JPL D-9847

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TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

SPECIAL REVIEW BOARD FINAL REPORT

May 29, 1992

1 of 214

D-9847

TOPEX SPACECRAFT HANDLING ANOMALY

APPROVAL OF REVIEW BOARD REPORT

The Report of the TOPEX Special Review Board chartered to investigate the March 8, 1992, Spacecraft Handling Anomaly is hereby approved by the members of the Board:

Chairman: Ronald A. Ploszaj

Ronald A. Ploszaj

A. G. Bryson for
Thomas E. Gindorf

Laurence J. Hart /FOR
Franklin L. Hornbuckle

Jerome Kosko
Jerome G. Kosko

John B. Webb
John B. Webb

2

TOPEX SPACECRAFT HANDLING ANOMALY

OUTLINE

Section	Title	Page
1.	**FORMATION OF REVIEW BOARD**	1-1
	a. Review Board Members	1-1
	b. Ex-Officio Review Board Members	1-2
	c. Other Contributors	1-2
2.	**EXECUTIVE SUMMARY OF INCIDENT**	2-1
	a. Discussion	2-1
	b. Root Cause of Problem	2-2
	c. Contributing Factors	2-2
	d. Additional Observations	2-3
	e. Litigation and Liability Issues	2-3
3.	**DESCRIPTION OF REVIEW PROCESS**	3-1
4.	**RESPONSIBILITY FOR CONDUCTING TEST**	4-1
	a. Organizations Involved	4-1
	b. Organization Chart	4-1
	c. Policies	4-1
	d. Procedures Used	4-1
	e. Personnel Involved	4-2
	f. Personnel Certification	4-2
	g. Location of Personnel	4-2

3

TOPEX SPACECRAFT HANDLING ANOMALY

OUTLINE

Section	Title	Page
5.	**DESCRIPTION OF SATELLITE MOVE ACTIVITIES**	5-1
	a. Summary Chronology	5-1
	b. Events Leading to Incident	5-1
	1. Move to Building 10	5-1
	2. Pre-Lift Operations	5-2
	3. Pre-Test Briefing	5-2
	4. East-West Move	5-2
	5. North-South Move	5-2
	6. Incident	5-3
	c. Recovery Activities	5-3
	1. Initial Recovery Activity	5-3
	2. Final Recovery Activity	5-4
6.	**LIFTING FIXTURE STABILITY ANALYSIS**	6-1
	a. Lack of Stability Analysis	6-1
	b. Friction Analysis	6-1
	c. H-Cross Beam Yielding	6-1
	d. Detailed Analysis	6-1
7.	**DAMAGE ASSESSMENT AND PROGRAMMATIC IMPACTS**	7-1
	a. Personnel	7-1
	b. Hardware	7-1
	1. Spacecraft	7-1
	2. T/V Test GSE	7-1
	3. T/V Fixture Assembly	7-2
	4. Mechanical Analysis	7-2
	c. Facilities	7-3
	1. General	7-3
	2. Crane	7-3

4

TOPEX SPACECRAFT HANDLING ANOMALY

OUTLINE

Section	Title	Page
	b. Programmatic Impacts	7-3
	1. Shortened Thermal Vacuum Test	7-3
	2. Overall Schedule Impact	7-3
8.	**HISTORY OF LIFTING FIXTURE**	8-1
	a. Responsibility for Design	8-1
	b. Responsibility for Stress Analysis	8-1
	c. Analysis of H-Frame Spreader Bar Assembly	8-1
	d. Design Review Process	8-1
	e. Designer Background	8-1
	f. Policies/Standards for Lifting Fixtures	8-2
	1. Fairchild Space	8-2
	2. Jet Propulsion Laboratory	8-2
	g. History of Lifting Sling	8-3
9.	**TEST TEAM PERFORMANCE**	9-1
	a. During Spacecraft Movement	9-1
	b. In Response to Emergency	9-1
	c. During Recovery	9-1
10.	**FINDINGS AND RECOMMENDATIONS**	10-1
	a. Findings	10-1
	1. Root Cause of Problem	10-1
	b. Contributing Causes	10-1
	1. Lack of Stability Analysis	10-1
	2. Inadequate Stability Testing	10-1

TOPEX SPACECRAFT HANDLING ANOMALY

OUTLINE

Section		Title	Page
	3.	Continued Postponement of GSE Review	10-2
	4.	Lack of Designer Experience and Peer Reviews	10-2
	5.	Lack of Functional Demonstration	10-3
	6.	Lack of Host Center Review of Hazardous Operations Procedures	10-4
	7.	Remaining Spacecraft Handling Operations	10-5
11.	LESSONS LEARNED		11-1
	a.	GSE Review	11-1
	b.	Review Material	11-1
	c.	Lifting Equipment Stability Analysis	11-1
	d.	Precursor Handling Experience	11-1
	e.	Project Overview of Contract	11-1
	f.	Dedicated Briefing	11-1
	g.	Functional Demonstration	11-2
	h.	Tilt Angle Requirements	11-3
	i.	Host Center Review of Hazardous Procedures	11-3
	j.	Video Recording of Hazardous Operations	11-4
	k.	Final Observations	11-4

TOPEX SPACECRAFT HANDLING ANOMALY

LIST OF FIGURES

Figure	Title
2-1	T/V Fixture Assembly Above Chamber
2-2	T/V Fixture Assembly After Handling Anomaly
2-3	Damaged H-Frame Spreader Bar
2-4	Spacecraft/SHSS Assembly Being Removed From T/V Chamber
2-5	Spacecraft/SHSS Assembly Being Returned To Normal Attitude
4-1	Test Organization Responsibility Chart
5-1	Spacecraft/SHSS Assembly At Floor Of T/V Chamber
5-2	Spacecraft SHSS Assembly Being Lifted From T/V Chamber
5-3	Spacecraft/SHSS Assembly During Recovery Process
5-4	Spacecraft/SHSS Assembly On Floor In Normal Attitude
7-1	Damaged DORIS Antenna Connector
7-2	Damaged TMR RF Shield
7-3	Damaged Thermal Shroud Nitrogen Coolant Tubing
7-4	Damaged SADA Cable Tray
7-5	Bent P1 Connector Strain Relief Jacket
7-6	Broken P2 Connector Strain Relief Jacket
7-7	Indentations on SHSS Clevis Pin Lug

7

TOPEX SPACECRAFT HANDLING ANOMALY

APPENDICES

Appendix	Title
1-A	Special Review Board Authorization Memorandum
3-A	Impound Release Authorization
3-B	Review Board Initial Report
4-A	Fairchild Space Policies/Procedures
4-B	Fairchild Space Procedure Outlines
4-C	Personnel Present and Location During Anomaly
4-D	Personnel Certification
5-A	Attendees at March 8, Failure Review Board Meeting
7-A	Impact Load Analysis
7-B	Pre-Incident Building 10 Crane Checkout
7-C	Post-Incident Building 10 Crane Inspection
8-A	FS Fixture Design Responsibility Flow

8

TOPEX SPACECRAFT HANDLING ANOMALY

ABBREVIATIONS AND ACRONYMS

CG	Center of Gravity
ESD	Electrostatic Discharge
ETRR	Environmental Test Readiness Review
FACAR	Fairchild Anomaly and Corrective Action Report
RF	Radio Frequency
FS	Fairchild Space
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
GSFC	Goddard Spaceflight Center
HP	Handling Procedure
HSI	Health and Safety Instruction
IM	Instrument Module
IR&D	Internal Research and Development
I&T	Integration and Test
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSI	GSFC Support Contractor
MMS	FS Multimission Spacecraft
MSR	Monthly Status Review
PP	Program Plan
psi	Pounds per Square Inch
RF	Radio Frequency

9

TOPEX SPACECRAFT HANDLING ANOMALY

ABBREVIATIONS AND ACRONYMS

SAD	Solar Array Drive
SADA	Solar Array Drive Assembly
SHSS	Spacecraft Horizontal Support Structure
TMR	TOPEX Microwave Radiometer
TOPEX	Ocean Topography Experiment
TP	Test Procedure
T/V	Thermal Vacuum

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

1. FORMATION OF REVIEW BOARD

On March 9, 1992 a Special Review Board was formed by the Deputy Director of the Jet Propulsion Laboratory to investigate the March 8, 1992 TOPEX/POSEIDON Spacecraft Handling Anomaly. A copy of the of the authorization memorandum is contained in Appendix 1-A.

1.a. Review Board Members

RONALD A. PLOSZAJ, Chairman --- Jet Propulsion Laboratory
Manager, Mechanical Systems Engineering and Research Division

THOMAS E. GINDORF --- Jet Propulsion Laboratory
Manager, Reliability Engineering Section

FRANKLIN L. HORNBUCKLE --- Fairchild Space
Vice President, Engineering

JEROME G. KOSKO --- Goddard Spaceflight Center*
Office of Flight Assurance
System Safety Branch

JOHN B. WEBB --- Goddard Spaceflight Center
Payload Systems Management Office
Applied Engineering Division

* J. G. Kosko replaced Ronald Casey as the GSFC Safety representative to the Review Board.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

1.b. Ex Officio Review Board Members

LAWRENCE HARTER --- Fairchild Space
Vice President, Product Assurance

WILLIAM E. LAYMAN --- Jet Propulsion Laboratory
Senior Member of the Technical Staff
Mechanical Systems Development Section

JOSEF WONSEVER --- NASA, Headquarters
SRM&QA Manager for OSSA

1.c. Other Contributors

JON C. OHMAN --- Goddard Spaceflight Center
Health, Safety and Security Office
Health and Safety Branch

PAUL HARDY --- Jet Propulsion Laboratory
Senior Engineering Assistant
Mechanical Systems Development Section

12

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

2. EXECUTIVE SUMMARY

2.a. Discussion - On Sunday March 8, 1992 the TOPEX/POSEIDON Spacecraft was being prepared for thermal vacuum (T/V) testing by the Fairchild Space (FS) Test Team in Building 10 of the Goddard Spaceflight Center (GSFC). As part of the procedure, the T/V Fixture Assembly consisting of the spacecraft, thermal test shrouding and instrumentation mounted on the Spacecraft Horizontal Support Structure (SHSS), suspended by four vertical cables from an H-frame spreader bar was lifted and positioned above the T/V chamber (See Figure 2-1). At approximately 11:25 a.m., during final north-south crane positioning maneuvers, the suspended assembly began a slow overturning rotation. The assembly rotated approximately 135° from horizontal before being halted by the entanglement of one of the four suspension cables with the SHSS. After some bouncing and jostling, it came to rest at approximately 115° (See Figure 2-2).

While resting in this anomalous position (+X end up), the Test Team visually determined that the H frame spreader bar assembly had sustained considerable damage during the rotation and might fail (See Figure 2-3). A decision was made by the FS Spacecraft Manager to remove the vertical load from the overstressed and damaged H frame spreader assembly as quickly as possible by lowering the spacecraft and test fixture to the chamber floor. Within ten minutes of the overturning incident the Test Team, augmented by personnel from the GSFC contractor NSI, lowered the rotated assembly to the chamber floor where it was temporarily secured. During the subsequent visual inspection of the secured assembly it was noted that sections of the thermal test shroud and support fixturing had partially yielded. However, no apparent damage to the spacecraft or to the lower frame of the SHSS could be seen.

An on site "failure review board" consisting of FS, JPL,

GSFC, and NSI personnel was convened to review and discuss the situation. A decision was made by the board that the Spacecraft/SHSS assembly should be removed and reoriented to a horizontal position outside of the chamber to minimize any further yielding of the supporting structures. An NSI rigging crew was on the scene at this time, and was given the go ahead by the board to proceed with the removal of the Spacecraft/SHSS assembly from the chamber.

The damaged H-frame spreader bar and the four suspension cables were removed. A pair of nylon slings were attached from the +X end of the SHSS to the crane hook and the Spacecraft/Thermal Shroud/SHSS assembly was raised vertically out of the T/V chamber (Figure 2-4) and moved directly adjacent to it. The assembly remained there suspended a few inches above the floor while the NSI team attached additional slings from the -X end of the SHSS to a forklift positioned on the -Z side of the load (See Figure 2-5). By alternating operations of the crane and the forklift, the spacecraft and fixture were reoriented horizontally and lowered to the floor. At approximately 6:51 p.m. the operation was completed with the Spacecraft/SHSS assembly safely on the floor in the normal attitude.

A video recording of both the anomaly and the recovery operation was made and is available from the TOPEX Project Office for viewing.

2.b. <u>Root Cause of Problem</u> - The <u>T/V Fixture Assembly</u> used for lifting the spacecraft into the thermal vacuum chamber was unstable in the TOPEX/POSEIDON configuration.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

2.c. Contributing Factors

1. A stability analysis of the total lifted assembly that was used in the T/V lift was not performed.

2. The lifting fixture guidelines contained in JPL900-501, Ground Handling Equipment Design Notebook were not adequately applied.

3. A GSE Review which would have included a review of the T/V handling fixture assembly, was repeatedly postponed, and not held prior to its use for lifting the spacecraft into the T/V chamber.

2.d. Additional Observations

1. The overall review process, at all levels (peer review to formal review) failed to identify the lifting fixture deficiency.

2. No precursor run through (dry run) of the T/V lifting exercise, using either the actual or a high fidelity simulation of the lifted assembly, was run prior to the lift with the flight spacecraft. There was a low fidelity dry run with the TOPEX/POSEIDON handling fixture, but it was performed without a spacecraft mass simulation and at different locations and orientations than the flight spacecraft handling. (The stated purpose for the dry run was to check the SHSS and thermal shroud interfaces and clearances to the T/V chamber, not to dry run the actual spacecraft lift.)

3. Just prior to the final crane move, the T/V Fixture Assembly was lifted by the crane and a "rocking test" was performed on the assembly by the test team to assess its stability. The T/V Fixture Assembly

5

appeared to be stable at that time because the lifting clevis friction was not exceeded during the rocking test.

2.e Litigation and Liability Issues

The California Institute of Technology Office of General Counsel has reviewed the Board Report and the terms of the JPL/FS contract and has advised that there are no litigation or liability issues.

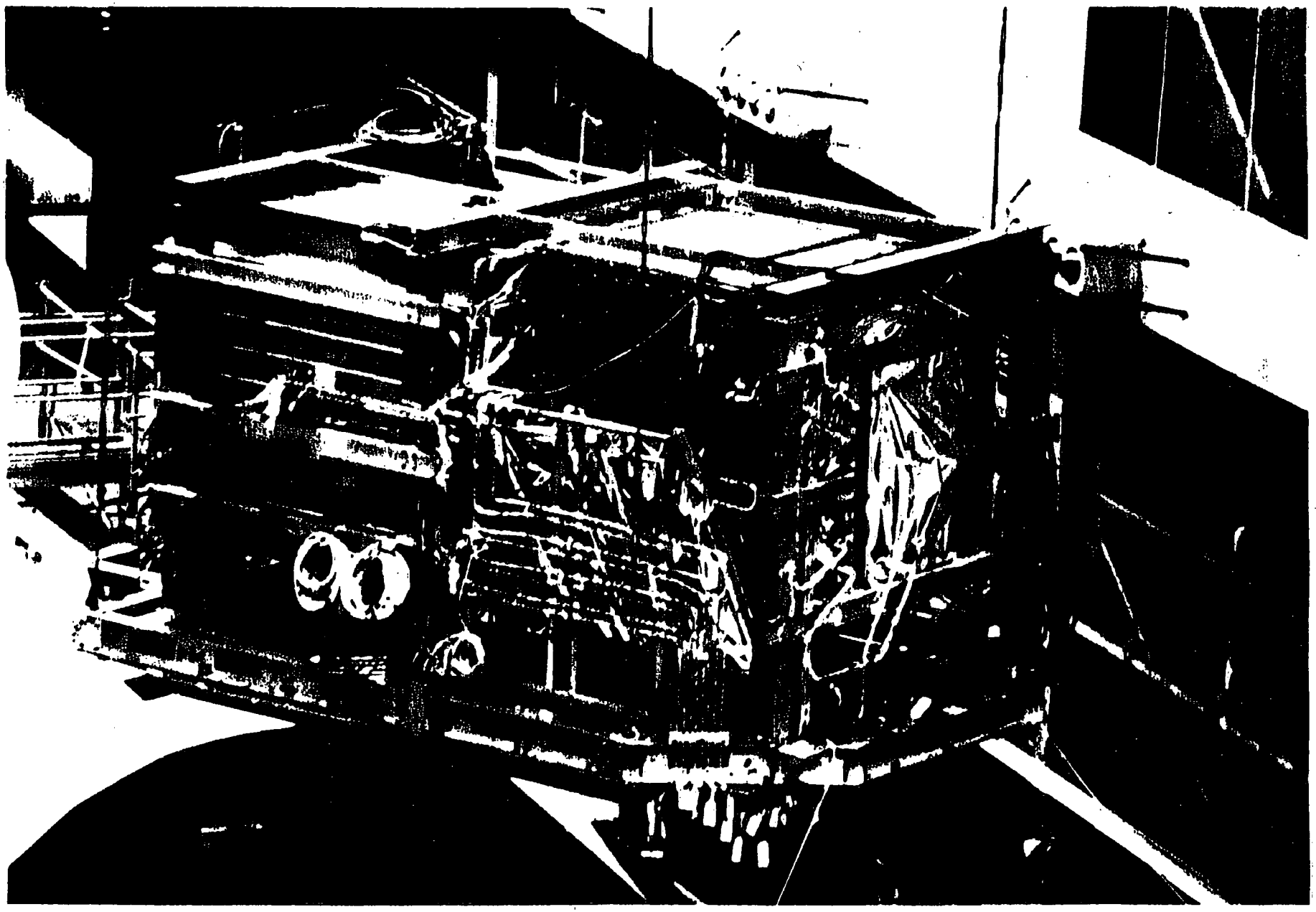


Figure 2-1, T/V Fixture Assembly Above Chamber

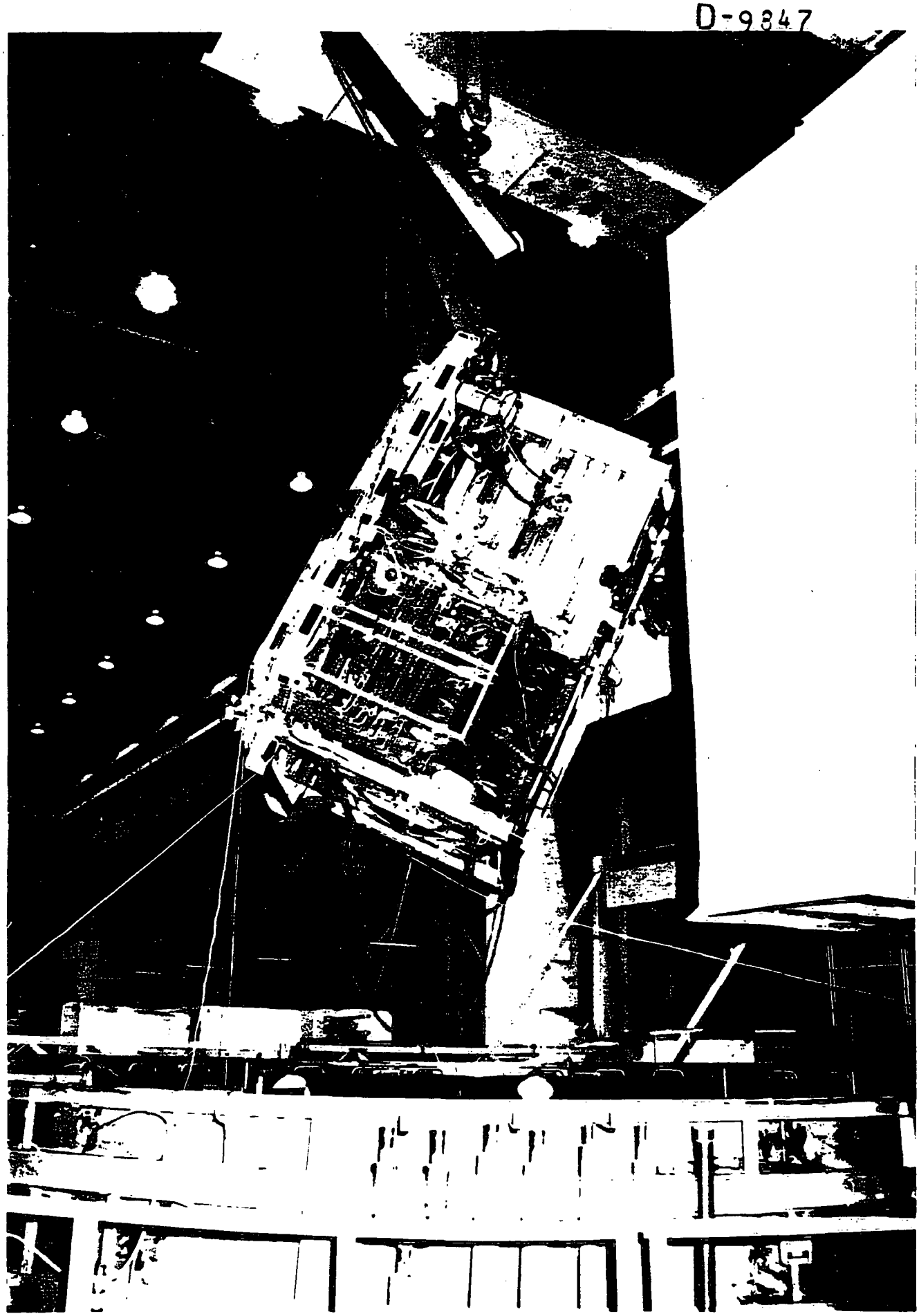


Figure 2-2, T/V Fixture Assembly After Handling Anomaly

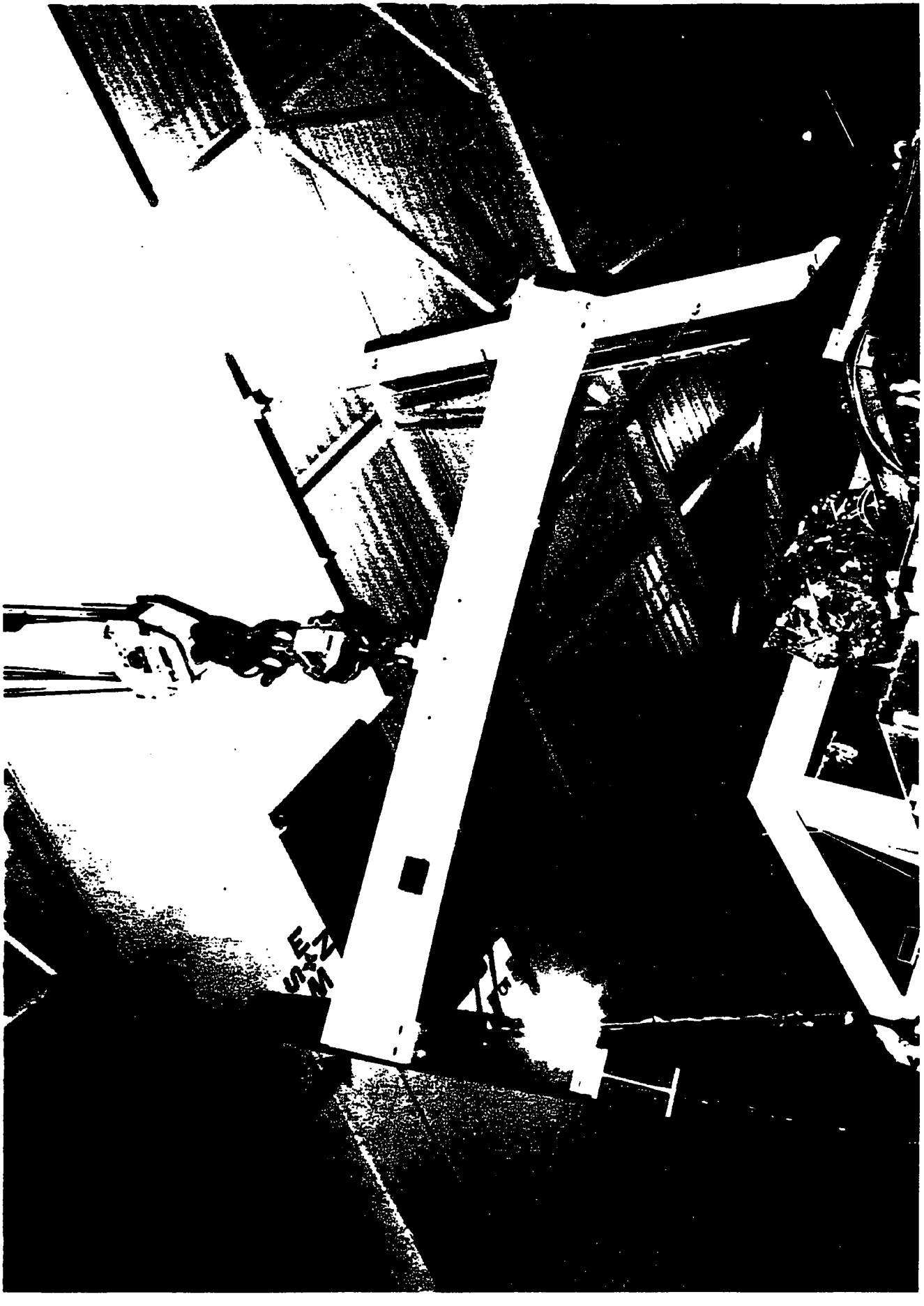


Figure 2-3, Damaged H-Frame Spreader Bar

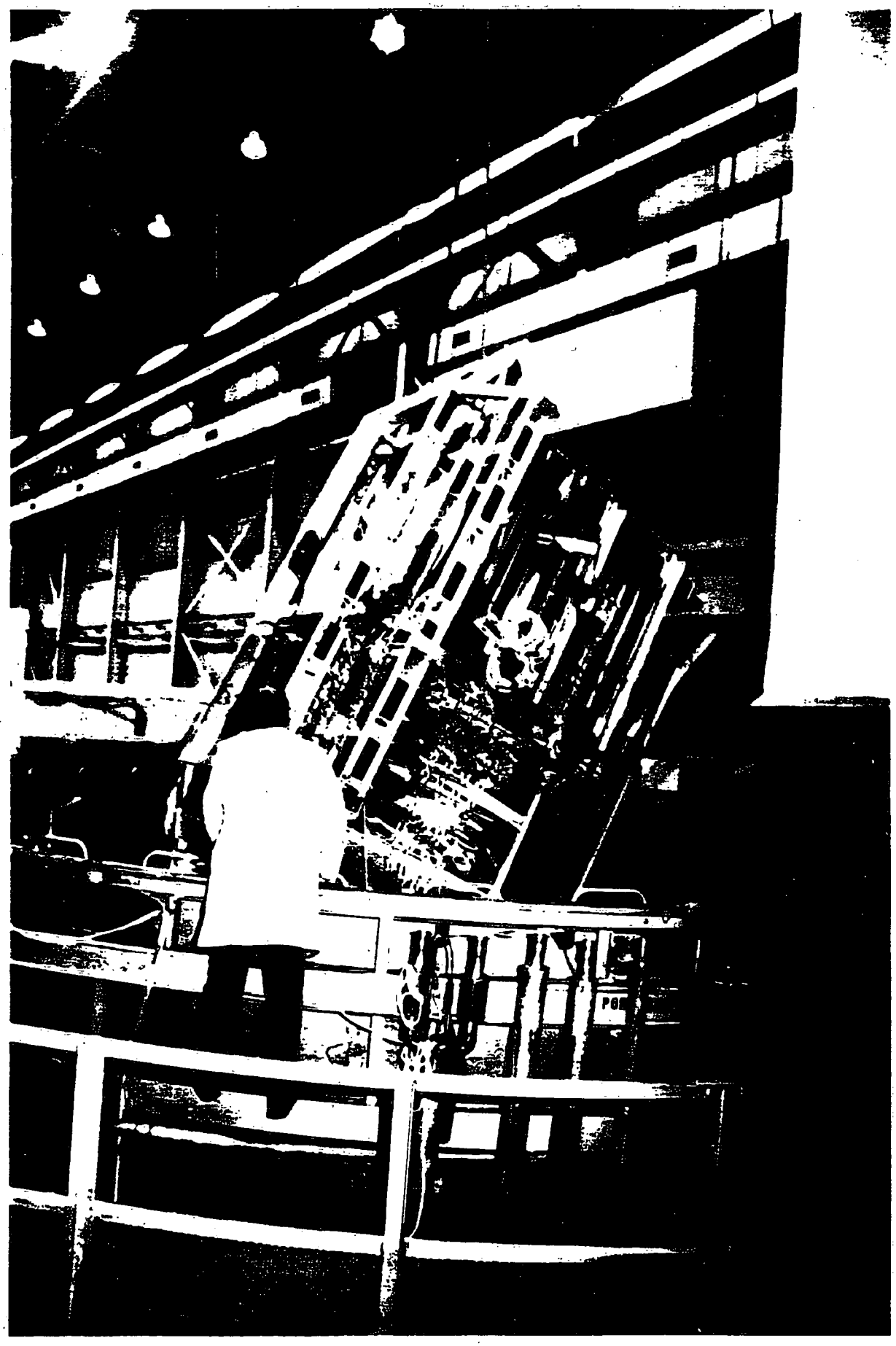


Figure 2-4, Spacecraft/SHSS Assembly Being Removed From T/V Chamber

D-9847

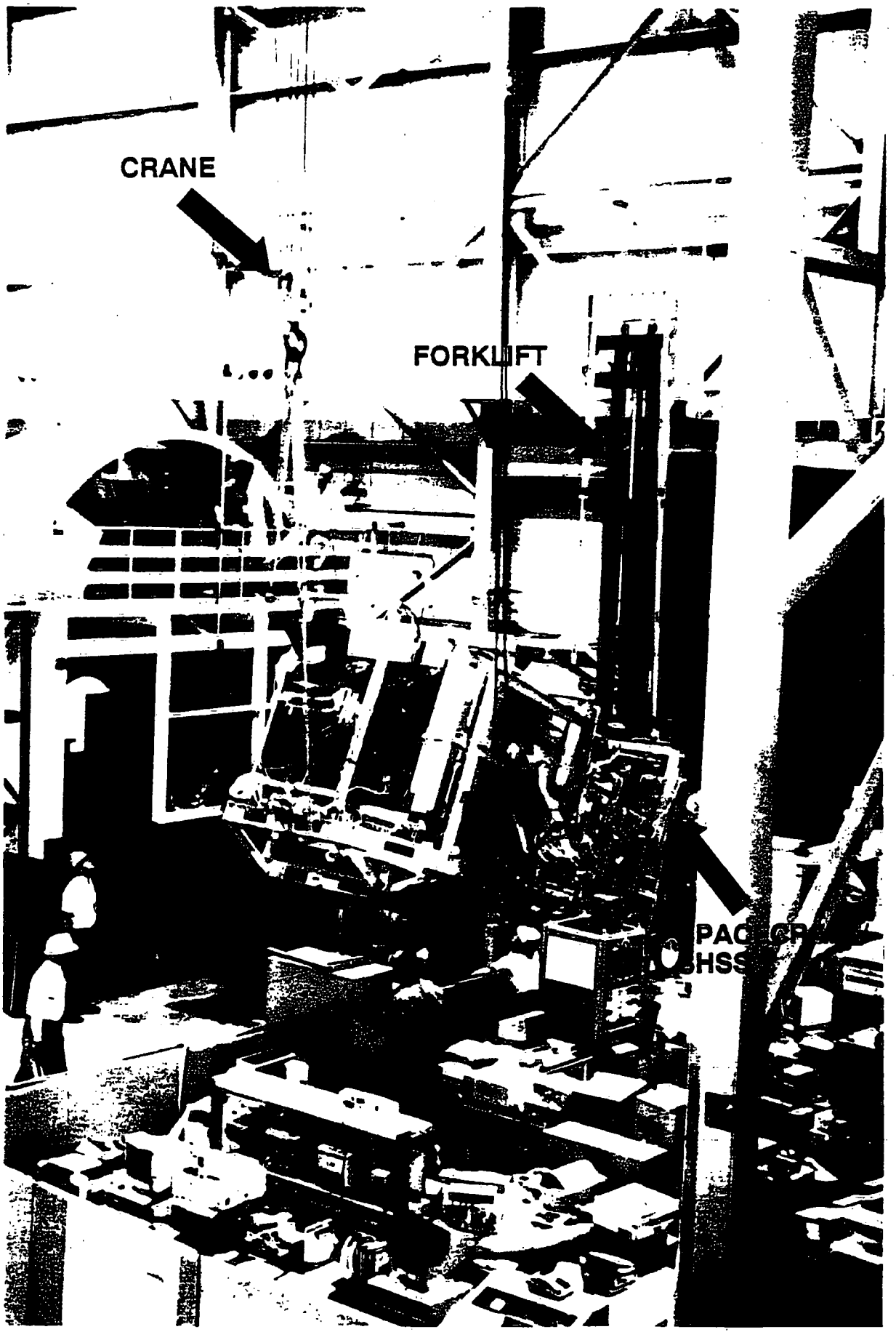


Figure 2-5, Spacecraft/SHSS Assembly Being Returned to Normal Attitude

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

3. DESCRIPTION OF REVIEW PROCESS

The TOPEX Special Review Board was established to provide an independent assessment of the circumstances that led to the March 8, 1992 handling anomaly that occurred during final positioning of the TOPEX/POSEIDON Spacecraft over the thermal vacuum chamber at the Goddard Spaceflight Center (GSFC).

Specifically, the Board was chartered (See Section 1) to conduct its investigations in two phases:

a. Assess the project's intended recovery plan, from the point of view of whether it provides for the safety of the spacecraft while minimizing the impact to the project schedule. Concur in the revised handling procedure before further steps are taken which could put the spacecraft at risk.

b. Determine the root cause of the handling anomaly, identify steps which should be taken in the future to prevent similar occurrences, and make recommendations regarding potential liability or litigation issues.

The Board first met at the GSFC on Tuesday, March 10, 1992 in Building 7, Room 246. As the first order of business the Board was given an in-depth briefing of the anomaly by project personnel and was taken on an inspection tour of the Spacecraft and the thermal vacuum handling fixture. At the conclusion of the tour, the Board Chairman concurred with the request to release the impounded configuration (See Appendix 3-A) to allow removal of the thermal shrouds surrounding the Spacecraft and facilitate a thorough visual inspection and electrical performance test to assess the condition of the Spacecraft.

During the balance of the Board's first session which continued

through Friday, March 13, 1992, the Board concentrated on determining the root cause of the anomaly and reviewing the corrective actions planned by the Project to recover from the anomaly and proceed with the thermal vacuum testing. The Board reviewed and analyzed various data which included the videotape of the incident, still photographs, witness statements, location of test personnel during the anomaly, interviews with selected witnesses to clarify their written statements, applicable procedures, team training and certification, and lifting crane operation and certification. The root cause of the handling anomaly was analytically determined to be an unstable T/V Fixture Assembly.

Board Members reviewed the project recovery plan and concurred with the reuse of the TOPEX Spacecraft horizontal support structure (SHSS) in conjunction with the existing Fairchild Space (FS) multi-mission spacecraft (MMS) shipping container lifting sling for installing the Spacecraft into the thermal vacuum chamber. A thorough review and verification of the stability analysis of the new MMS Sling/SHSS/Spacecraft assembly was conducted. The Board also concurred with the lifting and handling of the Spacecraft to support electrical and alignment tests prior to resumption of the thermal vacuum tests. At the completion of the first Board session an Initial Report was issued (See Appendix 3-B) stating: a) The Board's assessment that the root cause of the anomaly was a basic instability in the original lifting fixture design; and b) The Board's concurrence with the project recovery plan. The Board further recommended that the Project: a) Conduct a structured pre-test briefing prior to lifting the spacecraft; and b) Conduct a dry run of the lifting activities leading to the installation of the spacecraft in the chamber. Additional details of the Board's activity during its first session are contained in the Initial Report. Issuance of the Initial Report completed Phase A of the Board's assignment.

A second session of the Review Board was held at GSFC on March 24-25, 1992 to address second phase of the Board's charter.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Individual Board Member follow up assignments from the first session were presented and reviewed, an outline for the final report was generated, a draft of the executive summary generated, and the assignments and due dates for inputs to the final report were made. Release of the Review Board Report will constitute completion of the Phase B activities.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

4. RESPONSIBILITY FOR CONDUCTING TEST

4.a. Organizations Involved - The Spacecraft move was under the direction of Fairchild Space Test Team with support from JPL and facility crane operations performed by NSI (A support contractor for GSFC).

4.b. Organization Chart - For Test Hierarchy see Figure 4.1

4.c. Policies - For Fairchild Space Policies/Procedures see Appendix 4-A.

603	- Design Reviews
603.1	- Product Design Reviews - IR&D or Similar Efforts
603.2	- Internal Design Review
801	- System Integration and Test
1010	- Conduct of Test of Flight Hardware

4.d. Procedures Used - The following procedures were used to prepare and handle the spacecraft in support of the thermal vacuum activities. Summary outlines are reflected in Appendix 4-B.

1. 968-PP1011 TOPEX/Poseidon Spacecraft System Integration and Test Plan.

2. 968-TP8010 Rev A TOPEX/Poseidon Thermal Vacuum Test Procedure - calls out paragraphs of the handling procedure.

3. 968-HP8013 TOPEX/Poseidon Handling Procedure

- 5.1	Vertical Handling (Dolly to Ransome Table)
- 5.2	Rotation on Ransome Table
- 5.3	Horizontal Handling
- 5.3.1	Ransome Table to Spacecraft Horizontal Support Structure (SHSS)

25

- 5.3.3 Transport of SHSS with S/C Installed

4. 968-TP1057 TOPEX/Poseidon Horizontal Spacecraft Handling Equipment Proof Loading Procedure

4.e. **Personnel Involved** - The program integration and test team consisting of Fairchild Space; Program, I&T, Safety, and Product Assurance personnel supported by JPL on-site Manager, Quality Assurance Representatives and Spacecraft Technicians with GSFC facilities support by NSI Crane Operators and Spacecraft Move Specialists. Appendix 4-C identifies the personnel present during the incident.

4.f. **Personnel Certification** - Appendix 4-D contains personnel certification outlines and training syllabus listings.

1. Fairchild Space Crane Operator Certification

2. Fairchild Safety Manual HSI No. 12.1 - Crane and Rigging Safety

3. Standard Laboratory Operating Procedures No. 008 - Proof Testing of Crane Rigging

4. Equipment Handling Training and Certification - PC0005

5. ESD Training and Certification - PC0010

4.g. **Location of Personnel** - Appendix 4-C reflects the location of the personnel during the incident.

ORGANIZATION

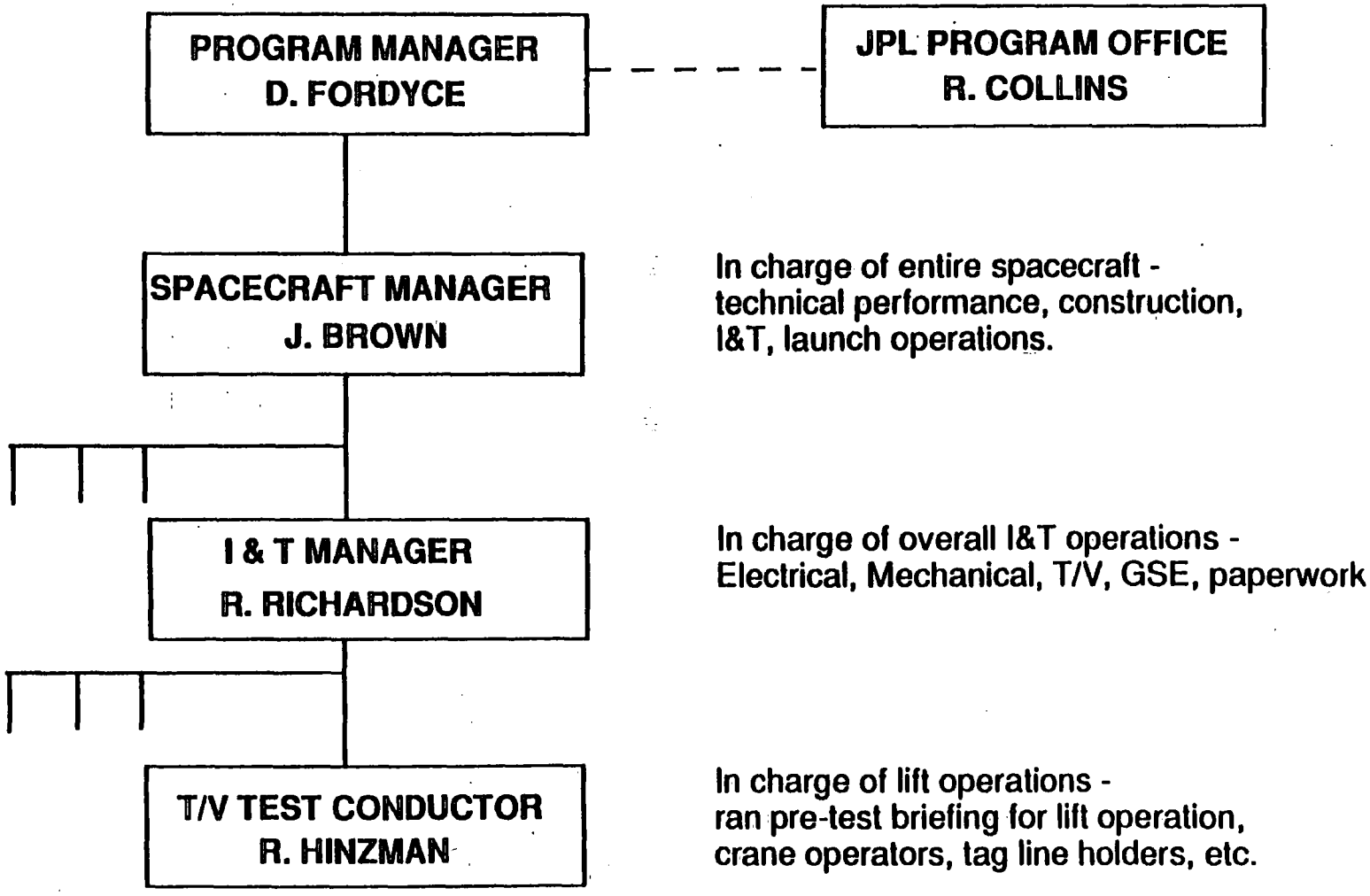


FIGURE 4-1,
TEST HIERARCHY

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

5. DESCRIPTION OF SPACECRAFT MOVE ACTIVITIES

5.a. Summary Chronology - Sunday, March 8, 1992

The following are approximate times the noted events occurred, details of which follow in "b" and "c" below:

8:00 am - Lifting Operations Began

11:15 am - Spacecraft in SHSS Lift to T/V Chamber Initiated

11:25 am - Spacecraft at T/V Chamber for Final Positioning

11:30 am - Spacecraft Rotation Incident Occurred

11:40 am - Spacecraft Lowered to T/V Chamber Floor

12:30 pm - Spacecraft Rigged Safe at T/V Chamber Floor

1:00 pm - Failure Review Board Meeting to Determine Next Actions

5:30 pm - Formal Planning Meeting for Removal from T/V Chamber

6:00 pm - Recovery from T/V Chamber Commenced

6:51 pm - Spacecraft Safe and Upright at Building 10 Floor

5.b. Events Leading to Incident

1. Move to Building 10 - The Spacecraft, prepared for the Thermal Vacuum test in the SHSS with all related thermal shrouds, instrumentation, and piping, was traversed from Building 29 to Building 10 via pneumatic air pads, in preparation for the lift to the T/V Chamber.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

2. Pre-Lift Operations (including Rocking Test) - The lifting sling, previously attached to the crane hook, was lowered with tag lines attached and mated to the lifting fittings on the SHSS. The NSI lead technician expressed concern that the load center of gravity (C.G.) was above the lifting points and suggested the addition of a "belly band" around the sling cables to compensate for the high C.G.. The lift configuration was raised and balanced using steel trim plates attached by 1/2" threaded hardware in pre-drilled holes. The balanced load was then lifted approximately two feet off the floor and rocked up and down approximately 6" in each direction in the north-south, east-west, and at 45° corners and appeared stable. No additional strap or band was utilized and the test conductor felt the load was stable.

3. Pre-Test Briefing - An informal pre-test or pre-operation briefing was held on the floor in the Spacecraft area prior to the move by the test conductor. This has been a standard practice for all tests and operations on the TOPEX/POSEIDON program. All personnel involved in the move and lift operation were present. Assignments to support the operation were made and discussed at this time.

4. East-West Move - The Spacecraft was then lifted and rotated in the horizontal plane 90° using the tag lines so the X-axis was in an east-west direction, and traversed east to the chamber center line. The Spacecraft was then lifted above the chamber lip and rotated using the tag lines so the X-axis was in the north-south direction.

