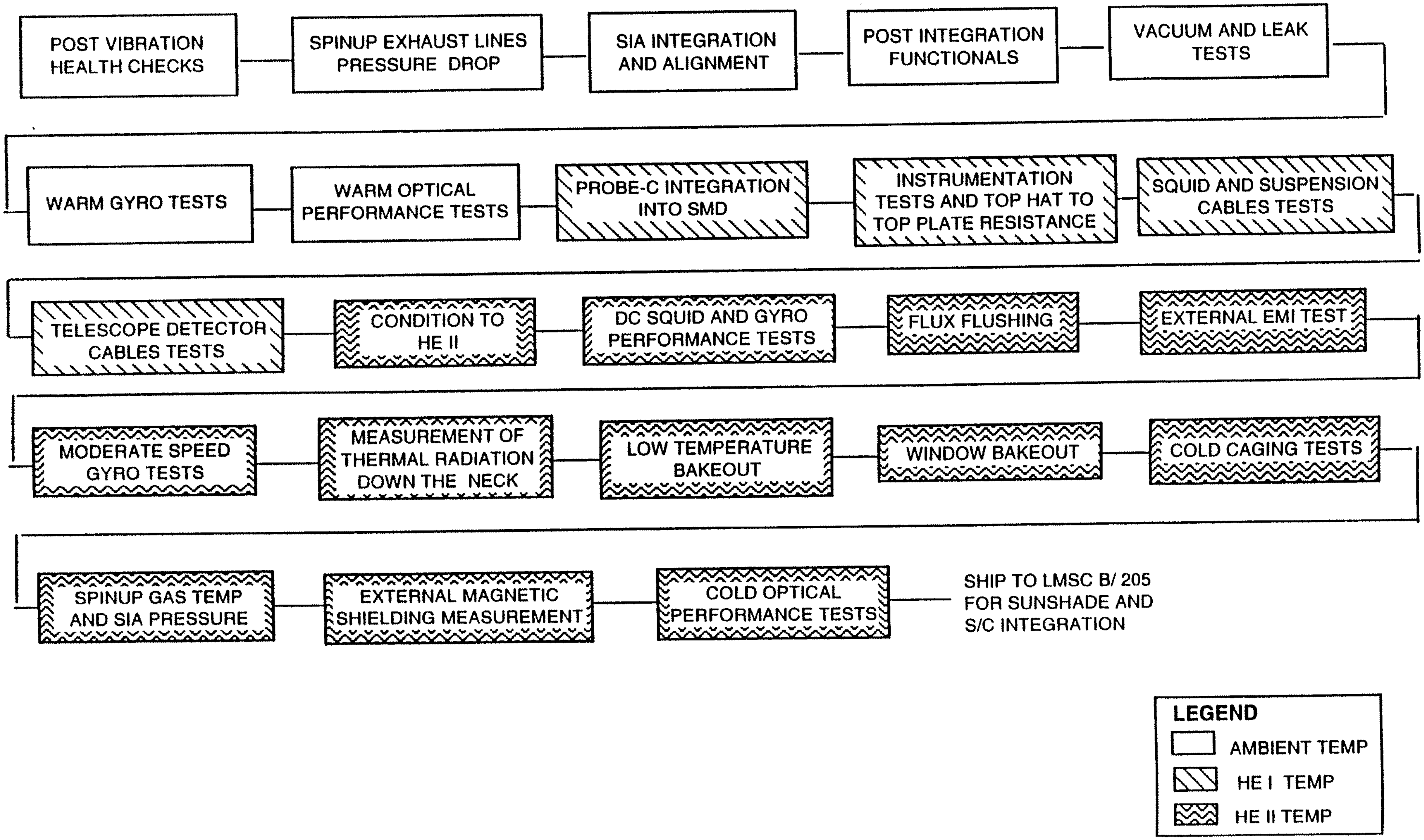
J. Turneaure, Stanford

PROBE-C ACCEPTANCE TEST FLOW AT LMSC



* TEST DONE WITH SPOOL AND BLANK OFFS IN POSITION OF X-FLANGE

PROBE-C VERIFICATION TEST FLOW AT STANFORD



Technical Performance Measures

3 March 1995

MASS PROPERTIES SUMMARY

	Latest Update	Basic Wt (kg)	Growth Contingency (kg)	Growth Contingency (%)	Projected Wt (kg)	Control Weight (kg)	Alloc.-Proj. [margin] (kg)
Dewar (Dry)	Feb/95	805.53	35.07	4.4%	840.60	862.00	21.40
Helium Cryogen	Feb/95	354.37	0.00	0.0%	354.37	354.00	-0.37
Helium (24 hr hold-launch abort)	Feb/94	4.00	0.00	0.0%	4.00	4.00	0.00
Dewar Subtotal (Wet)		**1163.90**	**35.07**	**3.0%**	**1198.97**	**1220.00**	**21.03**
Probe	Feb/95	105.29	68.53	65.1%	173.82	165.00	-8.82
SIA	Feb/95	36.60	2.35	6.4%	38.95	41.00	2.05
Sunshade & Shutter Assy	Dec/94	13.00	2.60	20.0%	15.60	15.00	-0.60
Spin-Up & Caging Assemblies	Jul/94	57.97	8.70	15%	66.66	70.00	3.34
Tubing (plumbing)	Feb/93	5.33	2.67	50%	8.00	8.00	0.00
Probe Assembly Subtotal		**218.19**	**84.85**	**38.9%**	**303.04**	**299.00**	**-4.04**
Electronics, Forward	Feb/95	59.18	2.08	4%	61.26	54.00	-7.26
Electronics, Aft	Feb/95	220.99	-46.59	-21%	174.40	160.00	-14.40
Forward Structure & Enclosure	Jul/94	26.90	5.38	20%	32.28	33.00	0.72
Cables, Forward & Aft	Feb/95	107.81	23.84	22%	131.64	112.00	-19.64
Electronics Subtotal		**414.87**	**-15.29**	**-4%**	**399.58**	**359.00**	**-40.58**
Total Science Payload (Wet)		**1796.97**	**104.63**	**5.8%**	**1901.59**	**1878.00**	**-23.59**
Margin for In-Scope Changes	Feb/95				98.41	74.81	
Total Allocation					**2000.00**	**2000.00**	

Main Payload, Wet:	Latest Update	Min-Reqmt	Current	Max-Reqmt
cm x (mm)	Feb/95	-4.0	-1.5	4.0
cm y (mm)	Feb/95	-4.0	-3.8	4.0
cm z (mm)	Feb/95	4260.0	4528.7	4500.0
Ixz (kg-m2)	Feb/95	-10.5	10.2	10.5
Iyz (kg-m2)	Feb/95	-10.5	0.1	10.5

FEBRUARY REPORT CHANGES

FOLLOWING CHANGES INCORPORATED INTO FEBRUARY REPORT:

- MAIN TANK HEATERS ADDED: + 2.0 KG
- ELECTRICAL AND INSTM ESTIMATES DECREASED: - 4.7 KG
- GRAPHITE RING REVISED WEIGHT ESTIMATE: + 5.0 KG
- TOP PLATE RELEASED DRAWING: -1.0 KG
- PROBE-C UPDATES INCLUDING:
  - SPIN-UP EXHAUST VALVE WEIGHT INCREASE: + 3.5 KG
  - 6” EXHAUST VALVE DEBRIS FILTERS ADDED: + 2.1 KG
  - VALVE STACK BRACKETS REVISED ESTIMATES: + 2.0 KG
  - BURST DISK WEIGHTS UPDATED TO PROBE-B ACTUALS: + 2.6 KG
- WINDOW 4 LAYOUT DESIGN: - 6.6 KG
- SIA UPDATE : - 2.4 KG
- HELIUM II MADE 100% FULL, CONT. REMOVED - NO NET CHG.
- CABLE ESTIMATES REVISED: + 9.0 KG