5. North-South Move - The Spacecraft was then traversed south to the edge of the chamber and stopped to permit the transfer of the tag lines from the floor to the chamber top lip platform. The Spacecraft was then

again moved to the south and as the load approached the chamber center mark, the crane operator was directed by the NSI team leader to stop and slowly move to the center of the T/V chamber by inching or "bumping" the crane, which is a normal GSFC procedure for centering a load. This crane activity resulted in the load developing a small swaying oscillation.

6. Incident - The upper tag line operators at the south side of the chamber attempted to stabilize the swaying of the load by pulling on the lines. The floor level tag line operators at the north side of the chamber could not see the load and held their lines slack. While inching the load in the -X direction to its centered position over the T/V chamber, the T/V Fixture Assembly pitched up slightly and then down, not fully recovering its initial position. This same motion occurred a second time in response to the next inching motion of the crane. The -X end pitched down a third time in response to the next "bumping" motion and continued a slow overturning rotation until the -X,+Y cable snagged on the +X,+Y corner clevis lug of the SHSS. The Spacecraft/SHSS assembly swung past vertical to approximately 135° and bounced and jostled before coming to rest at approximately 115° from horizontal (See Figure 2-2). This rotation resulted in only the two -X cables supporting the load, and would have permitted a complete 180° roll over had the one cable not caught on an upper clevis lug of the SHSS.

A video recording and still photographs of the overturning event are available for viewing from the TOPEX/POSEIDON Project Office.

5.c. Recovery Activities

1. Initial Recovery Activity - Immediately following the

rotation the Fairchild Spacecraft Manager took over control of the operation from the Test Conductor. The initial recovery action considered was to traverse the load northward from the chamber area and return it to floor level and secure the lifting operation. However, personnel on the upper south lip of the chamber who were able to visually inspect the rotated T/V Fixture Assembly and noted severe torsional bending and cracks in the sling "H" section center I-beam with indications of load settling and continued fixture failure. This condition was immediately reported to the crane operator by one of the test team members and concurrently to the Spacecraft Manager by another test team member resulting in an unwavering and unanimous decision to lower and safe the Spacecraft inside the chamber. The T/V Fixture Assembly was lowered to near the chamber floor within 15 minutes of the overturning anomaly. While the assembly was being lowered, additional NSI personnel reported in from other work areas to assist in the recovery operations. The JPL TOPEX On-Site Manager informed the GSFC NSI coordinator that the Fairchild Spacecraft Manager had full authority during the recovery operation. The GSFC Facility Manager authorized Fairchild Space access to any GSFC assets or support needed during the operation. The NSI team provided beams and chamber floor plates to adequately support the Spacecraft at the chamber base (See Figure 5-1), and attached two cables from the chamber wall to the SHSS for stability, permitting the >8,000 pound load on the damaged lifting fixture to be reduced to <700 pounds, thus safing the Spacecraft.

2. Final Recovery Activity - A "failure review board" consisting of FS, JPL, GSFC, and NSI personnel was convened to develop the recovery plan. The attendees are listed in Appendix 5-A. The board members concurred that the load was not in a completely safe configuration and removal from the chamber was

imperative to prevent further damage to the Spacecraft and support equipment. The agreed upon plan was executed starting with bracing the top of the SHSS thermal vacuum shroud fixture. The damaged lifting sling assembly was then removed and a nylon web sling was connected around the SHSS. The Spacecraft was then lifted from the chamber (See Figure 5-2) and lowered to within inches of the floor where another nylon web sling was attached between the SHSS and a forklift (See Figure 5-3). Rotation of the load back to the normal upright position (a rotation of ≈115°) was accomplished by slowly alternating crane and forklift movements, keeping the load within inches of the floor at all times. The Spacecraft SHSS assembly was safely placed on the building floor at ≈6:51 p.m. (See Figure 5-4) where it remained until released by the Chairman of TOPEX Anomaly Special Review Board on Tuesday, March 10, 1992 (See Appendix 3-A).

A video recording and still photographs of the recovery operations are available for viewing from the TOPEX/POSEIDON Project Office.

3.2

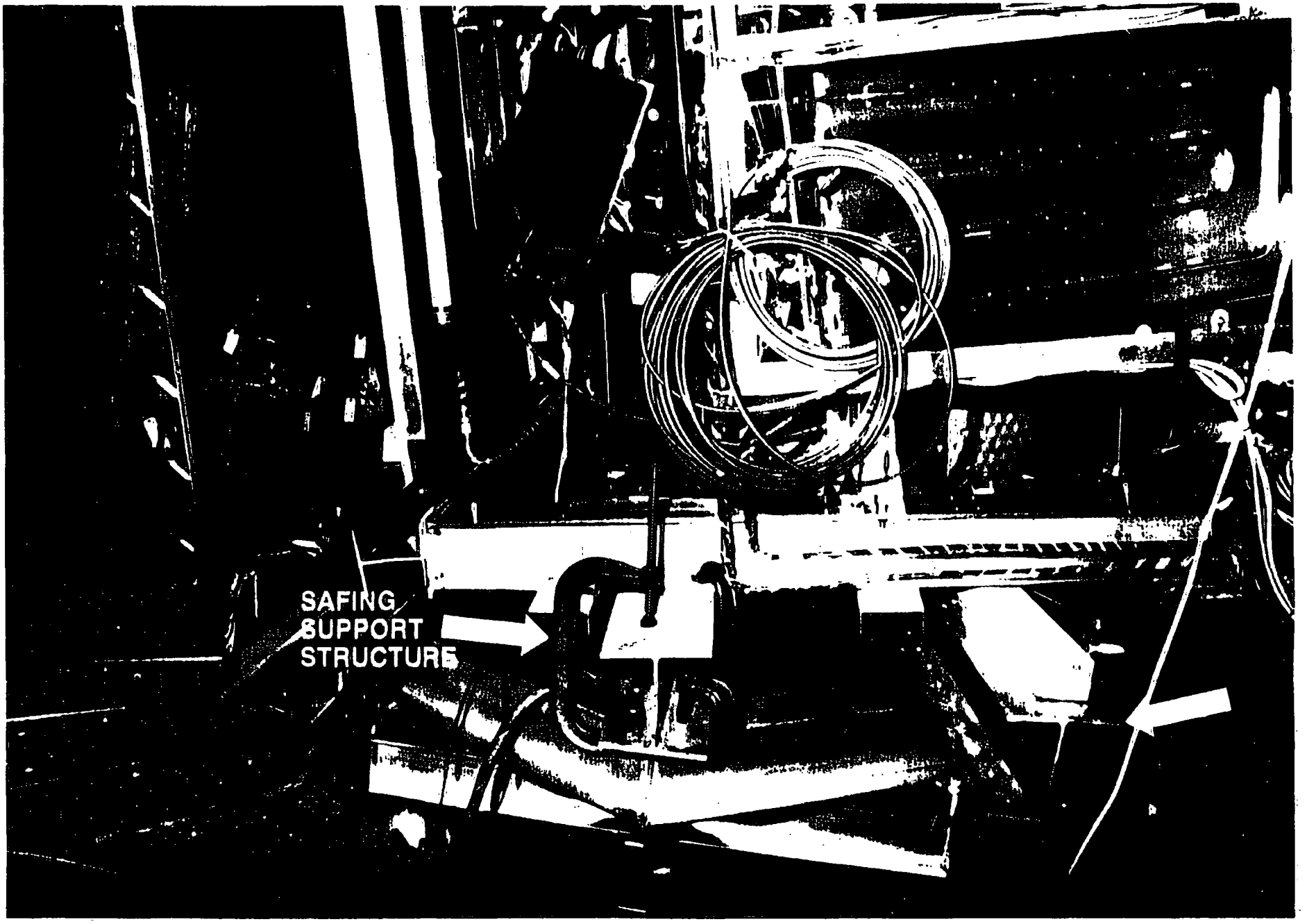


Figure 5-1, Spacecraft/SHSS Assembly at Floor of T/V Chamber

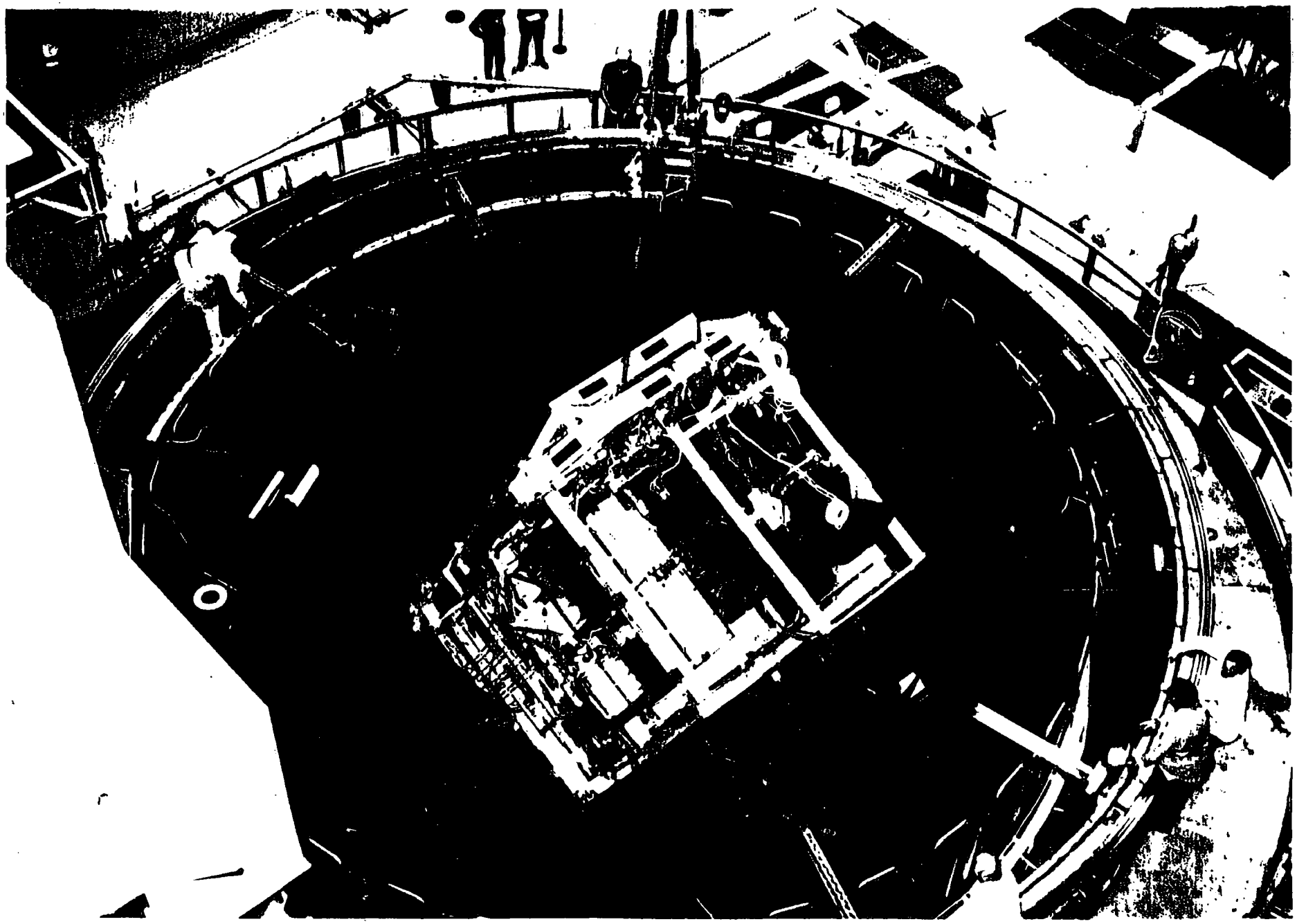


Figure 5-2, Spacecraft/SHSS Assembly Being Lifted From T/V Chamber

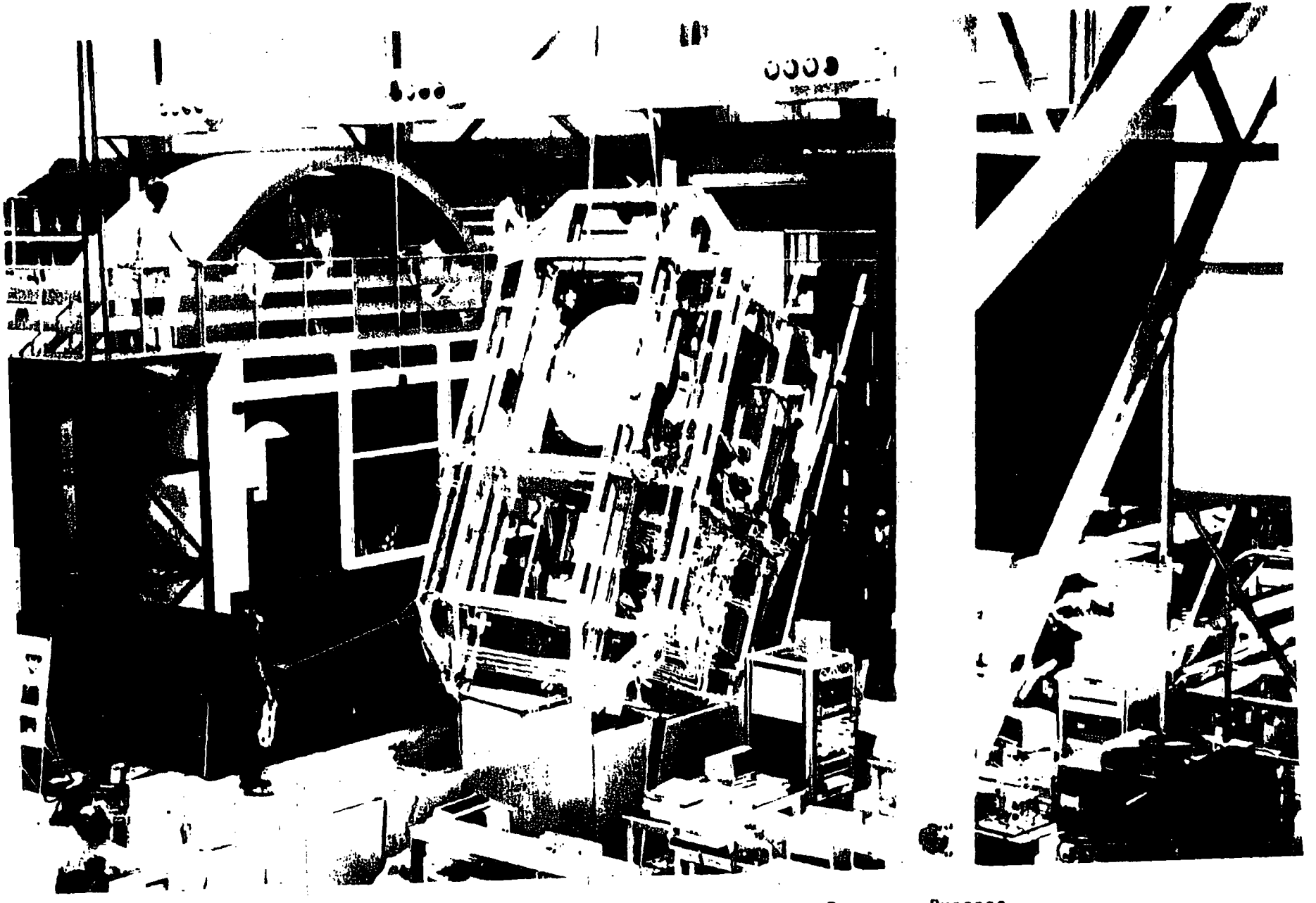


Figure 5-3, Spacecraft/SHSS Assembly During Recovery Process

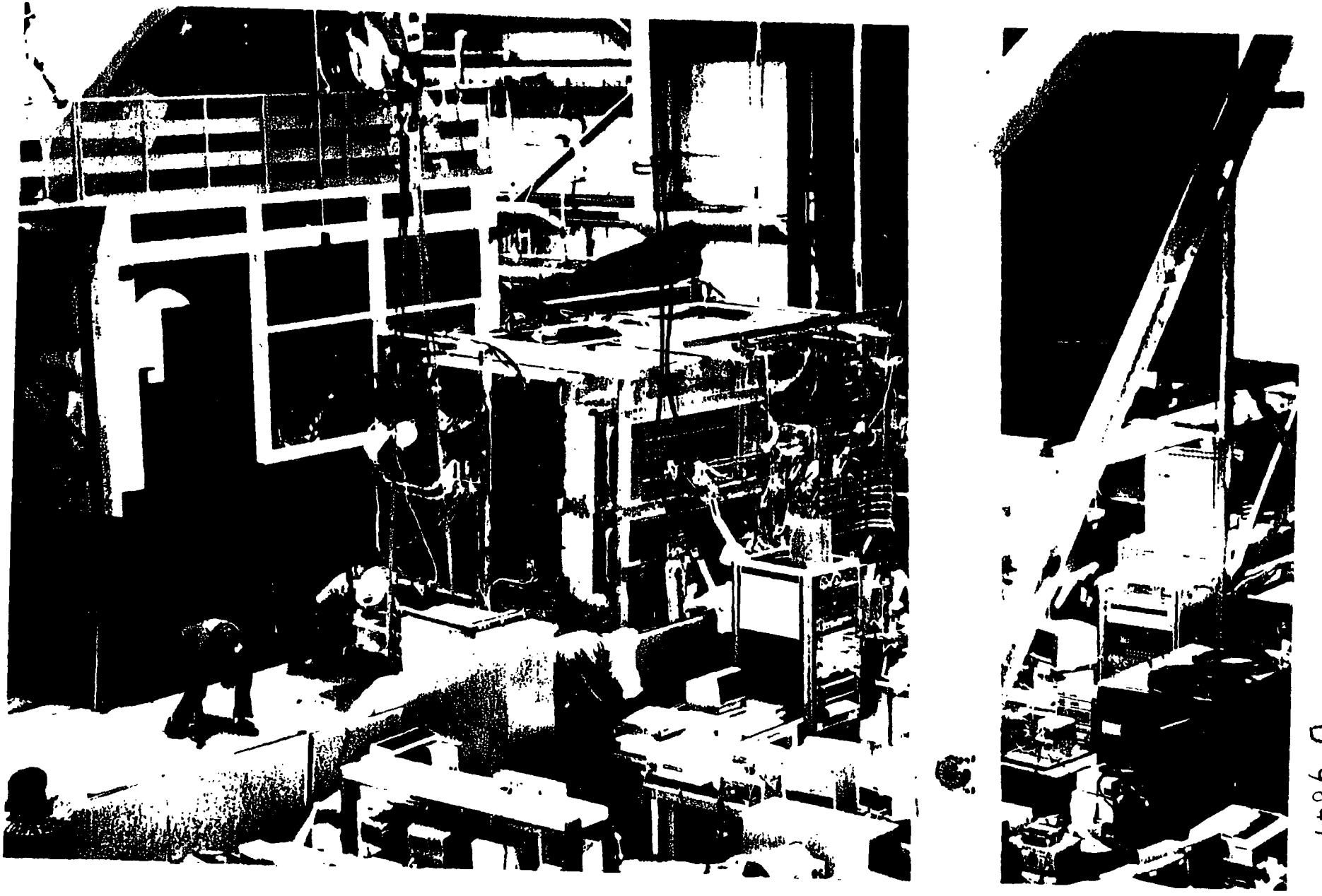


Figure 5-4, Spacecraft/SHSS Assembly on Floor in Normal Attitude

6. LIFTING FIXTURE STABILITY ANALYSIS

6.a. **Lack of Stability Analysis** - Prior to the unscheduled overturning event, a stability analysis of the lifted T/V Fixture Assembly had not been performed. After the event, independent FS and JPL analyses were done which established the rigid body stability factor (F_{STBL}) to be less than 1.0 (unstable). In effect, the lifted payload was an 8,000 pound upside down pendulum, approximately 8.6 inches tall.

6.b. **Friction Analysis** - In addition to the stability analysis, a friction analysis shows that clevis friction prevented an apparently reasonable stability test (rocking an end of the lifted assembly up and down several inched) from exposing the underlying instability. The friction analysis shows that the payload would not tip over (ie., overcome friction at the clevis pins) until it was tilted somewhere beyond ± 3.8° to ± 7.7° (This translates to a vertical motion of ± 5 to ± 10 inches at an end of the assembly).

6.c. **H-Cross Beam Yielding** Stresses in the fractured H-Cross Beam Lift Fixture were evaluated, versus overturning angle, to see if H-Cross Beam yielding contributed to the overturning. The stress analysis shows that the Payload tilt angle exceeded 8° to 10° when H-Cross Beam yielding began. Thus, yielding occurred after clevis friction had been overcome and overturning runaway had begun.

6.d. **Detailed Analysis** Figure 6-1 shows the "old" and "new" TOPEX/POSEIDON lifting sling geometries (viewed along their least stable axes). The "old" (unstable) lifting sling was involved in the overturning incident during the lift into the GSFC T/V chamber. The "new" (stable) lifting sling was used for the successful lift of the TOPEX into the GSFC T/V chamber.

Analysis of the overturning incident yields the following conclusions:

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

1. Per JPL D-6904 (Ground Handling Equipment Design Handbook) the stability factor (F_{STBL}, Figure 6-1) for the "old" sling was calculated. (A stability factor of less than 1.0 is unstable, JPL practice requires a factor of 1.5 and accepts waivers down to 1.2 under special circumstances). Using the equation of Figure 6-1 (which assumes no flexing of the sling geometry) the "old" lifting sling has a calculated stability factor of 0.83 (i.e., it is unstable). The sling is unstable because the lifted center of gravity height (Figure 6-1, dimension "D") above the lower-clevis plane is 6 inches more than the lift-point height (Figure 6-1, dimension "B") above the upper-clevis plane. A more refined calculation, taking flexibility into account, shows that the unstable payload lifting geometry was destablilzed an additional 2.6 inches by torsional compliance of the H-Cross-Beam, giving an actual stability factor of 0.76. *In effect the lifted-load was an 8,000 pound upside down pendulum, 8.6 inches tall.*

2. Despite the unstable lifting geometry, no overturning occurred during the initial and manual stability check of the TOPEX/POSEIDON T/V Handling Fixture Assembly. (To check stability before the ill-fated lift, the TOPEX T/V Handling Fixture Assembly was lifted and rocked by pushing down at the edge of the SHSS. The forced deflection remembered by the Test Team Members was between 3 and 12 inches (Tilt angle, β, between 2.1° and 8.6°). *It appears that clevis friction mislead the Test Team into thinking the lifted-load was stable.*

Calculations on the chart "TOPEX Lifting:Clevis Friction" (Figure 6-2) show the load could be tilted by 3.8° to 7.6° before overturning runaway occurred (i.e., before the overturning moment from the "upside down pendulum" exceeded the clevis friction.) Note on Figure 6-1 that until the clevis friction is overcome, the 10 inch long rigid clevises become part of the rigid beams, shortening the original dimensions "B" and "D" to "B'" and "D'" respectively and

make the assembly stable.

Using a friction coefficient (μ) of 0.3 to 0.6:

a) The clevises would rotate on their pins when forced to tilt to angles greater that 1.1° to 2.2°, but the upside down pendulum torque would not be large enough to force continued rotation.

b) The load would turn over when the tilt angle was forced beyond 3.8° to 7.6°.

3. Greater than 1.1° to 2.2° pendulum motion of the base relative to the H-Beam causes the clevises to pivot on their pins. (Normal crane traversing would induce such angles.)

It is probable that the clevis friction is slightly greater in one direction than the other. With this asymmetric clevis friction, each swing of the pendulum (induced by start-stop motion) tilts the payload slightly further in the favored direction until the "overturning runaway angle" is reached and uncontrolled overturning occurs. (This is not a problem on stable lifted-loads because the stabilizing force fights any frictional pumping.)

When pendulum motion is causing the clevises to rotate, very small asymmetrical tag-line forces would have the same effect as symmetric clevis friction. Four tag-line operators can not exert exactly equal forces on all their lines, so it is possible that tag line forces may have slightly contributed to (or resisted) the TOPEX overturn. *It is clear, however that tag line forces were modest and would have been no threat to a stable lifted-load.*

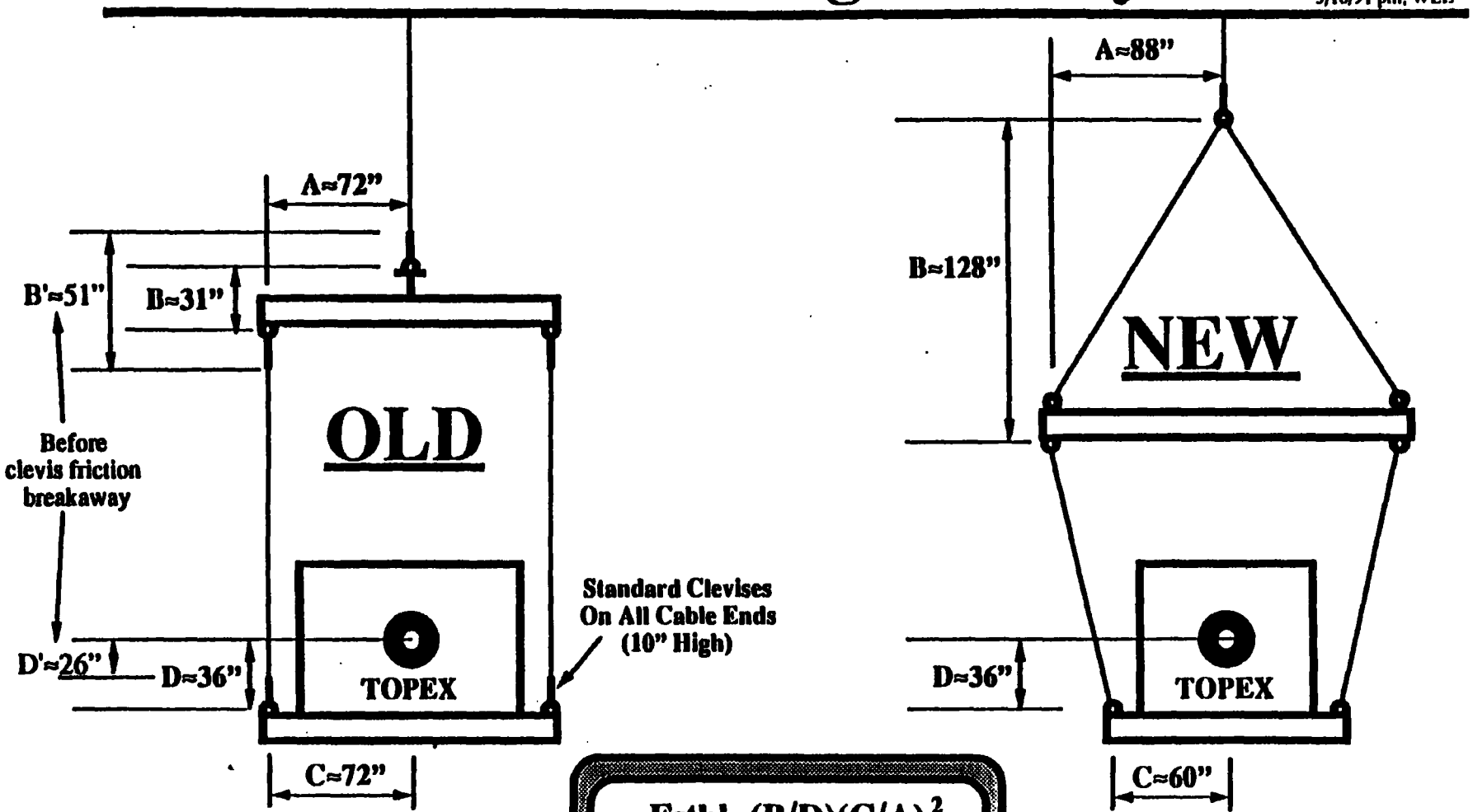
4. In the area of the H-Cross Beam which was cracked by the overturn, bending stress was calculated versus payload tilt angle. With the 8,000 pound load, a yield stress of 36,000 pounds per square inch (psi) is reached when the payload tilt angle (β) exceeds the crane-line pendulum angle by around 8° to 10°. (Much like bending a coat hanger, fracture

does not occur until a significantly larger angle.)

With stable lift loads the tilt angle follows the crane-line pendulum angle and bending stresses in the H-Beam are low. With unstable lift-loads, the tilt angle moves counter to the crane-line pendulum angle (eventually becoming very large), driving the beam into yield (and eventually fracture).

TOPEX Lifting Stability

3/16/91 pm, WEL



Original Lift Configuration
Unstable About Y-axis
(View Along Y-axis)

Before Clevis Friction Breakaway:
$F_{stbl}=(51/26)=1.96$ (Very Stable)

After Clevis Friction Breakaway (@ ± ≈ 1° Tilt):
$F_{stbl}=(31/36)=0.86$ (Unstable)

$$F_{stbl}=(B/D)(C/A)^2$$

[$F_{stbl}=1.0$: Neutral Stability]

JPL Practice: $F_{stbl} \geq 1.5$

New Lift Configuration
Least Stable About X-axis
(View Along X-axis)

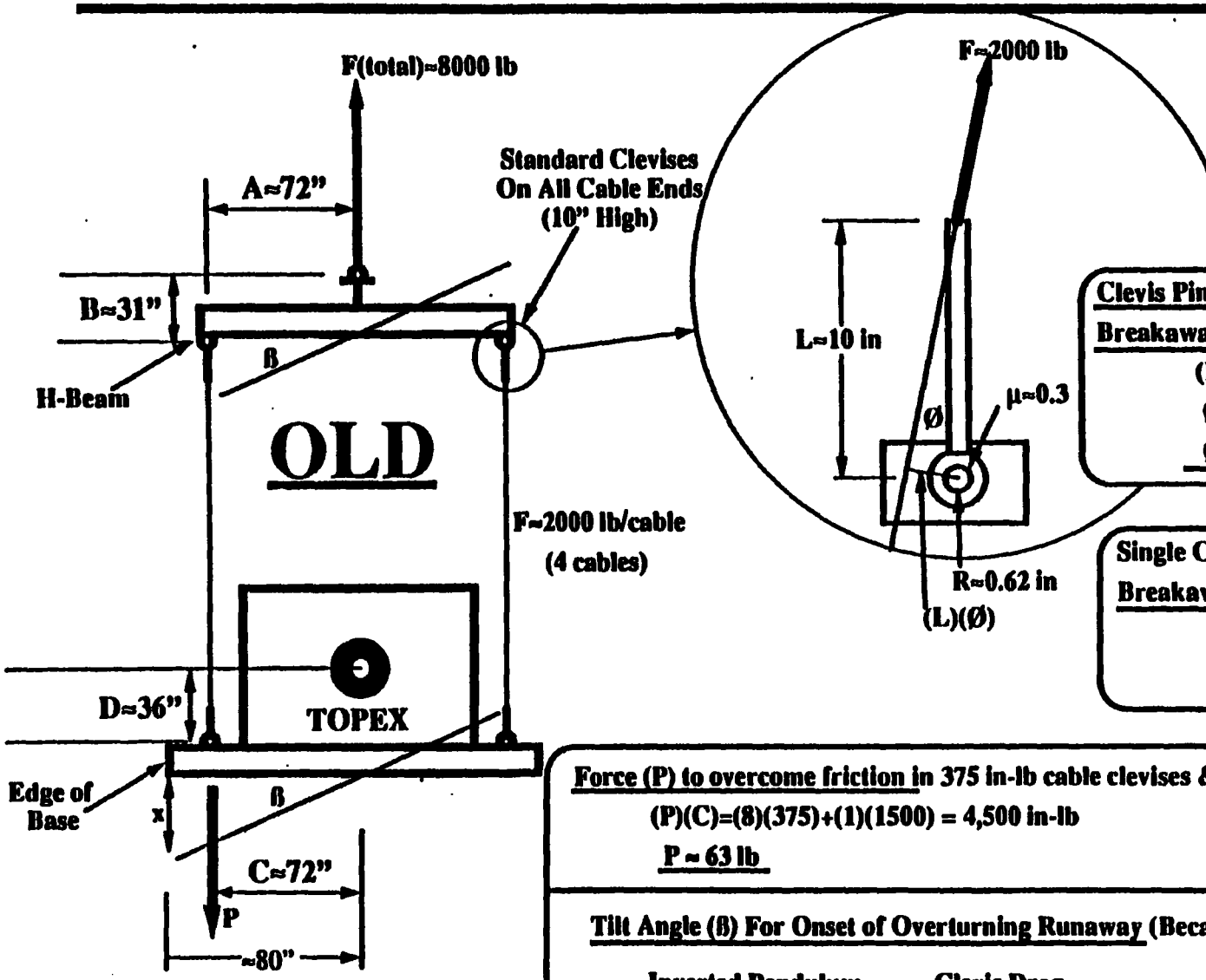
Flexible Kevlar Straps,
(Friction Insignificant)
$F_{stbl}=(128/36)(60/88)^2=1.65$
(Very Stable)

FIGURE 6-1

D-9847

TOPEX Lifting: Clevis Friction

3/19/91, WEL



Clevis Pin Friction

Breakaway Angle (Ø):

$(F)(L)(Ø)=(F)(\mu)(R)$

$Ø=\mu R/L\approx 0.019$ rad

$Ø\approx 1.1$ degrees

Single Clevis Pin Friction

Breakaway Moment (M):

$M=(F)(\mu)(R)$

$M=375$ in-lb/clevis

Force (P) to overcome friction in 375 in-lb cable clevises & 1500 in-lb top clevis

$(P)(C)=(8)(375)+(1)(1500) = 4{,}500$ in-lb

$P \approx 63$ lb

Tilt Angle (ß) For Onset of Overturning Runaway (Because D>B)

Inverted Pendulum Overturn Moment		Clevis Drag Friction Moment
$(ß)(D-B)(8{,}000\text{ lb})$	=	4,500 in-lb

$ß=0.11$ radian $= 6.4$ degrees

FIGURE 6-2

D-9847

7. DAMAGE ASSESSMENT AND PROGRAMMATIC IMPACTS

The incident reporting Fairchild Anomaly and Corrective Action Report (FACAR) C08261 was utilized to direct all unplanned activities required to safe the Satellite and to disassemble test GSE to adequately assess any and all damage to the flight and ground hardware. Direction to perform alignment tests per FS Spec. 968-AP6000 (MMS) and FS Spec. 968-AP8003 (TOPEX S/C) was also included. Additional FACARs were generated to record specific hardware damage as noted below.

7.a. Personnel

There were no injuries to personnel resulting from this incident.

7.b. Hardware

1. Spacecraft - Flight hardware damage was limited to the DORIS antenna where connector A865-J2 was bent (see Figure 7-1) due to tension on RF cables caused by contact from stressed thermal shroud nitrogen lines as reflected in FACAR C08270. During the recovery process, as reported on FACAR C08271, a small "V" shaped dimple was made on the TMR RF shield (see Figure 7-2) which does not degrade the RF performance and therefore did not require rework or repair. The visual inspection which included all GSE interface points (i.e., umbilical connectors and satellite attach lifting locations) did not reveal any damage. No mechanical anomalies during the alignment tests or electrical anomalies during the Extended Aliveness Test, the in Chamber Limited Performance Test, or the additional Sensor Tests were discovered.

2. T/V Test GSE - During the overturning action the -X,-Y and -X,+Y suspension cables scraped along the outside of the thermal shroud inflicting some damage to the

thermal shrouds and the liquid nitrogen coolant tubing (see Figure 7-3), the SADA GSE interface cables, and the tray holding the cables (see Figure 7-4). Damage and repairs for the GSE cables and fixturing for thermal vacuum testing were recorded on FACAR C08272. GSE Cable damage was limited to P1 and P2 SADA interface cables where pins were pulled back into the connectors. In addition, P1 had a bent strain relief jacket (see Figure 7-5) and P2 had a broken strain relief jacket (see Figure 7-6). An analysis was performed to determine the force required to bend and break the strain relief jackets and was found to be well below the SAD limits that could have damaged the SADA connectors. Required GSE cable rework and corresponding continuity tests are documented in this FACAR as well as verification of acceptable solar array simulator bolt torque and solar array drive alignment. Visual inspection of the diode bracket assembly and all related structure was completed with no additional findings.

3. T/V Fixture Assembly - The H-Frame Spreader Bar was severely damaged by the overturning action (see Figure 2-3). All four SHSS lift fittings (clevis lugs) had minor indentation marks from the lift cable clevis contact during the rotation (see Figure 7-7). The fittings and attach hardware were visually inspected and dye penetrant tested by GSFC revealing no anomalies. One of the four suspension cables had a slight bend (kink) in it as a result of hitting the cable tray during the overturning motion. The four Spacecraft/SHSS attach points were also visually inspected revealing no damage.

4. Mechanical Analysis - A mechanical analysis was performed on the Satellite to determine the loads incurred during the Satellite rotation and the position of the Satellite in the SHSS when safed at the interior

base of the thermal vacuum chamber. An analysis of the slip plate motion at the SHSS attach pedestals disclosed a worst case impact load of 0.6g maximum. The actual loads applied to the +Z corner fittings were well within the design load envelop. Appendix 7-A contains the impact loads analysis and the Satellite rotation analysis.

7.c. Facilities

1. General - No damage to the test facilities resulted from this incident.

2. Crane - The GSFC Building 10, Crane 10-1 used during the lifting exercise underwent the daily operator crane inspection the morning of Sunday, March 9, 1992. No discrepancies were found (see Appendix 7-B).

   The Board requested that a full inspection of Crane 10-1 be performed to assure that it was functioning properly and within specifications. A post-incident inspection of the crane was performed on Tuesday, March 11, 1992. The results of the inspection revealed no abnormalities or discrepancies in the crane (see Appendix 7-C).

7.d. Programmatic Impacts

1. Shortened Thermal Vacuum Test - In order to compensate for significant compromise to the assembly thermal vacuum test program, the Project originally planned to perform a 30-day T/V test at elevated temperatures. Initial evaluations of this tradeoff indicated that it was reasonable. In November 1991, the duration of the hot and elevated temperature thermal testing had been reduced to approximately 22 days. This reduction affected the tradeoff by increasing risk that problems may go undetected. By the time the test was ready to

start in March 1992, the elevated temperature test was reduced to approximately 17 days, which results in additional risk of not finding problems. As a result of the TOPEX handling anomaly,the elevated temperature test had to be reduced again to a duration of 12 1/2 days. At this point the compensating long duration T/V test at elevated temperature has been compromised to the extent that while it can be expected to accomplish normal system test objectives, it cannot be expected to reasonably compensate for the assembly test program as originally intended.

2. Overall Schedule Impact - The spacecraft was originally scheduled to go into the T/V chamber on March 8, but was delayed until March 18 due to the handling incident. Of this 10 day delay, approximately half was accommodated by shortening the T/V test, and the remainder was absorbed by replanning test sequences with more parallel activities. These changes have not affected the planned spacecraft shipping date.