FEBRUARY NET CHANGE = +12.6 KG

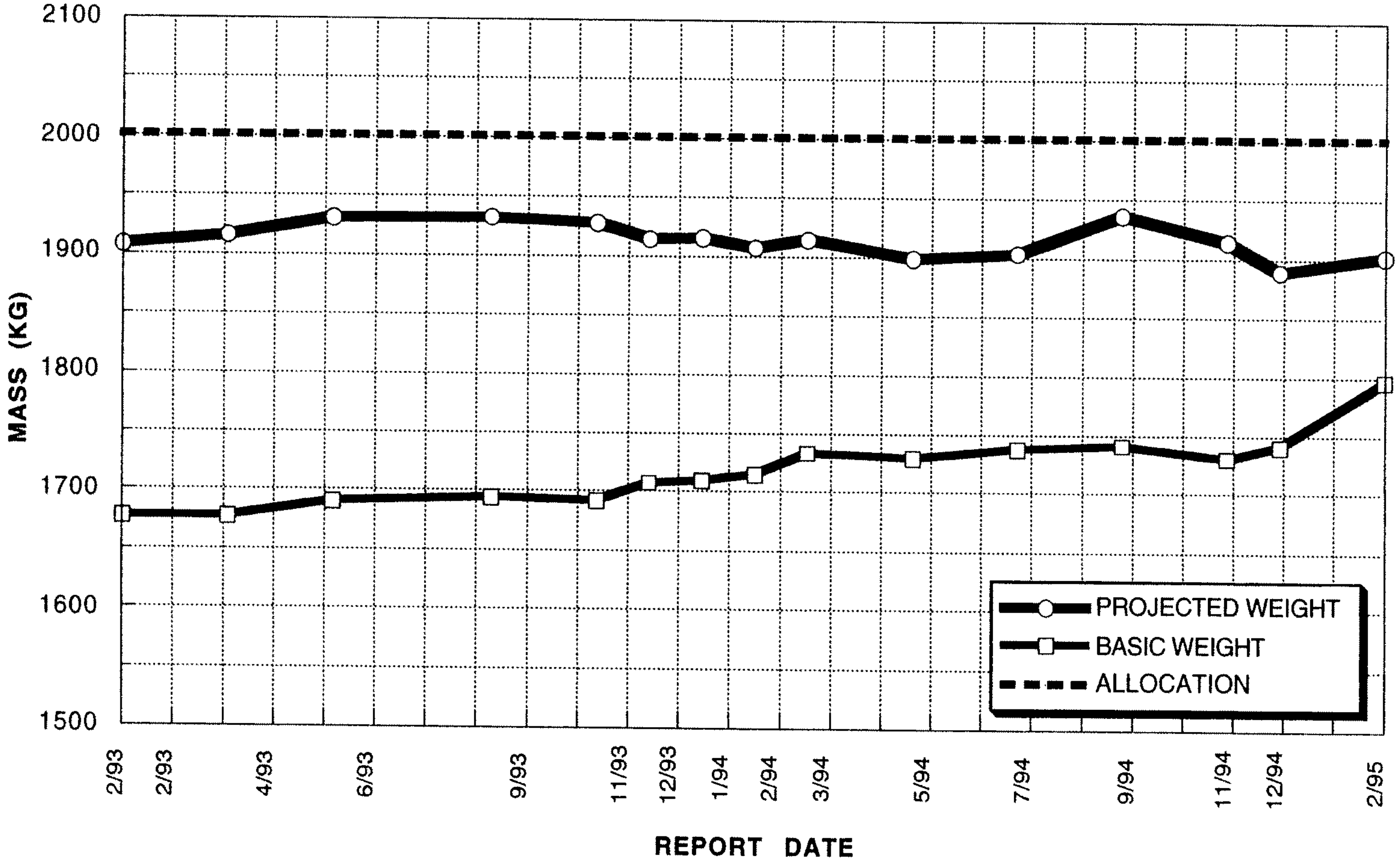
MASS PROPERTIES ISSUES

- COMPLETED WEIGHING OF MAIN TANK ASSEMBLY, VACUUM SHELL MID-CYLINDER, AND SUPPORT RING.
  - APPROXIMATELY 320 KG OF HARDWARE, ACTUAL WEIGHTS TO BE INCORPORATED IN NEXT REPORT.
- RECEIVED NEW WEIGHT CALCULATION FOR GMA. WILL BE INCORPORATED IN NEXT REPORT.
- NEW HARDWARE IDENTIFIED (NEXT REPORT):
  - COPPER STRAPS BETWEEN HEAT EXCHANGERS AND VAPOR-COOLED SHIELDS AND BETWEEN HEAT EXHANGERS 1 & 2 AND AXIAL LOK TUNNELS.
  - COPPER BRACKETS ON HEAT EXCHANGERS FOR COPPER STRAP ATTACHMENT.
  - PROBE-C SEGMENT 2 CABLE BRACKETS
  - PROBE-C FILTER CONNECTOR BRACKETS
  - P-9 PRESSURE SENSOR ON CROSS FLANGE