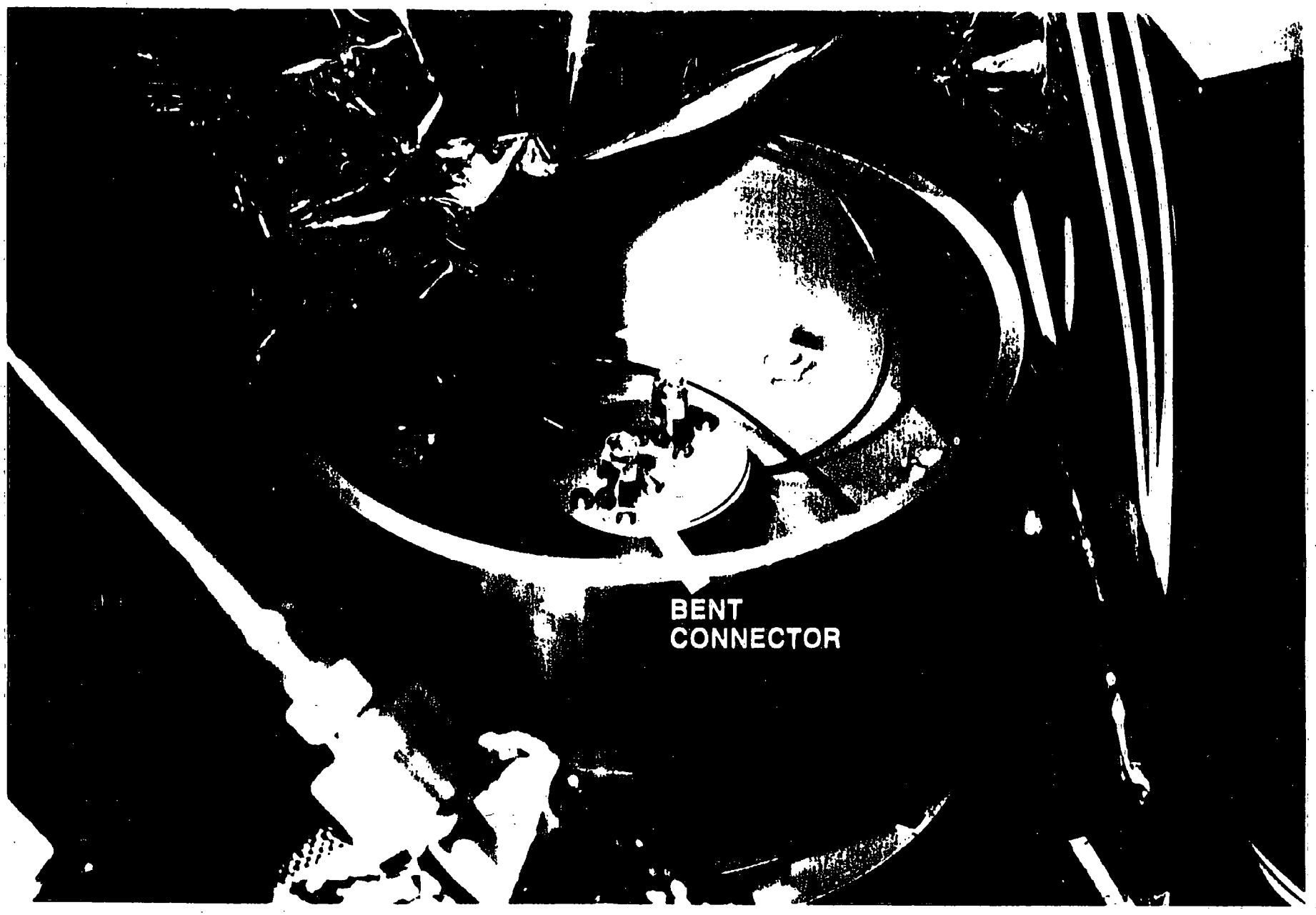


Figure 7-1, Damaged DORIS Antenna Connector

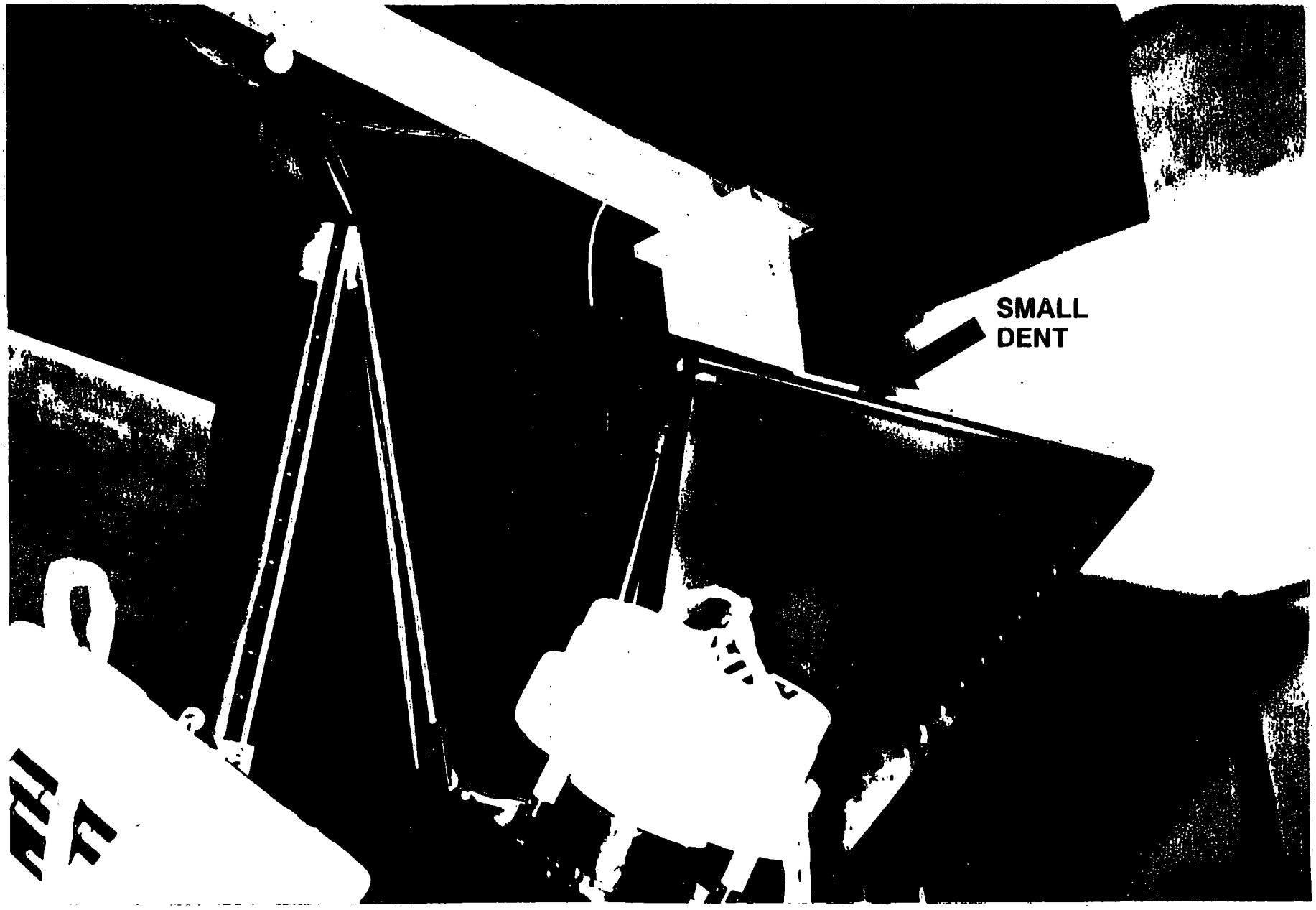


Figure 7-2, Damaged TMR RF Shield

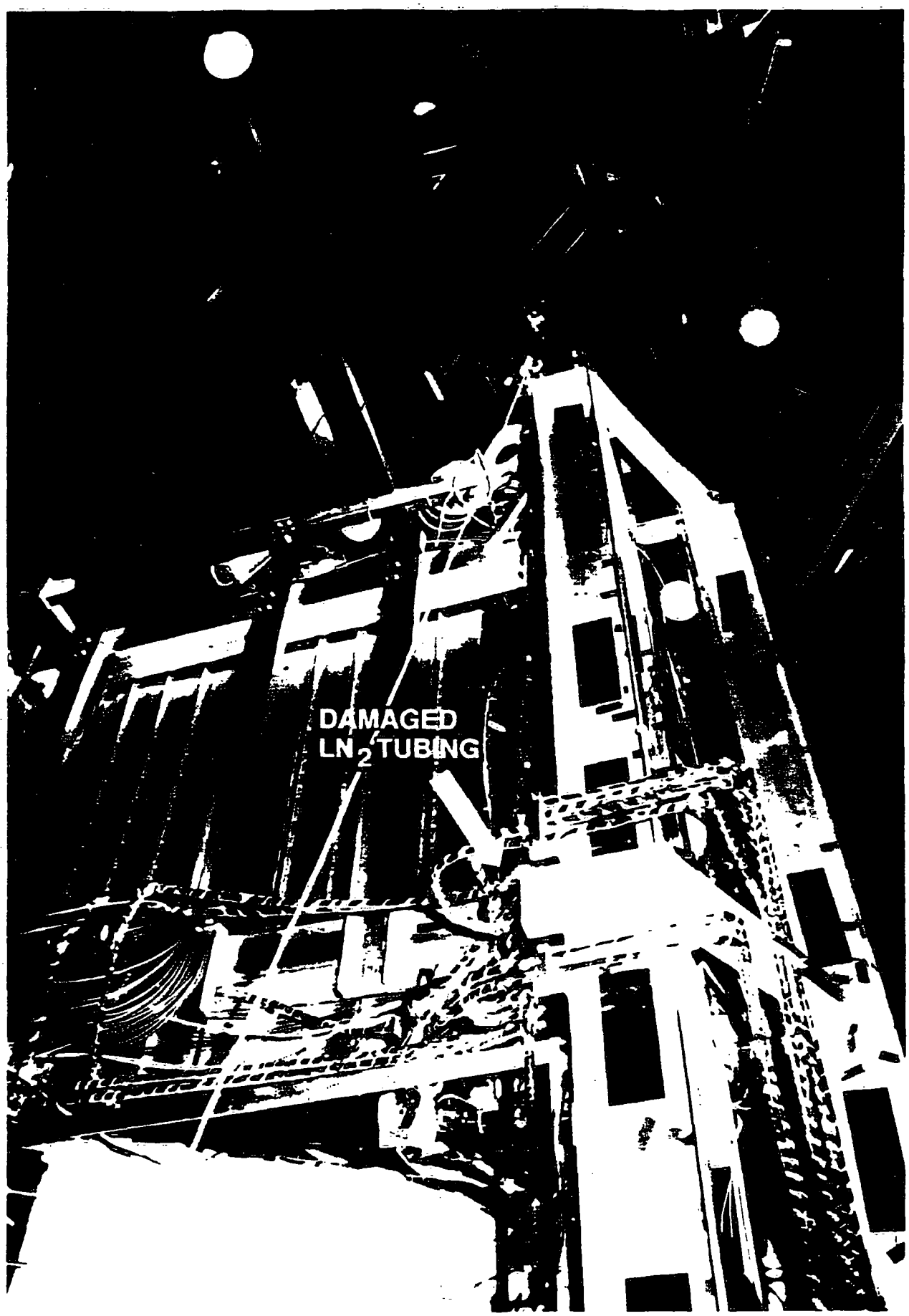


Figure 7-3, Damaged Thermal Shroud Nitrogen Coolent Tubing

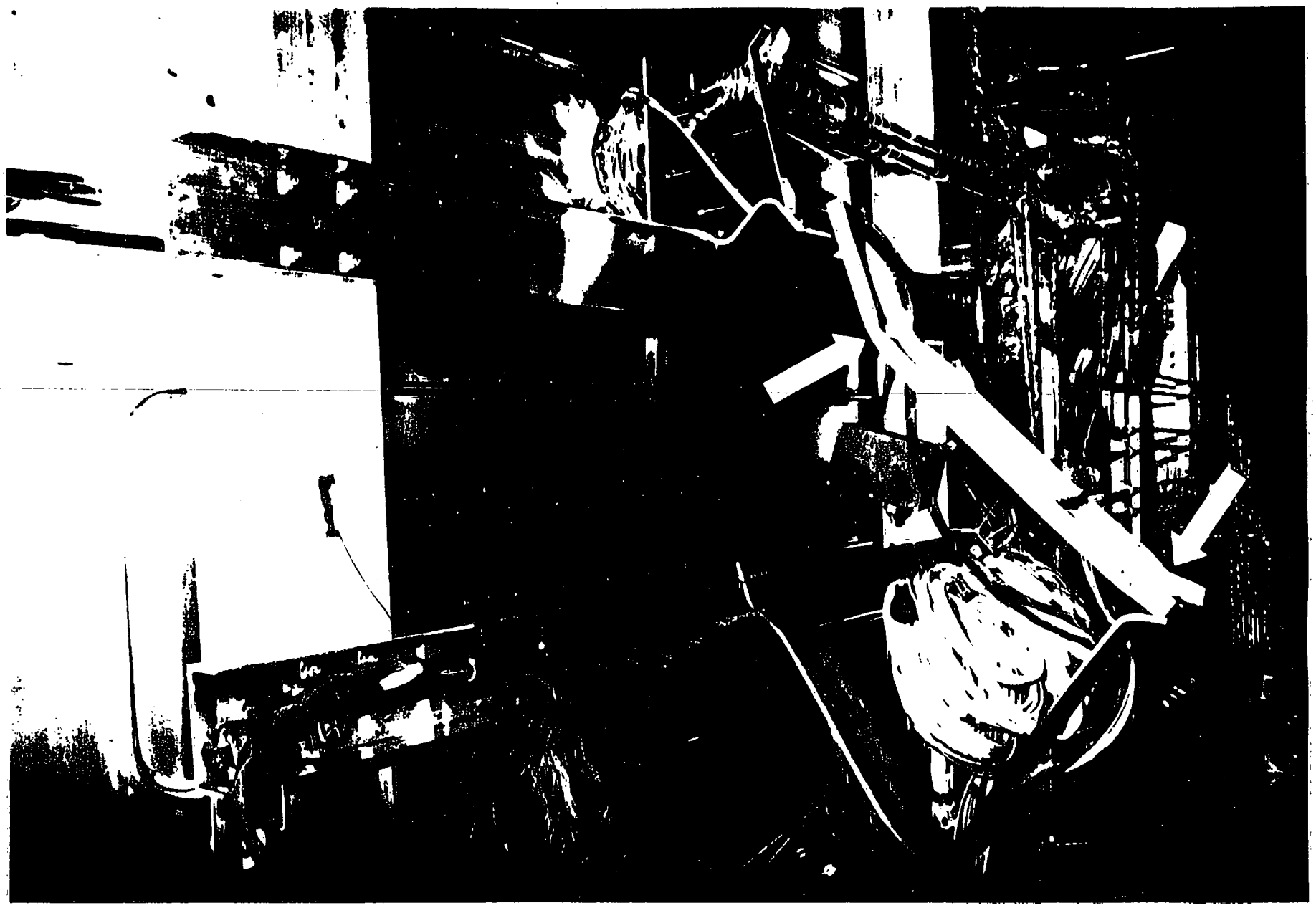


Figure 7-4, Damaged SADA Cable Tray

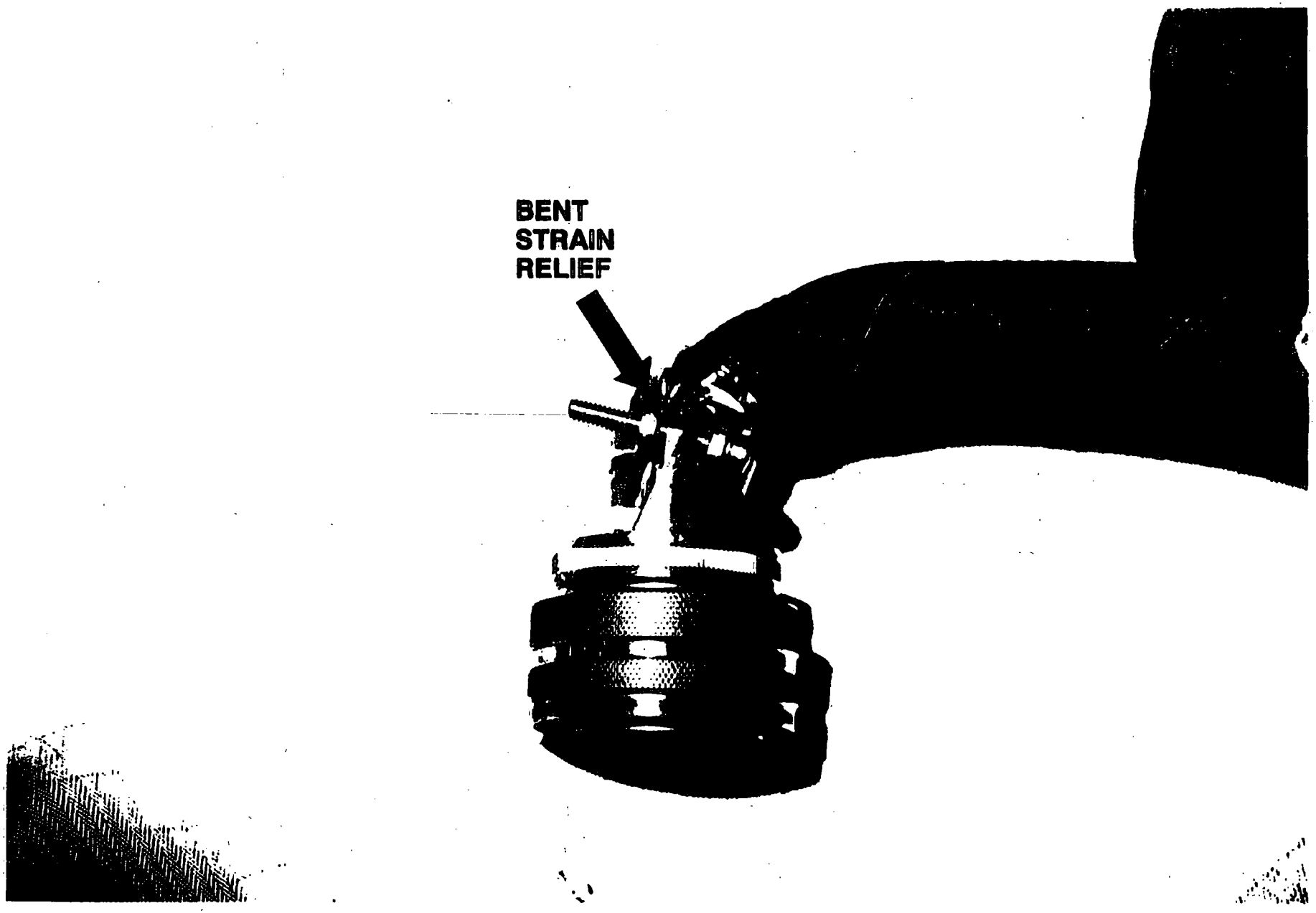


Figure 7-5, Bent P1 Connector Strain Relief Jacket

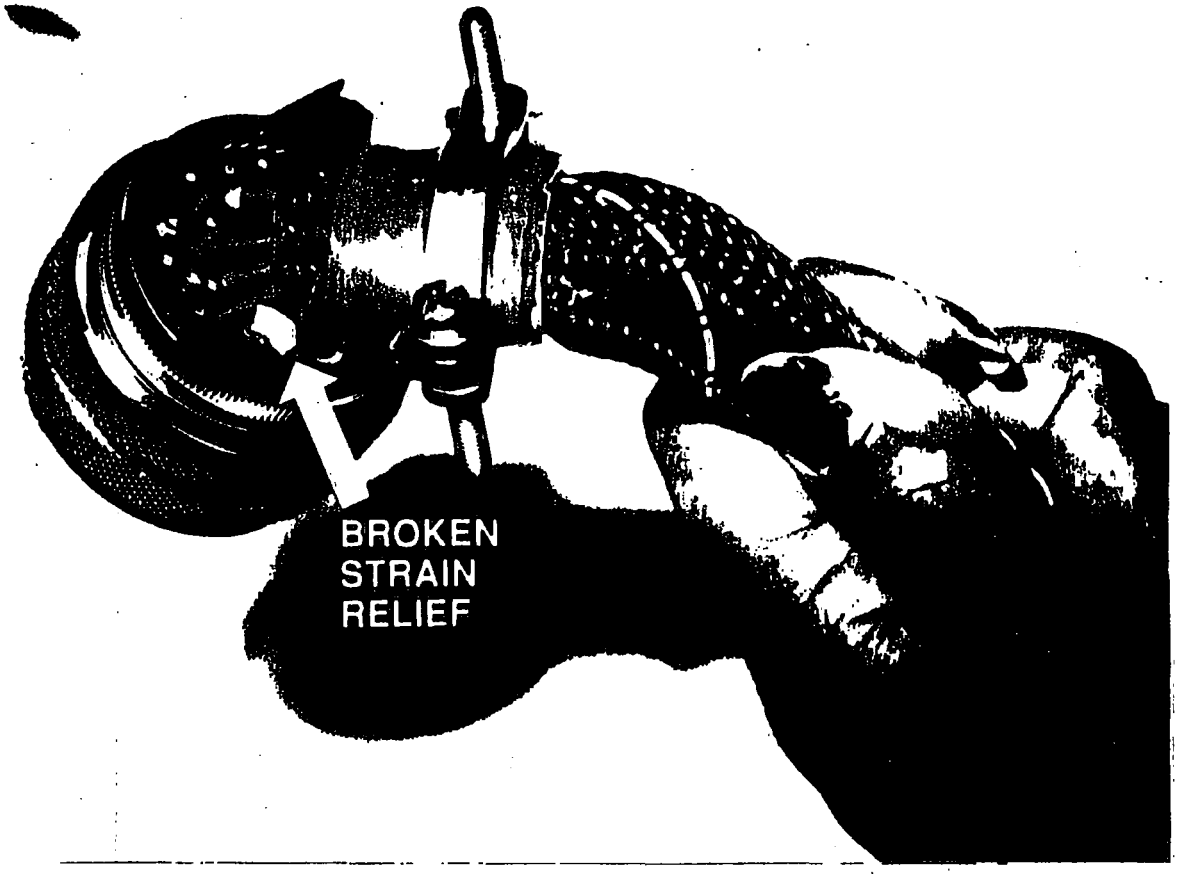


Figure 7-6, Broken P2 Connector Strain Relief Jacket

Figure 7-7, Indentations on SHSS Clevis Pin Lug

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

8. HISTORY OF LIFTING FIXTURE

8.a. **Responsibility for Design** - Fairchild Environmental Test Engineering was responsible for the design of the T/V Fixture Assembly, comprised of the SHSS and the lifting sling (T/V Lift Fixture).

8.b. **Responsibility for Stress Analysis** - Stress analysis is the responsibility of Fairchild Mechanical Structures Engineering.

8.c. **Analysis of H-Frame Spreader Bar Assembly** - No stability analysis, strength analysis, or stress analysis was performed on the GFE H-Frame Spreader Bar Assembly because the fixture had been previously proof load tested by JPL above intended TOPEX/POSEIDON proof and working loads. A proof test was performed with the SHSS as noted in Section 8.g. below.

8.d. **Design Review Process** - The design review process included (1) Test Engineering, (2) Mechanical Design Engineering, (3) Mechanical Structures Engineering, (4) Quality Engineering, and (5) Reliability/Safety Engineering. The Fairchild Space fixture design responsibility flow is listed in Appendix 8-A. The lifting fixture and SHSS were listed in the equipment list, within released engineering drawings, and the test procedures related to the Thermal Vacuum test. These documents were available during the Thermal Vacuum Test Readiness Review. However, nowhere in the review process was a stability analysis discussed or performed for the total lifted assembly including the Satellite and supporting thermal shrouds and instrumentation.

8.e. **Designer Background** - The SHSS was designed by the FS Principal Engineer within the Environmental Test Engineering organization of Fairchild Space. This design did not include the GFE sling assembly previously used on the

Galileo program that was made available to TOPEX/POSEIDON from KSC in October 1989. The Principal Engineer holds a Bachelor of Science Degree in Physics from the University of Maryland. Prior to college, he was trained in the USAF in techniques of handling, shipping, and storing munitions, and performed the duties of Munitions Maintenance Specialist. Prior to joining Fairchild in 1982, he was a General Physical Scientist for 3 years at the United States Department of Commerce (NOAA) performing testing and analysis on marine survey systems and equipment. At Fairchild he has held increasingly responsible positions within environmental test engineering with assignments including the design of three handling dollies, four lift fixtures, two dynamic test fixtures, three thermal vacuum test fixtures, and two climatic chamber fixtures.

The Principal Engineer was not familiar with stability analyses associated with lifting loads where the C.G. is above the lifting point. He, as well as others in the test team, were skeptical of the stability of the load and they performed a rocking test before the lift. This test convinced them that the load was stable and the lift proceeded. As discussed in Section 6, it is now known that the test was not adequate to reveal the instability.

8.f. Policies/Standards for Lifting Fixtures

1. **Fairchild Space** - The Policies/Standards for Fairchild Space are listed in Section 4.c. of this report and are contained in Appendix 4-B.

2. **Jet Propulsion Laboratory** - Lifting fixture guidelines for JPL are contained in JPL900-501, Ground Handling Equipment Design Notebook.

8.g. History of Lifting Sling

10/89 - FS Inventory of residual Galileo GSE at KSC to determine if any equipment could be used on TOPEX/POSEIDON program.

11/15/89 - Internal FS agreement to use Galileo H-Frame Spreader Bar Assembly with SHSS made with formal request to transfer to TOPEX/POSEIDON program.

11/04/91 - Galileo H-Frame Spreader Bar Assembly modified by FS to change the vertical lift points from 15' to 14' to match the SHSS. The assembly consisting of the H-Frame Spreader Bar Assembly was redesignated by FS as the TOPEX Thermal Vacuum Lift Fixture.

11/04/91 to 11/08/91 - SHSS and the T/V lift fixture proof loaded at Product Support Inc. to 20,033 pounds (2.19 X total load weight) using a 30 ton boom crane. The weight was provided by the use of the I.M. Simulator with all simulated masses in place with additional ballast weights to balance the load. The proof load testing included movement of the lift fixture and associated hardware in a rectangular pattern to simulate movement of the spacecraft.

9. TEST TEAM PERFORMANCE

9.a. During Spacecraft Movement - The Test Team consisted of personnel experienced in spacecraft moves who performed very efficiently in a well coordinated operation leading up to the incident.

9.b. In Response to Emergency - The Test Team responded extremely well to the incident, including the orderly transfer of responsibility, by reporting the condition of the spacecraft load immediately and to the proper personnel to permit the correct safing actions to occur. There was clear thinking under great stress/pressure by all elements of the test team. The correct decisions were made and implemented swiftly, thus averting additional damage to the spacecraft or the test facilities. In addition, the word was immediately passed to other experienced personnel, and in particular the NSI personnel working in adjacent areas, who joined the existing team and supplied additional equipment required to safe the Spacecraft load.

9.c. During Recovery - Experience and technical competence of the professional riggers and supporting personnel were the key ingredients to the successful recovery of the Spacecraft. The efficient and accurate use of handling straps to replace the damaged T/V Lift Fixture without causing further rotation and possible damage to the Spacecraft and related critical test support equipment was outstanding. The innovative use of the large forklift to rotate the Spacecraft to the upright position at floor level was remarkable. All of the moves were planned, discussed, and agreed upon as the operation proceeded resulting in a very deliberate, efficient, concise, and safe recovery.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

10. FINDINGS AND RECOMMENDATIONS

10.a. Findings

1. Root Cause of Problem - The T/V Fixture Assembly used for lifting the spacecraft into the T/V chamber was unstable in the TOPEX/POSEIDON configuration.

10.b. Contributing Causes

1. Lack of Stability Analysis - A stability analysis of the total T/V Fixture Assembly (T/V Lift Fixture, Cables, SHSS, Satellite, supporting thermal shrouds, and instrumentation) was not performed, reviewed, or approved prior to the overturning incident.

   Recommendation: A Stability analysis must be performed on all lifting devices in all lift configurations and must be repeated with each new application assigned. A stability factor of 1.5 or greater should be analytically demonstrated to cover possible differences between analysis and the actual lifted assembly. The stability analysis should be treated as a formal mandatory item in the same manner that stress analysis is addressed.

2. Inadequate Stability Testing - Stability testing was done during the proof loading tests of the lifting fixture, and again with the complete T/V Fixture Assembly. Because the impact of clevis friction was not taken into account, neither of these tests revealed the underlying instability. The two "rocking" tests were not analyzed for their adequacy in determining fixture instability.

   Recommendation: Detailed review of all elements of planned testing must be done to assure the testing will

58

accomplish the goals of the test. Stability analysis of lifted assemblies should be done whether or not stability testing is planned. This analysis is essential to determine the need for and the adequacy of any stability testing.

3. Continued Postponement of GSE Review - A GSE Review which would have included a review of the T/V Fixture Assembly was repeatedly postponed, and not held prior to use of the Assembly for lifting the spacecraft into the T/V chamber. (In preparation for thermal vacuum testing an Environmental Test Readiness Review was held November 20-21, 1991. There was one page that addressed the entire mechanical GSE in the review documentation. This page was simply a listing of the mechanical GSE and its status.) A supplemental handout available at the November 20, 1991, Environmental Test Readiness Review (ETRR) included an assembly drawing of the lift configuration, but the drawing reproduction did not clearly show the cable attach points. A viewgraph of the lift configuration drawing was not shown at the ETRR. However, it was shown at the previous Monthly Status Review (MSR).

   Recommendation: Formal mechanical GSE design reviews must be held to assure adequate design evaluation of the proposed lifting configurations. Discussions must include a detailed review of the proposed drawings and procedures for specific attach points, stability analyses, direction of motion, and expected accelerations for all moves.

4. Lack of Designer Experience and Peer Reviews - The Principal Engineer was not familiar with stability analysis of lifting fixtures for loads lifted below the C.G. and did not follow the lifting fixture guidelines contained in JPL900-501, Ground Handling Equipment

Design Notebook. Furthermore, no peer review, internal FS review, or Project review of the total T/V Fixture Assembly occurred. The review process failed.

Recommendation: Accepted guidelines should be followed in the design of all lifting fixtures. This is especially true when the designer has not designed a lifting fixture before and is unfamiliar with the shortfalls of various lifting fixture configurations. In all cases, a review of the design and margins should be held with peers and supervision to assure the design meets all requirements. A checklist which includes all aspects of the design e.g., stability, loads analysis, proof loading, etc. should be developed.

GSE Project reviews should be held and attended by personnel who are capable of assessing the adequacy of the design being reviewed.

5. **Lack of Functional Demonstration** - A functional demonstration (dry run) of the chamber lift activities was not performed prior to the incident. However, a lift of the T/V Fixture Assembly (without the spacecraft) was done earlier for a form fit of the SHSS and thermal shrouds. There were significant differences in C.G., fixture alignment, and personnel assignments between this lift and the actual spacecraft lift.

Recommendation: A high fidelity dry run, using the lifting fixture with the proper mass and C.G. simulator and following the procedures that will be used for the actual lift should be conducted. A formal briefing before the dry run and debriefing after the dry run of the personnel involved should be made for all high value one of a kind spacecraft and equipment.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

On protoflight spacecraft, the only precursor handling experience is with a dry run and mass mockups. The mass mockups handling dynamics, geometries, and sequences used for the dry run should simulate the protoflight spacecraft. Analysis and procedural checks are not always adequate to ensure surprises won't occur.

6. **Lack of Host Center Review of Hazardous Operations Procedures** - The GSFC (Host Center) did not review the hazardous procedures/operations planned by the outside user organizations (FS/JPL). Also the GSFC did not require advance notification of the Center Code 205 or 302 safety organizations of the expected date and time of the actual performance of each hazardous operation.

Recommendation: Host center personnel should be required to review all hazardous procedures/operations planned by outside user organization. Host center personnel are much more familiar with the characteristics (and quirks, if any) of their equipment and facilities. Also, they are more likely than the visiting organization to be highly experienced in the type of operations involved. A requirement for formal Host Center "Buy-Off" (signature of concurrence) would help ensure proper visibility and attention to hazardous procedures/operations.

In addition, the development of requirements for advance notification of the host center safety organization of the expected date and time of the actual performance of each hazardous operation should be considered. Advance notification would allow the safety organization the option of monitoring or witnessing selected hazardous activities and ensuring that all internal and external safety requirements are being satisfied.

7. **Remaining Spacecraft Handling Operations** - At this time the T/V spacecraft handling equipment has been redesigned, tested, analyzed, reviewed and used to move the spacecraft back into the T/V Chamber.

   Recommendation: The TOPEX Project must examine and approve the stability analysis for all remaining handling configurations, including those at the launch site. A GSE review should be conducted for all remaining handling operations as soon as possible.

11. LESSONS LEARNED

11.a. **GSE Review** - Ground support handling equipment should always be reviewed/approved by experienced designers and handling personnel prior to handling operations.

11.b. **Review Material** - Released drawings, analysis, and procedures for handling equipment should be available for review at least 60 days before a test to permit adequate evaluation.

11.c. **Lifting Equipment Stability Analysis** - No lifting equipment should ever be used without a complete stability analysis of the equipment with the load in its complete configuration.

11.d. **Precursor Handling Experience** - On protoflight spacecraft, the only precursor handling experience is with a dry run and mass mockups. The mass mockups handling dynamics, geometries, and sequences used for the dry run should simulate the protoflight spacecraft. Analysis and procedural checks are not always adequate to ensure surprises won't occur.

11.e. **Project Overview of Contract** - Project support from the cognizant JPL (or other NASA Center) divisions should ensure, for the area of overview of their organization, that the contractor is adhering to all applicable requirements. All contractual documents (such as JPL 900-501) relating to potentially hazardous operations should be clearly identified and should receive special attention.

11.f. **Dedicated Briefing** - A detailed and dedicated briefing structured to review the wording, text, diagrams, etc. is also a mandatory part of any functional demonstration. This briefing serves to inform the

personnel who may not have had the opportunity to read or review the written material or see the diagrams, etc. More importantly it is an opportunity for anyone who does not understand his assignment to have a clarification. If there are any reservations with regard to the technical approach of the upcoming activity this forum is the place to discuss them.

11.g. **Functional Demonstration** - A functional demonstration of all critical lifts, handling or maneuvers should be performed just prior to any event involving flight hardware. It may be judged too costly or redundant to a detailed procedure, but the value of such an exercise is particularly worthwhile if a high value item such as a one of a kind spacecraft is involved.

The actual demonstration (dry run), will reveal discrepancies in the written procedure. When the procedure lacks detail, the demonstration affords the opportunity to try out, or practice, different variations to the step-by-step approach. The unwritten or unspoken, yet implied instruction must be practiced and executed by the actual personnel involved. Where coordinated actions are required the exercise will help assure that everyone has the same response and timing to obtain the same end result.

An exact physical and mass mock up would be an ideal item to use for the demonstration, but it is rarely a possibility because of resource or other limitations. The importance of the duplication of the center of gravity with a mass mock up is self evident. The interface points or pickup points of the load can usually be replicated or borrowed from the flight article. However, in no case should they be over loaded or mispositioned from the designated lifting pattern. All shackles, rings, slings, chains, and everything in the load line should be assembled from a

sketch or a pictorial equivalent in the procedure which identifies each item as to capacity, size or other details. All parts should carry a dated tag stating the level of proof load sustained, and witnessed by the appropriate project official. Loadlines should not be torn down after a proof or demonstration load test to the levels and conditions stated in the procedure. If a partial tear down is required, the exact reassembly must be assured. This is particularly important with multiple joint assemblies using what appears to be identical hardware, but may have different loadings. Clevis pins must never be mixed from assembly to assembly. One final note on the load line drawings. It has been shown on numerous occasions that the facility does not fit the load line or vice versa even though everyone's opinion was to the contrary. It is prudent to include key dimensions on the load line sketch for later use.

11.h. <u>Tilt Angle Requirements</u> - Although it did not contribute to the TOPEX overturning incident, the yielding of the spreader bar at a tilt angle of only 8° to 10° raises an important point. Historically, there has been no design requirement for lifting equipment to tolerate a specified tilt angle. Lifting equipment requirements should be revised so the usual safety factors must be met at a specified tilt angle (ie., ≈15°).

11.i. <u>Host Center Review of Hazardous Procedures</u> - Host center personnel should perform a review of all hazardous procedures/operations planned by outside user organizations. In addition, development of requirements for advance notification of the host center safety organization of the expected date and time of the actual performance of each hazardous operation should be considered.

11.j. <u>Video Recording of Hazardous Operations</u> - All hazardous operations should be video recorded. The video recording of the overturning anomaly and the preceding and following activities was extremely helpful in the investigation and evaluation of this incident. Since mishaps may also occur during normal operations, consideration should be given to video recording all operations involving unique high value equipment. Use of inexpensive, off-the-shelf video cameras and recorders would permit very economical routine video recording of all activities

11.k. <u>Final Observation</u> - The TOPEX/POSEIDON overturning incident had the potential for being classified as a NASA Type A Mishap. Only a series of uncontrolled, but fortunate occurrences prevented this from initially being a much more serious anomaly with severe consequences.

Major damage to both the spacecraft and the T/V chamber were avoided only because the T/V Fixture Assembly was lifted higher than necessary to clear the lip of the chamber. This was done in the erroneous belief that the higher lift (shorter crane to assembly distance) would improve stability by reducing swaying of the load. If the lift had been at the same height as the dry run, the T/V Fixture Assembly might have struck the chamber lip during the rollover resulting in major damage to both the Spacecraft and the chamber.

The H-Frame spreader bar was severely damaged, and probably would have failed completely if one of the suspension cables had not snagged on one of the upper SHSS clevis lugs. Complete failure of the spreader bar would have dropped the 8000 pound load ≈40 feet to the floor of the T/V chamber, destroying both the Spacecraft and the chamber.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

The Spacecraft fortuitously rolled with the -X side down, where a significant amount of GSE structure was mounted. If the Spacecraft had rotated with the +X side down (or if it had fully inverted) placing it on the floor of the T/V chamber to relieve the loads on the H-Frame spreader bar might not have been possible without significant additional damage to the spacecraft.

Following the anomaly only the quick and professional response of the FS test team and NSI personnel prevented further (and potentially severe) damage to the Spacecraft and chamber facility.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 1-A

Special Review Board Authorization Memorandum

D-9847 APPENDIX 1-A

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
March 9, 1992

TO: J. R. Casani

FROM: P. T. Lyman

SUBJECT: Formation of Review Board for the TOPEX Spacecraft Handling Anomaly on March 8, 1992

REFERENCE: IOM FPO-MJC-92-031:jmm, Formation of a Special Review Board Regarding TOPEX Spacecraft Handling Anomaly, J. Casani, March 9, 1992

A Review Board for the TOPEX Handling Anomaly of March 8, 1992, is hereby appointed.

The members of the review board are:

Ronald Ploszaj, JPL, Chairman
Ronald Casey, GSFC
Thomas Gindorf, JPL
Frank Hornbuckle, Fairchild Space Company
John Webb, GSFC

The Review Board will:

A. Assess the project's intended recovery plan from the point of view of whether it provides for the safety of the spacecraft while minimizing the impact to the project schedule, and concur in the revised handling procedures before further steps are taken that could put the spacecraft at risk.

B. Determine the root cause of the handling anomaly, identify steps that should be taken in the future to prevent similar occurrences, and make recommendations regarding potential liability or litigation issues.

The review board is instructed to begin operations on March 10. The board should focus on Phase A first, since time is of the essence. It is the project's desire to place the spacecraft in the vacuum chamber at the earliest time possible.

Phase B should be worked in parallel only to the extent necessary to support the Phase A conclusions. Phase B should be completed by June 15, 1992.

cc: P. Burr, GSFC
J. Casani
L. Fisk, NASA/S
J. Klineberg, GSFC
G. Rodney, NASA/Q
W. Shipley
E. Stone
W. Townsend, NASA/SE
C. Yamarone
L. Yermack, FSC
Review Board

59

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 3-A

Impound Release Authorization

Upon being briefed on the incident of March 8, 1992, and reviewing the status of the TOPEX/POSEIDON Spacecraft at the NASA Goddard Space Flight Center (GSFC) today, we recommend the following be effected without loss of any evidence as to the cause of the incident.

a) Removal of the shrouds from the spacecraft.
b) Thorough inspection of the satellite.
c) Electrical Performance Test to thoroughly assess the condition of the satellite.

Richard F. Collins

Richard F. Collins - Jet Propulsion Laboratory

Donald Fordyce, Fairchild Space

Peter T. Burr 3/9/92

Peter T. Burr - NASA Goddard Space Flight Center

W. F. Townsend 3/9/92

William F. Townsend, NASA Headquarters

Concur:

Chairman, Review Board

D-9847

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 3-B

Review Board Initial Report

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
March 13, 1992
TSRB - 001

TO: C. A. Yamarone

FROM: R. A. Ploszaj

SUBJECT: Initial TOPEX Special Review Board Report

The special Review Board has completed its initial assessment of the TOPEX handling incident. We believe the root cause of the problem to be a basic instability in the lifting fixture design. The Board has assessed the intended TOPEX recovery plan and concurs that it will provide for safe handling of the spacecraft for installation in the thermal vacuum chamber provided the following actions are completed.

1) Document the spacecraft center of gravity and new fixture stability analysis.

2) Satisfactorily complete the proof test of the new lifting fixture assembly, including the SHSS.

The Board further recommends that the Project:

1) Conduct a structured pre-test briefing prior to lifting the spacecraft;

2) Conduct a dry run of the lifting activities leading to the installation of the spacecraft in the chamber.

Specific actions of the Board to date are reflected in Attachment A.

The board wishes to commend the TOPEX support team in their immediate and professional reaction to the incident that permitted a safing of the spacecraft under very hazardous conditions with a special recognition of the NSI team. All members are to be commended for their focus and drive to continue support of all activities necessary to return the spacecraft to normal processing.

Distribution:

Review Board Members
J. Brown - FS
J. Casani - JPL
R. Collins - JPL
D. Fordyce - FS
P. Hardy - JPL
L. Harter - FS
W. Layman - JPL
P. Lyman - JPL
J. Wonsever - NASA HQ

ATTACHMENT A

1. Reviewed video's and photographs of incident.
2. Read individual write-ups of witnesses.
3. Interviewed selected team members for clarification of written inputs (13 members).
4. Concurred with integrity verification of satellite horizontal support structure (SHSS).
   a) Verified no-destructive testing of cable attach fittings.
   b) Completion of visual inspection of structure and four spacecraft support fittings.
5. Reviewed structural/stress analysis of event to determine structural integrity of the spacecraft and SHSS.
6. Analytically confirmed the basic cause of spacecraft handling anomaly.
7. Concurred with use of existing Fairchild Space MMS shipping container lifting sling.
8. Concurred with validation procedure of new sling and SHSS to 2 1/2 times spacecraft weight.
9. Concurred with stability analysis of new sling/SHSS assembly in accordance with JPL ground support equipment guidelines.
10. Reviewed and concurred with lifting and handling of spacecraft to support electrical and alignment tests prior to thermal vacuum test operations.
11. Verified integrity of crane assembly.
    a) 21 Feb. 92, Annual certification with proof test load
    b) 8 Mar. 92, Daily inspection by crane operator
    c) 10 Mar. 92, Annual certification repeated without proof load test. NO anomalies discovered on any inspection.

D-9847

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 4-A

Fairchild Space Policies/Procedures

D-9847

POLICY/PROCEDURE

APPENDIX 4-A

FAIRCHILD

SUBJECT	NO. 603
DESIGN REVIEWS	REV.

I. This procedure outlines the requirement for design reviews on proposals and design/development programs whether performed on Contract, BRP, or IR&D funds. In many cases, customers stipulate the number, type and format of the reviews they require. However, where such direction is not given or is less stringent, the following procedure shall apply.

II. Proposal Design Reviews: (If Applicable)

At an appropriate time in the proposal period, a design review shall be scheduled. The Vice President of Engineering is responsible for scheduling and conducting the review. The review team shall include representatives from Engineering, Intergration & Test, Quality Assurance, Program Management, Manufacturing, and other departments as appropriate. The review team shall be responsible for reviewing the technical requirements of the RFP and for evaluating the proposed design for compliance with those requirements. Review team recommendations for design changes shall be fully discussed in the meeting and submitted in writing to the technical proposal Book Boss, and the Proposal Manager.

III. Program Design Reviews:

At an appropriate time in the development cycle, two (2) formal design reviews are to be scheduled. The Vice President of Engineering is responsible for scheduling and conducting a Preliminary Design Review (PDR) and a Critical Design Review (CDR). The specified reviews shall be scheduled on a timely basis, and the review team shall include representatives from Engineering, Integration & Test, Quality Assurance, Program Management, Manufacturing, and other departments as appropriate. The review team shall be responsible for conducting a thorough review of all aspects of the design and for identifying any required action items, establishing a schedule to accomplish the action items, and assigning key individuals to be responsible for accomplishing the action items. Appropriate reports covering the design reviews shall be prepared on a timely basis and copies provided to all departments concerned including the General Manager. Each affected program manager is responsible for responding to the review team's recommendations in a timely manner.

APPROVED		DATE ISSUED	PAGE
J. W. Townsend President	John W. Townsend	6/13/83	1 OF 1

00318 1-83

FAIRCHILD SPACE AND ELECTRONICS COMPANY

D-9847

PROCEDURE

FAIRCHILD

SUBJECT	NO. 603.1
PRODUCT DESIGN REVIEWS - IR&D OR SIMILAR EFFORTS	REV.

I. GENERAL

FSEC Procedure 603 outlines the requirement for Design Reviews on all new design/development programs in excess of $100,000 contract value, or of less value when production quantities may follow. Procedure 603 generally has been applicable to Government contracts and the design reviews are generally specified in the particular contract. To ensure that appropriate reviews are conducted for IR&D and similar type programs, particularly those leading to development of off-the-shelf products for commercial, industrial and where applicable, military users, the following procedure will be adhered to.

II. DESIGN REVIEWS

At an appropriate time in the development cycle, two (2) formal design reviews are to be scheduled. The Vice President, Engineering is responsible for scheduling and conducting a Preliminary Design Review (PDR) and a Critical Design Review (CDR). The specified reviews will be scheduled on a timely basis and the Review Team should include representatives from Engineering, Integration and Test, Manufacturing, Marketing, Product Line Managers, Program Management, Quality Assurance, and Finance as required. The Review Team will be responsible for conducting a thorough review of all aspects of the design and for identifying any required action items, establishing a schedule to accomplish the action items and assigning key individuals to be responsible for accomplishing the action items. Appropriate reports covering the design reviews will be prepared on a timely basis and copies provided to all departments concerned including the General Manager. Each affected IR&D program manager is responsible for responding to the Review Team's recommendations in a timely manner.

III. PRE-PRODUCTION REVIEWS

The Vice President, Programs will be responsible through the Program Directorate for scheduling a pre-production review. An appropriate Review Team will be activated by the Vice President, Programs with representatives from Production, Engineering, Integration & Test, Marketing, Product Line Managers, Programs, Quality Assurance, and Finance as required. The Review Team will schedule a pre-production review after the "brass-board" stage and will be responsible for determining the readiness

APPROVED		DATE ISSUED	PAGE
John W. Carmichael	President	1/28/80	1 OF 2

FSEC 0312 5-78

and plans for the production testing and acceptance of the product. This review is to include design-to-cost, testing plans, capital equipment requirements, facilities required, parts acquisition/availability and other aspects critical to economic and efficient product production and delivery. Timely reports will be issued identifying action items, establishing a plan with deadline dates to dispose of the action items and assigning responsibility for completion of the action items. Copies of the reports will be provided to all concerned departments including the General Manager.

POLICY/PROCEDURE D-9847

FAIRCHILD SPACE COMPANY

SUBJECT	NO. 603.2
INTERNAL DESIGN REVIEW	REV.

I. GENERAL

This procedure outlines the requirements for an internal engineering review of spacecraft hardware items during their development period. Objectives of the review process are to ensure compliance with program technical requirements and to identify and correct possible design deficiencies, prior to commitment for production, by means of in-depth "peer level" technical evaluation of each applicable subsystem and component.

Internal design reviews shall be budgeted and scheduled at appropriate program milestones. Unlike the more formal Customer design reviews, however, the internal reviews shall be limited in scope and numbers of participants to address specific critical aspects of the hardware or software design.

II. APPLICABILITY

Internal design reviews shall be required for Fairchild Space Company development programs involving new or modified spacecraft hardware and software designs and shall be conducted independently of, and in addition to, any contractually required design reviews (e.g., Preliminary and Critical Design Review). For each component or subsystem, the number, schedule and agenda may vary depending on equipment complexity, degree of design maturity, etc.

Formal engineering reviews shall not be limited to elements of the flight hardware and software design, but will also extend to ground support elements for those equipments which perform safety critical functions or are critical to the mission success of the flight system.

III. RESPONSIBILITY

For each new program or major program change, the Program Manager, Vice President of Operations, and Vice President of Product Assurance (or their representatives) shall review the program work content and mutually identify those critical technical areas for which the peer group internal design review is applicable. The Program Manager shall ensure that the required program resources (in terms of adequate cost and schedule) are properly included in the proposal and negotiated with the Customer.

APPROVED		DATE ISSUED	PAGE
Martin N. Titland President	Martin N. Titland	3/17/87	1 OF 2

00315 1-83

IV REVIEW PROCEDURE

At the appropriate time in the development cycle, the Vice President of Product Assurance shall request that the Program Office schedule the internal design review and issue the necessary implementing Program Directives. The Vice President of Product Assurance shall then appoint a Panel Chairman. Additional panel members shall be selected from the staff of Fairchild, and may vary for each review depending on the expertise and experience required.

The internal review agenda shall include a presentation of the technical design requirements and defense of the overall design approach, and supporting engineering analyses. This shall be followed by a thorough review by individual team members of design drawings, analysis assumptions and results, etc., in their areas of specialty. Based on this review, the review chairman shall identify any required action items and foreward them to the Fairchild Program Office for response, with copies provided to each affected Department.

Following the review, the Program Office shall prepare an implementation plan for resolution of all action items, and shall issue the necessary Program Directives for completion of each item.

PROCEDURE

FAIRCHILD

SUBJECT	NO. 801
SYSTEM INTEGRATION & TEST	REV.

1.0 PURPOSE

This charter describes the responsibilities of the System Integration and Test Directorate.

2.0 SCOPE

The System Integration and Test Directorate shall provide the FSEC capability for integration, test, and field operations for space and electronics products.