GPB-100417

SCIENCE PAYLOAD WEIGHT HISTORY

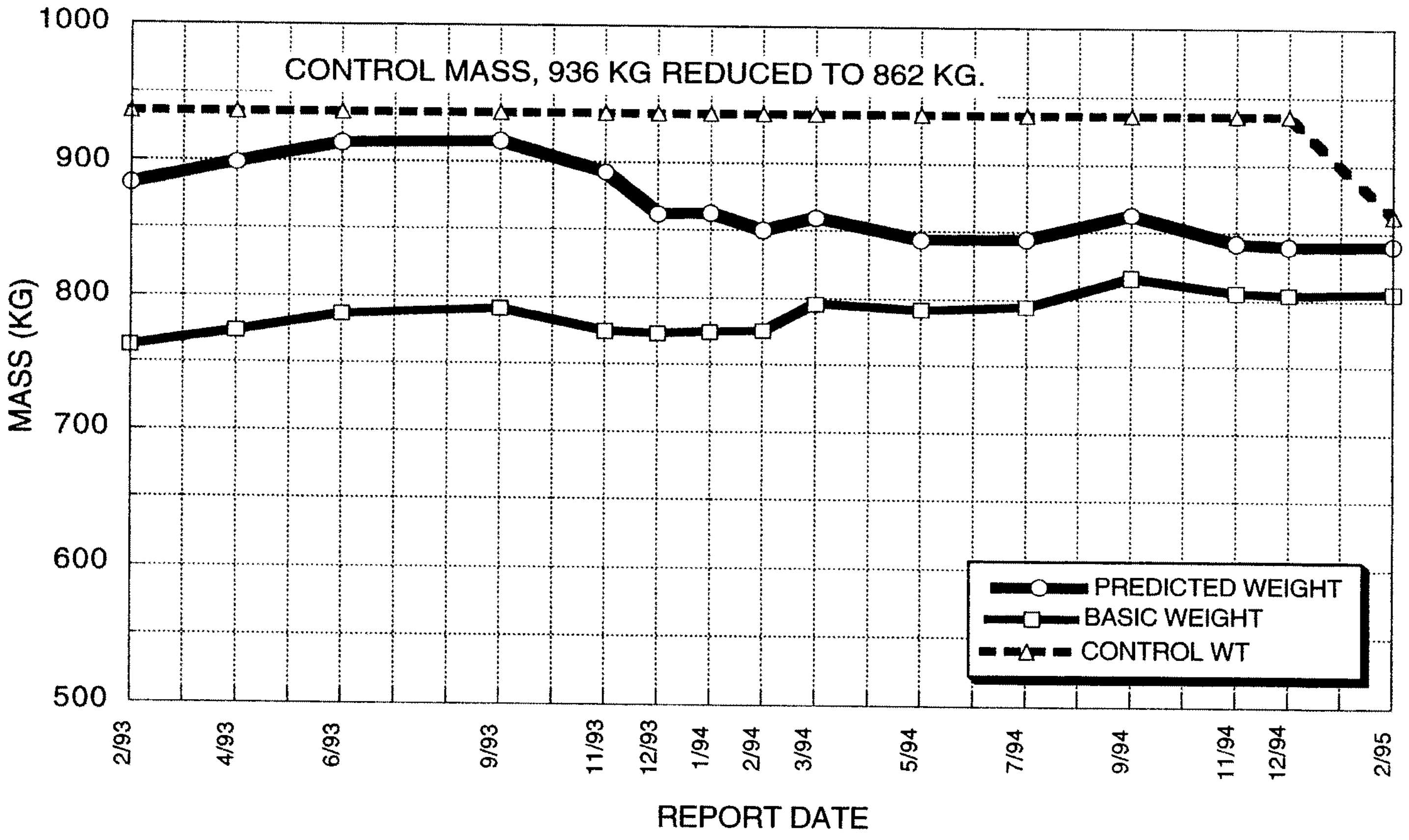
STANFORD
Lockheed
Probe-C CDR
29 March 95