3.0 CHARTER

3.1 During the proposal and design phase of new programs, the System Integration and Test Directorate shall have overall responsibility for:

- Developing, in coordination with the Engineering Directorate and the Quality Assurance Directorate, program test philosophies
- Defining requirements for test, test equipment, test software, and fixtures
- Participating in the development of design concepts
- Preparation of proposal test plans and associated facility descriptive material
- Participating in proposal costing
- Participating in all design reviews (PDR, CDR, etc.)

3.2 For each ongoing program, the System Integration and Test Directorate shall designate a test manager having responsibility for:

- Preparation of documentation and dissemination of test plans and procedures
- Definition of test manpower requirements
- Coordination of pre- and post-test reviews, including environmental and launch readiness reviews

APPROVED		DATE ISSUED	PAGE
John W. Gorman Jr.	President	4/16/80	1 OF 2

FSEC 0812 5-78

52

- Test performance and discipline

- Scheduling, coordination, and conduct of all manufacturing in-process and performance testing in preparation for acceptance processing by the Quality Assurance Directorate

- Planning and performing the mechanical and electrical integration of spacecraft major subassemblies and systems; and for providing off-site integration, test, and launch capabilities including ground station installation

3.3 The Directorate shall also be responsible for the acquisition and maintenance of test facilities and associated equipments; the provision of personnel to assure present and future FSEC test capability; and for maintaining cognizance of state-of-the-art advances in test requirements (specifications), techniques, and equipment.

3.4 SI&T shall be responsible for the performance of certification tests (not calibration) and the maintenance of on-site (non-portable) functional test equipment. Excluded is the certification, maintenance, and calibration of equipment used for general measurement (e.g., voltmeters, counters) and equipment and testing activities in the Engineering Development, Communications and Metrology Laboratories.

D-9847

POLICY/PROCEDURE

FAIRCHILD SPACE

SUBJECT: CONDUCT OF TESTS OF FLIGHT HARDWARE	NO. 1010 REV. 1

I. PURPOSE

To set forth specific requirements, with their associated responsibilities, that must be satisfied for acceptance and subsequent testing of flight hardware.

II. SCOPE

The provisions of this procedure apply to acceptance and subsequent tests to be performed on Fairchild Space (the Company) flight hardware. In-process testing and debug efforts prior to initial acceptance tests are not governed by this procedure.

III. DISCUSSION

It is necessary that the Company insure that proper planning is accomplished and proper conditions exist for carrying out regularly scheduled and special (i.e., unscheduled or partial) tests of flight hardware. Satisfaction of the requirements outlined below will insure a clear understanding by all involved of what is to be done and how it is to be accomplished.

IV. REQUIREMENTS AND RESPONSIBILITIES

A. For acceptance and subsequent testing of flight hardware, a Test Conductor shall be formally designated. Appointed by Test Operations, this individual shall be responsible for all aspects of the test operation. The Test Conductor shall control the conduct of the test, assuring that qualified test and quality assurance personnel are in attendance when necessary during the times when testing is in

SPONSORING V/P C. H. Oxrieder Vice President, Government Programs	Charles H. Oxrieder	DATE REVIEWED 11-8-91	
APPROVED Larry P. Yermack President, Fairchild Space	L P Yermack	DATE ISSUED 12-6-91	PAGE 1 OF 3

0031S 08-90C

progress. He/she shall have identified to him/her the engineer(s) to be called upon for advice and assistance related to hardware problems, anomalies and corrective action. If unforeseen circumstances arise, he shall take the necessary action to preserve the integrity of equipment under test and shall notify the designated members of the Failure Review Board (FRB).

B. The Program Office, Engineering and Quality Assurance shall, for acceptance and subsequent tests of flight hardware, designate and identify to the Test Conductor their respective participants or representatives indicating clearly in which capacity they are named.

C. Prior to such tests of flight hardware, a pre-test meeting attended by all test participants shall be convened and led by the Test Conductor. The pre-test meeting shall confirm the readiness of the test article, define specific responsibilities and disciplines to be observed, and establish restraints associated with the test conduct on the test article.

D. The responsibility for on-site test conduct shall be clearly identified and maintained throughout the test period.

E. Prior to the conduct of acceptance and subsequent tests of flight hardware, the applicable test procedure(s) shall be re-examined by the Quality Assurance representative to insure they are properly released and to insure that test set-up instructions are sufficiently detailed.

F. For environmental tests of flight hardware, the environmental test equipment operator and the Quality Assurance representative shall, as part of test set-up verification, affirm the proper set-up of the environmental equipment being employed, and affirm that the associated instructions for operating the equipment are available and used.

G. Test Operations shall provide appropriate limit systems for environmental test units to prevent excursions of electromagnetic stimuli, temperature, vibration, pressure, humidity, etc., beyond limits specified in the test procedure for the equipment under test. The limit systems, where applicable, shall be demonstrated functional as part of the pre-test checkout.

H. In the event a test (or series of tests) other than approved qualification or acceptance tests is (are) to be performed on flight hardware after initial acceptance test, a written procedure shall be prepared outlining the specific details of the examination(s) to be made. The procedure shall be prepared by the designated functional element and shall be approved by Program Management, Engineering, Quality Assurance and Test Operations.

I. In those instances where only a portion (or portions) of an approved test procedure is (are) to be performed, those portions shall be extracted and documented within a prepared document containing prerequisites, the test set up, and data required. In such instances, document shall be approved by Engineering and Quality Assurance prior to use.

V. ACTION

A. Program Offices, the Directors of Engineering, the Director of Test Operations, and the Director of Quality Assurance shall insure compliance with these requirements.

B. Any exception to the guidance herein must be approved by specific Program Directive having the concurrence of the appropriate Director of Engineering (i.e., Electrical and Mechanical), the Director of Quality Assurance, and the Director of Test Operations.

VI. REFERENCES

None

VII. FORMS

None

8C

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 4-B

Fairchild Space Procedure Outlines

TOPEX/POSEIDON SATELLITE SYSTEM INTEGRATION AND TEST PLAN NO. 968-PP1011

5.5 REVIEWS

5.5.1 Test readiness Reviews

A Test readiness Review (TRR) (also called Pre-Test readiness Review) will be performed prior to the satellite Integration, CPT, Modal Survey, EMI/EMC, Acoustic, Sine Vibration, Thermal Vacuum (including both TDRSS and DSN Compatibility testing) and Deployment tests. During these reviews the status of all hardware, fixtures, software, procedures, facilities and test equipment will be confirmed. Any changes or discrepancies in the configuration or function of flight hardware, MGSE, EGSE, test software or facilities will be addressed with representatives of the applicable disciplines. Then the impact of any unresolved changes or discrepancies on the forthcoming test will be evaluated. Only when there is an agreed disposition of any open items will the forthcoming test be performed. These TRRs will be conducted in accordance with FS QAP 7.2. The scheduled TRRs are shown in the flow chart within Appendix A.

(NOTE: Any discrepancies in the testing of flight hardware or software will be formally documented in FACARs and tracked, see 4.3)

EXCEPTS FROM PROCEDURES INTERRELATED WITH TOPEX SATELLITE HANDLING

TOPEX/POSEIDON SATELLITE THERMAL VACUUM/THERMAL BALANCE

PROCEDURE NO. 968-TP8010

4.0 TEST INITIAL REQUIREMENTS AND CONFIGURATIONS

4.1 TEST RESPONSIBILITIES

4.1.1 Test Team Responsibilities

The TOPEX/POSEIDON Thermal Vacuum Test team shall have responsibilities as specified herein. During Vacuum operations, there will exist three areas of separate control. These areas are satellite operations, Fairchild control system operation and GSFC chamber and control system operations. In addition during preparations for test, satellite handling operations will involve shared responsibility between GSFC and Fairchild handling operations and support. Figure 4.1-1 shows thE basic scheme of authority and reporting during vacuum test operations. During vacuum test, a complete list for each shift level shall be posted at the test control center identifying the personnel with their telephone number for these designated positions.

TOPEX/POSEIDON SATELLITE HANDLING PROCEDURE NO. 968-HP8013

1.0 INTRODUCTION

1.1 SCOPE

This document contains the instructions for the spacecraft handling of the TOPEX/POSEIDON Satellite (P/N 96801000000).

1.2 PURPOSE

The purpose of this procedure is to describe the step-by-step handling operations to be used during preparing/orienting the satellite for the different test phases. This procedure will define the methods of handling the satellite with the X Axis vertical, with the X Axis horizontal and how the satellite will be positioned into these two situations.

1.3 TEST OVERVIEW

This procedure is divided into stand alone handling sections of X-Axis vertical handling, X-Axis transition and X-Axis horizontal handling. This procedure is intended for repeated use in any sequence as required.

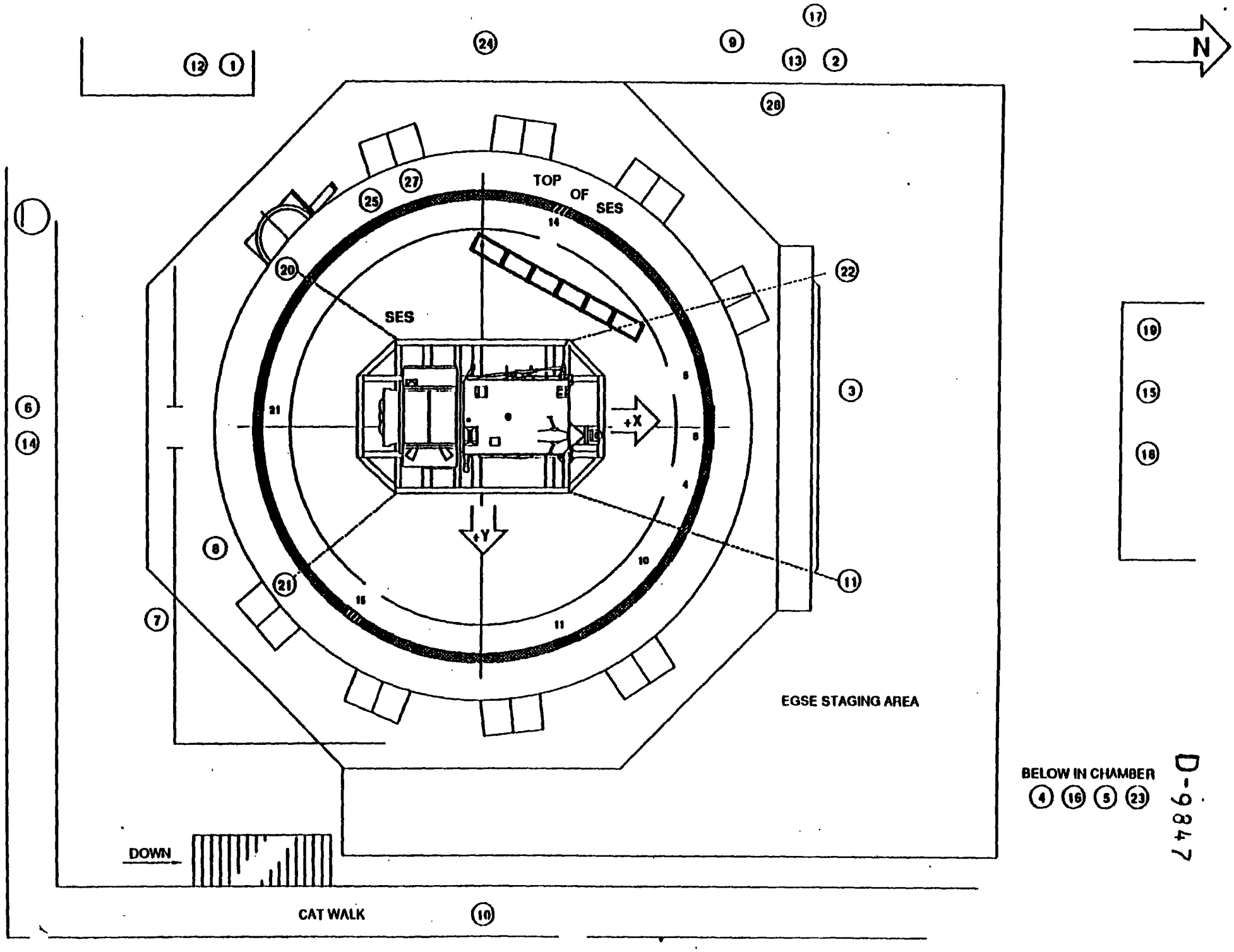
TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 4-C

Personnel Present and Location During Anomaly

Personnel Present During the Incident

	Name	Title	Org	Test Function
1.	Christi Gilbert	Contracts Manager	FS	
2.	Randy Hinzman	Test Conductor	FS	FS Test Director
3.	James Burdette	Test Engineer	FS	Held Ground Strap
4.	Mark Will	Test Technician	FS	
5.	Brian Langmyer	Test Technician	FS	
6.	Fred Robinson	Test Engineer	FS	Photographer (Video)
7.	Chuck Smith	Test Engineer	FS	
8.	Eric Stuckey	Test Engineer	FS	
9.	Terry Hamilton	Quality Engineer	FS	Quality Engineer
10.	Steve Turek	Quality Technician	FS	Inspector
11.	Rex Richardson	Integration/Test Director	FS	NE Tag line
12.	Dr. Jim Brown	Spacecraft Manager	FS	
13.	Don Fordyce	Program Manager	FS	
14.	Ron Benden	Photographer	FS	Photographer (Still)
15.	Tom Shain	Test Engineer	JPL	
16.	Tom Ramsey	Quality Engineer	JPL	
17.	Sean Howard	Quality Representative	JPL	
18.	Dick Collins	Deputy Satellite Manager	JPL	
19.	Floyd Olson	Test Engineer	JPL	
20.	Sherman Workman	Test Technician	JPL	SW Tag line
21.	Doug Montague	Test Technician	JPL	SE Tag line
22.	Don Herriott	Test Technician	JPL	NW Tag line
23.	Tony Pierro	Lead Crane/Hoist Technician	NSI	NSI Test Director
24.	Mike Gauss	Crane Operator	NSI	Crane Operator
25.	Wayne Ecklere	Asst. Crane/Hoist Technician	NSI	Communicating from above
26.	Kerry Waller	Chamber Personnel	NSI	
27.	Andy Makar	Chamber Personnel	NSI	
28.	Juan Roman	Thermal Vac Test Engineer	Goddard	Thermal Vac Test Director


N
TOP OF SES
SES
+X
+Y
EGSE STAGING AREA
DOWN
CAT WALK
BELOW IN CHAMBER
4 16 5 23
D-9847

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 4-D

Personnel Certification

FAIRCHILD SPACE CRANE OPERATOR CERTIFICATION

All crane operators at the SFTC have completed a forty hour training course in the basics of rigging and overhead crane operation. A list of certified crane and hydraset operators is posted conspicuously in the Environmental Test Lab. Only those personnel identified as certified are permitted to operate the 10 ton and 5 ton (clean room) overhead cranes at the SFTC. No exceptions to this rule are permitted.

CRANE AND RIGGING WORKSHOP TRAINING SYLLABUS

1. Overhead Crane Manual
   a. Scope definitions and references
   b. Construction and installation
   c. Inspection, testing and maintenance of overhead cranes
   d. Inspection, testing and maintenance of overhead hoists
   e. Rope inspection, replacement and maintenance
   f. Welded link chain inspection, replacement and maintenance
   g. Operation of overhead cranes
   h. Operation of overhead hoists
   i. Addendum - workshop material
2. Crane Operators Manual
3. Hooks
4. OSHA Safety and Health Standard
5. OSHA Slings Standard
6. Rigging Standard

Training course conducted by Crane Operational Services, Inc. Baltimore, MD. Inspection and certification service accredited by the U.S. Dept. of Labor under 29 CFR Part 1919.

QUALIFIED CRANE OPERATORS

1. B. Butcher
2. R. Wensell
3. H. Petty
4. R. Eburg
5. L. Dove
6. J. Burdette
7. M. Selepak
8. J. Bryan
9. T. Thomson
10. R. Hinzman
11. J. Duncan
12. T. Haldis
13. P. Martin
14. F. Robinson
15. G. Weigle
16. M. Will
17. G. Hodges
18. E. Grebenstein
19. B. Langmyer
20. D. Mathews
21. L. Roberts

D-9847

QUALIFIED PNEUMATIC HYDRA-SET OPERATORS

1. Jim Burdette
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FAIRCHILD SPACE STANDARDS FOR CRANE LIFTING AND HANDLING

1. SFTC Health and Safety Manual - HSI No. 12.1 - Crane and Rigging Safety

2. Standard Laboratory Operating Procedure for proofload testing, Procedure No. 006.

3. Standard Laboratory Operating Procedure for proofload testing of crane rigging, Procedure No. 008.

SFTC
HEALTH AND SAFETY INSTRUCTIONS

FAIRCHILD SPACE COMPANY

FAIRCHILD COMMUNICATIONS & ELECTRONICS COMPANY

Subject: CRANE AND RIGGING SAFETY	HSI No. 12.1 Rev.

I. Purpose: To describe and set standards which will apply to any lifting and moving that is not performed manually, excluding Forklift operations. This procedure establishes the minimum requirements for all Fairchild operations and may only be superseded by more stringent requirements.

II. Applicable Documents: In addition to the requirements of this procedure, pertinent information contained in the following references, latest revision will apply.

A. AMERICAN NATIONAL STANDARDS

ANSI B 30.2	- 1976	Overhead and Gantry Cranes
ANSI B 30.9	- 1971	Slings
ANSI B 30.10	- 1982	Hooks
ANSI B 30.16	- 1973	Overhead Hoists
ANSI B 30.17	- 1980	Cranes

B. OSHA

1910.179	- 1983	Overhead and Gantry Cranes
1910.184	- 1983	Slings

C. MOSHA

1910.179	- 1983	Overhead and Gantry Cranes

D. FAIRCHILD

QAP - 8.1	Universal Discrepancy Reporting
QAP - 8.2	Material Review System

E. MISCELLANEOUS

HYDRA - SET	Operation and Service Manual Auxiliary Hoist Control, Model D

APPROVED		DATE ISSUED	PAGE
T. L. Barlow	Vice President, Human Resources and Administration	8/1/86	1 OF 11

III. Definitions

A. Authorized Operator - A person recognized as having successfully completed the training class in Crane operation and rigging and whose name appears on the Authorized Crane Operators list.

B. High Value Item - Determined by either cost of the item to be moved or the cost and time delay impact on a given program should that item be damaged.

C. Lift Ticket - This form authorizes lifting of an item requiring use of proofload tested cables or fixtures.

D. Pre-Lift Inspection - Procedure to verify suitability of cables and fixtures to be used in lifting item.

E. Proofload Test - Procedure to qualify cables and fixtures for lifting to desired maximum stress limits.

F. Proofload Test Log - A written record maintained by Quality Assurance of all proofload testing.

G. Proofload Test Tag - Identifying tag fixed to each cable/fixture/fitting having been proofload tested.

H. Proofload Test Interval - Period not exceeding 18 months unless otherwise specified by the proofload test procedure.

I. Special Fixture Designs - A fixture specifically designed to support the lifting of a particular object.

J. Special Lifting Designs - Non-standard combination of cables, fixtures and fittings arranged to lift a particular object.

K. Standard Lab Cables - Cables and slings designed for general purpose lifting whose proofload certification need not be current.

IV. Requirements

A. Proofload Testing of Lifting Fixtures

Proofload testing is required for all cables or lifting fixtures used in the lifting of any item that is either:

1. greater than 2000 lb. in weight;
2. an item intended for "Flight" use ; or
3. any item determined by the Crane Operator to be a "High Value Item."

Should there be any doubt as to the value of any specific item, the Test Operations Manager should be contacted. Only proofload tested cables or fixtures shall be used for its moving if a questions still remains. The use of proofload tested cables and fixtures shall be documented on the "Lift Ticket." Items not covered by the criteria listed above may be lifted using standard lab cables without the use of a "Lift Ticket."

B. Proofload Test Procedures

1. All special lifting designs must be proofload tested in accordance with an approved test procedure. The proofload test procedure must be reviewed and approved by the affected Program Stress and/or Mechanical Engineers as well as Quality Engineering and the Test Operations Manager or their designees.

2. Proofload Test Weight - Unless otherwise required by program specifications, all proofload testing shall be performed to 2.0 times the maximum weight to be lifted. Exceptions to this requirement may be made on an individual basis due to specific design limitations of the lifting device and/or availability of very heavy weights. Test Weight exceptions must be approved by the Program Stress and/or Mechanical Engineers, Quality Engineering and the Test Operations Manager or their designees. At no time shall the proofload weight exceed the manufacturer's recommended safe workload weight.

3. Proofload Test Duration - All proofload testing configurations shall be tested to the designated proofload test weight for not less than three minutes or the time limit as specified by the applicable proofload test procedure; whichever is the longer.

C. Proofload Test Interval

1. If the lifting equipment is placed into inactive storage, proofload testing will not be required until it is returned to active use. (See definition #III 8.)

2. Should there be any reason to suspect that a proofload tested cable has been used in a configuration other than that configuration for which it was originally tested, that cable or fixture must be proofload tested again in the configuration for which it will be used.

D. Lift Documentation

1. Lift Tickets - All lifting fixtures and cables shall be proofload tested prior to use and each successive lifting operation thereafter shall be noted on the cable or fixture "Lift Ticket.

LIFT TICKET

Page_____ of _____

Date _____

LIFT/PROOF-TEST AUTHORIZATION FORM

WORK STATEMENT_____
_____EST. LOAD_____

REQUESTED BY:_____

HANDLING EQUIP. PROOF TAG #	WORK LOAD	PROOF TAG #	WORK LOAD

SEE BELOW FOR DIAGRAM TO SHOW LIFT ANGLES, WEIGHT VECTORS, AND CONFIGURATION.

PROOF LOAD, REQUIREMENTS_____LBS.

DOCUMENT COMPLIED WITH _____

DATE _____

DESIGN/MOVE APPROVED_____
DATE_____

PROOF TEST WITNESSED_____
Inspector

DATE_____

FIGURE 1

FORM #_____

2. Proofload Test Tags

Each item proofload tested will be identified with a tag attached to the handling device. The tag shall specify the following:

1. TAG NUMBER _____
2. PROOFLOAD TESTED TO _____
3. WORK LOAD _____
4. DATE _____
5. NEXT PROOFLOAD TEST REQUIRED _____

_____

In cases of web slings, the above information will be stenciled on the flat of the sling. Under no circumstances will a hole be put into the web material for the I.D. tag.

3. Proofload Test Log

From this log a proofload test Tag Number shall be assigned to the proof test authorization. The log shall contain the following information:

Unit Name	Part No.	S/N	Date	Tag No.

A duplicate record of each proofload test shall be maintained by the Test Operations Group.

E. Lift Equipment

1. Special Fixture Designs

All special fixture designs used for lifting shall be permanently identified with a unique proofload test Tag Number. All special fixture designs shall be approved by the Program Stress Engineer.

2. Standard Cable Configuration

A special proofload test is not required for combinations of lift cables whose proofload certifications are still current. Approval of lift rigging made up from proofload tested lab cables and/or strap assemblies may be obtained based on the cable and strap assembly lift tickets. Approval must be obtained in the same manner as for proofload test procedures.

3. Purchased Equipment

If purchased equipment is proofload tested at the Vendor's facility an initial proofload test at Fairchild will not be mandatory if the following conditions are met:

a. The Vendor's Proofload Data or an FSC Source Inspection Report is provided for insertion in the Proofload Test Log.

b. The Vendor Data or Source Inspection Report must indicate the part number, serial number, design load, and proofload test load.

c. The Proofload Test Tag Number must be entered on the Vendor Data or Source Inspection Report upon assignment.

4. Equipment Storage

Lifting equipment shall be stored in a controlled area within the Test Building. Large fixtures may be stored in the warehouse providing they are environmentally controlled.

F. Lift Precautions

1. Pre-Lift Inspections

An inspection shall be performed prior to lifting of any item requiring proofload tested cables or fixtures to insure that all cables and fixtures used have current proofload test certifications.

a. The crane operator shall visually inspect all rigging prior to use.

Any physical degradation of the equipment shall invalidate the proofload test certification. All damaged equipment shall be tagged as non-conforming items per QAP 8.1 and QAP 8.2 and held for disposition by the Quality Department.

b. Verification of valid proofload testing of all rigging equipment shall ensure compliance with time interval requirements.

2. Cable Lift Angle Restrictions

The maximum angle between the lift cable and the vertical shall be 30 degrees, as shown in Figure 2 unless otherwise specified by the sling design and/or approved by Stress Engineering.

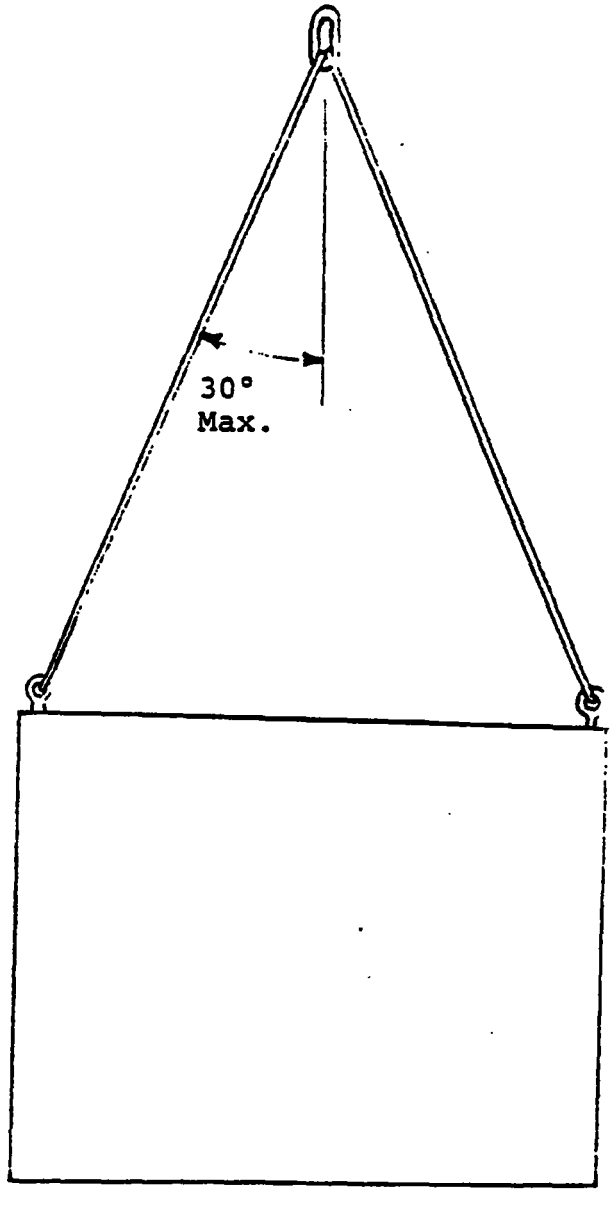


Figure 2 - Maximum Angle for Cable Separation

V. Responsibilities

A. The Environmental Test Lab

1. Performing proofload testing as required.

2. Identifying new equipment with a test lab number.

3. Designating storage areas for lifting and moving equipment.

4. Storing and maintaining the lift and moving equipment in the designated area.

5. Presenting program-oriented procedures to the Quality Department for insertion in the Proofload Log.

6. Preparing and/or approving equipment proofload test procedures.

7. Originating and approving "Lift Tickets" for facility service operations.

8. Monitoring all moves to assure compliance with approved lift designs and to verify there is no physical damage, i.e. visible defects in the lifting equipment.

9. Maintaining a file of approved lift designs, by Tag. No., in the Test Lab Office.

10. Conducting certification training of potential crane operators. All operators will be retested annually.

11. Maintaining a list of certified crane operators and posting said list beside the crane control box.

12. Preparing a list of "DO'S and DON'T'S" for the crane operators and posting said list beside the crane control box.

13. Retaining the training records of the certified crane operators and providing the Safety department with copies.

B. Quality Inspection

Quality Inspection shall be responsible for:

1. Verifying that lifting and moving equipment is permanently identified and stored in the designated area.

2. Verifying that each proofload test is performed as specified herein.

3. Verifying that each piece of equipment is listed in the Proofload Log.

4. Entering the lab number, part number, program number (where applicable), load capacity, proofload, and date of test in he Proofload Log Book.

5. Processing a copy of the Vendor Proofload Data and/or the Source Inspection Reports on purchased equipment.

6. Verify the identification of proofload tested items.

7. Performing inspection as required in program oriented lifting/moving procedures.

8. Notifying DCAS (when required for proofload tests and moves/lifts).

C. Quality Engineering

Quality Engineering shall be responsible for:

1. Ensuring the Work Orders for lifting equipment include:

   a. Proofload testing at weight determined by specifications or drawings.

   b. Proofload Test Certification.

2. Approve and sign off Work Orders for proofload testing.

D. Lift/Move Test Conductor/Supervisor

The Move Supervisor/Test Conductor shall be responsible for the following:

1. Coordinating the move with the applicable personnel (Director, Project Engineer, Test Conductor, Inspection, etc.)

2. Originating and approving "Lift Tickets" (except in the case of facility service type operations).

3. Attaching a copy of photo or sketch to lift ticket or work order (with Lab. No. and Date Approved) of lift designs.

E. Crane Operator

The Crane Operator has the authority and in fact the ultimate responsibility to refuse to lift or move any piece of equipment in a manner that poses a threat to personnel or property. In addition, the Crane Operator shall:

1. Inspect the crane prior to each use for any signs of wear or damage.

2. Verify all periodic inspections have been performed successfully.

3. Examine the lift fixture to assure there has been no damage or movement of the fixed parts.

4. Verify that the Overhead Crane is free of any obstructions to it's motion.

5. Report all refusal to lift or move any piece of equipment to the Safety department within 24 hours.

F. Test Program Office

1. Mechanical Engineer

The Program Mechanical Engineer shall be responsible for:

a. Establishing lift requirements applicable to their program.

b. Coordinating stress decisions with Stress Engineers in the Engineering Department.

c. Determining the actual weight to be lifted.

2. Stress Engineer

The Stress Engineer (designated by the Program Office) shall be responsible for:

a. Approving new lift procedures and designs, i.e., sling arrangements, sizes of sling, shackles, etc.

b. Designating the proofload test weight and approving proofload test procedures.

c. Designating the number of consecutive lifts (or period of time) between proofload tests. (see III 8)

FAIRCHILD SPACE COMPANY

TITLE EQUIPMENT HANDLING TRAINING AND PERSONNEL CERTIFICATION OUTLINE	DOCUMENT NUMBER PC0005	REV. A	PAGE NO. 1 OF 3

1.0 PURPOSE

All personnel, regardless of discipline, should be thoroughly instructed in the proper methods and techniques related to handling and control of flight equipment prior to engaging in actual operations. Each time a flight item is transported or relocated the potential for inadvertent damage can be greatly reduced simply by insuring that each person understands and uses the correct methods.

2.0 TRAINING

The training shall consist of a minimum of one hour of lectured and vu-graph presentations. Appropriate video presentations may be used if and when deemed appropriate for special equipment constraints by the designated instructor.

3.0 CERTIFICATION

At the conclusion of this course, personnel will be tested to determine their comprehension of the information presented. Personnel that successfully demonstrate the required skill level will be certified. Those personnel who do not demonstrate the required skill level will be offered additional instruction and limited retesting.

4.0 TRAINING COURSE OUTLINE

I. Each attendee shall be provided a "hand out" consisting of:
   - A. Quality Assurance Procedure 7.4 (Handling and Control of Flight Articles)
   - B. PC0005 (This document)
   - C. Copy of all vu-graphs presented

II. The instructor will review the training program purpose, content, and certification requirements

III. Video material selected as appropriate should be described and shown at this time

IV. Lecture (assisted by Vu-graphs)
   - A. Why are you attending this training class?
     1. You may be handling flight equipment in conjunction with your assignment, and
     2. It is vital that you understand the proper methods, and
     3. By using the proper methods we can avoid inadvertent damage
   - B. Why is it so important?
     1. Space Flight equipment is usually one-of-a-kind
     2. Highly expensive
     3. Reliability critical
     4. Not easily repairable

PREPARED BY:	APPROVED BY:	REV. DATE	APPROVED:
A. CONNORS	W. COLE	7-24-89	A Connors

C. Identification techniques (Vu-graphs)
   1. T^2 labels
   2. QA Acceptance Tag
   3. Work Orders
   4. Log books
   5. Test Procedures
D. Contols (Vu-graphs)
   1. Build documents
   2. Test documents
   3. Log books
   4. Integration procedures
E. Product (WIP) Movement
   1. Within work centers
   2. Outside of work center
   3. Finished items
   4. General cautions
      (a) Approved containers
      (b) Specialized coverings
      (c) Documentation
      (d) Custodial responsibilities

V. Stock (Vu-graphs)
   A. Receiving inspection pass-thru
   B. T^2 packaging
   C. Withdrawal
   D. Kit verification
   E. Restocking

VI. Manufacturing (Vu-graphs)
   A. ESD stations
   B. Documentation vs hardware
   C. Rework authorization
      1. UDR
      2. NCMR
      3. FACAR
      4. ECN
      5. Manufacturing Change Order
   D. Restocking

VII. Test
   A. Movements
   B. Testing definition
   C. QA operations

VIII. Component Stock
   A. Visual
   B. Data
   C. Cleaning and packing
   D. Tags, logs, data

IX. Integration
- A. Component withdrawal
- B. Transportation and protection
- C. ESD stations, smocks
- D. Environmental controls
- E. Procedures
- F. QA Log

5.0 SUMMARY

This course has provided a definition of the correct techniques to be followed. You should now be aware of what to do in most situations - if you are placed in a position where you are confused or do not understand what to do, please contact your supervisor or manager and request assistance. Are there any questions or clarifications from anyone before we start the test — if not, Good Luck.

EQUIPMENT HANDLING

PC0005

WHY ARE WE HERE

WHY ARE WE HERE

- MAY HANDLE AS PART OF ASSIGNMENT

WHY ARE WE HERE

- MAY HANDLE AS PART OF ASSIGNMENT
- VITAL TO UNDERSTAND PROPER METHOD

EQUIPMENT HANDLING PC0005

NOTES

WHY ARE WE HERE

- MAY HANDLE AS PART OF ASSIGNMENT
- VITAL TO UNDERSTAND PROPER METHOD
- AVOID INADVERTENT DAMAGE

WHY IS IT IMPORTANT

WHY IS IT IMPORTANT

- ONE OF-A-KIND

WHY IS IT IMPORTANT

- ONE OF-A-KIND
- HIGHLY EXPENSIVE

EQUIPMENT HANDLING PC0005

NOTES

WHY IS IT IMPORTANT

- ONE OF-A-KIND
- HIGHLY EXPENSIVE
- RELIABILITY CRITICAL

WHY IS IT IMPORTANT

- ONE OF-A-KIND
- HIGHLY EXPENSIVE
- RELIABILITY CRITICAL
- NOT EASILY REPAIRABLE

IDENTIFICATION TECHNIQUES

IDENTIFICATION TECHNIQUES

- T^2 LABELS

EQUIPMENT HANDLING PC0005

NOTES

IDENTIFICATION TECHNIQUES

- T^2 LABELS
- QA ACCEPTANCE TAG

IDENTIFICATION TECHNIQUES

- T^2 LABELS
- QA ACCEPTANCE TAG
- WORK ORDERS

IDENTIFICATION TECHNIQUES

- T^2 LABELS
- QA ACCEPTANCE TAG
- WORK ORDERS
- LOG BOOKS

IDENTIFICATION TECHNIQUES

- T^2 LABELS
- QA ACCEPTANCE TAG
- WORK ORDERS
- LOG BOOKS
- TEST PROCEDURES

FAIRCHILD
SPACE COMPANY

EQUIPMENT HANDLING PC0005

NOTES

CONTROL

CONTROL

- BUILD DOCUMENTS

CONTROL

- BUILD DOCUMENTS
- TEST DOCUMENTS

CONTROL

- BUILD DOCUMENTS
- TEST DOCUMENTS
- LOG BOOKS

EQUIPMENT HANDLING PC0005

NOTES

CONTROL

- BUILD DOCUMENTS
- TEST DOCUMENTS
- LOG BOOKS
- INTEGRATION PROCEDURES

PRODUCT (WIP) MOVEMENT

PRODUCT (WIP) MOVEMENT

- WITHIN WORK CENTERS

PRODUCT (WIP) MOVEMENT

- WITHIN WORK CENTERS
- OUTSIDE OF WORK CENTER

FAIRCHILD
SPACE COMPANY

EQUIPMENT HANDLING PC0005

NOTES

PRODUCT (WIP) MOVEMENT

- WITHIN WORK CENTERS
- OUTSIDE OF WORK CENTER
- FINISHED ITEMS

PRODUCT (WIP) MOVEMENT

- WITHIN WORK CENTERS
- OUTSIDE OF WORK CENTER
- FINISHED ITEMS
- GENERAL CAUTIONS
  - . APPROVED CONTAINERS
  - . SPECIALIZED COVERINGS
  - . DOCUMENTATION
  - . CUSTODIAL RESPONSIBILITIES

STOCK

STOCK

- RECEIVING INSPECTION PASS-THRU

EQUIPMENT HANDLING PC0005

NOTES

STOCK

- RECEIVING INSPECTION PASS-THRU
- T^2 PACKAGING

STOCK

- RECEIVING INSPECTION PASS-THRU
- T^2 PACKAGING
- WITHDRAWAL

STOCK

- RECEIVING INSPECTION PASS-THRU
- T^2 PACKAGING
- WITHDRAWAL
- KIT VERIFICATION

STOCK

- RECEIVING INSPECTION PASS-THRU
- T^2 PACKAGING
- WITHDRAWAL
- KIT VERIFICATION
- RESTOCKING

EQUIPMENT HANDLING PC0005

NOTES

MANUFACTURING

MANUFACTURING

- ESD STATIONS

MANUFACTURING

- ESD STATIONS
- DOCUMENTATION vs. HARDWARE

MANUFACTURING

- ESD STATIONS
- DOCUMENTATION vs. HARDWARE
- REWORK AUTHORIZATION
  - . WORK ORDER
  - . UDR
  - . NCMR
  - . FACAR
  - . ECN
  - . CHANGE ORDER (MANUFACTURING)

EQUIPMENT HANDLING PC0005

NOTES

MANUFACTURING

- ESD STATIONS
- DOCUMENTATION vs. HARDWARE
- REWORK AUTHORIZATION
  - . WORK ORDER
  - . UDR
  - . NCMR
  - . FACAR
  - . ECN
  - . CHANGE ORDER (MANUFACTURING)
- RESTOCKING

TEST

TEST

- MOVEMENTS

TEST

- MOVEMENTS
- QA OPERATIONS

EQUIPMENT HANDLING PC0005

NOTES

TEST

- MOVEMENTS
- QA OPERATIONS
- TEST DEFINITION

TEST

- MOVEMENTS
- QA OPERATIONS
- TEST DEFINITION
  - PART
  - ASSEMBLY
  - COMPONENT
  - SUBSYSTEM
  - SYSTEM

LIFTING

- EQUIPMENT AND HARDWARE
- PROOF LOADING
  - LOAD CAPACITY
  - PROOF LOADED TO
  - DATE OF PROOF LOAD
  - NEXT PROOF LOAD REQUIRED
  - HYDRASET

HANDLING

- PROCEDURES
- WORK ORDER
- ADDITIONAL PRECAUTIONS
  - SHIRT/SMOCK POCKETS
  - GLOVES AND SMOCKS
  - HAND TOOLS
  - THERMAL BLANKET

EQUIPMENT HANDLING PC0005

NOTES

MOVEMENT

- PERSONNEL SAFETY
- SPECIAL PRECAUTIONS

PROTECTION

- PROTECTIVE COVER
- GROUNDING

COMPONENT STOCK

COMPONENT STOCK

- VISUAL

EQUIPMENT HANDLING PC0005

NOTES

COMPONENT STOCK

- VISUAL
- DATA

COMPONENT STOCK

- VISUAL
- DATA
- CLEANING AND PACKING

COMPONENT STOCK

- VISUAL
- DATA
- CLEANING AND PACKING
- TAGS, LOGS, DATA

INTEGRATION

EQUIPMENT HANDLING PC0005

NOTES

INTEGRATION

- COMPONENT WITHDRAWAL

INTEGRATION

- COMPONENT WITHDRAWAL
- TRANSPORTATION AND PROTECTION

INTEGRATION

- COMPONENT WITHDRAWAL
- TRANSPORTATION AND PROTECTION
- ESD STATIONS, LAB COATS

INTEGRATION

- COMPONENT WITHDRAWAL
- TRANSPORTATION AND PROTECTION
- ESD STATIONS, LAB COATS
- ENVIRONMENTAL CONTROLS

EQUIPMENT HANDLING PC0005

NOTES

INTEGRATION

- COMPONENT WITHDRAWAL
- TRANSPORTATION AND PROTECTION
- ESD STATIONS, LAB COATS
- ENVIRONMENTAL CONTROLS
- PROCEDURES

INTEGRATION

- COMPONENT WITHDRAWAL
- TRANSPORTATION AND PROTECTION
- ESD STATIONS, LAB COATS
- ENVIRONMENTAL CONTROLS
- PROCEDURES
- QA LOG

SUMMARY

EQUIPMENT HANDLING

- PROPER PLANNING
- CONTROL
- DOCUMENTED SYSTEM

EQUIPMENT HANDLING PC0005

NOTES

IDENTIFICATION METHODS

- T^2 TRACEABILITY LABELS
- QA ACCEPTANCE TAGS
- ACCEPTANCE LABELS
- AGE CONTROL LABELS
- WORK ORDERS
- LOG BOOKS
- TEST PROCEDURES

CONTROLLED BY

- BUILD DOCUMENTS
- TEST PROCEDURES
- LOG BOOKS
- INTEGRATION PROCEDURES

MOVEMENT

- WITHIN WORK CENTERS
- OUTSIDE OF WORK CENTERS
- PAINTED/FINISHED PARTS
- APPROVED CONTAINERS/FIXTURES
- SPECIAL COVERINGS
- DOCUMENTATION

WITHDRAWAL AND RESTOCKING

- MMA
- PACKING LIST
- REQUISITION, INVOICE/SHIPPING
- WORK ORDER
- PLANNED DOWN TIMES

EQUIPMENT HANDLING PC0005

NOTES

WHEN IN DOUBT

- SEE YOUR SUPERVISOR
- FOLLOW PROCEDURES STEP-BY-STEP
- ERROR IN PROCEDURE
- USE THESE GUIDELINES WHEN APPLICABLE

1.0 PURPOSE

The purpose of this certification procedure is to see that all personnel associated with the production manufacturing/inspection of electronic components using ESD sensitive parts (ESDS) shall be instructed in the proper procedures required to eliminate electronic equipment failures caused by ESD.

2.0 TRAINING

The training & certification shall consist of movies & a special training course written for FSC personnel. The training course consists of a lecture along with practical demonstrations of cause & effects of ESD. The course was written to show effects of ESD on everyday life, at work, types of ESD protection & why protection is required. The course was written that personnel attending can relate to and understand these problems. Personnel are shown why their future with the company & the company's future depends on their efforts to control & eliminate ESD problems in electronic equipment. ESD prevention must become second nature to them, so that they are aware of ESD at all times.

3.0 CERTIFICATION

At the conclusion of training, personnel are assessed as to their comprehension of the information presented and when they show awareness they are certified as having been trained in ESD awareness. At the conclusion of the lecture they are given a copy of the course and a copy of FSC Handling Procedures for ESDS devices for future reference. A copy of the course outline is shown for reference.

4.0 RECERTIFICATION

Recertification shall be required when the following actions occur:

a. Certificate holder changes employment
b. Certificate holder performance unsatisfactory

5.0 ESD TRAINING COURSE

I. What is ESD
   A. Description of ESD
      1. Visual effect
      2. Non visual effects
      3. Hidden dangers
      4. Part flow

B. Everyday ESD problems
   1. Body movement
   2. Womens clothes & computers
   3. Static cling in clothes
   4. Shocks walking on carpet
   5. EMI radiated tests
C. Serious ESD problems
   1. Ordinance tests
   2. Orbiting solar lab disaster at Cape Kennedy 3 dead, 11 injured
D. Static electricity generated
   1. Tribo electric effects
      (a) Untreated Plastics
      (b) Insulators
   2. Electro static field
   3. Direct discharge from charged personnel or objects
E. ESD Demonstrations
   1. Triboelectric generators
      (a) Untreated plastic materials (ESD meter)
      (b) Plastic tape (using finger to prove static electricity)
      (c) Static guard spray to remove static charge from materials
   2. Conductive materials (ESD meter)
   3. Antistatic material (ESD meter)
F. ESD meter (pro's & cons of ESD meter operation)
G. ESD stations
   1. Conductive mats
      (a) Table mats advantages/disadvantages
      (b) Floor mats advantages/disadvantages
      (c) Shoes
   2. Static dissapative mats
      (a) Table mats advantages/disadvantages
      (b) Floor mats advantages/disadvantages
      (c) Shoes
   3. Control methods
      (a) High Humidity
      (b) Ionized air Pro's/Cons
      (c) Grounding
      (d) Topical antistats
      (e) Protective handling
      (f) Removal of all untreated plastics/insulators from ESD area
      (g) Wrist straps
         (1) Protection of ESD's part/assemblies
         (2) Protection of personnel

H. Handling procedures
   1. ESD handling procedures for everyone
   2. Shippng department
   3. Receiving Inspection
   4. Storeroom
   5. Kit verification
   6. Production/Processing/Assembly/Repair/Revork
   7. Functional test
   8. System test
   9. Test monitors

I. FSC work stations
   1. Table mat
   2. Floor mat
   3. Wrist strap
   4. Air ionizers
   5. Protective materials
      (a) Tote boxes, trays, bag, carriers
   6. Protective apparel
      (a) Smocks
         (1) Treament
         (2) Use
         (3) Measurement

J. Tables
   1. Typical electro-static voltages
   2. Typical prime charge sources
   3. Static control examples
   4. Bench tops/floor mats
   5. List of ESD parts
   6. General application
   7. ESD formed shapes

K. Conclusion

I hope this session has been informative and has given you an insight into ESD problems and possible solutions. However, to make any ESD program work requires the cooperation of each on of us. If anyone does not follow the guidelines it jeopardizes the entire system. Any questions?

D-9847

PC0010

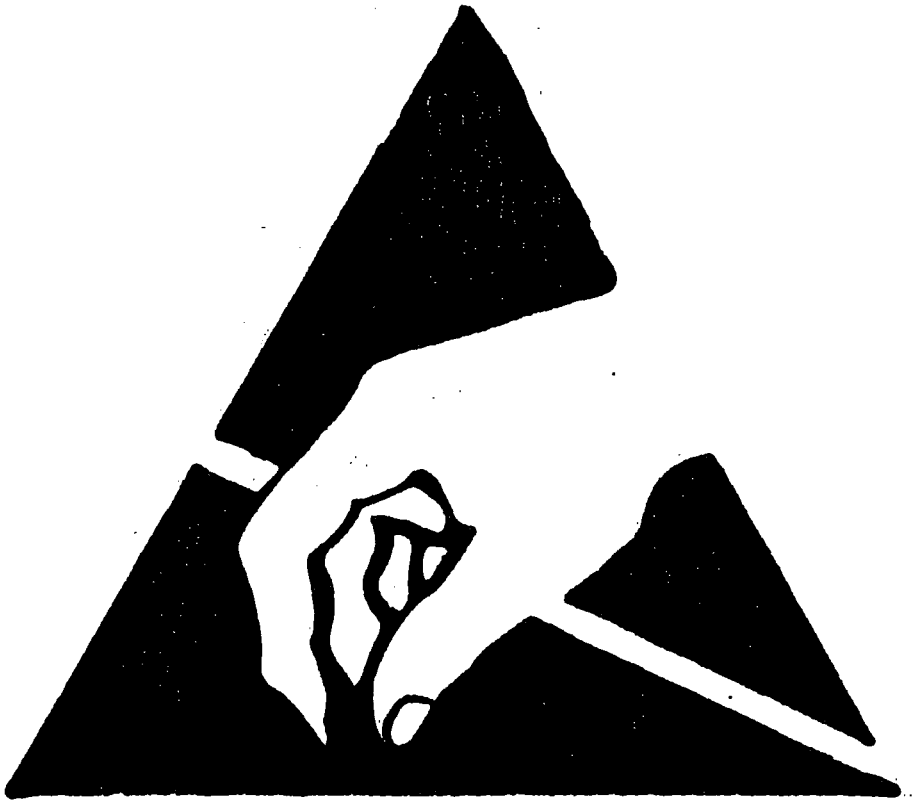
E S D A W A R E N E S S

VOLUME 2

February 1992

REFERENCE DOCUMENTS

MIL-STD-2000A	14 Feb 1991	Standard Requirements for Soldered Electrical and Electronic Assemblies
MIL-STD-1686A	08 Aug 1988	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices) (Metric)
MIL-HDBK-263A	22 Feb 1991	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices) (Metric)
STD-GR7000		ESD Handling Procedure
QAP 3.6		Electrostatic Discharge Control Plan



CAUTION

STATIC CONTROL AREA

USE OF PROPER ESD CONTROLS REQUIRED

D-9847

J. T. Kafer Co Inc
213-822-7430

CAUTION

CONTENTS SUBJECT TO DAMAGE BY
STATIC ELECTRICITY

DO NOT OPEN !

EXCEPT AT APPROVED
STATIC-FREE WORK STATION

ATTENTION
Contents
Static-Sensitive

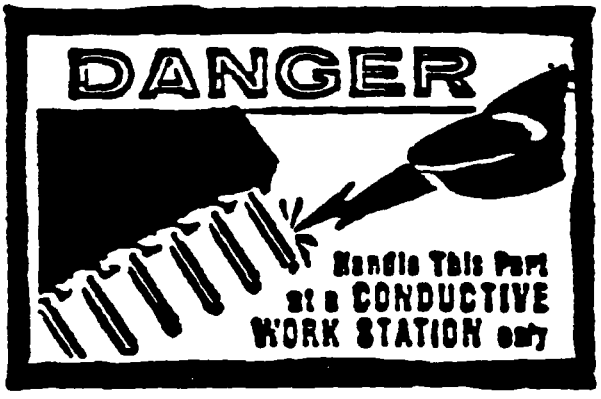
Handling
Precautions
Required

Contents _____

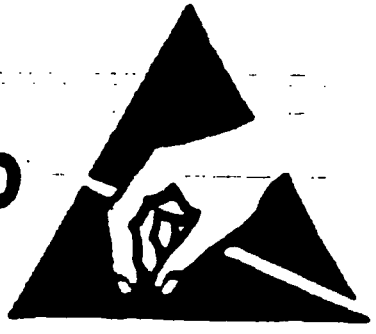
_____

_____

JEDEC-14/Symbol



ATTENTION
STATIC SAFEGUARDED WORK AREA



WHAT IS ESD?

ESD STANDS FOR ELECTROSTATIC DISCHARGE, WHICH IS IN ESSENCE A MINIATURE LIGHTNING BOLT. BUT UNLIKE A LIGHTNING BOLT, IT MAY NOT BE SEEN. TO BE SEEN IT MUST EXCEED 3500 VOLTS IN AMPLITUDE. IN THE OLD MOVIES YOU HAVE SEEN PICTURES OF A GOD HURLING A LIGHTNING BOLT AT A SHIP, MOUNTAIN, OR SOME OBJECT AND DESTROYING IT. YOU CAN DO THE SAME THING ON A SMALLER SCALE. THE LIGHTNING BOLT YOU HURL CAN TOTALLY DESTROY OR DEGRADE AN ELECTRONIC PART WHICH COULD LATER CAUSE A SATELLITE FAILURE. WHILE THIS IS VERY EYE-CATCHING, THERE ARE ADDITIONAL PROBLEMS CAUSED BY ESD WHICH ARE NOT SEEN. THOUGH NOT SEEN, THEY CAN ALSO DAMAGE OR DEGRADE ELECTRONIC PARTS. THIS CAN BE DONE WITH VOLTAGE AROUND 250 VOLTS OR LESS. COMPARE THIS TO A SUPREME BEING YOU CANNOT SEE, BUT FAITH TELLS YOU IT IS THERE. I SHALL DO THE SAME. I SHALL TELL YOU OF THE DAMAGE ESD CAUSES WHEN NOT SEEN, AND YOU MUST BELIEVE THE PROBLEM EXISTS EVEN THOUGH YOU DON'T SEE IT.

BY MOVEMENT OF YOUR BODY, YOU CAN GENERATE A VOLTAGE FROM 100 TO 20,000 VOLTS. AS MOST PEOPLE ARE UNAWARE OF THE DESTRUCTIVE ENERGY CREATED BY MOVEMENT OF THEIR BODIES, COMPANIES MUST TAKE STEPS TO ELIMINATE OR CONTROL THIS FORCE. TABLE I INDICATES WHAT ARE "TYPICAL ELECTROSTATIC VOLTAGES" GENERATED BY WALKING, AND TABLE II, "TYPICAL PRIME CHARGE SOURCES," LISTS SOME OF THE MEANS OF GENERATING THESE VOLTAGES.

YOU CAN SEE HOW EASY ESD VOLTAGES CAN BE GENERATED. YOU CAN UNDERSTAND THE PROBLEMS. FIGURES 1 AND 2 SHOW JUST HOW MANY TIMES A PART MAY BE HANDLED FROM THE TIME IT ENTERS THE COMPANY TILL IT LEAVES AS AN ASSEMBLY, COMPONENT, SUBSYSTEM, OR SYSTEM. AS YOU CAN SEE, ANYWHERE ALONG THE LINE FAILURES MAY OCCUR. IN THE CASE OF ESD YOUR DEDICATION AND WORK IS AS IMPORTANT TO THE COMPANY AS ANY PERSON AT FSC, FROM PRESIDENT ON DOWN. IF WE ALL FOLLOW THE RULES I SHALL OUTLINE IN THIS COURSE, WE SHALL HAVE NO PROBLEMS. IF WE DO OUR JOB CORRECTLY, THE COMPANY BENEFITS AND SO DO EACH OF YOU.

IN ADDITION TO BELIEVING, I SHALL EXPLAIN SOME ESD PROBLEMS ENCOUNTERED OVER THE YEARS.

IN THE EARLY DAYS OF COMPUTERS, IT WAS FOUND THAT WOMEN WEARING SYNTHETIC CLOTHES (NYLON, ORLON, ETC.) COULD CAUSE A LARGE COMPUTER TO MALFUNCTION AND PRODUCE ERRONEOUS DATA. THIS WAS TRACED TO THE STATIC ELECTRICITY GENERATED DURING NORMAL MOVEMENTS OF THE HUMAN BODY. THE EARLY SOLUTION TAKEN BEFORE COMPUTERS AND SURROUNDINGS COULD BE MODIFIED WAS TO REQUEST THE WOMEN TO WEAR COTTON GARMENTS WHICH DO NOT GENERATE AS MUCH STATIC ELECTRICITY.

EVEN AT HOME WE EXPERIENCE PROBLEMS CAUSED BY STATIC ELECTRICITY. WHEN DRYING CLOTHES IN A DRYER, THE CLOTHES TEND TO STICK TOGETHER DUE TO STATIC ELECTRICITY GENERATED BY FRICTION AS THE CLOTHES TUMBLE AROUND IN THE DRYER. MANUFACTURERS PROVIDE LIQUIDS OR MATERIALS TO ADD TO THE WATER OR TO THE DRYER TO HELP NEUTRALIZE THESE STATIC CHARGES. WHILE STATIC CLING DOES NO DAMAGE, IT IS ANNOYING TO HAVE CLOTHES CLING TOGETHER.

ANOTHER ANNOYANCE IS TO HAVE A LARGE STATIC CHARGE ON CLOTHES THAT CLING TO ONE'S BODY IN A MOST UNFLATTERING MANNER. THEY HAVE DESIGNED SPRAYS THAT CAN BE SPRAYED ON CLOTHES TO NEUTRALIZE THESE STATIC ELECTRIC CHARGES AND TO MAKE SOMEONE'S APPEARANCE PRESENTABLE AGAIN.

MANY YEARS AGO, DURING THE WINTER, I ENCOUNTERED STATIC PROBLEMS WHILE LAYING CARPET IN A LARGE BUILDING. NORMALLY STATIC CHARGES ARE HIGHER IN WINTER DUE TO THE LOWER HUMIDITY. WE HAD JUST INSTALLED CARPET IN THE MAIN 50 FOOT HALLWAY. ONE OF THE EMPLOYEES CAME DOWN THE HALL AND STOPPED TO GET A DRINK. THE ARC FROM HER TEETH TO THE DRINKING FOUNTAIN ALMOST SCARED HER TO DEATH. YOU

Figure 1 Part Flow

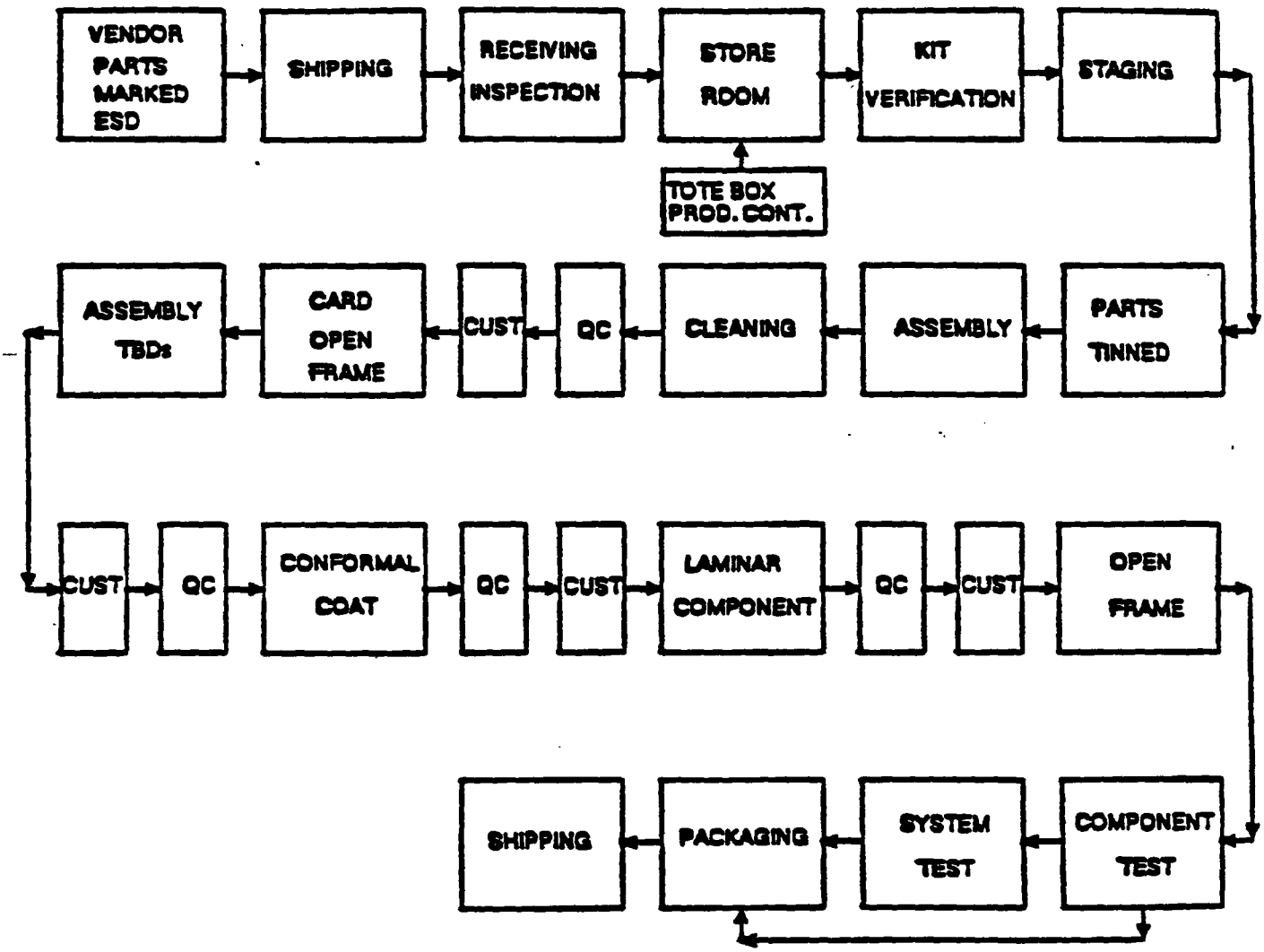
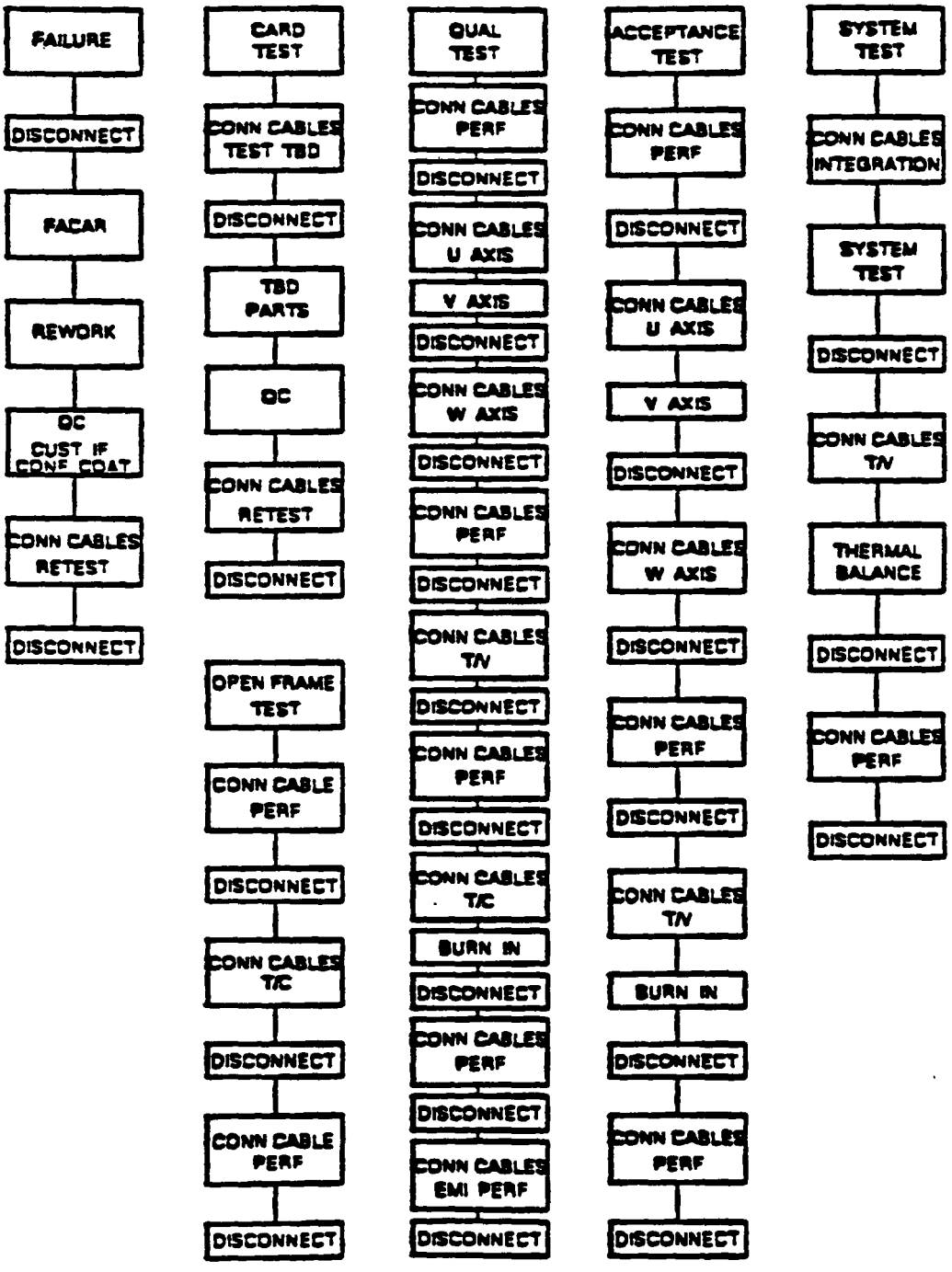


Figure 2 Part Flow in Test



COULD WALK FAST DOWN THE HALL AND DRAW 3-5 INCH ARCS FROM YOUR BODY TO SOME CONDUCTOR. ANOTHER FUN THING WAS TO STAND BEHIND SOMEONE, SHUFFLE YOUR FEET, AND POINT YOUR FINGER A COUPLE OF INCHES FROM HIS EAR. THE RESULTS WERE AMAZING. THE SMALL LIGHTNING BOLT WOULD CAUSE HIM TO JUMP ABOUT 2 FEET HIGH. THE ONLY SOLUTION AT THAT TIME WAS TO HOLD A METAL OBJECT IN ONE HAND TO DISSIPATE THE ARC TO ANY CONDUCTIVE SURFACE (LIGHT SWITCHES, DOOR KNOBS, ETC.). WHAT THE FINAL END RESULT WAS I NEVER FOUND OUT.

WHEN PERFORMING EMI RADIATED TESTS, YOU MUST KEEP PERSONNEL OUT OF THE SHIELDED ENCLOSURE OR KEEP MOVEMENT TO A MINIMUM. ANY TIME THERE IS MOVEMENT IT RESULTS IN ESD WHICH SHOWS ON THE EMI METER AS A TRANSIENT. TO MAKE SURE THE ANTENNA IS PROPERLY CONNECTED TO THE EMI METER, YOU SLIDE YOUR FINGER DOWN THE ANTENNA CREATING A TRANSIENT IN THE METER. IN ONE CASE IT ACTS AS A HINDRANCE; IN ANOTHER IT'S AN AID. WHILE WORKING IN THE ADMINISTRATION BUILDING A FEW YEARS BACK, I WAS GETTING SO MANY SHOCKS I STARTED TO GET GUN SHY. WALKING THROUGH DOORWAYS RESULTED IN DISCHARGES FROM ELBOWS AND OTHER PARTS OF MY BODY TO DOOR FRAMES, DESKS, ETC. IN ORDER TO PREVENT THIS, I HAD TO BUY LEATHER SHOES WHICH HAVE A TENDENCY TO DISCHARGE VOLTAGES BEFORE THEY BUILD UP TO EXCESSIVE LIMITS. WHEN THE COMPANY HAD THE NEW FCEC BUILDING CONSTRUCTED, THEY INSTALLED CONDUCTIVE CARPETS TO HELP PREVENT STATIC BUILDUP.

WHEN SOMEONE IS HANDLING ORDNANCE (SQUIBS, IGNITERS, ETC.), THEY MUST BE CAREFUL THAT NO LARGE STATIC VOLTAGES ARE GENERATED. IF THEY ARE NOT CAREFUL THEY CAN, AT THE VERY LEAST, LOSE A FEW FINGERS. HERE AGAIN THE COMPANY REQUIRES COTTON CLOTHES AND LEG STRAPS TO DISSIPATE ANY STATIC ELECTRIC CHARGE AND GUIDELINES TO FOLLOW FOR ADDITIONAL EMPLOYEE PROTECTION.

DURING SYSTEM TESTS AT GSFC ON THE ISEE-C SPACECRAFT, WE WERE PERFORMING SOME ORDNANCE TESTS IN GSFC'S SHIELDED ENCLOSURE. THIS INVOLVED THE USE OF LIVE ORDNANCE TO BE INSTALLED IN BOLT CUTTERS, CABLE CUTTERS, IGNITERS, ETC., FOR THE EMI TEST. WHILE I WAS LOADING THE ORDNANCE SOMEONE WALKED OVER TO THE SPACECRAFT AND DREW ABOUT A FOUR INCH ARC. HE IMMEDIATELY NOTIFIED ME TO BE CAREFUL. HE HAD ASSUMED THE SHIELDED ENCLOSURE FLOOR WAS GROUNDED, BUT IT HAD A LINOLEUM FLOOR WHICH WAS HIGHLY CONDUCIVE TO GENERATING STATIC ELECTRICITY. HERE AGAIN CARELESSNESS COULD HAVE CAUSED SERIOUS PROBLEMS.

I HAVE JUST SHOWN SOME EXAMPLES OF ESD HAVING SERIOUS EFFECTS ON EQUIPMENT AND ANNOYING EFFECTS ON HUMANS. IN ADDITION TO THOSE PROBLEMS, THERE IS A MORE SERIOUS PROBLEM WHERE ESD CAN KILL.

DURING TESTS ON THE ORIBITING SOLAR OBSERVATORY SPACECRAFT AT CAPE KENNEDY IN 1966, THERE WAS A FATAL ACCIDENT. A POLYETHYLENE COVER OVER THE SPACECRAFT WAS ROLLED UP AND ALLOWED TO FALL BACK CHARGING IT TO 37,000 VOLTS. WHILE THE COVER PRODUCED NO SPARK, IT INDUCED ITS CHARGE ON THE NEAREST CONDUCTOR. IT SET OFF THE IGNITER SQUIB SO THAT THE ROCKET ENGINES IGNITED ON THE SPIN TEST STAND IN THE HANGERS CAUSING 3 DEATHS, HOSPITALIZING ELEVEN, AND DESTROYING THE SPACECRAFT. AFTER THIS TRAGIC ACCIDENT CAUSED BY STATIC ELECTRICITY, A NEW COVER WAS DESIGNED TO PREVENT FUTURE ACCIDENTS.

ANOTHER METHOD OF GENERATING STATIC ELECTRICITY IS BY MEANS OF THE TRIBOELECTRIC EFFECT. THIS BIG WORD MEANS STATIC ELECTRICITY BEING GENERATED BY FRICTION OR RUBBING. THIS EFFECT IS CAUSED BY RUBBING TWO DIFFERENT MATERIALS TOGETHER. WHEN TWO PIECES OF THE SAME MATERIAL IN CONTACT ARE SEPARATED (ESPECIALLY COMMON PLASTIC), THEY ALSO GENERATE A CHARGE. THE PRIME SOURCES ARE INSULATORS, TYPICALLY SYNTHETIC MATERIALS (UNTREATED PLASTICS, POLY FOAM, ETC.).

(1) RUB MATERIALS TOGETHER AND MEASURE.

(2) OPEN TAPE USING FINGER AND METER.

JUST THINK, BY UNROLLING TAPE OFF A SPOOL, ONE CAN GENERATE VOLTAGES IN EXCESS OF 1500 VOLTS. SEE HOW EASY THAT IS.

(3) CHARGE POLY FOAM. USE STATIC GUARD TO DISCHARGE.
(4) CONDUCTIVE MATERIALS.
(5) ANTISTATIC MATERIALS.
(6) ANTISTATIC WIPES.

THERE ARE ALSO PROBLEMS ASSOCIATED WITH THE USE OF THE ESD METER IN CURRENT USE AT FAIRCHILD. THE RESULTS ARE OFTEN MISLEADING AND COULD POSSIBLY LEAD TO PROBLEMS. THE METER IS EXCELLENT FOR READING CHARGES ON UNTREATED PLASTICS DUE TO TRIBOELECTRIC GENERATION.

A MORE LIMITED BUT PRACTICAL METHOD OF ESTIMATING THE TRIBOELECTRIC GENERATION CAPABILITY OF A MATERIAL IS TO RUB THAT MATERIAL BRISKLY OR SEPARATE IT FROM A KNOWN STATIC GENERATOR, SUCH AS COMMON POLYETHYLENE, AND MEASURE THE RESULTANT VOLTAGES ON EITHER OR BOTH MATERIALS WITH AN ELECTROSTATIC FIELD METER. THIS TEST CAN BE USED ON BENCH TOPS, PACKAGING MATERIALS, FLOORS, CLOTHING, OR ANY OTHER MATERIAL. CONDUCTIVE OR STATIC DISSIPATIVE MATERIALS WILL GENERALLY DISTRIBUTE THE CHARGES OVER THESE SURFACES FASTER THAN THE METER CAN RESPOND, DISALLOWING ACCURATE MEASUREMENTS. IF CONDUCTIVE OR STATIC DISSIPATIVE MATERIALS ARE HELD OR TOUCHED BY A PERSON DURING THE RUBBING OR SEPARATION ACTION, THE CHARGE WILL BE CONDUCTED TO THE PERSON, AGAIN INVALIDATING THE TEST RESULTS.

AS CAN BE SEEN IT REQUIRES MANY PEOPLE DOING MANY JOBS BEFORE THE UNIT LEAVES THE COMPANY, ANY ONE OF WHICH CAN CAUSE THE UNIT TO MALFUNCTION.

ESD CONTROL METHODS

ESD STATIONS (CONDUCTIVE)

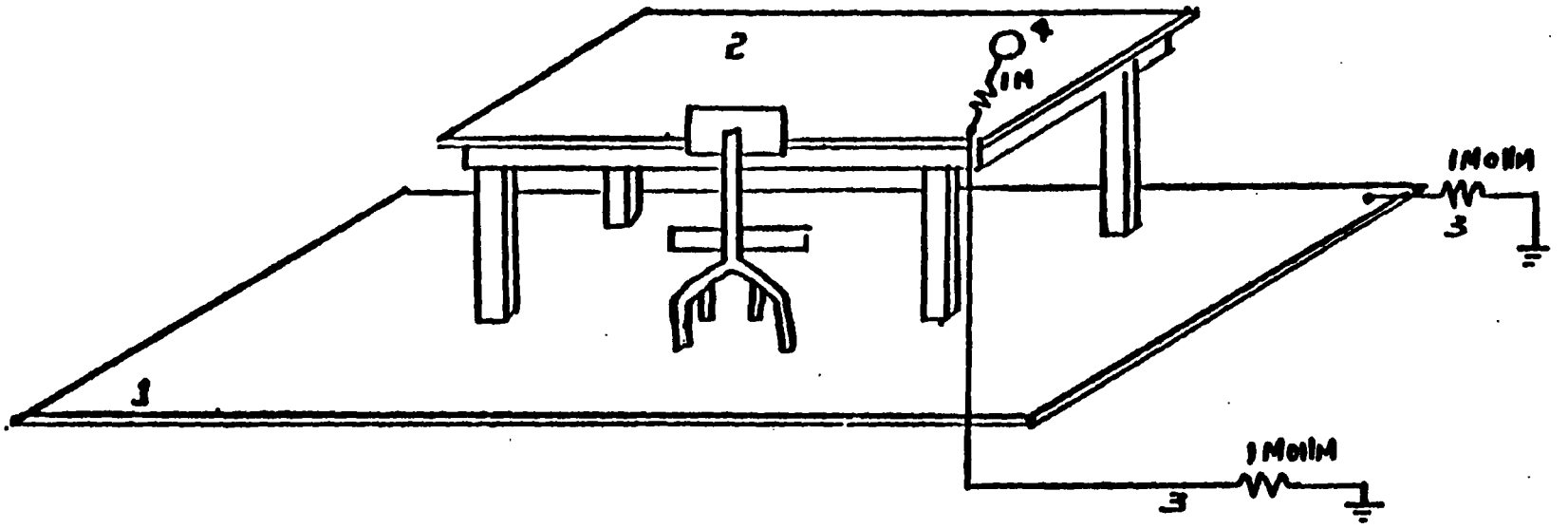
THE FIRST GROUND STATIONS SET UP IN THE COMPANY CONSISTED OF A HIGHLY CONDUCTIVE TABLE MAT CONNECTED TO A HIGHLY CONDUCTIVE FLOOR MAT WITH A ONE MEGOHM RESISTOR TO GROUND. THE ORIGINAL SETUP HAD A WRIST STRAP WHICH DID NOT CONTAIN A ONE MEGOHM RESISTOR CONNECTED TO THE TABLE MAT. THE ONE MEGOHM RESISTOR FROM THE FLOOR MAT TO GROUND WAS AN OSHA REQUIREMENT TO PREVENT PHYSICAL HARM TO PERSONNEL IN CASE OF EQUIPMENT SHORTING OUT.

THE THEORY BEHIND THE USE OF CONDUCTIVE MATS WAS THAT IF EVERYTHING WAS AT THE SAME POTENTIAL, THERE COULD BE NO ARCING OR ESD. THE PROBLEM WITH THIS WAS THAT AS A CHARGED BODY APPROACHED A TOTE BOX OR TABLE TOP, A SPARK COULD OCCUR. THE MORE CONDUCTIVE THE MATERIAL, THE HIGHER THE PROBABILITY OF CREATING A SPARK AND THE HIGHER THE DISCHARGE CURRENT.

ESD STATIONS (STATIC DISSIPATIVE)

THE TABLE MAT AND FLOOR MAT WAS THEN CHANGED TO A STATIC DISSIPATIVE TYPE MATERIAL. THIS ALLOWS A CHARGE TO BE DISCHARGED SLOWLY WITHOUT CAUSING A SPARK. THE NEW GROUNDED ESD STATION HAS A TABLE MAT AND FLOOR MAT CONNECTED THROUGH ONE MEGOHM RESISTORS TO GROUND. THE WRIST STRAP IS CONNECTED TO THE TABLE MAT THROUGH A ONE MEGOHM RESISTOR. (REFERENCE FIGURE 3. DISCUSS CONFIGURATIONS NOW IN USE.)

THE CONDUCTIVE TABLE MAT NOT ONLY PROVIDES A SURFACE THAT IS FREE OF STATIC CHARGE ON WHICH TO WORK, BUT IS ALSO CAPABLE OF REMOVING THE STATIC CHARGE FROM CONDUCTIVE ITEMS PLACED ON IT. FOR EXAMPLE, IF A CONDUCTIVE TOTE BOX OR BAG OF



1. Floor Mat 3M8200
2. Bench Top 3M8210
3. Ground Cord 3M3043
4. Wrist Strap 3M2066

Conductive Work Station

FIGURE 3

ELECTRONIC COMPONENTS IS BROUGHT TO THE TABLE FROM STORES, BOTH THE PERSON CARRYING IT AND THE BOX MAY BE HIGHLY CHARGED. IN THE EVENT THAT NO FLOOR MAT IS AVAILABLE TO DISCHARGE THE PERSON AND BOX AS THE PERSON APPROACHES THE STATION, THE TABLE MAT MUST PROVIDE THIS FUNCTION AND, LIKE THE FLOOR MAT, SHOULD BE CAPABLE OF DOING SO WITHIN ONE SECOND.

THE PURPOSE OF THE CONDUCTIVE AND STATIC DISSIPATIVE FLOOR MATS IS PRIMARILY TO REMOVE THE STATIC CHARGE FROM TRANSIENT PERSONNEL WHO APPROACH THE WORK STATION, E.G., SUPERVISORS, MANAGERS, ENGINEERS, QUALITY ASSURANCE, ETC. SECOND, IT IS FOR THE WORKER WHO, AFTER RETURNING TO THE WORK BENCH, FORGETS TO PUT ON HIS OR HER WRIST STRAP. THE FLOOR MAT IS NOT A SUBSTITUTE FOR GOOD WORK HABITS, BUT PROVIDES A SIGNIFICANT AMOUNT OF PASSIVE PROTECTION AROUND THE OFTEN WELL TRAVELED ELECTRONICS ASSEMBLY AREAS.

A PERSON STEPPING ONTO A CONDUCTIVE FLOOR MAT IS GENERALLY ONLY ONE OR TWO STEPS AWAY FROM CONTACT WITH A STATIC SENSITIVE PIECE OF EQUIPMENT. SUCH A PERSON CAN EASILY EXPOSE THAT DEVICE OR ASSEMBLY TO DAMAGING LEVELS OF STATIC WITHIN ONE SECOND.

AS THE STATIC DISSIPATIVE MAT RESISTANCE IS VERY HIGH AND IN ALL LIKELIHOOD THE VISITOR IS WEARING NONCONDUCTIVE SHOES WITH APPROXIMATELY 1000 MEGOHMS RESISTANCE, THERE IS ALWAYS A POSSIBILITY OF ESD DAMAGE. TO PREVENT THIS NO ONE SHALL BE ALLOWED TO STAND ON THE MAT WITHOUT A WRIST STRAP. THIS INCLUDES SUPERVISORS, MANAGERS, ENGINEERS, VISITORS, ETC. SHOWN BELOW ARE TYPICAL EXAMPLES OF SHOE RESISTANCE:

EFFECTIVE SHOE RESISTANCE

SHOE TYPE	EFFECTIVE RESISTANCE THROUGH ONE SHOE TO GROUND
LEATHER SOLES	10 TO 100 MEGOHMS
COMPOSITION SOLES	175 TO 750 MEGOHMS
CREPE AND THICK RUBBER SOLES	1000 TO500,000 MEGOHMS

AS THE FLOOR MATS ARE NOT VERY EFFECTIVE, FSC IS CONSIDERING REMOVING THE FLOOR MATS AND MARKING OFF AREAS AROUND THE STATION (1 METER). ANY PERSONNEL ON THE FLOOR MAT OR WITHIN THIS AREA MUST WEAR A WRIST STRAP. THE FIRST THING TO DO WHEN NEARING THE ESD STATION IS PICK UP THE WRIST STRAP AND CONNECT TO THE WRIST. THIS SHALL DISCHARGE YOU BEFORE ENTERING THE WORK STATION.

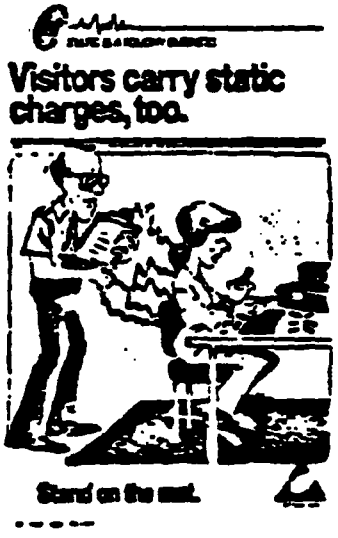
CONTROL METHODS

HUMIDITY

ONE METHOD OF REDUCING STATIC GENERATED LEVELS IS TO CONTROL THE AMOUNT OF HUMIDITY IN THE AREA. (REFERENCE TABLE I, "TYPICAL ELECTROSTATIC VOLTAGES.") THE PROBLEM IS HIGH HUMIDITY REDUCES THE LEVEL OF THE ELECTROSTATIC VOLTAGE BUT INCREASES THE DISCOMFORT OF PERSONNEL WORKING AT THESE HIGH LEVELS. THE HUMIDITY IS NORMALLY SET AT 40% WHICH WILL GENERATE FAIRLY HIGH LEVELS OF ESD, BUT IS NOT AN UNCOMFORTABLE ENVIRONMENT. IN ORDER TO REDUCE THE LEVEL OF HUMIDITY TO 40%, ALL OF THE RULES STATED SO FAR MUST BE FOLLOWED.

FLOOR MAT. YOU BECOME GROUNDED WHEN YOU STEP ON THE CONDUCTIVE FLOOR MAT, AND YOUR BODY WILL NOT HOLD A STATIC CHARGE. AS YOU APPROACH YOUR WORK AREA, BE SURE THAT YOU HAVE CONTACTED THE FLOOR MAT BEFORE REACHING FOR YOUR WRIST STRAP OR TURNING ON THE IONIZING AIR BLOWER.

PERSONNEL VISITING YOUR WORK AREA WITHOUT WRIST STRAPS MUST ALSO CONTACT THE FLOOR MAT BEFORE APPROACHING THE WORK BENCH. THIS INCLUDES YOUR SUPERVISOR.



WE ARE PRESENTLY IN THE PROCESS OF SETTING UP RULES COVERING WORK AT THE VARIOUS ESD STATIONS. THESE RULES SHALL BE REQUIRED TO REDUCE ESD, AND COMPLIANCE SHALL BE MANDATORY. THESE GUIDELINES, IF AND WHEN POSTED, SHALL BE PUT UP ON POSTERS AT THE VARIOUS DISCIPLINES.

ANOTHER METHOD OF PREVENTING THE GENERATION OF ESD IS TO USE IONIZED AIR TO NEUTRALIZE STATIC ELECTRICITY. THIS IS AN EXCELLENT METHOD OF REMOVING CHARGES FROM AN INSULATOR. HOWEVER, THERE ARE DRAWBACKS TO THEIR USE.

FROM AN OCCUPATIONAL HEALTH STANDPOINT, IT SHOULD BE NOTED THAT SOME IONIZERS DEVELOP HIGH VOLTAGES WHICH COULD CAUSE DANGEROUS ELECTRICAL SHOCK TO PERSONNEL. OTHER CONSIDERATIONS IN THE USE OF ELECTRICAL IONIZERS ARE THE DEVELOPMENT OF ELECTROMAGNETIC INTERFERENCE AND THE PRODUCTION OF OZONE WHICH CAN CAUSE NAUSEA IN PERSONNEL. (REFERENCE ALERT.) NUCLEAR IONIZERS COULD AFFECT RADIATION DETECTING FILM BADGES WORN BY PERSONS IN NUCLEAR AREAS. HOWEVER, THERE IS NO PROBLEM WITH THEIR USE AT FSC. THIS HAS BEEN RESEARCHED BY THE MATERIALS DEPARTMENT.

FAIRCHILD HAS RESTRICTED THE USE OF THESE IONIZERS TO CERTAIN AREAS WHERE THEY HAVE HAD NO PROBLEMS WITH PERSONNEL DISCOMFORT. IT MUST BE POINTED OUT THAT WHEN SOME PROTECTION IS NOT USED, OTHER FORMS OF PROTECTION MUST BE USED.

SMOCKS (LAB COATS)

THE COMPANY SUPPLIES CONDUCTIVE CLEAN ROOM SMOCKS TO COVER SYNTHETIC GARMETS. AS THE CHAIRS ARE COVERED WITH NONCONDUCTIVE, CLOTH COVERED FOAM ON METAL CHAIRS, ANY MOVEMENT GENERATES A STATIC CHARGE. TO PREVENT PROBLEMS EITHER WEAR SHORT SLEEVE GARMENTS OR PREVENT THE GARMENTS FROM EXTENDING PAST THE SMOCK SLEEVES. THIS MAY REQUIRE SNAPPING THE SNAPS SHUT ON THE SLEEVES.

THE LAB COAT MUST BE PUT ON AND TAKEN OFF AWAY FROM THE STATIC FREE STATION.

LAB COATS WORN IN ESD PROTECTED AREAS MUST BE STATIC PROTECTED. THESE RULES HAVE BEEN IN EFFECT FOR MANY YEARS, BUT ARE NOT ALWAYS ENFORCED. THESE UNPROTECTED LAB COATS MADE OF SYNTHETIC SHINY MATERIAL APPEAR FROM TIME TO TIME WHEN THE PROTECTED LAB COATS ARE UNAVAILABLE. IT SHALL BE THE RESPONSIBILITY OF THE LAB SUPERVISOR OR QUALITY PERSONNEL TO PREVENT THEIR USE IN A STATIC FREE AREA. THEY MUST BE GIVEN THE AUTHORITY TO ENFORCE THIS RULE.

*LAB COAT TEST WITH RULER AND METER.

TOPICAL ANTISTATS

THE OTHER METHOD OF CONTROLLING ESD GENERATED BY TRIBOELECTRIC ENERGY IS TO PREVENT THE GENERATION OF ESD. THIS METHOD INVOLVES CHANGING THE LUBRICITY OF THE SURFACE BEING RUBBED. ANOTHER METHOD OF STATING THIS IS TO REDUCE THE FRICTION BY MOISTENING THE SURFACE OR THE MATERIAL WHICH REDUCES THE GENERATED CHARGE. THIS IS ACCOMPLISHED BY TREATING PLASTICS WITH A TYPICAL ANTISTATIC MATERIAL. THIS IS DONE WITH TOOLS AND PLASTIC BOTTLES WHICH MUST BE USED AT THE WORK STATION. ANOTHER EXAMPLE OF ANTISTATIC MATERIAL IS PINK POLY WHICH HAS MANY APPLICATIONS.

PROTECTIVE HANDLING

PROTECTIVE HANDLING REQUIRES THAT ALL PARTS BE HANDLED USING THE GUIDES OUTLINED THROUGHOUT THIS COURSE.

UNTREATED PLASTICS

THERE ARE TWO METHODS TO REDUCE STATIC ELECTRICITY GENERATED BY TRIBOELECTRIC ENERGY. ONE METHOD IS TO PROHIBIT THE ENTRY OF THESE PRIME GENERATORS INTO THE PROHIBITED AREA. ANOTHER IS TO KEEP UNTREATED PLASTICS,

TAPES, AND POLY FOAM AWAY FROM ESD AREAS. TABLE II IS A LIST OF THE PRIME GENERATORS OF ESD, "TYPICAL PRIME CHARGE SOURCES."

BECAUSE STATIC CHARGE CANNOT FLOW THROUGH AN INSULATOR (BY DEFINITION), IT CANNOT BE REMOVED BY CONTACT WITH A CONDUCTOR. CONNECTING A NONCONDUCTOR TO GROUND WILL DO NOTHING. THEREFORE, IF THE ITEM TO BE DISCHARGED IS AN INSULATOR, SUCH AS A WORK SHEET HOLDER, A PLASTIC BOX OR EVEN A PERSON'S CLOTHING, IONIZED AIR MAY BE REQUIRED.

JET PROPULSION LAB REQUIRES THAT THE WORK AREA BE PROVIDED WITH AN IONIZED AIR GENERATOR THAT BATHES ENTERING PERSONNEL AND EQUIPMENT WITH POSITIVE AND NEGATIVE IONS, THEREBY NEUTRALIZING CHARGES THAT MAY BE CARRIED ON ELECTRICALLY ISOLATED PARTS OF CLOTHING.