GPB-100417

DEWAR WEIGHT HISTORY

STANFORD
Lockheed
Probe-C CDR
29 March 95



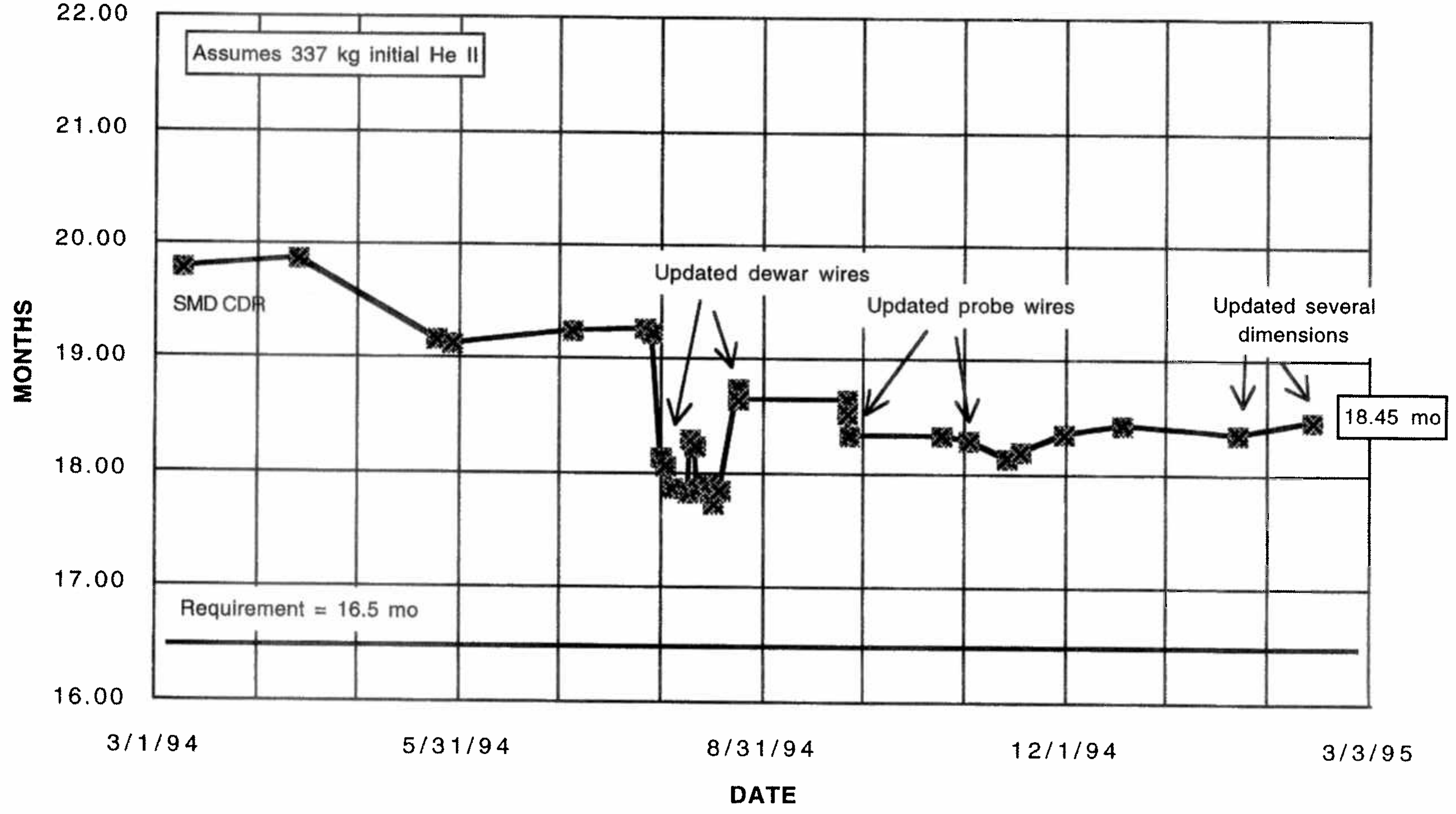
GPB-100417

TECHNICAL PERFORMANCE MEASURE
SM DEWAR LIFETIME

STANFORD
Lockheed
Probe-C CDR
29 March 95

PREDICTED LIFETIME

PREDICTED = CALCULATED / 1.3



CDR-7

MISSION LIFETIME ESTIMATE INCORPORATING ORBIT TRIM

- 18.45 MO IN LIFETIME CHART ASSUMES STEADY STATE OPERATION (6.95 MG/S) WITH 337 KG INITIAL HE II
- DURING ORBIT TRIM, THRUSTERS USE AVERAGE OF 13.5 MG/S
  - 1σ INJECTION ERROR - 14 DAYS DURATION TO CORRECT
  - 3σ INJECTION ERROR - 54 DAYS DURATION TO CORRECT