AS WE DO NOT USE THIS METHOD OF REDUCING STATIC ELECTRICITY GENERATED BY CLOTHING, WE MUST OBEY ALL RULES ASSOCIATED WITH PERSONAL CLOTHING AND LAB COATS.

WRIST STRAPS

SIGNS SUCH AS "STATIC DISCHARGE CAN DAMAGE COMPONENTS. DO NOT HANDLE UNLESS WRIST STRAP IS WORN." SHOULD BE PLACED AT EVERY STATION TO REMIND THE WORKER TO DON THE STRAP BEFORE TOUCHING ANY WORK, EVEN IF IT IS NOT ESD SENSITIVE, FOR ONLY IN THIS WAY CAN THE HABIT BE FORMED FOR THE DAY WHEN THE DEVICES GROW EVEN MORE VULNERABLE, AS IS THE TREND TODAY.

ANOTHER THING NOT POINTED OUT THUS FAR AND OF MORE IMPORTANCE IS THAT ELECTRICITY CAN KILL PEOPLE, AND THAT IS ANOTHER REASON THE WRIST STRAP IS WORN.

ALL STRAPS MUST CONTAIN A RESISTANCE OF 250 KILOHMS MINIMUM, ALTHOUGH A NOMINAL ONE MEGOHM IS GENERALLY FOUND TODAY, TO PREVENT SHOCK HAZARD BY LIMITING CURRENT THROUGH THE BODY IF A HAND OR ONE CONTAINING A METAL BAG WERE TO CONTACT LIVE CIRCUITRY.

AS CAN BE SEEN IT IS OF THE UTMOST IMPORTANCE THAT THE WRIST STRAP BE WORN NOT ONLY TO PROTECT THE PART, BUT ALSO YOU. IN SOME CASES THERE IS ONLY A WRIST STRAP TO PREVENT STATIC GENERATION, AS THERE IS NO GROUND MAT OR TABLE MAT. FOR THESE REASONS A WRIST STRAP MUST BE CHECKED DAILY. THERE SHOULD BE A LOG KEPT FOR RECORDS AND PROOF TO A CUSTOMER THAT WE CONFORM TO THE REQUIREMENTS OF A GOOD ESD PROGRAM. WHEN CHECKING A WRIST STRAP IT MUST BE WORN ON THE ARM AS WORN DURING WORK. IT DOES NO GOOD TO MOVE THE STRAP UP THE ARM TO PASS A TEST WHEN IT WILL NOT PERFORM SATISFACTORILY DURING WORKING HOURS. IT MUST BE SNUG AND COMFORTABLE AND BE ABLE TO PASS THE TEST.

REMEMBER A GOOD ESD PRORAM DEPENDS ON YOU. THE COMPANY SUPPLIES THE MEANS TO CONTROL ESD, BUT IT WILL NOT WORK WITHOUT YOUR HELP. ONE MUST THINK OF ESD AND METHODS TO PREVENT IT AT ALL TIMES. IT IS MUCH EASIER TO KEEP AND OBSERVE GOOD HABITS THAN IT IS TO STOP BAD HABITS. TREAT ALL PARTS AS IF THEY CAN BE DESTROYED BY ESD.

WE HAVE HAD FAILURES WITH PARTS THAT HAVE BEEN TRACED TO ESD. UNFORTUNATELY, THERE IS NO WAY TO DETERMINE HOW THESE FAILURES HAVE OCCURRED. WE HAVE RECENTLY CONDUCTED AUDITS ON ALL ESD DEPARTMENTS. THIS WAS NOT TO FIX BLAME BUT TO DETERMINE WHERE OUR ESD CONTROLS MAY BE INADEQUATE. UNLESS FAILURES DROP TO ZERO, THERE SHALL BE ADDITIONAL AUDITS. YOUR COOPERATION DURING THIS AUDIT HAS BEEN EXCELLENT AND INFORMATIVE. I HAVE LEARNED THINGS THAT WERE NOT IN THE BOOKS, AND WITH YOUR ASSISTANCE I HAVE GAINED AN INSIGHT INTO HOW THE SYSTEM WORKS. MANY TIMES PEOPLE WORKING WITH SOMETHING SEE AREAS THAT MAY BE CHANGED TO UPGRADE THE ESD PROGRAM. I WOULD BE HAPPY TO DISCUSS ANY OF THESE CHANGES AT ANY TIME AND TO CHANGE PROCEDURES IF NECESSARY.

AUDITS ARE ALSO PERFORMED PERIODICALLY TO ASSURE PROPER ESD REQUIREMENTS ARE BEING MET PER CONTRACT REQUIREMENTS.

ESD PROGRAM

THE COMPANY'S PHILOSOPHY AT THIS TIME IS TO TREAT ALL PARTS AS ESD SENSITIVE. BY DOING THIS, IT REDUCES THE KNOWLEDGE SOME PEOPLE REQUIRE TO DO THEIR JOBS. USING FIGURE 1 AS A GUIDELINE, LET US EXAMINE THE PROGRAM.

AN ELECTRONIC PART IS ORDERED AND HANDLED AS ESD SENSITIVE. IT WILL COME INTO THE HOUSE PACKAGED AND IDENTIFIED AS SUCH. IT DOES NOT HELP TO TREAT IT AS ESD SENSITIVE IN-HOUSE IF IT WAS NOT SHIPPED AS SUCH. LISTED BELOW ARE THE GUIDELINES FOR VARIOUS DEPARTMENTS AS SPECIFIED IN QAP 3.6:

SHIPPING DEPARTMENT

THE SHIPPING DEPARTMENT RECEIVES AND SHIPS ESD SENSITIVE PARTS, SUB-ASSEMBLIES, ASSEMBLIES, COMPONENTS ETC.

WHEN RECEIVED AND MARKED ESD THE ITEM MUST IMMEDIATELY BE SENT TO RECEIVING INSPECTION. UNDER NO CIRCUMSTANCES ARE THE PACKAGES TO BE OPENED WITHOUT A CONDUCTIVE WORK STATION.

WHEN A UNIT IS SHIPPED IT IS PROVIDED PREPACKAGED IN ESD SENSITIVE MATERIALS. THE SHIPPING DEPARTMENT THEN PACKAGES THE UNIT PER CONTRACT REQUIREMENTS. AS THE UNIT IS ALREADY PACKAGED IN ESD MATERIAL, THE PACKING OF THE UNIT DOES NOT REQUIRE AN ESD STATION. UNDER NO CONDITIONS ARE PREPACKAGED UNITS TO BE OPENED WITHOUT A CONDUCTIVE WORK STATION.

RECEIVING INSPECTION DEPARTMENT

ALL PARTS WHICH ARE ESD SENSITIVE AND ARE OBVIOUSLY NOT PROPERLY MARKED SHALL BE RETURNED TO THE SUPPLIER AS UNACCEPTABLE IMMEDIATELY.

ESD SENSITIVE ITEMS

REMOVE THE UNIT PACKAGE OF ESDS ITEMS FROM THE SHIPPING CONTAINER USING A CONDUCTIVE WORK STATION. DO NOT OPEN UNIT PACKAGE. EXAMINE THE ITEM FOR PROPER LABELING AND ESD PROTECTIVE PACKAGING.

NON-ESD ITEMS

ITEMS WHICH ARE NOT IDENTIFIED AS ESD SENSITIVE SHALL NOT BE REMOVED FROM BAGS OR CONTAINERS UNLESS THE OPERATIONS ARE CONDUCTED AT A GROUNDED WORK STATION. ALL NONCONDUCTIVE MATERIALS AND INNER WRAPS SHALL BE DISCARDED AND APPROVED MATERIALS/HANDLING SUBSTITUTED FOR USE.

RECEIVING INSPECTION OPERATIONS

UNIT PACKAGES ARE OPENED AND TESTS PERFORMED ON ITEMS USING AN APPROVED TEST STATION OR AT AN ESD GROUNDED WORK STATION.

ALL ITEMS ARE REPACKAGED IN ESD PROTECTIVE SEE-THROUGH UNIT PACKAGING MATERIAL.

UNIT PACKAGES ARE PLACED IN ESD PROTECTIVE TOTE BOXES OR TRAYS FOR TRANSPORTING TO STORES.

ALL ESD STATIONS IN RECEIVING INSPECTION SHALL OBSERVE THE DESIGN GUIDELINES OF THIS PROCEDURE.

STOCKROOM AREA

THE FOLLOWING ESD GUIDELINES ARE APPLICABLE TO THE STORE ROOM AREA:

- ALL EEE ITEMS ARE TRANSPORTED TO AND FROM THE STOCKROOM AREA IN STATIC PROTECTIVE TOTE BOXES OR TRAYS WHICH WILL PROVIDE PROTECTION FROM TRIBOELECTRIC CHARGES, DISCHARGES FROM PERSONNEL OR OBJECTS, ELECTROSTATIC FIELDS AND EMP FROM ESD HIGH VOLTAGE SPARK DISCHARGES.
- UNIT PACKAGES SHALL NOT BE OPENED FOR COUNT ISSUANCE OR KITTING UNDER NORMAL CIRCUMSTANCES. HOWEVER, WHEN REQUIRED, THE UNIT PACKAGE MAY BE OPENED AND REPACKAGED USING A GROUNDED WORK STATION.
- INDIVIDUALLY OR BULK PACKAGED PARTS WHICH ARE MARKED AS ESD SENSITIVE SHALL NOT BE OPENED IN THE STOCK AREAS UNDER ANY CIRCUMSTANCES.
- AS APPLICABLE, RACKS AND BINS SHALL BE CONDUCTIVE AND BE GROUNDED TO PREVENT STATIC BUILDUP.

KIT VERIFICATION

AS EACH KIT IS ASSEMBLED THE EEE PARTS SHALL BE PLACED IN AN ESD CONDUCTIVE CONTAINER FOR PROCESSING THROUGH VERIFICATION. (DO NOT REMOVE THE PARTS FROM THEIR INDIVIDUAL PROTECTIVE ENVELOPES FOR IDENTIFICATION.)

CLEANING AREA

WHEN CLEANING PROCESSES ARE PERFORMED USING CONDUCTIVE CLEANING FLUIDS OR SOLVENTS, EEE PARTS ARE "AIR SPRAYED" USING IONIZED AIR.

WITH THE EXCEPTION OF THE VAPOR DEGREASER ALL "SUBMERGED" SOLVENT CLEANING SHALL BE PERFORMED USING A CONDUCTIVE CONTAINER AND A GROUNDED WORK STATION.

WHEN EEE ITEMS ARE MANUALLY CLEANED WITH BRUSHES, ONLY BRUSHES WITH NATURAL BRISTLES ARE USED WITH IONIZED AIR BEING DIRECTED OVER THE ITEM DURING CLEANING. THE CLEANING EQUIPMENT SHOULD BE GROUNDED IF PRACTICABLE, AND LEADS AND CONNECTORS OF EACH ITEM SHOULD BE SHORTED TOGETHER DURING THE CLEANING OPERATION. ONLY THOSE CLEANING SOLVENTS LISTED WITHIN SHOULD BE USED WHERE PRACTICABLE WHEN CLEANING ESD ITEMS.

*****CAUTION*****

CAUTION SHOULD BE OBSERVED IN USING SOLVENTS SUCH AS ACETONE AND ALCOHOL. THE USE OF SUCH SOLVENTS CAN REDUCE THE EFFECTIVENESS OF SOME ESD PROTECTIVE MATERIALS, ESPECIALLY THOSE EMPLOYING DETERGENT TYPE ANTISTATIC WHICH BLEED TO THE SURFACE TO FORM A SWEAT LAYER WITH MOISTURE IN THE AIR.

****

ALL CLEANING STATIONS SHALL CONFORM TO THE GENERAL DESIGN REQUIREMENTS OF THIS PROCEDURE.

REWORK AND REPAIR AREA

SUSPECTED DEFECTIVE PARTS AND ASSEMBLIES SHALL BE HANDLED ACCORDING TO THIS SPECIFICATION. SPECIAL CONSIDERATION SHALL BE OBSERVED ON THOSE PARTS WHICH ARE KNOWN TO BE ESD SENSITIVE SO THE CAUSE OF FAILURE CAN BE DETERMINED. THE DEFECTIVE PART SHALL BE PLACED IN A CONDUCTIVE BAG BEFORE PLACING IT INTO THE DEFECTIVE PART ENVELOPE. THE PART ENVELOPE SHALL SPECIFY ALL INFORMATION PERTINENT TO THE DEFECTIVE PART (PART NO., DATE CODE, MANUFACTURER, T^2, FACAR NO., ETC.).

ALL REWORK STATIONS SHALL CONFORM TO THE GENERAL DESIGN REQUIREMENTS OF THIS PROCEDURE.

PACKAGING

SPARES, PRINTED WIRING BOARD ASSEMBLIES, OR COMPONENTS WHICH ARE TO BE SHIPPED INDIVIDUALLY SHALL BE SEALED IN CONDUCTIVE INNERWRAPS WHICH COMPLETELY ENCLOSE THE PART OR ASSEMBLY.

ESDS CAUTION LABELS (FIGURE 2) SHALL BE AFFIXED TO THE CONTAINER.

THE PRINTED WIRING BOARD ASSEMBLIES OR COMPONENTS ARE PACKAGED IN PROTECTIVE ESD PROOF CONTAINERS WHILE BEING SPRAYED BY IONIZED AIR. THIS IS DONE PRIOR TO TRANSPORTATION TO THE SHIPPING DEPARTMENT.

THE PACKAGING STATIONS SHALL INCORPORATE IONIZED AIR SPRAY IN ADDITION TO MEETING THE GENERAL DESIGN REQUIREMENTS OF THIS PROCEDURE.

TRANSPORTATION OF PARTS/ ASSEMBLIES/COMPONENTS

ALL INPROCESS PRINTED CIRCUIT CARDS, SUB ASSEMBLIES, ETC. SHALL BE INSERTED IN CONDUCTIVE BAGS AND PLACED IN CONDUCTIVE CONTAINERS. PAPERWORK WHICH ACCOMPANIES THE ITEM SHALL BE PLACED IN A CONDUCTIVE OR ANTISTATIC BAG AND ATTACHED TO THE EXTERIOR OF THE CONTAINER.

UPON COMPLETION OF EACH ASSEMBLY OR PROCESSING OPERATION, THE ESD ITEM SHALL BE REPACKAGED IN THE PROTECTIVE PACKAGING MATERIAL AND PLACED INTO PROTECTIVE TOTE BOXES OR TRAYS FOR TRANSPORTING TO THE NEXT WORK OPERATION.

*****CAUTION*****

CARE SHOULD BE EXERCISED TO AVOID CONTACT BETWEEN THE ITEM BEING PROCESSED AND THE ACCOMPANYING PAPERWORK AT ALL TIMES.

****

ALL ASSEMBLY WORK STATIONS SHALL CONFORM TO THE GENERAL DESIGN REQUIREMENTS OF THIS PROCEDURE.

FUNCTIONAL TEST

ALL PERSONNEL INVOLVED IN TROUBLESHOOTING MUST WEAR WRIST STRAPS. TEST EQUIPMENT PROBES SHALL BE TOUCHED TO GROUND BEFORE PROBING OR CONDUCTING OTHER TROUBLESHOOTING STEPS. EXTERNAL POWER SUPPLIES USED FOR TESTING SHALL BE CHECKED FOR VOLTAGE TRANSIENTS PRIOR TO CONNECTION.

POWER SHOULD NOT BE APPLIED TO EQUIPMENT OR ASSEMBLIES WHILE ITEMS, ESPECIALLY THOSE CONTAINING MOS DEVICES, ARE BEING REMOVED OR INSERTED. ADDITIONAL PRECAUTIONS FOR MOS ARE AS FOLLOWS:

A. SIGNALS ARE NOT APPLIED TO THE INPUTS WHILE MOS DEVICE POWER IS OFF.
B. WHEN TESTING MOS, ALL UNUSED INPUT LEADS SHOULD BE CONNECTED TO EITHER SOURCE GROUND, OR V_{DD}, WHICHEVER IS APPROPRIATE FOR THE CIRCUIT INVOLVED.

THE FOLLOWING GUIDELINES SHOULD BE OBSERVED DURING ALL TESTING OPERATIONS:

A. TEST EQUIPMENT IS CHECKED FOR PROPER VOLTAGE POLARITY BEFORE CONDUCTING PARAMETER OR FUNCTIONAL TESTING. CARRIERS, HOLDERS, OR CONTAINERS ARE ELECTRICALLY CONNECTED TOGETHER BEFORE TRANSFERRING ASSEMBLIES/COMPONENTS FROM ONE CONTAINER TO THE OTHER.
B. THE CASES OR CHASSIS GROUNDS OF TEST EQUIPMENT AND ITEMS BEING TESTED ARE ELECTRICALLY CONNECTED TOGETHER PRIOR TO CONNECTING OR DISCONNECTING ANY TEST CABLES.
C. WHEN CONNECTING TEST CABLES, SHUNTING BARS REMAIN IN PLACE UNTIL CHASSIS GROUNDS ARE SHORTED. SHUNTING BARS ARE REPLACED UPON REMOVAL OF TEST CABLES.
D. ITEMS UNDER TEST TRANSPORTED OUTSIDE AN ESD AREA MUST BE IN A CLOSED CONDUCTIVE BOX OR HAVE CONDUCTIVE COVERS OVER THE CONNECTORS.
E. ALL TEST SET CABLES SHOULD HAVE SHORTING BARS ON CONNECTORS WHEN TEST CABLES ARE NOT IN USE.

ALL TEST STATIONS SHALL CONFORM TO THE GENERAL DESIGN GUIDELINES OF THE PROCEDURE.

SYSTEM TEST AREA

PRIOR TO CONTACTING A TEST ITEM, ALL PERSONNEL SHALL ATTACH A WRIST STAT AND CONNECT THE GROUND SIDE TO THE EQUIPMENT CABINET OR CHASSIS GROUND. PERSONNEL MAY TOUCH EARTH GROUND WITH ONE HAND PRIOR TO CONTACTING THE FLIGHT EQUIPMENT WHEN

TRANSPORTING ITEMS OR WHEN EXTENUATING CIRCUMSTANCES PREVENT THE USE OF A WRIST STAT.

EACH ITEM RECEIVED INTO THE SYSTEM TEST AREA SHALL BE PROTECTED BY APPROVED CONTAINERS AND MATERIALS. EACH ITEM REMOVED FROM THE SYSTEM TEST AREA SHALL BE PROTECTED USING APPROVED CONTAINERS AND MATERIALS.

ITEMS UNDER TEST SHALL NOT BE PROBED OR TOUCHED WITH TEST EQUIPMENT LEADS UNLESS NECESSARY AND IDEALLY UNDER CONTROLLED CONDITIONS SUCH AS WITH IONIZED AIR OR OTHER APPROVED METHODS. METER PROBES OR TEST LEADS SHALL BE GROUNDED TO PRECLUDE ANY POTENTIAL PRIOR TO TOUCHING THE TERMINALS OF THE TEST ITEM.

WHEN RECEIVING REPLACEMENT PARTS THE PACKAGE SHALL BE GROUNDED TO THE EQUIPMENT CHASSIS OR A CONDUCTIVE WORK STATION PRIOR TO OPENING TO DISSIPATE ANY ACCUMULATED CHARGE ON THE PACKAGE.

WHEN COMPONENTS ARE TRANSPORTED TO THE SYSTEM TEST AREA THEY MUST BE TRANSPORTED IN CONDUCTIVE TOTE BOXES OR CONDUCTIVE OUTERWRAP.

ASSEMBLY STATIONS

PERSONNEL SHALL WEAR ESD PROTECTIVE LAB COATS DURING ALL INSPECTION, FABRICATION, AND TEST OPERATIONS. THE FRONT AND SLEEVES MUST BE FASTENED SO THAT NO PERSONAL CLOTHING EXTENDS OUT OF THE LAB COAT.

LAB COATS SHALL BE MONITORED PERIODICALLY WITH STATIC METERS TO ASSURE STATIC DECAY EFFECTIVENESS.

ALL SOLDERING IRONS SHALL INCORPORATE GROUNDED TIPS - STRAY VOLTAGE MEASUREMENTS SHALL BE PERFORMED AS REQUIRED BY APPENDIX B.

ALL PARTS AND ASSEMBLIES SHALL BE MAINTAINED IN CONDUCTIVE ENCLOSURES WHEN NOT BEING WORKED WITH THE EXCEPTION OF BREAKS, LUNCH TIME, OR OTHER SHORT TERM DELAYS.

WHEN PARTS OR ASSEMBLIES ARE RESTARTED EACH SHALL BE PLACED IN CONTACT WITH THE WORK STATION MAT FOR ONE MINUTE PRIOR TO OPENING. THIS ALLOWS STATIC CHARGES ON CONTAINERS TO BE DISSIPATED.

WHEN A SUPPORT AID IS REQUIRED AT THE WORK STATION, THE SUPPORT USED MUST BE CONDUCTIVE AND IN CONTACT WITH THE GROUNDED MAT.

UNTREATED PLASTICS MAY NOT BE USED OR BE IN CLOSE PROXIMITY TO A GROUND STATION. A DISTANCE OF ONE METER MUST BE MAINTAINED.

HAND TOOLS MUST BE GROUNDED BY CONTACTING THE TABLE MAT (OR MANUALLY GROUNDED BY THE OPERATOR) PRIOR TO USE. NONCONDUCTIVE TOOLS SHALL BE TREATED WITH ANTISTATIC SOLUTIN OR FOIL/CONDUCTIVE TAPE WRAP.

ESD PROGRAM RESPONSIBILITIES

TO BE EFFECTIVE, THE ESD PROGRAM REQUIRES THE COOPERATION AND AWARENESS OF EACH OPERATING DEPARTMENT. SOME OF THE IMPORTANT GUIDELINES TO BE OBSERVED ARE AS FOLLOWS.

QUALITY ASSURANCE

QUALITY ENGINEERING

PREPARES AUDIT PROCEDURES, PERFORMS AUDITS, AND PROVIDES FOR CORRECTIVE ACTION TO CORRECT OUT-OF-TOLERANCE CONDITIONS.

VERIFIES, DURING REVIEW, THAT DRAWINGS, WORK INSTRUCTIONS, INSPECTION INSTRUCTIONS, AND TEST PROCEDURES INCORPORATE THE REQUIREMENTS OF THIS DOCUMENT DIRECTLY OR BY APPROPRIATE REFERENCE.

PERFORMS SURVEYS AND AUDITS OF SUBCONTRACTOR AND SUPPLIER TO VERIFY SIMILAR PROGRAMS ARE MAINTAINED.

MAINTAINS AUDITABLE RECORDS AND DOCUMENTATION AS NECESSARY. INVESTIGATES SUSPECT ESD CONTRIBUTED DEFICIENCIES ASSOCIATED WITH MANUFACTURING, TEST AND SUPPLIERS.

PREPARES AND CONDUCTS TRAINING COURSES TO ENSURE PERSONNEL AWARENESS ASSOCIATED WITH THE HANDLING OF ESD DEVICES.

MANUFACTURING AND TEST SUPERVISORS

MANUFACTURING AND TEST SUPERVISION MUST POLICE THEIR INDIVIDUAL AREAS FREQUENTLY TO ASSURE CONTINUED COMPLIANCE TO THE ESD PROGRAM. WHEN DEFICIENCES ARE NOTED IMMEDIATE CORRECTIVE MEASURES MUST BE INCORPORATED AND FREQUENT RE-EVALUATIONS PERFORMED TO INSURE THEIR EFFECTIVENESS.

ALL PERSONNEL SHALL ADORN STATIC RETARDANT LAB COATS UPON ENTERING THE MANUFACTURING OR TEST AREAS; THOSE PERSONNEL NOT ACTUALLY INVOLVED WITH THE OPERATION SHALL MAINTAIN A MINIMUM OF ONE METER SEPARATION FROM THE EQUIPMENT OR STATION.

TEST AND MANUFACTURING PERSONNEL ALWAYS WEAR WRIST STRAPS ANY TIME THEY ARE NEAR FLIGHT OR NON-FLIGHT HARDWARE. THIS ALSO APPLIES TO ALL OTHER PERSONNEL WHICH BRIDGE THE ONE METER SAFETY ZONE.

THAT WORK STATIONS ARE CERTIFIED PRIOR TO USE AND PERIODICALLY RECERTIFIED. (REF. APPENDIX A AND B)

THAT ESD GUIDELINES ASSOCIATED WITH TEST AND MANUFACTURING INSTRUCTIONS/PROCEDURES ARE COMPLIED WITH AND PROMPTLY CORRECTED WHEN DEFICIENCIES ARE OBSERVED.

INTEGRATION AREAS

THE I&T TEAM SHALL OBSERVE THE FOLLOWING AT ALL TIMES:

- O VERIFY THAT ALL TOTE BOXES ARE SET ON A MAT, THE UNIT REMOVED, AND PLACED ON AN ESD WORK TABLE PRIOR TO INSTALLATION IN THE SPACECRAFT.
- O VERIFY COMPONENTS THAT ARE TRANSPORTED TO AND FROM SPACECRAFT ARE IN CONDUCTIVE TOTE BOXES AND/OR WITH CONNECTORS HAVING CONDUCTIVE COVERS.
- O WRIST STRAPS ARE CONNECTED TO TABLE MAT BEFORE PERSONNEL TOUCH ANY DEVICE, ASSEMBLY, SUBASSEMBLY, COMPONENTS, ETC.
- O ASSEMBLIES, SUBASSEMBLIES, COMPONENTS, ETC., ARE PLACED IN CONDUCTIVE BAGS/BOXES DURING BREAKS, LUNCH PERIODS, AND OTHER WORK INTERRUPTIONS.

DESIGN ASSURANCE

RELIABILITY AND PARTS ENGINEERING SHALL OBSERVE THE FOLLOWING:

- O DETERMINE THAT ALL EEE PARTS RECEIVED FOR FAILURE ANALYSIS ARE PROPERLY PACKAGED IN ESD PROTECTIVE MATERIAL. IF SUCH ITEMS ARE NOT PROPERLY PACKAGED, NOTIFY THE SENDER OF THE ITEM TO PREVENT FUTURE UNPROTECTED FAILURE ANALYSIS SUBMITTALS.
- O INVESTIGATE POSSIBLE ESD RELATED FAILURE TRENDS AND PROBLEM AREAS AS A RESULT OF PART FAILURE.

HANDLING PROCEDURES FOR EVERYONE

THE PROCEDURES THAT ORIGINALLY WERE PART OF THIS COURSE WERE INCORPORATED INTO THE SEPARATE DEPARTMENT PROCEDURES.

FSC WORK STATION

TABLE MAT

FSC USES A STATIC DISSIPATIVE MAT WITH A ONE MEGOHM RESISTOR TO GROUND.

FLOOR MAT

AT THE PRESENT TIME FSC USES A STATIC DISSIPATIVE FLOOR MAT WITH A ONE MEGOHM RESISTOR TO GROUND. THESE FLOOR MATS MAY BE REMOVED AT A LATER DATE AFTER NEW WRIST STRAP REQUIREMENTS ARE IN EFFECT.

WRIST STRAPS

1. NEW WRIST STRAPS PURCHASED MUST HAVE GROUNDING SNAPS FOR LAB COATS.
2. WRIST STRAPS MUST BE CONNECTED TO ESD STATION BEFORE USING STATION.
3. WRIST STRAPS MUST BE CHECKED AT THE START OF EACH SHIFT AND WHEN RETURNING FROM LUNCH. WRIST STRAP LOG MUST BE CHECKED OFF AS PROOF.
4. WRIST STRAPS MUST BE CHECKED AS THEY ARE WORN.
5. WRIST STRAPS CONTAINING METAL FIBER CANNOT BE USED.
6. VISITORS (MANAGERS, SUPERVISORS, ENGINEERS) MUST WEAR A WRIST STRAP AND HAVE OPERATOR CONNECT IT TO THE ESD STATION BEFORE THESE PERSONNEL APPROACH THE ESD STATION. IT IS THE RESPONSIBILITY OF THE OPERATOR OF THE STATION TO SEE THIS IS DONE. IF NOT, NOTIFY VISITORS THAT THEY MUST EXIST THE IMMEDIATE AREA. IF THIS IS NOT DONE, NOTIFY SUPERVISOR IMMEDIATELY.

LAB COATS

1. SNAP ALL FASTENERS TO PREVENT CLOTHING FROM PROTRUDING FROM THE LAB COATS, WHICH PERMITS THE TOP SNAP AT THE COLLAR TO BE OPEN AND WRIST SNAPS OPEN IF THE SHIRT OR BLOUSE SLEEVES DO NOT PROTRUDE FROM COAT.
2. PUT ON AND REMOVE LAB COATS AWAY FROM THE WORK AREA.
3. LAB COATS MUST NOT BE WORN OUTSIDE WORK BUILDINGS.
4. PROTECT LAB COATS BETWEEN BUILDINGS.
5. ONLY LAB COATS WHICH DO NOT GENERATE ESD ARE TO BE WORN.
6. IF NEW LAB COATS HAVE GROUNDING POINT, ATTACH TO WRIST STRAP.
7. LAB COATS ARE TO BE CLEANED BY PROFESSIONAL CLEANERS.
8. COORDINATE USE WITH FSEC IN COMMON WORK AREAS.

AIR IONIZERS

FSC SHALL USE AIR IONIZERS IN AREAS WHICH PREVENT NORMAL METHODS BEING EFFECTIVE.

1. LAMINAIR FLOW BENCH
2. CLEANING AREA
3. CONFORMAL COAT AREA

PROTECTIVE MATERIALS

PROTECTIVE MATERIALS USED ARE TOTE BOXES, TRAYS, BAGS, ANTISTATS, PINK POLY MATERIAL, AND CONDUCTIVE FOAM.

TABLES

1. TYPICAL ELECTROSTATIC VOLTAGES
2. TYPICAL PRIME CHARGE SOURCES
3. STATIC CONTROL EXAMPLES
4. LIST OF ESD PARTS
5. GENERAL APPLICATION

THESE TABLES ARE SHOWN FOR INFORMATION ONLY.

CONCLUSION

I HOPE THIS SESSION HAS BEEN INFORMATIVE AND HAS GIVEN YOU AN INSIGHT INTO ESD PROBLEMS AND POSSIBLE SOLUTIONS. HOWEVER, TO MAKE ANY ESD PROGRAM WORK REQUIRES THE COOPERATION OF EACH ONE OF US. IF ANYONE DOES NOT FOLLOW THE GUIDELINES IT JEOPARDIZES THE ENTIRE SYSTEM. ANY QUESTIONS?

Table 1 Typical Electrostatic Voltages

MEANS OF STATIC GENERATION	Electrostatic Voltages	
	10 to 20 percent Relative Humidity	65 to 90 percent Relative Humidity
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Common poly bag picked up from bench	20,000	1,200
Work chair padded with polyurethane foam	18,000	1,500

TABLE II Typical prime charge sources

Object or Process	Material or Activity
Work Surfaces	• Waxed, painted or varnished surfaces • Common vinyl or plastics
Floors	• Sealed concrete • Waxed, finished wood • Common vinyl tile or sheeting
Clothes	• Common clean room smocks • Common synthetic personnel garments • Non-conductive shoes • Virgin cotton [1/]
Chairs	• Finished wood • Vinyl • Fiberglass
Packaging and Handling	• Common plastic - bags, wraps, envelopes • Common bubble pack, foam • Common plastic trays, plastic tote boxes, vials, parts bins
Assembly, Cleaning, Test and Repair Areas	• Spray cleaners • Common plastic solder suckers • Solder irons with ungrounded tips • Solvent brushes (synthetic bristles) • Cleaning or drying by fluid or evaporation • Temperature chambers • Cryogenic sprays • Heat guns and blowers • Sand blasting • Electrostatic copiers

[1/] Virgin cotton can be a static source at low relative humidities such as below 30 percent.

TABLE III STATIC CONTROL

PROBLEM	SOLUTION
1. Teflon spin drying racks (8kV)	1. Stainless steel spin dry racks.
2. Some ungrounded operators (10kV)	2. Ground all operators
3. Some ungrounded table tops (5kV)	3. Ground all open handling tables
4. Glass beakers, dishes and slides (4kV)	4. Stainless steel beakers, etc.
5. Chip trays (6kV)	5. Carbon filled chip trays and lids
6. Wafer boxes (5kV)	6. Carbon filled wafer boxes
7. Plastic storage cabinets (10kV)	7. Faraday cage storage
8. Plastic vacuum chip pickups (1.5kV)	8. Transparent Ni coated vacuum tips
9. K-drys for drip dry (3kV)	9. Stainless drip pans
10. Run sheets on parts (1.5kV)	10. Run sheets forbidden on parts
11. Rubber chem gloves (3kV)	11. Conductive gloves/grounded tweezers
12. Antistatic shipping tubes (3kV)	12. Metal coated shipping bags
13. Finger cots (5kV)	13. Antistatic finger cots (use only once)
14. Wafer break papers (2kV)	14. Aluminum coated wafer break papers
15. Personal clothing (30 kV)	15. Conductive (not antistatic) smocks

TABLE IV BENCH TOPS

Conductive	Static Dissipative	Anti-Static
1. Dissipates charges rapidly throughout the material and to ground, and will not maintain a high static voltage. 2. Could discharge an ESD in the form of a spark causing EMP. 3. Could cause a high current discharge through an ESDS part. 4. Could present a safety hazard or short if a high voltage source contacted the bench top. Could hard ground the table top if test equipment with grounded chassis contacted the bench top surface. 5. Safety could require that series resistances be provided in connection to ground where high voltages can be contacted by personnel.	1. Charge dissipation rate generally adequate for most ESDS parts. 2. Provides greater resistance for personnel protection from high voltages or hard grounding if the table top is contacted with test equipment ground. 3. Reduces discharge currents through ESDS parts. 4. Safety could require that series resistances be provided in connection to ground where high voltages can be contacted by personnel.	1. Provides slow bleed-off of static charges. If ground straps are used by personnel working at the work bench high ESD voltages should be rapidly dissipated through the ground strap. 2. Reduces the possibility of a spark from ESD. 3. Limits discharge currents through ESDS parts to low levels. 4. Generally provides adequate resistance for personnel safety.

FLOOR MATS

Conductive	Static Dissipative	Anti-Static
1. Dissipates charges rapidly throughout the material and to ground, and will not maintain a high static voltage. 2. Safety could require that series resistances be provided in connection to ground where high voltages can be contacted by personnel.	1. Provides adequate conductivity for dissipation of charges. 2. Generally provides sufficient resistance for personnel safety. External series resistance to ground may not be required.	1. Provides slow bleed-off of high static charges. 2. Accumulations of dirt, contaminants and wear reduce anti-static properties. Requires frequent cleaning and treatment with a topical antistat.

TABLE V List of ESDS parts by part type

CLASS 1: SENSITIVITY RANGE 0 TO ≤1000 VOLTS
• Metal Oxide Semiconductor (MOS) devices including C, D, N, P, V and other MOS technology without protective circuitry, or protective circuitry having Class 1 sensitivity
• Surface Acoustic Wave (SAW) devices
• Operational Amplifiers (OP AMP) with unprotected MOS capacitors
• Junction Field Effect Transistors (JFETs) (Ref.: Similarity to MIL-STD-701: Junction field effect, transistors and junction field effect transistors, dual unitized)
• Silicon Controlled Rectifiers (SCRs) with Io<0.175 amperes at 100° Celsius (°C) ambient temperature (Ref.: Similiarity to MIL-STD-701: Thyristors (silicon controlled rectifiers))
• Precision Voltage Regulator Microcircuits: Line or Load Voltage Regulation <0.5 percent
• Microwave and Ultra-High Frequency Semiconductors and Microcircuits: Frequency >1 gigahertz
• Thin Film Resistors (Type RN) with tolerance of ≤ 0.1 percent;power >0.05 watt
• Thin Film Resistors (Type RN) with tolerance of > 0.1 percent;power ≤0.05 watt
• Large Scale Integrated (LSI) Microcircuits including microprocessors and memories without protective circuitry, or protective circuitry having Class 1 sensitivity (Note: LSI devices usually have two to three layers of circuitry with metallization crossovers and small geometry active elements)
• Hybrids utilizing Class 1 parts
CLASS 2: SENSITIVITY RANGE >1000 TO ≤4000 VOLTS
• MOS devices or devices containing MOS constituents including C, D, N, P, V, or other MOS technology with protective circuitry having Class 2 sensitivity
• Schottky diodes (Ref.: Similiarity to MIL-STD-701: Silicon switching diodes (listed in order of increasing trr))
• Precision Resistor Networks (Type RZ)
• High Speed Emitter Coupled Logic (ECL) Microcircuits with propagation delay ≤1 nanosecond
• Transistor-Transistor Logic (TTL) Microcircuits (Schottky, low power, high speed, and standard)
• Operational Amplifiers (OP AMP) with MOS capacitors with protective circuitry having Class 2 sensitivity
• LSI with input protection having Class 2 sensitivity
• Hybrids utilizing Class 2 parts

List of ESDS parts by part type (Cont'd)

CLASS 3: SENSITIVITY RANGE >4000 TO ≤15,000 VOLTS
• Lower Power Chopper Resistors (Ref.: Similarity to MIL-STD-701: Silicon Low Power Chopper Transistors)
• Resistor Chips
• Small Signal Diodes with power ≤ 1 watt excluding Zeners (Ref.: Similarity to MIL-STD-701: Silicon Switching Diodes (listed in order of increasing trr))
• General Purpose Silicon Rectifier Diodes and Fast Recovery Diodes (Ref.: Similarity to MIL-STD-701: Silicon Axial Lead Power Rectifiers, Silicon Power Diodes (listed in order of maximum DC output current), Fast Recovery Diodes (listed in order of trr))
• Low Power Silicon Transistors with power ≤5 watts at 25°C (Ref.: Similarity to MIL-STD-701: Silicon Switching Diodes (listed in order of increasing trr), Thyristors (bi-directional triodes), Silicon PNP Low-Power Transistors (Pc ≤5 watts @T_A = 25°C), Silicon RF Transistors)
• All other Microcircuits not included in Class 1 or Class 2
• Piezoelectric Crystals
• Hybrids utilizing Class 3 parts

5 M REPORTED SUSCEPTIBILITY RANGES OF VARIOUS DEVICES EXPOSED TO ELECTROSTATIC DISCHARGE FROM A PERSON OR ELECTRONIC EQUIVALENT (Ref. 1,2,3)

DEVICE TYPE	RANGE OF ESD SUSCEPTIBILITY (VOLTS)
MOSFET	100 - 200
JFET	140 - 10,000
CMOS	250 - 2,000
SCHOTTKY DIODES, TTL	300 - 2,500
BI-POLAR TRANSISTORS	380 - 7,000
ECL (FOR HYBRID USE, PC BOARD LEVEL)	500 -
SCR	680 - 1,000

TABLE VI General application considerations

Conductive	Static Dissipative	Anti-Static
1. Could present a personnel safety hazard when contacting high voltages and hard grounds.	1. Presents the same hazards as listed under "Conductive" 1 and 2 except to a lesser degree. Hazards depend upon the magnitude of the voltages and the types of parts and circuits tested.	1. The effectiveness of hygroscopic antistatic materials are reduced in low relative humidities since their antistatic properties are dependent upon absorbing moisture from the air.
2. Could damage electrical circuitry of parts or assemblies during testing if electrical connections contact conductive surfaces.	2. See item (6) under "Conductive".	2. The accumulation of dirt, oils and silicone have an adverse effect on the anti-static properties of hygroscopic antistats. Cleaning with solvents such as alcohols, ketones and other hydrocarbon based solvents can remove the antistats. May require periodic treatment with a topical antistat.
3. Steels (except corrosion resistant) are prone to corrosion. Protective coatings such as paint will destroy the surface conductive properties and could be static generative.	3. See item (7) under "Conductive".	3. Antistats used in some hygroscopic anti-static materials can track onto items and act as a foreign substance which could react with other materials
4. Aluminum will form aluminum oxide on its surface reducing conductivity and increasing its ability to generate static.		
5. Hard surfaces such as metal provide little protection from physical shock to items dropped thereon.		
6. Materials should be reviewed for flammability, corrosivity, toxicity, bacterial growth, crumbling, powdering, shedding, flaking, brittleness, outgassing, long term chemical reaction with parts.		3. (Cont'd). adversely. This has been shown to be a problem with the lubricant in miniature bearings.
		4. See item (6) under "Conductive".
7. Protection against triboelectric generation depends upon the material used. (See 7.1.4).		5. Hygroscopic antistatic materials generally provide protection against triboelectric generation. The triboelectric generation characteristics of other anti-static materials depends upon the material used (See 7.1.4).

TABLE VII Additional application information for different types of ESD protective formed shapes

Application	Conductive	Static Dissipative	Anti-Static
Tote boxes and parts trays	1. Same as for packaging material except that openings in box or tray could reduce protection from electrostatic fields.	1. Same as for packaging material except that openings in box or tray could reduce protection from electrostatic fields.	1. Same as for packaging material except that openings in box or tray could reduce protection from electrostatic fields.
Shunt bars, clips, foam (Also see 7.2.9)	1. Provides low impedance shunt and good protection for ESDS parts.	1. Provides relatively high impedance shunt which could be suitable for ESDS parts with impedances considerably higher than the shunt impedance.	1. Typically is too high in resistance to act as a good shunt.
Personnel Apparel (smocks, gauntlets, finger cots, etc.) (Also see 7.2.7)	1. Provides good dissipation over its surface and will conduct charges from a person's body to ground if a ground strap is worn.	1. Provides good dissipation over its surface and will conduct charges from a person's body to ground if a ground strap is worn.	1. Provides slow bleed-off of charges from person's body to ground when a strap is worn.
Packaging Material (bags and other containers used to enclose ESDS items. Note: Combination of different ESD protective materials may be required to provide the best protection from triboelectric generation, direct discharge and electrostatic fields. Multi-layered packaging containers using different types of ESD protective materials as intimate and outside wraps are available.	1. Provides protection of highly sensitive ESDS items from high ESD voltages. 2. Provides protection of ESDS items from electrostatic fields. 3. Thin metallized coatings on some containers can be abraded reducing shielding effectiveness from electrostatic fields.	1. Provides protection of moderately sensitive ESDS items from high ESD voltages. 2. Provides protection of highly sensitive ESDS items from moderate voltages. 3. Provides moderate protection of ESDS items from electrostatic fields.	1. Provides protection of moderately sensitive ESDS items from moderate ESD voltages, highly sensitive items from low voltages.

U-9847

PLAIN PLASTIC

One of the most common generators of triboelectric energy is the common plastic material which comes in many forms (sheets, bags, containers etc.).

This little gem is found in abundance in all static free area's at FSC.

This insulator has one unique trait. Once it receives a charge it does not readily give it up. One missconception is to place it on a grounded surface to dissipate the charge, which unfortunately does not work. The only method of removing the charge is to neutralize it, which requires the use of air ionizers.

All reference material written for use of static suppression forbids the use of any untreated plastic in static free area's.

1. Impound all common plastics in the area or coat with antistatic material. "How to stop static damage" RICHMOND TECHNOLOGY.
2. Static removal from non conductors:

   Although tight control and restriction of non conductors from static sensitive work areas is the recommended solution to the problem of charged insulators it has been the authors experience that it is virtually impossible to enforce this.

   Basic electrical considerations in the design of a static safe work enviroment Don Venni 3M company.
3. One of the basic principles in the design of the protected area is to prohibit the use of prime generators in the design and construction and to restrict the entry of these prime generators by personnel working in these areas, Example: Common plastic bags, wraps, envelopes and common bubble pack, foam "Electrostatic discharge handbook" DOD-HDBK-263.
4. Of equal importance is the prevention of electrostatic-potential generation in the work area. This affects which materials can be

allowed in the work area. Ordinary untreated plastic items are forbidden, they are notorious generators of electrostatic potentials. "Preventing electrostatic discharge damage to electronics" written by JPL for NASA.

All one has to do to check out areas is to walk through the static free area's. Many items are apparent, while some need to be checked with a static measuring device. There are five recomendations:

(1) Don't allow the use of untreated plastics in the static free areas.

(2) Use air ionizers to periodically neutralize charges on plastic material.

(3) Use only approved plastic containers which must be checked prior to use.

(4) Conduct weekly surveys to assure compliance assign personnel to each area.

(5) Purchase additional static meters, one per each area, manuf. test etc. that all material can be checked prior to use.

TRIBOELECTRIC ENERGY DESCRIPTION SH29 DOD HDBK-263

Triboelectric generation is a friction process, the higher the lubricity of the surface being rubbed, the loser the friction and hence the lower the generated charge. Moistness on the surface of materials being separated provides progressive neutrilization of opposite charges by furnishing a conductive path between the surfaces until separation is complete.

This is what antistatic material does. Check all suspected material with a static meter, first lightly rubbing against clothing to charge them.