- INCORPORATING ORBIT TRIM DECREASES HELIUM LIFETIME TO
  - 18.0 MO (1σ INJECTION ERROR)
  - 16.8 MO (3σ INJECTION ERROR)
  - ASSUMES ALL OTHER OPERATIONS PERFORMED WITHIN THE NOMINAL BOIL-OFF

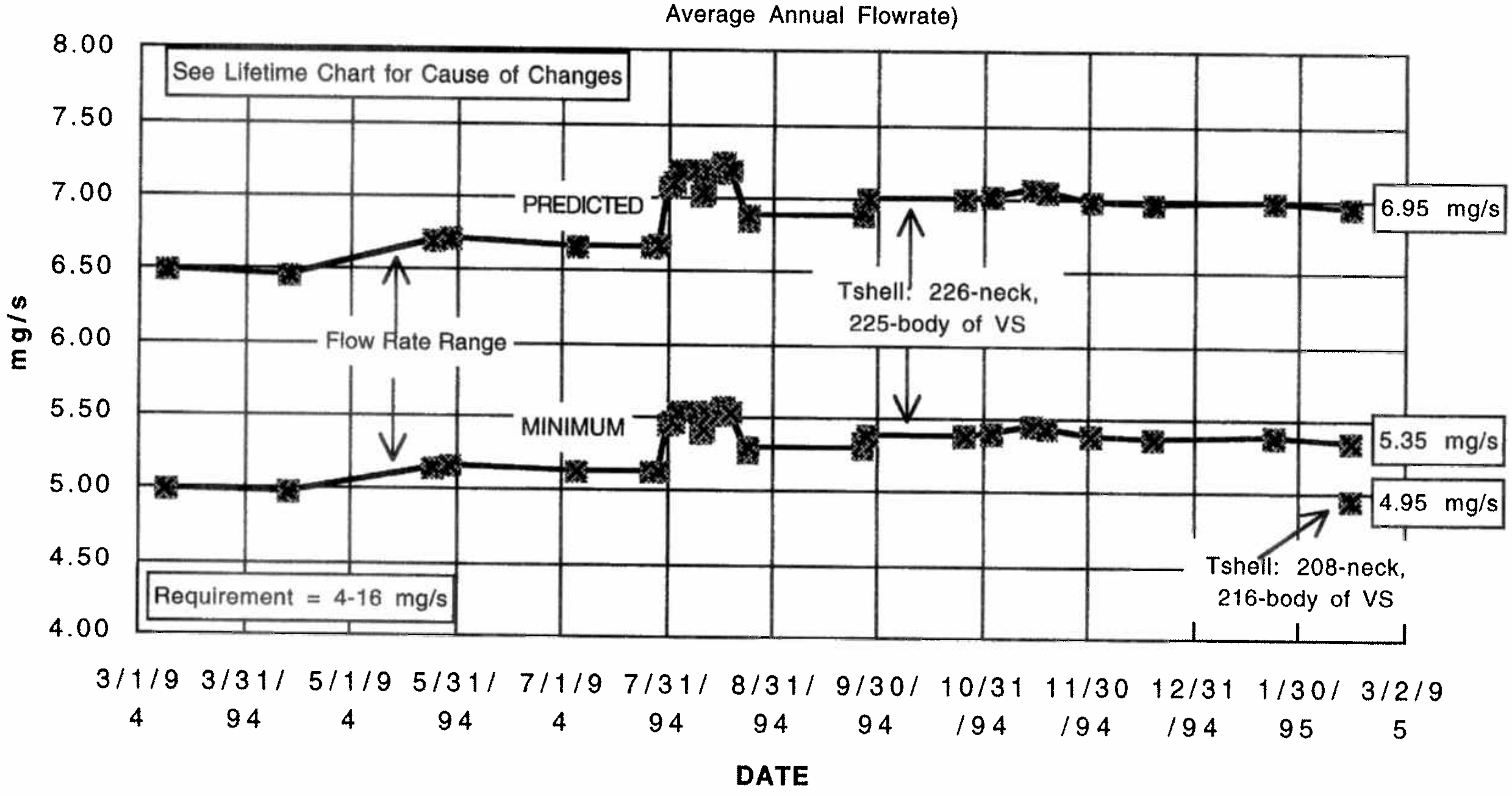
LIFETIME CALCULATION	1σ INJECTION ERROR	3σ INJECTION ERROR
HE USAGE FIRST 2 DAYS @ 6.4 MG/S	1.1 KG	1.1 KG
HE USAGE ORBIT TRIM @ 13.5 MG/S	16.3 KG (14 D)	63 KG (54 D)
REMAINING HELIUM AFTER ORBIT TRIM	320 KG	273 KG
LIFETIME OF REMAINING HE @ 6.95 MG/S*	17.5 MO	14.9 MO
TOTAL LIFETIME AFTER LAUNCH §	18.0 MO	16.8 MO

* SCALE 18.45 MO BY REMAINING HE IN TANK
§ ADD BACK ORBIT TRIM TIME SPAN + FIRST 2 D

GPB-100417

HELIUM MASS FLOW RATE

STANFORD
Lockheed
Probe-C CDR
29 March 95

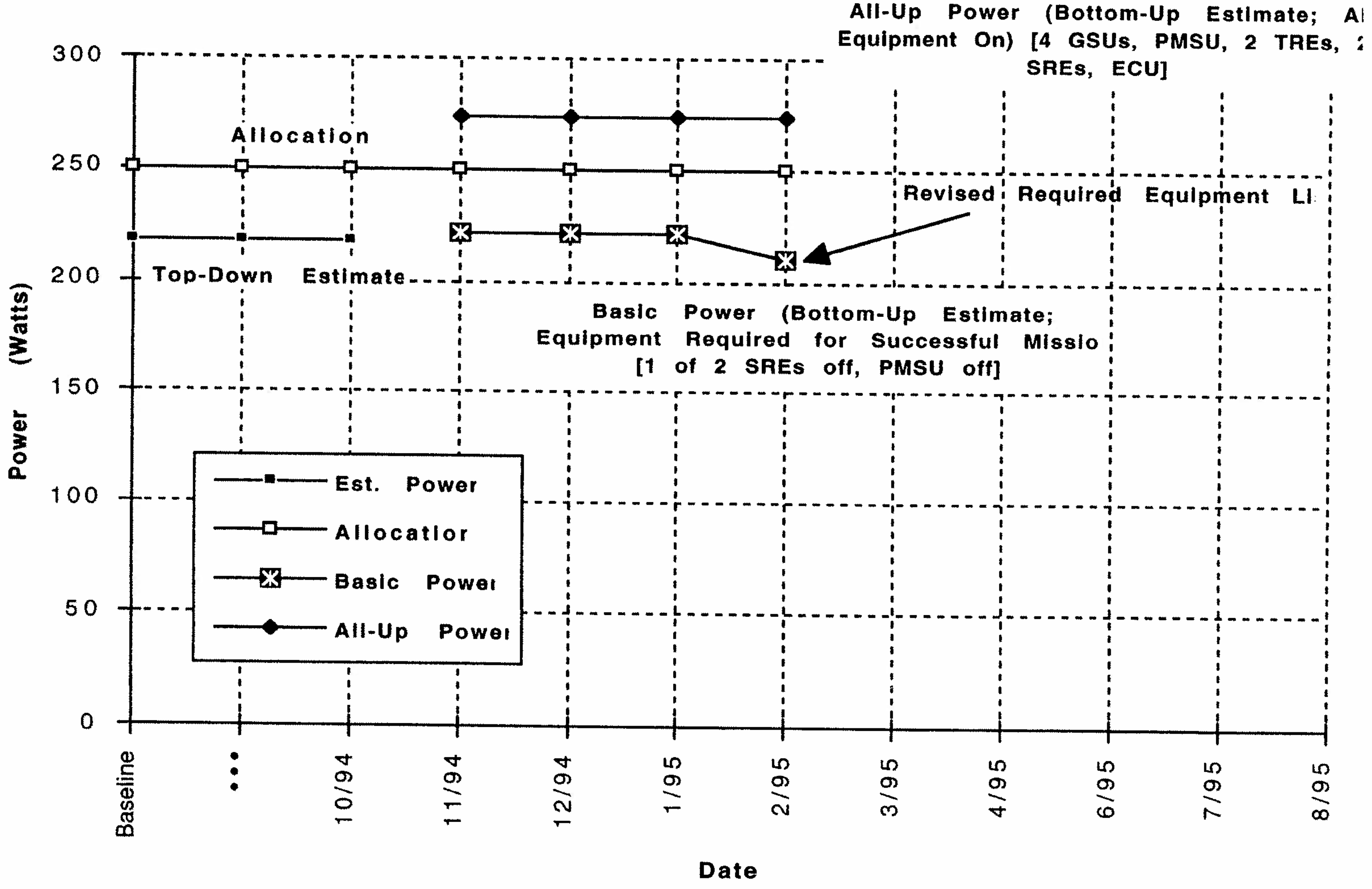


GPB-100417

TECHNICAL PERFORMANCE MEASURE
~~TOTAL PAYLOAD POWER~~

STANFORD
Lockheed
Probe-C CDR
29 March 95

Payload Electronics Powe



CDR-10

TECHNICAL PERFORMANCE MEASURE

DATA SUBMITTALS

DATA SUBMITTALS DURING THE PAST SIX WEEKS

SOW #	DR#	TITLE	DELIVERY DUE	DATE DUE
1.2	PLPM-09	Financial Management Reports	monthly	2/15/95
1.2	PLPM-03	Monthly Progress Reports	at monthly reviews	2/24/95
1.3.1	PLSE-11	Mass Properties Report	quarterly, plus	2/15/95

DATA SUBMITTALS DURING THE NEXT SIX WEEKS

SOW #	DR#	TITLE	DELIVERY DUE	DATE DUE
1.3.3	PLIT-01	Payload Verification and Test Plan	each PDR, CDR	3/29/95
1.3.3	PLIT-03	Verification Reqts Compliance Document	each PDR, CDR	3/29/95
1.3.1	PLMO-01	Payload Operations Reqts Document	updates as needed	3/29/95
1.3.4	PLPA-01	Safety, Reliability, & PA Plan	each PDR, CDR	3/29/95
1.3.4.2.1	PLPA-08	FMEA and CIL	each PDR, CDR	3/29/95
1.3.1	PLPA-10	Payload Matls & Processes Control Plan	each CDR & as reqd	3/29/95
1.3.4.2.2	PLPA-12	Limited-life Items List	each CDR & as reqd	3/29/95