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 5-A

Attendees at March 8, Failure Review Board Meeting

Failure Review Board Members
(During the Incident)

Terry Hamilton	Quality Engineering	FS
Paul Goodwin	Reliability Engineering	FS
Randy Hinzman	Test Engineering	FS
Paul Larkin	Stress Engineering	FS
Dr. Jim Brown	Program Management	FS
Rex Richardson	Integration/Test Director	FS
Don Fordyce	Program Management	FS
Richard Collins	Program Management	JPL
Carol Jones	Integration Engineering	NSI
Alda Simpson	Integ/Test Branch Head	NASA
Ken Gardner	Mech. Integration Section Head	NASA

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 7-A

Impact Load Analysis

FAIRCHILD SPACE

TOPEX INCIDENT

DAMAGE ASSESSMENT

SPACECRAFT AND SHSS

D-9847

SUMMARY OF DAMAGE ASSESSMENT

	PAGE
○ **SPACECRAFT**	
❑ CONCLUSIONS	3
❑ INSPECTION OF SPACECRAFT	4
❑ RESULTS OF TEST CONDUCTED AFTER DAMAGE	
▲ ELECTRICAL	5
▲ ALIGNMENT	9
❑ IMPACT LOAD/STRESS ANALYSIS	10
❑ VIDEO ANALYSIS	19
○ **SHSS**	
❑ LUG FITTING SHRESS ANALYSIS	12

D-9847

TOPEX INCIDENT

- **CONCLUSIONS**
  - SPACECRAFT
    - NO DAMAGE SUSTAINED BY THE SPACECRAFT
    - MINOR DAMAGE TO DORIS ANTENNA RF-CONNECTOR
  - SHSS
    - AMPLE MARGIN OF SAFETY AGAINST THE CALCULATED IMPACT LOAD

D-9847

DAMAGE ASSESSMENT: INSPECTION

FAIRCHILD SPACE

FACAR NO.	STEP NO.	DESCRIPTION	RESULTS	DISPOSITION
C-08261 IM STRUCTURE	27 30	+Z CORNER FITTINGS OF IM REMOVED FOR INSPECTION -Z CORNER FITTINGS OF IM REMOVED FOR INSPECTION	REINSTALLED WITH CORRECT TORQUE AND RUNNING TORQUE ON ALL BOLTS: NO DAMAGE	CLOSED
C-08270 DORIS ANTENNA	4	J2 CONNECTOR ON DORIS ANTENNA IS BENT 10°. POSSIBLE FRACTURE NOTED AT BASE OF J2 NEAR POINT OF BEND APPROXIMATELY 0.030 LONG.	ANTENNA SENT BACK TO CNES FOR THOROUGH CHECK-OUT	OPEN
C-08272 SAD	4	SOLAR ARRAY YOKE SIMULATOR BOLTS: FLIGHT MOUNTING BOLTS	CORRECT TORQUE	CLOSED
	5	SAD SURROUNDING AREA FOR DEFORMATION (CRACKS/NICKS, ETC.)	NO PROBLEMS	
	6	SAD ALIGNMENT CHECK	CONING CHECK O.K.	
	7	SAD PITCH ALIGNMENT	ALIGNMENT CHECK O.K.	
	8	OPEN/DIODE BOX J1/P1 CONNECTOR	VERIFIED O.K.	

D-9847

DAMAGE ASSESSMENT - TESTS

ELECTRICAL CHECKS

- THE SPACECRAFT WAS ELECTRICALLY TESTED (AFTER THE INCIDENT) WITH THE RELEASED STOL SOFTWARE VERSION
  - 968-SMD8001, REV. C
  - 968-SMS8001-04
- SEE DETAILED REPORT
- DISPOSITION:
  - ALL DATA NOMINAL
  - NO ANOMALIES NOTED

D-9847

D-9847

FAIRCHILD SPACE

From: Premi Thilagar

To: Rex Richardson

Subject: Post TOPEX Incident Satellite Electrical Tests

Date: 3-17-92

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1. The following electrical tests were performed on the TOPEX Satellite after the "TOPEX Satellite Incident":

   - Satellite Aliveness Test (reference attached description)
   - Solar Array Alignment Verfication Test
   - NASA Altimeter UCFM Tests

2. Satellite Aliveness Test: A TOPEX Satellite Aliveness Test was performed on 3-11-92 (refer to the attached list for a detailed description of the test.) During the test, current, voltage and temperature telemetry was limit-checked by the ground computer with no limit failures.

   One FACAR was generated which was not in any way related to flight hardware. The DORIS Time Correction value sent from the Ground Computer was out-of-range and was rejected by the DORIS. In the future, the DORIS GSE will verify the Time Correction Value is within the specified range prior to transmitting it to the DORIS.

   The Solar Array Drive Position Telemetry indicated the same position as it was in prior to the rotation incident.

   As an addition to the normal Aliveness Test, the TMR Test Targets were installed to collect performance data. All test data was nominal.

3. Solar Array Alignment Verification: The Solar Array Alignment was checked on 3-12-92 and no anomlies were noted. The Solar Array Drive was rotated twice due to the prior absence of a Nitrogen Purge.

4. NASA Altimeter UCFM Tests: During the Solar Array Alignment Check, the NASA Altimeter was turned on and six hours of UCFM Data was taken by the APL Engineers. No anomalies were noted.

Satellite Aliveness Test

MMS Primary Side Power-On:

- Connect Batteries
- CDH A-Side Power On and initizalation
- MPS A-Side initizalation
- SCCU A-Side initizalation
- PM B-Side initizalation
- ESAM Power On and initizalation
- MACS B-Side Power On and initizalation

Instrument Module (IM) Primary Side Power On:

- IMIU-A power on and initialization
- FRU-A power on
- DORIS MVR/USO-1 Power ON
- SADA-A power ON (no rotation)
- HGAS SCEs not installed (no testing)
- TMR A-Side power on and initialization
- GPSDR A-Side Power On and initialization
- DORIS Functional Tests (DRSDIV)
- Altimeter A-Side Power On and Aliveness Test
- Altimeter A-Side Power Off
- CNES SSALT Power On/Memory Upload
- CNES SSALT,TMR, GPSDR,DORIS,SADA,IMIU Power Off
- MMS Primary Side Power Off
- FRU-A power off

MMS Redundant Side Power-On (batteries still connected):

- CDH B-Side Power On and initizalation
- MPS B-Side initizalation
- SCCU B-Side initizalation
- PM A-Side initizalation
- ESAM Power On and initizalation
- MACS A-Side Power On and initizalation

Instrument Module (IM) Redundant Side Power On:

- IMIU-B power on and initialization
- FRU-B power on
- DORIS MVR/USO-2 Power ON
- SADA-B power ON (no rotation)
- HGAS SCEs not installed (no testing)
- TMR B-Side power on and initialization
- GPSDR B-Side Power On and initialization
- DORIS Functional Tests (DRSDIV)
- Altimeter B-Side Power On and Aliveness Test
- Altimeter B-Side Power Off
- CNES SSALT Power On/Memory Upload
- CNES SSALT,TMR, GPSDR,DORIS,SADA,IMIU Power Off
- MMS Redundant Side Power Off
- FRU-B power off
- Disconnect Batteries

DAMAGE ASSESSMENT - TESTS

FAIRCHILD SPACE

ALIGNMENT CHECKS				
EQUIPMENT	AXIS	ALLOWABLE	PRE-INCIDENT	POST-INCIDENT
DORIS	ROLL	±31'	-06' 43"	-03' 59"
	PITCH	±31'	+06' 29"	+05' 42"
TMR	ROLL	13.86' 5.38' (DESIRED)	-03' 54"	-05' 35"
	PITCH	13.86' 5.38' (DESIRED)	-02' 13"	-02' 07"
PM	ROLL			
	PITCH			
ALT. FEED	ROLL			
MMS/IM	ROLL	200"		-34"
	PITCH	200"		-16"
	YAW	200"		-44"

D-9847

DAMAGE ASSESSMENT - ANALYSIS

IMPACT LOAD/STRESS ANALYSIS

- SPACECRAFT IM MGSE LUG-FITTING ANALYZED FOR IMPACT LOAD AND MARGIN-OF-SAFETY WITH COMPARISON TO THE DESIGN LOADS.
- CONCLUSIONS: UNDER WORST-CASE ASSUMPTION OF IMPACT LOAD, THERE IS A MINIMUM MARGIN-OF-SAFETY OF 0.53
- NO STRUCTURAL PROBLEMS, AS CONFIRMED BY SUBSEQUENT SUCCESSFUL ALIGNMENT CHECKS

IMPACT LOAD SUMMARY

- WORST-CASE LATERAL LOAD AT LUG-FITTING, TAKING INTO ACCOUNT ADDITIONAL IMPACT LOAD OF 0.426g (BASED ON LATERAL LOAD TAKEN BY ONE FITTING/SUPPORT) IS 5890 LBS (X - DIRECTION)

- MORE REALISTIC SCENARIO OF LATERAL LOAD SHARED BY TWO BOTTOM SUPPORTS GIVES IMPACT g LOADING OF 0.6g → 3,304 LBS

IMPACT LOAD SUMMARY (CONTINUED)

- MAXIMUM DESIGN LOAD AT A FITTING

	SHSS -TV-FIXTURE SIDE	S/C SIDE
F_X =	2,750 LBS	4,500 LBS
F_Y =	2,539 LBS	4,500 LBS
F_Z =	15,229 LBS	9,000 LBS

- LUG-FITTING MINIMUM MARGIN-OF-SAFETY IS AT CLEVIS-HOLE, WHICH IS CALCULATED FOR F_Z OF 15,229 LBS

MINIMUM MARGIN-OF-SAFETY AT IM FITTING 1.01

- WORST-CASE FACTOR-OF SAFETY AGAINST IMPACT LATERAL LOAD

$$\frac{15{,}229}{5{,}890} \longrightarrow \frac{\text{SHSS-TV-FIXTURE FITTING}}{2.58}$$

$$\frac{\text{S/C IM FITTING}}{\text{MINIMUM M.O.S FOR THE IMPACT LOAD}}$$

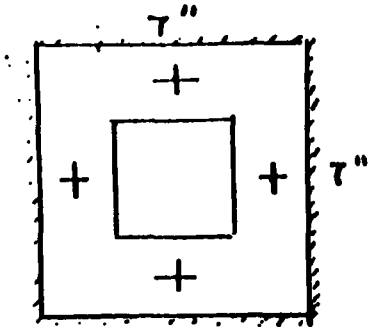
$$\frac{(4{,}500)(2.01)}{5{,}890} - 1 = 0.53$$

D-9847

Impact Loads Caused By Slip Plate Motion

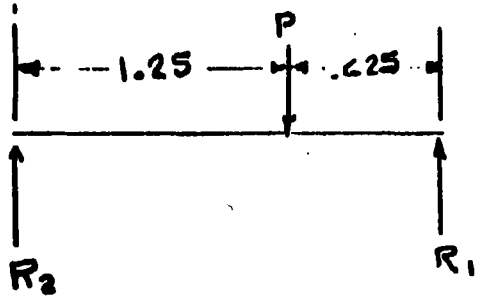
- Worst Corr. Impact Load = 0.6 g
- Actual loads applied to +Z corner fittings and adjacent IM structure are still enveloped by the design loads.

Pad Friction Energy



Preload - (4) 3/8 - 24 160 ksi screws

$P_{rel.} = 4 \times 7030 = 29120$ lb



$$R_2 = 29120 \cdot \frac{.625}{1.875} = 9707^{\#} \quad \text{say } 9500^{\#}$$

$N = 9500^{\#}$ theoretical

$F_f \simeq 0.25 \times 9500 = 2375^{\#}$ [max. available to prevent slippage]

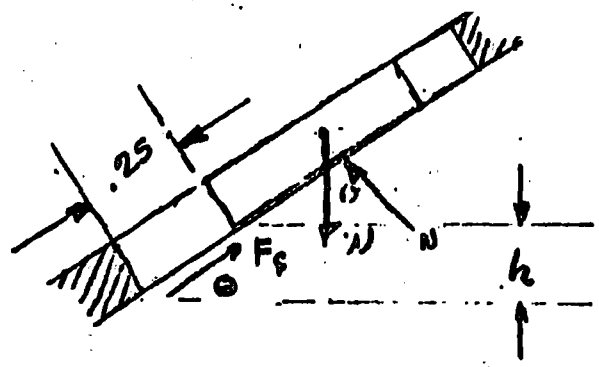
Since slippage did occur, F_f must be less than $\frac{W}{2} = \frac{1130}{2} = 2065^{\#}$

$\therefore$ Set $F_f = 2000$ lb.

Friction Energy dissipated during 0.25 in. travel:

$FE \simeq 0.8 \times 2000 \times 0.25 = 400$ #in

Impact Load Calculations



$h = 0.25 \sin\theta$

$W \simeq \frac{4130}{2} = 2065$ lb.

Assume slippage did not occur until $\theta = 90°$: [$h = .25$]

Kinetic Energy at impact: [Potential Energy − Friction Energy]

$KE = W \cdot h - F_f \cdot 0.25 = 2065 \cdot .25 - 0.8 \cdot 2000 \cdot 0.25$

$KE = 116.25$ # in.

Strain Energy of Jack in lateral bending:

$SE = P^2 \cdot l^3 / 3EI = P^2 \cdot 7.5\text{-}5$ lb in.

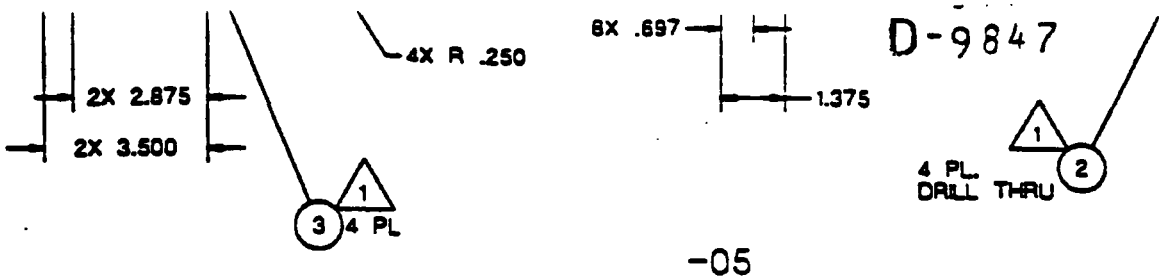
$P^2 = \frac{116.25}{7.5\text{-}5} = 1.55 + 6$

$P = 1.245 + 3$ lbf

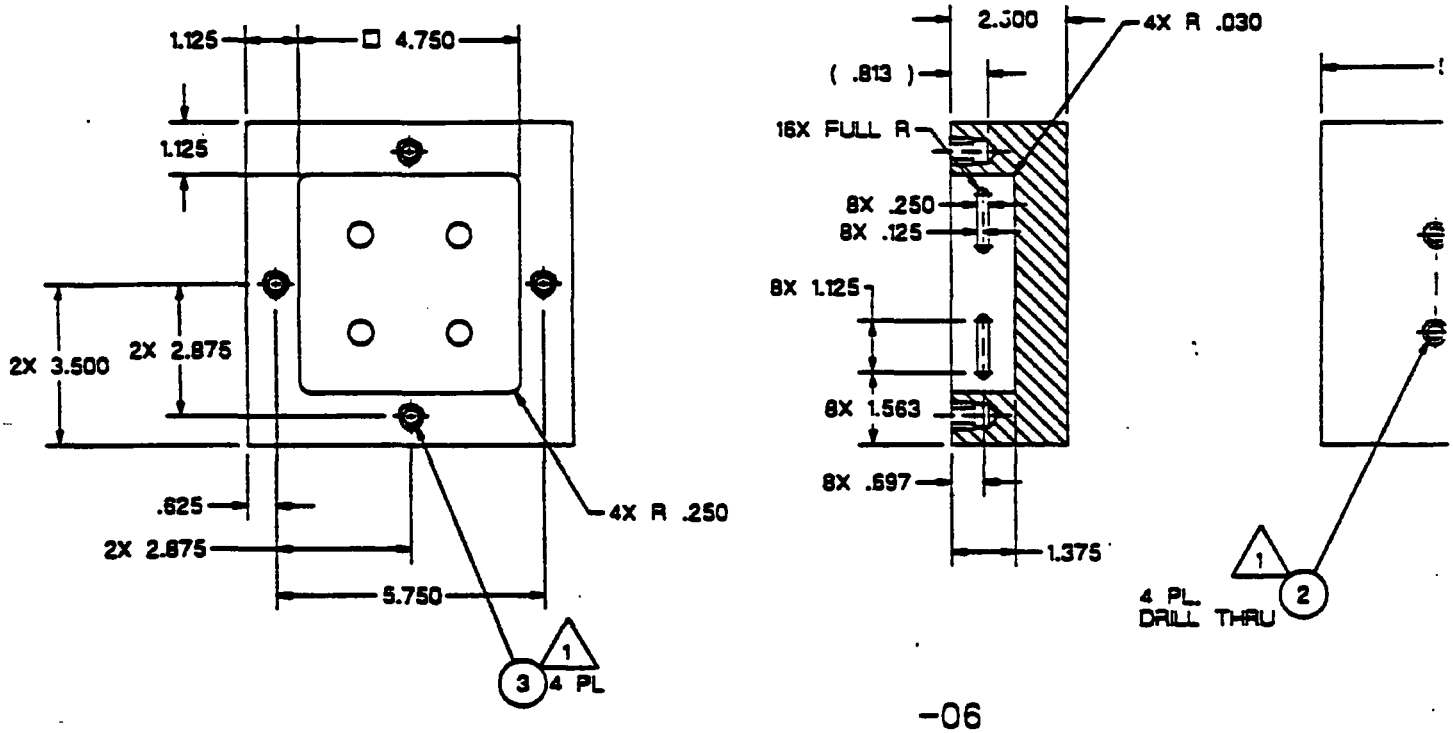
$N_x = \frac{1245}{2065} \simeq \boxed{0.6\,g}$

D-9847

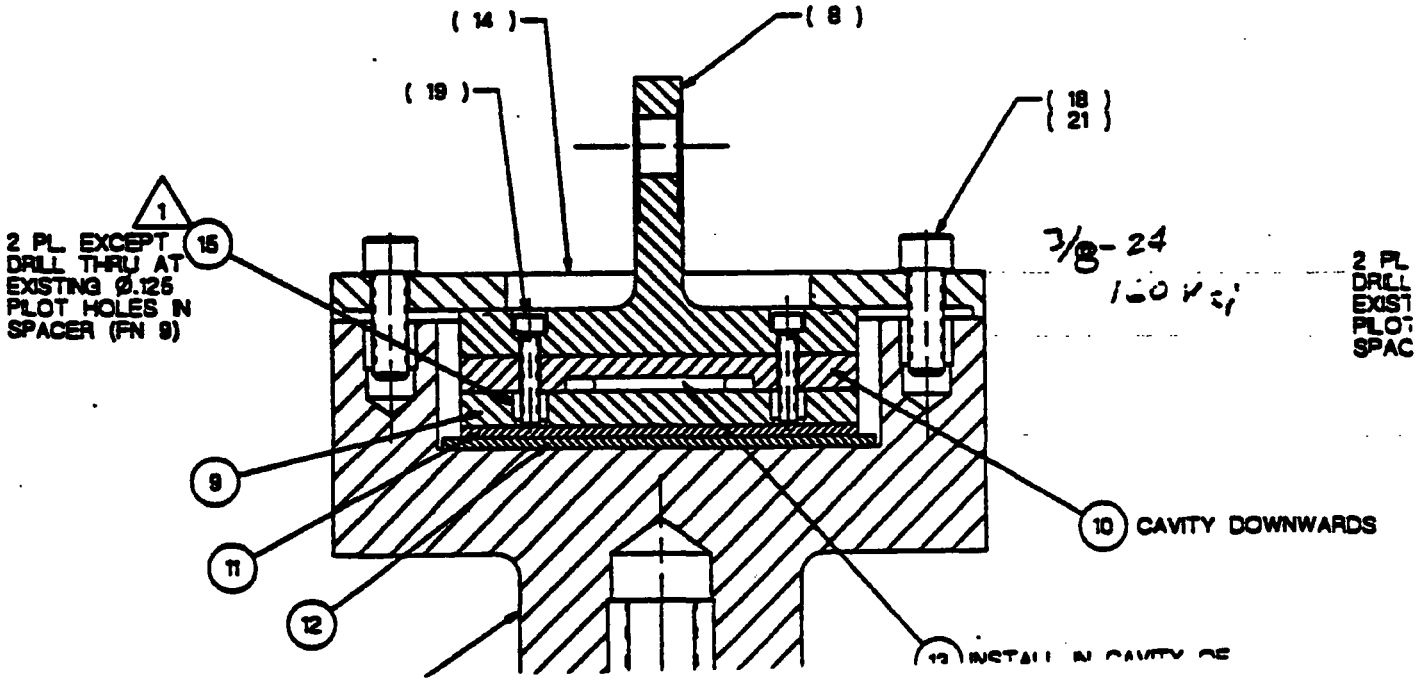
D-9847


2X 2.875
2X 3.500
4X R .250
3
1
4 PL
8X .697
1.375
1
2
4 PL.
DRILL THRU

-05


1.125
4.750
1.125
2X 3.500
2X 2.875
.625
2X 2.875
5.750
4X R .250
3
1
4 PL
2.500
4X R .030
(.813)
16X FULL R
8X .250
8X .125
8X 1.125
8X 1.563
8X .697
1.375
1
2
4 PL.
DRILL THRU

-06


(14)
(8)
(19)
(18)
(21)
1
2 PL EXCEPT
DRILL THRU AT
EXISTING Ø.125
PILOT HOLES IN
SPACER (FN 9)
15
3/8-24
9
11
12
10 CAVITY DOWNWARDS
2 PL
DRILL
EXIST
PILOT
SPAC

Jack Strain Energy in Lateral Bending U-9841

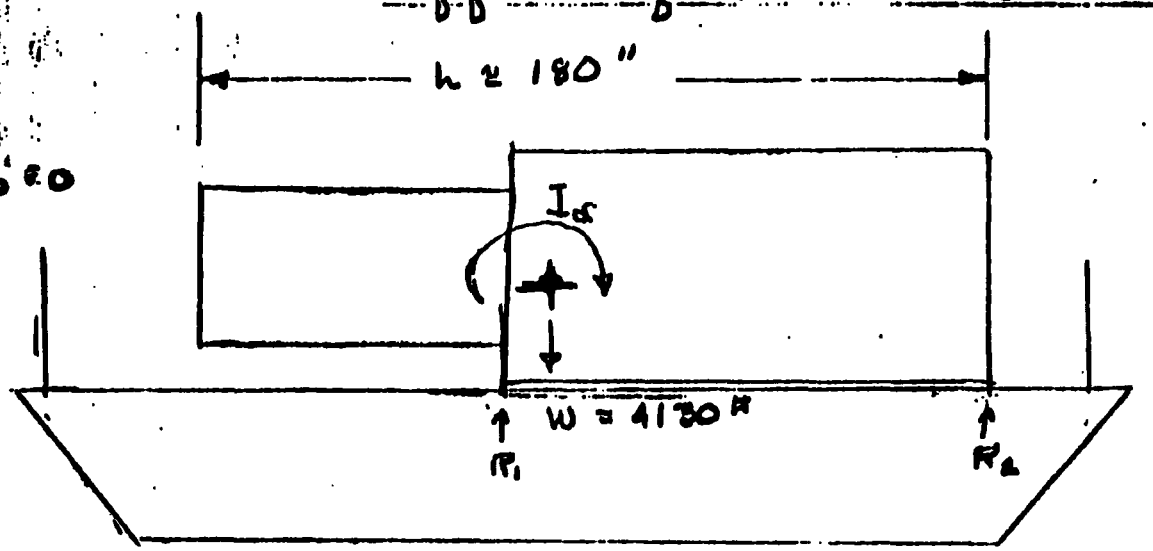
Grid.		δ in	Δδ in.	F lb	Δδ/F = $\frac{l^3}{3EI}$
1123	X	.06426	.17038	2280	7.473-5
	Y	-.01447		3329	
	Z	-.03913		12498	
1623	X	-.23464			
	Y	-.29671			
	Z	-.39983			
1163	X	-.24540	.20309	2750	7.385-5
	Y	-.02328		2539	
	Z	-.41802		15229	
1663	X	-.44849			
	Y	-.29411			
	Z	-.42845			
1127	X	-.07739	.16256	830	19.586-5
	Y	-.00263		1072	
	Z	-.13562		5661	
1627	X	-.23995			
	Y	-.27188			
	Z	-.13950			
1167	X	-.24883	.20471	1572	13.022-5
	Y	-.00611		492	
	Z	-.22338		3659	
1667	X	-.43356			
	Y	-.02601			
	Z	-.22086			

Effect of Rotational Acceleration

$V_f := V_o + a\,\Delta t$

$V_f = V_o + \frac{\Delta S}{\Delta t}$

$\frac{\Delta S}{\Delta t \cdot \Delta t} = \alpha$ for $V_o = 0$



From video-analysis, estimate 90° rotation in 3 seconds:

$$I \approx \frac{1}{12} \cdot 4130 \cdot \overline{180}^2 = 1.115 + 7 \text{ lb in}^2$$

$$\alpha \approx \frac{\Delta S}{\Delta t^2} = \frac{\cancel{10}\ 90 \text{ deg}}{(3)^2 \text{ sec}^2} = \cancel{1.11}\ 10 \frac{\text{deg}}{\text{sec}^2} = \cancel{.0194}\ 0.1745 \frac{\text{rad}}{\text{sec}^2}$$

$$M = \frac{1.115 + 7 \text{ lb in}^2}{386.4 \frac{\text{in}}{\text{sec}^2}} \times \cancel{.0194}\ 0.1745 \frac{\text{rad}}{\text{sec}^2} = \cancel{560}\ 5036 \text{ lb in}$$

$$R = \frac{\cancel{560}\ 5036}{90} = \cancel{6.2}\ 56 \text{ lb on Jack Posts due to Moment}$$

[Negligible]

D-9847

DAMAGE ASSESSMENT - VIDEO ANALYSIS

- START OF INSTABILITY IS VISIBLE FROM THE VIDEO
- THE ANGULAR ROTATIONAL RATE DURING THE TIP-OVER WAS APPROXIMATED TO CALCULATE ADDITIONAL LATERAL LOAD DUE TO ROTATIONAL ACCELERATION. THE VALUE ASSESSED FROM THE VIDEO ANALYSIS RESULTS IN A NEGLIGIBLE ADDITIONAL LOAD COMPARED TO THE LATERAL IMPACT LOAD ASSUMING A (WORST-CASE) VERTICAL DROP

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 7-B

Pre-Incident Building 10 Crane Checkout

D-9847

Date: 3/2/92

Daily Operator Crane Inspection Log

	Pass	Fail	Remarks
Pendant and Cable	/		
Functional Operations	/		
Trolley	/		
Bridge	/		
Hoist	/		
Hook Block	/		
Hoist Rope	/		
Grease or fluid leaks	/		

Signature of inspector: Wayne [illegible]

Limit Switch Test (Performed only after the Daily Inspection)

Operator Signature	Pass	Fail	Remarks

Comments/Unusual Conditions, etc.

190

Memorandum

NSI Technology Services Corporation
A Subsidiary of
ManTech International Corporation

To: J. Stecher

From: C. Jones

Subject: Building 10 Crane Checkout

Date: March 11, 1992

Copies: T. Amacher

In reply refer to:

On the morning of Sunday, March 9, 1992, Wayne Eklund performed the daily operator crane inspection. A copy of the inspection log for that day is attached.

The inspection consisted of moving the hook approximately 10 feet in each direction (North, South, East, and West). This checks the basic functional operation of the bridge, trolley, hoist, and pendant controls. The directional checks were performed at the normal operating speeds; i.e., trolley in SLOW, bridge in MEDIUM, and hoist in NORMAL. Additionally, the hoist was checked in the INCH mode.

A general overall visual inspection of the hook block and hoist rope was performed, looking for any kinks in the cables, proper wrapping on the drum, and any abnormal rubbing of the wire rope in the hook block. All were found to be normal. Visual inspection also did not reveal any grease or fluid leaks.

Finally, the upper limit switch was tested and found to be operating properly. The crane was then used to begin the activities of the day.

Carol S. Jones

Carol S. Jones
Supervisor
Integration & Field Support

CSJ/jld

Attachment

TOPEX/POSEIDON SPACECRAFT HANDLING ANOMALY

Appendix 7-C

Post-Incident Building 10 Crane Inspection

Memorandum

NSI Technology Services Corporation
A Subsidiary of ManTech International Corporation

To: J. Stecher/750

From: T. Schafer

Subject: Crane 10-1 Inspection Results

Date: March 11, 1992

Copies: T. Amacher

In reply refer to: NSI-4004-5.2-018

A post-incident inspection of the subject crane was performed on March 11, 1992. The inspection was performed in accordance with RECERT's periodic inspection procedure for Crane 10-1 with special emphasis on the condition of the bridge and trolley rails. A rated load test was not performed, since the annual periodic inspection of the crane occurred February 21, 1992. The results of the March 11 inspection revealed no abnormalities of either the bridge or trolley rails or wheelsets. Furthermore, no mechanical, electrical, structural, or operational discrepancies were noted. A copy of the inspection report is attached hereto for your information. If you have any questions or we can be of further assistance, please advise.

T. Schafer
Senior Engineer
Recertification Support

Attachment

TPS/slb

D-9847

****
* N S I *
*
* DOCUMENT NO. 25-06-021 *
****

APPENDIX

PERIODIC INSPECTION/MAINTENANCE REPORT
FOR
BRIDGE CRANE 10-1
BUILDING #10, HI-BAY

NSI Report Number

25-06-021

March 1992

INSPECTED BY: R. Gayo 3-11-92
R. Gayo, Lifting Device Inspector, NSI — Date

INSPECTED BY: E. Wieneke 3-11-92
E. Wieneke, Lifting Device Inspector, NSI — Date

REVIEWED BY: N/A
J. McWilliams, Safety Officer, NSI — Date

APPROVED BY: for 3/11/92
D. Luce, REGERT Manager, NSI — Date

Recertification Support
NSI Technology Services, Incorporated
A Subsidiary of ManTech International Corporation
Goddard Space Flight Center
Greenbelt, Maryland 20771

TABLE OF CONTENTS

	Page
REVISION SHEET	A-ii
CRANE DATA SHEET	A-iii
INSPECTION DISCREPANCY REPORT	A-iv
1.0 GENERAL IDENTIFICATION AND MARKINGS	A-1
2.0 OPERATIONAL TESTS	A-2
3.0 HOIST	A-5
4.0 TROLLEY	A-9
5.0 BRIDGE	A-10
6.0 ELECTRICAL CONTROLS	A-11
7.0 STRUCTURE	A-13
8.0 TESTING	A-14
CRANE MAINTENANCE SCHEDULE	A-16

CRANE DATA SHEET

GSFC Crane No. 10-1 Maryland Department of Labor and Industry
SC No. 1453

Location: Building 10, Hi-Bay

Manufacturer: Dresser Industries, Shaw Box Bridge and Trolley

Serial Number: 51-39196

Catalog No: 41-52677

Capacity: 15 tons Lift: 84'

Rope Size: 9/16", 6x37

Hoist Motor: Stator Wound Rotor Slip Ring

Type: COSO Frame WEO-324U

Serial Number:

Electrical: 440 VAC, 3 Ph, 60 Hz, 20 HP, 38 Amp, 1800 RPM,
55C Rise, 30 min duty

Hoist Limit Switch:

Trolley Motor: Stator Wound Rotor Slip Ring Motor

Type: COSCO Frame: WEA-213

Serial Number:

Electrical: 440 VAC, 3 Ph, 60 Hz, 2 HP, 2.1 Amps, 1800 RPM,
55C Rise, 30 min duty

Trolley Brake: Model A, 6 lb-ft

Bridge Motor: Frame AEO-23P

Type: JOFH-4-18

Model Number: 5458X29

Electrical: 440 VAC, 3 Ph, 60 Hz, 1/8 HP, 1.15 Amps, 1800 RPM,
55C Rise, 30 min duty

Motor Reducer: Helical Worm, Ratio 36/10, RPM 22/45, Rated 6 ft-lb
Clutch: Warmer SF-825 D.C., 440VAC, 9 Amp

D-9847
25-06-021

INSPECTION DISCREPANCY REPORT
CRANE 10-1

CRANE 10-1 INSPECTORS R. Gayo / D. Burtis DATE 3-11-92

ITEM	DESCRIPTION OF DISCREPANCY	ACTION
P.M & INSPECTION	- OK.	
LOAD TEST 30,000#	2-21-92	

The complete report is available for review. It is filed with Lifting Device Maintenance and Inspection Section of NSI.

This crane has been inspected and load tested to 30,000 lbs and is/~~is not~~ liftworthy.

Inspector R. Gayo Inspector David C. Burtis

PERIODIC INSPECTION AND MAINTENANCE REPORT

When this inspection is performed, the rated load test must also be completed.

The inspectors should refer to the "Parts, Care and Operations Manual", located in the files, for a more complete discussion of maintenance, troubleshooting, parts, and schematics if necessary.

Conditions: (✓ - Satisfactory) (x - Unsatisfactory) (*✓ - Corrected)

Initial	Date	Condition		
			1.0	**GENERAL IDENTIFICATION AND MARKINGS**
RCB	3-11-92	✓	1.1	Rope off work area and install warning signs.
		✓	1.2	Verify warning sign on pendant for the following items:
		✓	1.2.1	Do not lift more than rated load.
		✓	1.2.2	Do not operate hoist with twisted, kinked, or damaged chain or rope.
		✓	1.2.3	Do not operate damaged or malfunctioning hoist.
		✓	1.2.4	Do not lift people.
		✓	1.2.5	Do not move loads over people.
		✓	1.2.6	Do not operate hoist with other power source.
		✓	1.2.7	Do not operate hoist when load is not centered under hoist.
		✓	1.2.8	Do not move or obscure warni labels.

Initial	Date	Condition		
RG/EB	3-11-92		1.3	Verify load rating marked on hoist block and bridge.
"	"	✓	1.4	Verify that the controller clearly indicates directions of motion.
"	"	✓	1.5	Verify crane clearly indicates directions of motion.

2.0 OPERATIONAL TESTS

An audio and visual examination of the crane components shall first be conducted from the ground with the pendant control station.

"	"	✓	2.1	The circuit breaker switch for Crane 10-1 is located in panel IP1-CRT 7, on the south wall at the S.W. corner of the Building 10. Remove the lock from the circuit breaker switch and turn the disconnect switch on.
"	"	✓	2.2	Operate TROLLEY controls to produce maximum travel in both directions. Evaluate the following:
		✓		2.2.1 Start and stop response.
		✓		2.2.2 Smoothness of travel.
"	"	✓	2.3	Operate HOIST controls to produce rise and fall:
		✓		2.3.1 Start and stop response.
		✓		2.3.2 Smoothness of travel.
		✓		2.3.3 Effectiveness of upper limit switch.

Initial	Date	Condition		
PG/DB	3-11-92	✓	2.4	Operate BRIDGE controls to produce maximum travel in both directions. Evaluate the following:
		✓		2.4.1 Start and stop response.
		✓		2.4.2 Smoothness of travel.
		✓		2.4.3 Effectiveness of limit switch.
"	"	✓	2.5	Operate all pendant controls to verify that all are functional.
"	"	✓	2.6	While operating crane components move pendant power switch to STOP and verify power shut-off.
				A close-up audio and visual examination of the crane components shall now be conducted. Ascend to the crane level balcony by using the fixed ladder on the north wall.
"	"	✓	2.7	Place the pendant at the second balcony level.
"	"	✓	2.8	Raise the tool bucket with lanyard to the working platform.
"	"	✓	2.9	Operate the TROLLEY controls to accomplish the following:
		✓		2.9.1 Check the motor for audio/visual indications of bearing wear and excessive play, abnormal smells or high temperature.
		✓		2.9.2 Check the reduction drive for audio/visual indications of gear wear and excessive play.

Initial	Date	Condition		
		✓	2.9.3	Check the wheels for audio/visual indications of bearing wear and looseness on the axle.
		✓	2.9.4	Check the festoon system for smooth operation.
RGDB	3-11-92	✓	2.10	Operate the BRIDGE controls to accomplish the following:
		✓	2.10.1	Check the motor for audio/visual indications of bearing wear and excessive play, abnormal smells or high temperature.
		✓	2.10.2	Check the reduction drive for audio/visual indications of gear wear and excessive play.
		✓	2.10.3	Check the wheels for audio/visual indications of bearing wear and looseness on the axle.
		✓	2.10.4	Check the coupling shaft of drive wheels for audio/visual indications of bearing wear and looseness.
		✓	2.10.5	Check the collector shoe for smooth operation.
		✓	2.11	Operate the HOIST controls to accomplish the following:
		✓	2.11.1	Check the motor for audio/visual indications of bearing wear and excessive play, abnormal smells or high temperature.

Initial	Date	Condition		
		✓	2.11.2	Check the reduction drive for audio/visual indications of gear wear and excessive play.
		✓	2.11.3	Check the drum for audio/visual indications of bearing wear and looseness on the axle.
		✓	2.11.4	While raising the hoist, listen for clicking sounds of mechanical load brake pawl. If heard, adjust pawl setting
			3.0	**HOIST**
RG/DB	3-11-92	✓	3.1	When directed, the pendant operator will lower the hook and block to ground level and keep the cable untangled as the mechanical technician guides all the cable from the drum.
"	"	✓	3.2	Check the drum assembly as follows:
		✓	3.2.1	Unwind cable completely and inspect rope socket and drum.
		✓	3.2.2	Verify that the inactive rope on the drum has been properly lubricated and shows no sign of rusting or other deterioration.
		✓	3.2.3	Wear of the grooves in the drum and general condition of the grooves and the land between the grooves for cracking and deterioration.

Initial	Date	Condition		
		✓	3.2.4	Check the hoist support nuts and cotter pins for tightness.
RG/DR	3-11-92	✓	3.3	Raise the hook and block and check rope for the following conditions. Definitions and criteria for replacement are defined in Procedure Section 10.2.
		✓	3.3.1	Reduction of rope diameter, due to loss of core support, internal or external corrosion, or wear of outside wires.
		✓	3.3.2	Broken wires or worn outside wires.
		✓	3.3.3	Corroded or broken wires at end connections, or improperly applied end connections.
		✓	3.3.4	Severe kinking, crushing or any other damage resulting in distortion of the rope structure.
		✓	3.3.5	Inadequate lubrication.
		✓	3.3.6	Excessive dirt and grease.
"	"	✓	3.4	Check motor for loose mounting bolts, and clean off excessive dirt and grease.
"	"	✓	3.5	Remove drain plug from reduction drive and sample lubricant for freedom from water, metal particles, sludge, or other contamination.
"	"	✓	3.6	Remove breather and level plugs and, if necessary, lubricate gears with Dexron gear case oil. Clean breather in solvent.

Measured Rope Diameter

.578	.577
.578	.577

202

Initial	Date	Condition		
AG/DB	3-11-92	✓	3.7	Check brake assembly for the following items.
		✓	3.7.1	Brake disc for adequacy and symmetrical wear pattern.
		✓	3.7.2	Brake disc, plates, and armature perimeter for cracking, discoloration, or excessive wear.
		✓	3.7.3	Armature pivot points for free movement and cleanliness.
		✓	3.7.4	Check armature gap for 1/32" - 1/8" spacing.
		✓	3.7.5	Clean brake, armature, and cover of dust.
		✓	3.7.6	Check electrical wiring and connections.
		✓	3.7.7	Remount brake housing.
"	"	✓	3.8	Check equalizer sheave assembly for the following:
		✓	3.8.1	Adequate lubrication.
		✓	3.8.2	Freedom to rotate.
		✓	3.8.3	Worn or damaged groove.
"	"	✓	3.9	Check lower block assembly as follows:
		✓	3.9.1	Unscrew cover plates.
		✓	3.9.2	Lubricate all parts of sheaves, sheave pin and bearings, thrust bearing, and hook shank.
		✓	3.9.3	Insure rope groove of each sheave is smooth and free from burrs or other surface defects.

Initial	Date	Condition		
		✓	3.9.4	Check each sheave for freedom of rotation.
		✓	3.9.5	Check for excess bearing play.
KG/DB	3-11-92	✓	3.10	Check hook as follows:
		✓	3.10.1	Dowel pin holding nut to hook is securely in position.
		✓	3.10.2	Verify that safety latch is in good operating condition and lubricate.
		✓	3.10.3	Throat opening: Check across trammel points for reference dimension. The hook must be replaced if the throat opening exceeds 15% of the original opening, or if the hook is twisted more than 10 degrees from the unbent plane.
		✓	3.10.4	Cracks. Hooks showing signs of cracks must be replaced.
		✓	3.10.5	Check for wear in the saddle area.
"	"	✓	3.11	Verify that nondestructive testing of hook to detect the presence of surface or near-surface cracks is current.
"	"	✓	3.12	Reassemble hook block.
"	"	✓	3.13	Grease all hoist block fittings with Rykon #2 E.P. or equivalent.
"	"	✓	3.14	Lubricate the Paddle Upper Limit Switch bearings with a small amount of SAE-30 motor oil.

Last Throat Measurement
7 27/32

Current Throat Measurement
7 27/32

115% = _____

Date of last NDT
2-21-92

204

Initial	Date	Condition		
			4.0	**TROLLEY**
RC/DB	3-11-92	✓	4.1	Check motor for loose mounting bolts and clean off excessive dirt and grease.
"	"	✓	4.2	Drop drip pan and remove level plug from reduction drive. Sample lubricant for freedom from water, metal particles, sludge, or other contamination.
"	"	✓	4.3	Remove filler plug and lubricate gears with P&H No. 486 or equivalent.
"	"	✓	4.4	Check trolley truck for loose bolts and cracks.
"	"	✓	4.5	Check collector rails, shoes and connections for abrasion, excessive wear, and alignment. Replace if necessary.
"	"	✓	4.6	Check limit switches for proper mounting, looseness, position, and alignment. Adjust or replace if necessary.
"	"	✓	4.7	Check limit switch trip for proper attachment, position, and alignment. Adjust if necessary.
"	"	✓	4.8	Check stops for proper attachment, cracks, deformations or other structural defects.
"	"	✓	4.9	Check wheels for abnormal wear, flaking, chipping, or cracking.
"	"	✓	4.10	Check wheel drive gears for abnormal wear pattern and excessive backlash.
"	"	✓	4.11	Check trolley runway for wear, flaking chipping and cracking, and beam twist.

Initial	Date	Condition		
PG/DB	5-11-92	✓	4.12	Check the North and South end sections for secure connections and evidence of movement.
			5.0	**BRIDGE**
"	"	✓	5.1	Check motor for loose mounting bolts and clean off excessive dirt and grease.
"	"	✓	5.2	Drop drip pan and remove level plug from reduction drive. Sample lubricant for freedom from water, metal particles, sludge, or other contamination.
"	"	✓	5.3	Remove filler plug and lubricate gears with P&H No. 486 or equivalent.
"	"	✓	5.4	Check shaft coupling for end play and looseness.
"	"	✓	5.5	Check power supply wires for loose connections, fatigue, deterioration or abrasion of insulating wire. Clean or replace if necessary.
"	"	✓	5.6	Check collector and shoes for abrasion, excessive wear, and loose or improperly aligned attachments. Replace if necessary.
"	"	✓	5.7	Check limit switches for proper mounting, looseness, position and alignment. Adjust or replace if necessary.
"	"	✓	5.8	Check stops for proper attachment, cracks, deformations or other structural defects. Replace if necessary.

Initial	Date	Condition		
RG/DB	5-11-92	✓	5.9	Check drive wheels for tracking and tread wear.
"	"	✓	5.10	Check drive wheel bearings for wear and looseness on the axle.
"	"	✓	5.11	Lubricate drive wheel with P&H No.476, or equivalent. There are two (2) bearings and one (1) axle fitting.
"	"	✓	5.12	Check rail wheels for abnormal wear, flaking, chipping, or cracking.
"	"	✓	5.13	Check rail wheel bearing for wear and looseness on the axle.
"	"	✓	5.14	Lubricate rail wheel with P&H No. 476, or equivalent. There are four (4) fittings per wheel set for a total of eight (8) fittings on each side of the bridge.
"	"	✓	5.15	Check direct drive motors and attachments.
"	"	✓	5.16	Sparingly lubricate open drive gears with P&H No. 464, or equivalent.
"	"	✓	5.17	Check bridge runway for alignment.
"	"	✓	5.18	Check bridge runway for excessive flange wear, flaking, chipping or cracking, and weld imperfections.

6.0 ELECTRICAL CONTROLS

"	"	✓	6.1	Check electric cable sheath to insure freedom from cuts or abrasions which could present electrical hazard to operating personnel Clean or replace if necessary.