1.2	PLPM-03	Monthly Progress Reports	at monthly reviews	3/31/95
1.3.1	PLPM-04	Design Review Data Package	each PDR, CDR	3/29/95
1.2	PLPM-09	Financial Management Reports	monthly	3/15/95
1.3.4.1.1	PLSA-01	Safety Compliance Data	each PDR, CDR	3/29/95
1.3.1	PLSE-11	Mass Properties Report (Probe update)	quarterly, plus	3/15/95
1.3.1	PLSE-12	Science Payload Specification	updates as needed	3/29/95

Interface Requirements for Probe-C

Probe-C has interfaces to a number of different components that are being produced by the Lockheed payload contract, the Lockheed spacecraft contract, and by Stanford. The interfaces to these components are controlled by the following documents:

Probe-C to Science Instrument Assembly	Science Payload Specification F277277, section 3.7.2 Interface Control Drawing 1C34103
Probe-C to External Payload Assemblies	Science Payload Specification F277277, section 3.7.6 Interface Control Drawing 1C34102
Probe-C to Science Mission Dewar	Science Payload Specification F277277, section 3.7.4 Interface Control Drawing 5834159 Interface Control Drawing 5833117
Probe-C to Spacecraft	Science Payload to Spacecraft Interface Control Document F277233 Interface Control Drawing 5833115