Initial	Date	Condition		
EG/DB	3-11-92	✓	6.2	Check support chain to insure good conditions and proper adjustment to provide adequate support to control station.
"	"	✓	6.3	Check exterior of control box to insure good condition of all fasteners, cover plates, connectors, and strain relief to preclude electrical hazard to operator. Replace if necessary.
"	"	✓	6.4	Remove cover and internally check control box push buttons and switches for worn contacts, loose connections, weak springs, and defective wiring. Replace if necessary. DO NOT file contacts and replace in complete sets if necessary.
"	"	✓	6.5	Clean and polish contacts with contact cleaner and burnishing tool. Wipe residue with lint-free cloth.

Conduct the following inspection at the hoist control panel.

"	"	✓	6.6	Remove the cover plate and check for worn contacts, loose connections, and defective wiring.
"	"	✓	6.7	Clean and polish contacts with contact cleaner and burnishing tool. Wipe residue with lint-free cloth.

Conduct the following inspection at the BRIDGE CONTROL PANEL.

"	"	✓	6.8	Remove the cover plate and check for worn contacts, loose connections, and defective wiring.

Initial	Date	Condition		
RG/DB	3-11-92	-	6.9	Clean and polish contacts with contact cleaner and burnishing tool. Wipe residue with lint-free cloth.
"	"	✓	6.10	Inspect the entire work area of the crane to insure that no loose tools, parts, or materials are lying on the crane.
"	"	✓	6.11	Lower the tool bucket to ground level. Remove the lock from the circuit breaker switch and turn the disconnect switch on to restore power to the crane. At the panel, use an ammeter to take current readings of crane motors and record their values for the file records. If any amperage reading is abnormal, proceed with megger readings.
		N/A	6.12	Subject the suspected motor stator windings to an insulation resistance test using a 500 volt megger. The insulation resistance between the stator windings and ground must be a minimum of one (1) megohm.

Measured Hoist Current
Fast 9 A. Slow 1 A.

Measured Trolley Current
Fast 2 A. Slow 2 A.

Measured Bridge Current
Fast 11 A. Slow 6 A.

Hoist megger reading
____

Trolley megger reading
____

Bridge megger reading
____

7.0 STRUCTURE

Check structure for deformed, cracked, or corroded members, welds, bolts, and rivets. Various methods of nondestructive examination such as ultrasonics, x-ray, magnetic particle and dye penetrant may be utilized if needed.

RG/DB	3-11-92	✓	7.1	Weld joints.
"	"	✓	7.2	Bolted connector plates.

Initial	Date	Condition		
RG/DB	3-11-92	/	7.3	Alignment of columns, posts, and rails.
"	"	/	7.4	Hanger brackets.

8.0 TESTING

When conducting Operational Tests that require lifting a proof or rated load, provision shall be made to secure any existing basement area under the lift area in the event of drop of test weights.

		N/A	8.1	Proof Load Test.
		"	8.1.1	Determine if components directly involved with the lifting or holding capability have been repaired, replaced or altered.
		"	8.1.2	Determine if upgrading of capacity of the crane has occurred.
		"	8.1.3	If lifting or holding components have been changed or upgrading has occurred, prepare 37,500 lbs. of weight for an operational test.
		"	8.2	Rated Load Test. If a proof load test is not required, prepare 30,000 lbs. of weight for an operational test.
		"	8.3	Operational Test.
		"	8.3.1	Lift weight 1 foot off ground to ascertain brake holding capability.

2/5

Initial	Date	Condition		
		N/A	8.3.2	With weight 1 foot above ground, lower and stop at contract speed to test brake stopping capability.
		✓		
		N/A	8.3.3	Allow weight to suspend 3 minutes.
		"	8.3.4	Travel extreme length of bridge to the south with trolley.
		"	8.3.5	Travel length of bridge runway in the defined inspection area.
		"	8.3.6	Lower weight to floor and unhook for completion of operational test.
		"	8.4	After the proof load or rated load test, perform a post-test inspection of the crane and lifting components to ensure that there is no damage prior to the crane being released for service.
		✓	8.5	Permanently affix a tag to the pendant cable with the following information:
		✓		8.5.1 25-06-021
		✓		8.5.2 CRANE 10-1
		✓		8.5.3 NEXT REQ'D RATED LOAD 2-21-93 (Date)
		✓		8.5.4 PERIODIC INSPECTION, MAINTENANCE, RATED LOAD TEST COMPLETE 2-21-92 (Date)
		✓		8.5.5 SAFE LOAD 30,000 LBS.
EGDB	3-11-92	✓	8.6	Open and lock out the main disconnect switch with the floor lock.

Bldg #10 Hi Bay

U-9847
25-06-021-8

CRANE MAINTENANCE SCHEDULE

2.21.92
(Date)

Before an inspection or any type of maintenance is performed on any critical crane (see attached list), the following procedure must be adhered to:

Circulate an approval signature sheet notifying each of the following persons, at least 3 days in advance, that one of the following will occur.

Check Action	Action	Est. Time in Hrs. Off Line
✓	Inspection & Load Testing	4
✓	Preventive Maint. Schedule	4
	Corrective Maint. Schedule	

This action will be performed on (DATE) 21 (day) 2 (month) 92 (year)

Approval Signature List:

Russ Springham 3-1-92 R. Springham, Ext. 5145, FOM

D. W. Stanfill 3/2/92 D. Stanfill, Ext. 3487, 5858, LDE, Code 750

Lyman S. Knight L. Knight, Ext. 6058, Section Head & Tech. Mont.

J. McWilliams 3/28/92 J. McWilliams, Ext. 8691, NSI Safety Officer

On the day of the inspection, notify responsible Technical Monitor of the crane work before work is started.

For any emergency work, notify above person or persons as soon as possible.

Appendix 8-A

FS Fixture Design Responsibility Flow

FAIRCHILD SPACE FIXTURE DESIGN RESPONSIBILITY FLOW

INCEPTION TO COMPLETION

1. Environmental Test Engineering develops basic concept of fixture design related to specific intended use.

2. Mechanical Design working with Environmental Test Engineering designs fixture and prepares full detailed design drawing with all component parts, materials and associated fabrication techniques and requirements identified.

3. Structural Analysis reviews design and verifies that the structural configuration satisfies all safety, strength and stability requirements imposed by designated lift load considerations.

4. Drawing is then processed through other cognizant organizations (program contract requirements) Program Office, Safety, Quality, Configuration departments, etc.

JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

3520-RG-93-001

February 1, 1993

TO: Distribution

FROM: R. Grippi RG

SUBJECT: TOPEX Lessons Learned

Introduction

This memo briefly documents the lessons learned by Division 35 during the development phase of the TOPEX Project. This includes Satellite contractor mechanical monitoring at Fairchild Space Company (FSC), Global Positioning System (GPS) deployable boom development at JPL and the Topex Microwave Radiometer (TMR) mechanical development at JPL. Recommendations are made to improve the Division's performance and reduce risks at similar costs.

Lessons Learned

Division Responsibilities

1. Avoid giving away or not performing tasks which are Division institutional responsibilities. Agreements, written or verbal, are infrequently remembered when problems occur in activities which are Divisional responsibilities. Document any agreement with an acknowledgement IOM involving direction to descope a Division responsibility.

   During the satellite monitoring phase the Project directed workforce reductions. As a result it was my decision to eliminate monitoring in the AHSE area for two reasons, 1) a qualified/ experienced person was not available for an assignment at FSC, 2-3 weeks per month for a year and 2) the activity was being monitored by the Division 37 Integration and Test group (persons whom I felt were qualified). The Project and Division 37 were aware and concurred with my decision. Unfortunately this agreement was not documented. The agreed upon plan was to keep the Division aware of the AHSE activities so that we could participate on an ad-hoc basis. Unfortunately this did not happen and also the AHSE CDR was cancelled. The satellite tip over incident may have been the result. Clearly, it is risky to give away Divisional tasks even upon Project direction. In hindsight the plan should have included periodic interfacing and trips to Fairchild by an experienced AHSE engineer with the Division 37 person, rather than waiting for status information from Division 37, which never came. If the Division's task is taken away it is important to insure that it is being accomplished properly.

Structural and Thermal Engineering

2. Structural and thermal engineering activities requires experience in five areas; analysis, engineering, test, systems and integration. Very few thermal and structural engineers are qualified in all five areas. The shortfall should be picked up by the supervisor, technical manager or others to avoid problems.

   These areas are:
   a. Analysis- computer coding of math models.
   b. Engineering- applying the results and tradeoffs of the analysis to real hardware solutions.
   c. Test- writing the test plans and conducting the test.
   d. System engineering- performing the tradeoffs, recommending the changes and influencing the managers such that the design risk and complexity is equally shared on both sides of an interface.
   e. Integration-participating in negotiating reasonable requirements and interfaces.

If these tasks are not recognized and performed in an acceptable manner by experienced engineers, problems will occur. These activities do not necessarily have to be performed by the same engineer or even by engineers in the Division, but they all need to occur in a coordinated manner. It is unlikely that a single individual is highly qualified for the five tasks. Some of these GPS boom and TMR engineering functions were being performed outside the Division by engineers that were inexperienced or lacked serious interest, which resulted in some of our difficulties.

Thermal Engineering Design Guidelines

3. Thermal engineering should generate generic design guidelines, requirements, analysis and test margins for in-house development. This document will be similar to existing structure design requirements guidelines. Several significant TMR thermal issues would have been avoided if this document existed.

Mechanical Systems Engineering

4. Mechanical systems engineering should be more actively performed by the Division. Participation in this function insures that the correct detail tradeoffs are being made by knowledgeable persons and reasonable requirements are being established. The Division should continue to develop this expertise and perform this function in every activity, to some extent. The activity could vary from monitoring the activity of the system engineering function within the project to performing the majority of the mechanical systems engineering.

   Systems engineering needs to be performed even on small tasks. This function was to be performed outside the Division for the GPS boom and TMR. However, it did not happen on the GPS boom because it was considered a low priority and the TMR system engineer lacked any serious interest. If system engineering had been adequately performed we could have avoided the trauma of the GPS boom deployment timeline, criticism of a conservative thermal analysis on the GPS boom for non tested hardware (the only equipment on TOPEX), the lack of several watts of heater power for both GPS and TMR (TOPEX launched with significant power margin during the launch phase) and concern for not demonstrating boom deployment in a 0-G environment

Mechanical Functional and Design Requirements

5. Functional and design requirements documents should be written for every major task to avoid confusion and misunderstanding, even if the customer does not want to pay for it. A generic outline would simplify the task, minimize the effort and should not be a significant cost element. On the GPS boom and TMR, functional requirements documents were not written, at Project direction. However, the risk was acceptable since the jobs were small, engineers were experienced and there was a good working relationship between the engineers.

Contractor monitoring

6 Monitors of contractor hardware activities need to recognize that there are other methods of developing hardware and it is not necessary to impose our culture, if other methods can be justified. Over influencing the contractor to our culture results in an impact on cost and schedule. For example, keenserts are great, but if the contractors' experience is with helicoils and they know how to deal with helicoil problems, leave it alone.

Contractor Monitoring Level of Effort

7. Contractor monitoring level-of effort depends upon the contractor's work unit engineers' experience and rapport with the JPL counterpart. To minimize the costs, this effort should be reviewed with the project early in the contract and adjustments made accordingly. In some mechanical areas the workforce allocation was greater than required, such as mechanical devices, since the FSC engineers were highly qualified. The launch vehicle adapter development was handled by an in experienced FSC engineer who relied heavily on JPL support.

   The Divisions' areas of contractor monitoring responsibilities needs to be continually defined and enforced with the Project and the other Divisions. In the case of solar array and high gain antenna subsystem, the division of responsibilities agreed upon with the Project was not always followed by other Divisions. This is situation is dependent upon the assertiveness of the personalities involved and requires close monitoring by the Division 35 representative to insure that other Divisions are not giving technical direction or concurrence in our areas of responsibilities.

Budget Performance

8. The Divisions' budget was never overspent for the eleven years of the Project. Good work plans, realistic schedules, understanding and accepting responsibilities by the doing persons, communicating with the JPL customers and FSC, continually emphasizing cost control and close monitoring were the major contributors for maintaining budget.

   Good work package agreements are essential. During the TMR development the customer continued to ask for additional support. The WPA was the simple justification for additional funding and showed that the new task was not in our plan. As such, the TMR mechanical final costs were around 9% higher than the original estimate plus all liens.

Distribution:

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12/07/93
T. ALMAGUER
ORB-PLNT.DOC

POTENTIAL DIFFERENCES BETWEEN EARTH ORBITERS AND PLANETARY SPACECRAFT

Item	Earth Orbiters	Planetary
Typical Agencies	GSFC/NRL/AF	JPL
Mission Life Time	Typically 3 years	Typically 5 years or longer
NASA Class	Class B	Class A (S level parts)
Space Repairable	Generally Retrievable	Non-Retrievable
Autonomy	Highly interactive with Ground System	Autonomous control stressed, the spacecraft could be unmonitored for days at a time and must be capable of withstanding faults during these periods.
Margin Management	Generally has more: Mass Margin Power Margin Functional Redundancy Control Modes Sensors	Tight Margins in: Mass Power
Telecon Margin	The short communications distance and constant coverage allows transmitters to be turned on from the ground and commands to be gotten into the spacecraft at almost any spacecraft attitude and at high bit rates	The planetary distances at times require communications at low bit rates and commanding may be precluded at some spacecraft attitudes. Spacecraft antenna coverage may be limited, and ground tracking may also be limited.
Major Propulsion Events	Performed early in the Mission and with nearby Telecon coverage	Late Mission critical propulsion events. There could be multiple propulsion events separated by relative long time periods (a year or longer). This requires long term storage of propulsion propellants, valves, and pyro devices and opens the possibility for regulators to leak and pressures to build up, valves to leak, and materials to deteriorate..

Temperature Control	Fairly constant solar input (1AU) except for occultation's	Solar inputs vary significantly depending on the planet and mission. The solar flux at Mars is lower by a factor of 3 than it is at Earth. Additionally, the high solar flux at earth results in excess solar power that must be dissipated or accounted for.
Attitude Sensors	Horizon Scanners, Magnetometers, Earth Sensors	During transit cruise, spacecraft must rely on Sun and star references. Horizon scanners are workable once spacecraft is in planetary orbit.
Telecon Hardware	The short communication distances allow low power, solid state transmitters and omni antennas.	The longer communication distances require high power TWTs for routine communications. Bit rates are lower over the low gain antennas, and higher bit rate high gain antennas require pointing and have a very narrow beam.
Ground Based Antenna Tracking	The Earth ORBITERS have the potential for continuous coverage and communications in real time. Anomalies may be detected immediately by various users. Recovery from a safe mode is more efficient. RF round trip times are in the order of a few seconds.	Due to the DSN coverage and the need for the DSN to track other spacecraft, you may lose spacecraft contact for days at a time. This requires more autonomy and a robust fault protection system. It also requires more time to send commands, verify them, and activate a spacecraft from a safe mode. RF round trip times are long (40 minutes at Mars and 8 hours at Jupiter). Critical events like a planet insertion maneuver only get one chance and require considerably more contingency planning and fault protection due to the RF round trip time.
Heritage	The large business base and commercial base have resulted in flight hardware designs, materials, fabrication processes, and test philosophies that have good heritage if they are backed by adequate reliability analysis and attention to test and flight problems.	There is little heritage carry-over from one planetary spacecraft to another. Some spacecraft components may have carry-over if used in the same application and manner and in addition are thoroughly reviewed.

Experience	There are numerous experienced companies that build scientific, military, and commercial spacecraft for Earth orbiting missions. There is continuous world wide activity in the Earth orbiting spacecraft business. This large business base allows for spacecraft bus designs to develop and to achieve an acceptable level of maturity.	There are few experienced companies with current planetary spacecraft experience. The long time periods between planetary missions and the long duration of the missions tend to dilute the experience base and does not attract top-quality contractor teams. An adequate numbers of subcontractors are available, but they require adequate planetary requirements.
Subcontractor Management	The subsystem providers have developed an adequate understanding of the requirements for Earth orbiting spacecraft applications. The large business base allows them to maintain an adequate staff of engineering personnel. This can allow JPL technical management teams to de-emphasize their penetration of the subcontractors and interface at a higher level.	The system contractors providing spacecraft systems lack the business base to maintain an adequate staff of experienced engineers to specify and develop the technical requirements for a planetary spacecraft. This requires JPL to implement a thorough definition phase and to support him in critical areas where he lacks experience.

JET PROPULSION LABORATORY
INTEROFFICE MEMO
3132-92-341-MN
8 June, 1992

To: SPAT, R Frauenholz, G Chin, F Salamone, R Gustavson
J Rose, R Zieger, T Adamski, C Cleven, R Stiver, R Salazar

From: M Nachman

Subject: **Mike Bay Memo: Lessons Learned from EP**

Attached, for your information, is a memo from Mike Bay entitled "Preliminary Launch Flow Lessons Learned from EP for TOPEX."

It is noted that EP (Explorer Platform) was successfully launched on Sunday, June 7.

cc. C. Yamarone

M Nachman

FAIRCHILD SPACE

Subject: PRELIMINARY LAUNCH FLOW LESSONS LEARNED FROM EP FOR TOPEX

To: Jim Brown, Brian Fischer, CHETTY, MOSHER, NAZIMIAN, LEE, SAMNSMAN, MITCHELL, JEYASUNDAR

From: Mike Bay

Date: 4 JUNE 1992

I have collected ~~a~~ some notes from our EP experience at KSC that might be of use to TOPEX. The following list in no particular order.

- To provide the maximum flexibility in contingency situations plan to keep one of the transmitters on radiating via the omnis for the first few days.
- Plan to use a TDRS command uplink at the launch site to provide the maximum link margin and noise immunity. STDN acquisition will not occur below -108 dBm where as TDRS will acquire down to -130 dBm providing an additional 20+ dB margin..
- Be sure contingency flow charts and procedures exist for activities inside the last 20 minutes before lift off.
- Configuration codes between the POCC and NASCOM should be tested with the spacecraft.
- Double check any separation analysis to be sure stowed mass properties were used. Examine the "fly out" trajectory of the PM and its thrusters and plume shields. Very tight clearances probably exist between the spacecraft and the umbilical bracketry mounted on the PAF. EP only had 0.050" clearance with a 3 sigma trajectory and a 0.14 degrees per second tip off rate. The ACS software should not start commanding wheels or thrusters until the spacecraft is clear of the PAF.
- Be prepared for ACS phasing problems by thinking through contingencies that would be used to stabilize the spacecraft.
- Onorbit activation timelines should be structured such that a loss of communication would not endanger the spacecraft. Maneuvers and major mode changes should be planned within gound contact.
- Simulations should be planned with failures or "green cards" to exercise procedures and the management team. Major contingencies are loss of communication, loss of OBC, failure to deploy the solar array and High Gain Antenna. These simulations can also exercise the POCCs data analysis capablity.
- Gyro data has proven invaluable for trouble shooting appendage deployment and operations problems. The POCC needs to be able to plot the Gyro data (Gyro differences) at the .512 second rate.
- The CMU B should be loaded with an executable memory image. Any patches and unique table loads should be in the memory at the time of launch so it is a "hot" backup.
- Umbilical retract contingencies have been a challenge. EP is launching with the PMP hardlines on so we can get telemetry immediately if the umblical is remated during a contingency.

FAIRCHILD SPACE

Subject: EP SYSTEM CONTINGENCIES 4/2/92

SUBSYSTEM	CONTINGENCY	TESTED	STATUS
	GENERAL		
	. Establish Communication		
	. Set aside Tape Recorder TU until Playback Possible		
	. Establish Spacecraft Attitude Position		
	. Establish Spacecraft Rates		
	. Establish Wheel Speed and Torques		
	. Establish Power status, PMON report		
	. Review Status Buffer		
C&DH	- Loss of command capability	Spacecraft	Yes
	- Loss of Downlink	Spacecraft	Yes
	- Switch to 1 KB from Normal 32 Kb	Spacecraft	S/C 4/22/92
	. Command Transmitter A on TDRSS PN codes on		
	. Command Non-Coherent Mode		
	. Select Engineering Data		
	. Select PMP Mode F		
	. GCMR/Reschedule TDRS for RHC/Mode 2		
	- OBC Halt during Launch	SDVF	Yes
	- Tape Recorder Failure (switch ops to redundant)	Spacecraft	Yes
	- Transponder Failure (switch ops to redundant)	Spacecraft	Yes
	- OBC Switch	Spacecraft	Yes
	- CMU Switch	Spacecraft	Yes
	- CU switch	Spacecraft	Yes
	- Leap Second	Spacecraft	Yes
MACS	- 2 Deg per second Tip off	SDVF	Yes
	- Switch to ACE B	Spacecraft	Yes
	- Update filter convergence using FSS plus FHST	SDVF	Yes
	- Command Inertial Mode without Update Filter	SDVF	S/C 4/22/92
	. Stop 1.3 RPO Roll		
	. Command Ground Control		
	. Send FDF Quaternion Update		
	. Allow auto transition for all flags		
	. Set ACQ_CONV_NUM to 0		
	- Update Filter Divergence	SDVF	Yes
	- Safe Point Mode Recovery	SDVF&S/C	Yes
	- Safehold Recovery	SDVF&S/C	Yes
	. Turn Wheel & Gyro FDC Off		
	- Component Failure		
	(switch and continue for CSS,Gyro)		
	(leave FHST off for a TAM failure as UFLTR switch, switch TAMs, command ground control if neither TAM is unknown)		
	(switch wheel and go to safehold)		
	(Power failed Torquer off and go)		
	(FHST failed s/w switch off, FSS on)		
	(RIU switch)		
	- Launch delay	SDVF	Yes
	- Sensor / Actuator Phasing problem	Paper Procedure	
	- CSS		
	- Gyro		
	- Wheel		
	- Torquer Bar		

MPS / ARRAY	- Array does not deploy (manual array deploy)	Spacecraft	Yes
	- One Solar Array Stuck	SDVF	No
	. Manually Command Pyros		
	. Use Solar Array Drives to Shake Arrays		
	- Power Emergency (Power Shed)	Spacecraft	Yes
SCCU / PED	- PED Module Power Failure	Spacecraft	No
	- SADE switch, PSM switch, S/A Drive motor change	Spacecraft	Yes
MAPS	- Reel Cycles	SDVF	Yes
	. Use RTS 19 to start deploy		
	- Failure to deploy (switch to B side)	Spacecraft	Yes
	- Delayed Deply (switch to UVACAL, turn on PLM CDP, start ION pumps, allow MAPS deploy during UVACAL. Enough data to safe Gimbals)		
PAYLOAD	- Cross Strap mode, RIU A to CDP B, RIU B to CDP A	Spacecraft	Yes
	- Failure to turn CDP On and get Ion Pumps on	Spacecraft	No
SOFTWARE	- COP failure and switch to B side	Spacecraft	Yes
	Power COP off during normal mode		
	- All FDC Off	SDVF	No
FOT	- Replan for MAPS deploy at MET 16 Hrs & FDF Calibration Slews Delay	Paper Plan	
	- Ground System Failure		
	- Precanned Tables		Yes

DIST: ALMAGUER
POWELL
KELLUM
CLEVEN
SALAZAR

JAMES W. FORTENBERRY

NOV 13 1991

JPL

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
5214-91-012
February 22, 1991

TO: A. J. Spear

FROM: J. F. Clawson James F. Clawson

SUBJECT: Magellan "Lessons Learned" for Reliability Engineering (Section 521)

REFERENCE: Note 270/AJS-91.787, "Magellan Lessons Learned", A. J. Spear to Distribution, January 4, 1991.

Attached are recommended inputs to the Magellan "Lessons Learned" (reference) from Section 521.

The reference has a suggested organization in terms of major sections, subsections, etc. This format was followed for these inputs. In other words there are paragraphs proposed for the Introduction, Developmental Lessons, Integration and Test Lessons, etc.

These inputs were developed by the various groups in Reliability Engineering. Per the reference, the first draft of the total Lessons Learned document is planned for June 1991. It is anticipated that a further review (and perhaps some refinement) of these inputs will occur after release of that draft.

Note that two key Lessons Learned are recommended for the Introduction section of the draft document. These relate to the high temperatures of most subsystems and the Rocket Engine Modules.

Concurrence: Tom Gindorf
T. E. Gindorf, Manager
Reliability Engineering Section

JFC:sw

cc: J. Arnett, J. Barengoltz, A. Beck, D. Boatman, A. Brejcha, R. L. Crabtree, T. E. Gindorf, Group 5214 personnel, M. Grossman, A. Hoffman, D. Kern, J. A. Koch, R. Kuberry, E. J. Marian, R. Miyake, G. Murphy, J. Plamondon, S. Potts, E. J. Roschke, J. Schlue, W. S. Shipley, M. Trummel

MAGELLAN LESSONS LEARNED - RELIABILITY ENGINEERING

1.0 INTRODUCTION

- **Key Lessons Learned**

Spacecraft High Temperatures

The high temperatures experienced by most Magellan subsystems, which may lead to early failures, may well be due to unanticipated increases in solar absorptance of the louver cover surfaces (Optical Surface Reflectors - OSR's). Fairly recent theoretical and experimental work by the Aerospace Corporation (references 1 & 2) shows the possibility that contaminants (organic molecules in particular) outgassed by the spacecraft and/or solar panels may have a higher probability of adhering to the OSR's than previously assumed. The idea is that, in the presence of ultraviolet light (i.e. sunlit surfaces), the molecules may break into more chemically active forms which adhere much more easily. These then photolyze (i.e. turn dark) and increase the solar absorptance of the OSR's. Adherence to the OSR's can even occur when the OSR temperature is greater than that of the outgassing surface, which is contrary to most condensation theories.

The apparent increase in solar absorptance for Magellan is generally global and appears greater than any seen previously in Earth orbiting spacecraft. This could be due to the greater ultraviolet energy at Venusian solar distances compared to Earth (about 2 solar constants).

A laboratory experiment duplicating known Magellan outgassing species and the higher ultraviolet energy is recommended.

See attachments 1 and 2 as well as references 1 & 2 for additional details.

REM High Temperatures

The Rocket Engine Module high temperature issue can be linked to several issues discussed in Attachment 1. The most important is that the normal JPL requirement of proof by retesting of any design fix was not followed. The System Thermal Vacuum Test identified the problem, but the fix was not verified by test due to cost/schedule considerations.

4.0 DEVELOPMENT LESSONS

- **System Design**

Inherited Designs: System choices must be part of trade-off studies and not just arbitrary or for non-technical reasons. A case in point is the decision to "inherit" the CDS (and

incidentally the AACS) which is too slow and small to process the radar data. The result was to force the inclusion of such a data processor in the radar design. The resulting crisis in development led to JPL taking the design in house to redo it resulting in considerable impact on schedules and added costs. It may have been better to design an upgraded CDS which would provide a new generation of computers for MGN and future missions.

- **Redundancy**

The occurrence of anomalies related to lack of isolation in cross strap arrangements points out the need for more detailed policy guidance in this regard. A case in point is the AACS where there is non-isolated cross strapping. Further, the requirement of careful design review at these interfaces should be part of the review criteria. This can be extended to all interface situations where propagation of failure effects can occur in such a way that further proper function is compromised or precluded.

One of the reasons for using redundance in computing is the need to recover from single event upsets or any other transient fault condition. The ability to switch to the standby unit is one means of compensation. The use of error detection and correction code (EDAC) is a form of redundance not requiring the lost time of switching and reinitializing and using a smaller bit reserve. As a minimum, spaceborn memories should have EDAC for SEU and related faults.

The case of incomplete redundance in the Magellan Tape Recorders used for data storage is another problem of implementation. For true redundance to exist each recorder must be capable of handling the full data storage load from scans between transmittal to earth. When a second unit must be used to complete the scans, there is no real redundance. This must be true at end of mission, so extra capacity must exist to account for degradation by wear of heads and tape.

- **Parts**

Use of Opticouple interface in Radar Sensor Subsystem led to the uncontrolled delay that forced use of a synchronous buffering to guarantee the +/-15 ns max required.

Prom - use of a non-radhard Prom led to SEU induced Latchup. The use of a thinner epilayer (11 to 6μ) reduced susceptibility to a tolerable level but required a major interaction with the part manufacturer.

54LS73 - mask misregistration caused device failure-to-operate in toggle mode. Pre-seal visuals plus adequate testing could have avoided the problem.

HM6504 - gate oxide breakdown and data retention at low temperature. Specification and test problem for user.

LM105 - Voltage regulator with ionic contamination produces a transient drop from 5 to 4.7 volts. The cause lies in the means of the test specified which is unable to detect the contamination effects.

TCC 244 - parts specification and test management problems.

1. Entrained moisture in cases.
2. Read disturb problem.
3. Burn-in circuits defective design.
4. Oxide breakdown
5. Power transient latchup

The TCC 244 problems were generally caused by the failure of specification coverage and inadequate review of test equipment design. The care in these elements of project performance should be part of enforced parts reliability discipline.

CD4053 - Lack of attention to operational sequences required to protect circuits led to H/W Damage. For example, the turn-on of support equipment, before flight (CDS) was turned on, caused Latch in CDS, etc. The FMEA should contain a section on operational sequence failure modes.

- **Grounding**

The existence of many EMI related anomalies and the subsequent failure review/analyses point out the need for a system level design policy/practice that will assure that cross talk or induced interference is an absolute minimum. Magellan inherited a good AACS design with respect to isolation since no signal and dc path could interact. At the interface to other systems the use of transformer isolation prevented a return path for transients floating on the ground. The contractor engineers used direct coupling at these points providing just such a path. The CDS was done the same way, with obvious results. The EMP susceptibility of these ground loops is enhanced and must be considered. EMP analysis should be considered for future projects.

The length of ground paths can be critical to timing in computer design. In the AACS installation, for example, some grounds had lengths measured in feet not inches. An attempt was made to improve timing. Phase shift prevented this approach from being an effective fix. Design review must be at the level of detail to look at cable and ground practices. Policy must exist and be enforced to prevent these non-standard practices.

It has been demonstrated in laboratory experiments that, upon ignition, the bridge wire in pyro devices can short to electrical ground. When this occurs a potentially harmful current surge is produced which can be propagated to sensitive circuitry. Methods to reduce the electrical noise effects from this source should be implemented. This was one of several sources considered as causes for Magellan anomalies but not verified.

All disengage electrical connectors on a spacecraft must be covered with a conductive lid. Transition through the Earth's radiation belts, during active periods, can result in charge accumulation. Transients from subsequent ESD events can be coupled to sensitive circuitry by means of exposed inactive conductors in cable bundles. While this was of concern, because of the high level of magnetic field activity during the launch phase, no anomaly was verified as being caused by this source.

The thermal blanketing on the spacecraft adapter and booster rocket must be adequately grounded to assure that unacceptable levels of surface charging will not occur. Visual inspection by a qualified EMC engineer should be made prior to launch.

- **Star Scanner**

Thermal blanketing made of Astroquartz was found to be a likely source of particulate contamination. Laboratory experiments have demonstrated that ultraviolet energy can cause minute particles of this material to be released from the surface. Low level electrostatic potentials on non-conductive surfaces, such as lenses, can attract these particles. Incident light striking the particles may have contributed to the anomalous behavior of the star tracker. The use of Astroquartz on spacecraft with optical devices should be prohibited.

Any detector containing solid state devices such as CCD's will be sensitive to cosmic rays and solar events. The sensitivity of the Star Scanner to solar flare protons should have been anticipated and measures should have been in place before launch to assure reliable attitude control during solar events. In the past we have tended to treat radiation as only a total dose problem - we will find more and more in the future that radiation presents operational problems due to Single Event Effects and detector interference long before dose becomes an issue.

- **Power**

The sun's behavior is statistical. Our observance of flares over a short 35 years or so is inadequate to give very reliable estimates of what a spacecraft may encounter and must design to. The Dao-Gibner/Feynman model showed that the concept of "anomalously large flare" had no basis statistically. New predictions for Magellan showed that the solar array had only a design margin of ~1. Subsequently Magellan experienced particle events which consumed much of its lifetime power margin early in the mission, lesson: the risk from solar event particles is real, our estimates involve a lot of error and low risk design demands adequate margin. There is no such thing as a "worst case" solar event.

- **Thermal**

External surface optical properties need proper inspection criteria to conclusively prove the desired values. The use of Iridite or (or Alodine) as an external structural surface conversion coating should be discouraged: Anodic coatings are preferred thermally. These two lessons relate to the SRM high temperatures early in the cruise phase: further discussion is in attachment 1.

Also see earlier discussions about Spacecraft high temperatures and the Rocket Engine Module and attachments 1 & 2.

- **Gyro**

Any Gyro used in a spacecraft should not have any questionable behavior characteristics. This is especially true of spin motor behavior in terms of thermal and power sensitivity,

vibration output levels, steadiness of power consumption, and related torque anomalies. Null uncertainty errors must be carefully specified and tested.

- **Subsystem Testing**

Subsystems involving complex thermal control elements should have developmental or protoflight Solar Thermal Vacuum testing at the subsystem level.

Assembly protoflight or flight acceptance thermal tests should be performed under vacuum conditions in order to achieve proper internal temperature rises.

Also see Attachment 1 relative to these two issues

With respect to assemblies and/or subassemblies inherited from, or shared with, other flight projects (e.g. Galileo CDS), independent assembly level EMC testing must be performed. It cannot be assumed that the other flight project will have completed EMC testing prior to installation on the spacecraft. The Magellan subassembly only received EMC testing at the system level.

5.0 INTEGRATION AND TEST LESSONS

- **End to End System Test**

S/C gimbal fixtures for System Thermal Vacuum tests should be designed for maximum altitude simulation flexibility. *See Attachment 1.*

Accelerometer instrumentation was poorly installed in several instances for the spacecraft system level acoustic test. JPL had only been able to review "cartoon" sketches of the installation prior to the tests. Many accelerometers were hidden by blankets, installed internally, etc: so were not visible while test was being run. Many of these measurements are used to validate assembly random vibration test levels. On MGN some problem accelerometer installations led to an erroneous conclusion (later discovered and corrected) that the radar sensor random vibration levels were inadequate. It is recommended that JPL be more actively involved in instrumentation of system hardware when performed by contractors.

8.0 SYSTEM CONTRACTING LESSONS

- **JPL Monitoring**

Set up environmental test and analysis tracking system with contractors early. It would amount to the applicable line of the Test and Analysis Configuration List for each assembly. Completion of this sheet (with waivers and PFRs and other applicable documents listed) would permit tracking of environmental programs progress and be usable for HRCRs and final consent to ship and launch reviews.

JPL was generally soft on the system contractor. We need stronger policy guidance from the lab to projects on the management of contractors in general. The lack of critical focus in the interface from project to contractor led to a diffuse sense of control. We are generally worried about being the nice guys and often to our deficit. Specific examples include the extremely late performance of worst case analysis, part stress analysis, thermal analysis, etc. The result has been many areas of anomalous behavior. By contrast, for HAC the JPL interface was quite strong and the same analyses were done earlier and in time to benefit design in most cases.

- **Writing the Contract**

Put Environmental Program Policies and Requirements (document) in the RFP. At least then the contractors equivalent processes can be documented and understood in the contract as part of the proposal and negotiations process.

- **Contractor to Contractor and JPL to Contractor Interfaces**

Get contractors to establish a single point of (environmental) contact. Current system contracts (and most companies) do not have the equivalent of an ERE requiring multiple contacts.

- **Subcontracts**

Thermal Control integration should remain the responsibility of the prime contractor. *See Attachment 1.*

REFERENCES:

1. Photo Enhanced Spacecraft Contamination, AIAA Paper 85-0953, D. F. Hall, T. B. Stewart, and R. R. Hayes

2. Photochemical Spacecraft Self-Contamination: Laboratory Results and Systems Impacts, AIAA Paper 88-2728, T. B. Stewart, G. S. Arnold, D. F. Hall, D. C. Marvin, W. C. Hwag, R. D. Chandler, and H. D. Marten.

3. IOM 5135-87-023, Trummel to Parker "New Magellan Radiation Environmental Estimate with Potential Impacts"

4. IOM 5137-87-294 Dao-Gibner to M. Trummel, "Reviewing 1-10 MeV solar Proton Fluence.

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
5214-90-36
April 3, 1990

TO: M. Trummel/J. Fortenberry

FROM: J. F. Clawson James F. Clawson

SUBJECT: Lessons Learned from MGN Ground Thermal Tests and Flight Experience

REFERENCES:

1) Telecons: J. F. Clawson & J. Neuman (MMAG) May 17, 1989, May 26, 1989, May 30, 1989, July 7, 1989, July 17, 1989, Aug. 16, 1989, Sept. 5, 1989, Sept. 25, 1989, Oct. 31, 1989, Nov. 7, 1989, Dec. 12, 1989, & Apr. 2, 1990

2) Telecons: J. F. Clawson & J. Plamondon Aug. 17, 1989& Oct. 31, 1989

3) MMAG MARS Report B16080 dated 12/15/88

SUMMARY

A review of the currently identified thermal issues from the Magellan mission to date is presented. There are eight lessons-learned from these issues. Five of these involve generally early programmatic decisions which precluded identification of thermal issues during the ground environmental test program. Two involve the use of surface conversion coatings and/or their inspection. The eighth involves assumptions about the degradation of optical properties due to contamination.

Perhaps the biggest lesson-learned is that transient thermal control design for multiple attitudes is difficult (at best) for Spacecraft missions inward from the Earth. The previous concept of 3-axis inertial S/C (e.g. Mariner 10) with a large solar shield is still easier and therefore better.

JFC/lc

cc:
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There have been three significant incidents thus far during the MGN cruise flight in which temperatures have exceeded predictions. These involve the Rocket Engine Module (REM), the Solid Rocket Motor (SRM), and the On Board Computer (OBC) in Bay 3. This IOM will discuss each of the three and identify lessons-learned that may be applicable to Mars Observer, TOPEX/Poseidon, and other future JPL Projects.

Most of the data on which this IOM is based came from the many telecons listed as references 1 and 2. It is believed that these lessons-learned reflect the consensus of the three parties involved: J. Neuman (MMAG Thermal Control), J. Plamondon (JPL MGN Div. 35 Representative) and this author.

Rocket Engine Module (REM):
Very early in the MGN flight, certain REM temperatures exceeded predictions by over 20° C. This caused changes in orientation to avoid overheating the REMs.

During the MGN System Thermal Vacuum Test (STV) in July, 1988, the REM exhibited a similar problem in that temperatures were about 25° C warmer than expected. The STV included only one attitude of any significance for the REM, sun on the +X side. This one attitude did not allow solar energy towards the inside the 2 large 100 1bf thrust engine nozzles. Another simulated attitude, sun on the +Y side, unfortunately gimbaled the REM assemblies outside of the solar beam.

The reference 3 MMAG MARS was written for the STV incident. The REM supplier, Rocket Research (RRC), used data from the one STV attitude along with their detailed thermal math model to propose a hardware fix to reduce REM temperatures. Their modification involved a thermal shield near the thermal standoff of the catalytic Bed/Thrust Chamber of the 100 1bf engines. Analytically this change looked promising and was implemented without any test verification. This violates one of the principals in closure of PFRs, namely that the fix passes the gate which caused the problem. The flight REMs were already installed on the S/C and there was no spare or developmental REM. There was no schedule or budget for a retest at the system level.

MMAG personnel (J. Neuman et al) have been diligently trying to find out why the RRC fix did not solve the problem identified in STV. Many theoretical issues have been addressed. The current thinking is that there are two key elements (in addition to nozzle entrapment of solar energy): The thermal model was simplified too much in the Catalytic Bed/Thrust Chamber region; and the optical properties of the bare metal 100 1bf engines supplied by RRC may be too low. Independent estimates performed by this author following receipt of the first flight data support the latter.

Other possible partial causes include better than anticipated thermal blanket performance, and solar entrapment by the small 0.2 lbs & 0.5 lb engines that was not demonstrated during STV.

Much of the above is somewhat speculative awaiting additional analyses and optical property test data. It is clear, however, that certain things should have been done differently to avoid the REM issue:

1) Thermal integration of the REM should have been the responsibility of the Prime Contractor, not the REM supplier. Math modeling deficiencies, oversimplification, optical property questions, etc. would then be resolved by an organization more knowledgeable in thermal issues.

2) A flight spare or developmental REM (or the first flight protoflight REM) should have been subjected to a series of solar thermal vacuum attitudes at the subsystem level. This would have provided early identification of the problem. Multiple attitude data would have allowed definition of the real issue, not just a possible source such as came out of the single STV attitude. No subsystem solar thermal testing existed for MGN due to early programmatic cost/schedule reasons. Propulsive element subsystem tests are usually hot-firings without regard to the solar thermal environment.

3) Given the lack of a REM subsystem solar thermal vacuum test, the System Thermal Vacuum test fixturing should have allowed much greater flexibility in attitude simulation (as originally planned). As noted above, more attitudes (especially sun towards the rear of 100 1bf nozzles) would have better defined the problem. This particular conclusion does carry a strong element of hindsight.

4) After the RRC fix was implemented, the normal JPL requirement of a retest should have been accomplished. Had a flight spare (or developmental) REM existed, such a retest would have easily shown that the problem was not solved.

Solid Rocket Motor (SRM) Temperatures:

Early in the MGN cruise, the upper SRM temperature measurement showed levels above those expected by up to 10° C. The mass (i.e. thermal inertia) of the SRM is very high, therefore, such relatively small differences are significant.

The current thinking is that the four brackets which tie the S/C to the IUS adapter structure have different optical properties than expected. After IUS separation, these brackets are in the sun. The brackets include a shear socket with a polished pin and a hole. Polished metal pins have an inherently high solar absorptance to infrared emittance ratio (α_s/ϵ_{ir}), generally 2 to 4 (or greater). The hole may cause unmodeled solar energy entrapment.

It was intended that the pins would be treated with a high emittance (but visually transparent) coating. The presence of such a coating could only have been verified during inspection by a direct measurement of emittance (which was not required).

One originally hypothesized source was the possibility that the bracket surfaces received an "Iridite" (or Alodine) surface conversion coating instead of the required Anodize treatment. The absorptance/emittance ratio (α_s/ϵ_{ir}) for anodic coatings is generally less than 1, whereas Iridite coatings have α/ϵ's of 2 to 8. This particular possibility has been disproven mathematically on the basis that the flight data deviations from expected levels would have been even more dramatic.

The problem is attitude dependent (similar to the REM) and only exists when the sun is essentially at the rear of the MGN spacecraft. The recent S/C attitude history has allowed the SRM temperature to return to expected levels.

SRM propellant coupon tests were performed at elevated temperatures (80° C), and any concern for the remainder of the SRM's function has been eliminated.

The bracket surfaces speculated as the source of the energy were covered by other ground structural support elements in the System Thermal Vacuum Test. Even if a tail-to-sun attitude had been simulated, the hypothesized coating optical properties would not have been observed.

The source of the SRM temperature issue appears to have been lack of proper detailed inspection definition for exposed surface optical properties. Careful coordination between thermal control engineers, manufacturing, and QA is recommended to avoid this in the future.

Another recommendation for future projects is to reject Iridite or Alodine as a normal aluminum alloy conversion coating (for corrosion protection purposes) especially for any external surface (whether blanketed or not). The known high solar absorptance-to-emittance ratio for these coatings always leads to concern of direct solar irradiation. It is recognized that other considerations (especially the cost of changing processes for certain system contractors) may complicate this recommendation.

<u>On-Board Computer (OBC-Bay 3)</u>:

To alleviate the REM high temperature issue, the MGN S/C attitude was changed such that the sun stayed on the +Y side for an extended period. This put Bay 3 (OBC) close to direct sunlight at distances from the sun of well under 1 astronomical unit (A.U.). Bay 3 is usually the highest power bay in the MGN S/C bus. The S/C thermal control design was not intended for steady state operation with the sun on this side inside .75 A.U., with End-of-Life (EOL) optical properties.

The bay 3 structural and OBC temperature measurements began to show levels some 15° C warmer than expected for this attitude. The speculated sources of this increase include degradation of the bay 3 Optical Surface Reflectors (OSRs) optical properties and math modeling uncertainties.

Initially, it was thought that only a very large increase in the OSR's solar absorptance (α_s) would explain the increase. However, more refined analyses (including some of the effects described later) show that an increase of α_s from the 0.10 Beginning-of-Life (BOL) level to only 0.16 will match the early flight data. Possible sources of this increase include basic Shuttle Payload Bay contamination, MGN S/C self contamination or several scenarios of Louver Cover (OSR) damage.

Theoretical work by Dr. J. Barengoltz (JPL Contamination Control Group) and this author suggests that contaminants in the Shuttle bay can explain an increase in α_s of 0.06 fairly easily. Similar effects could be expected from most S/C self-contaminants. One aspect of the theory implies that the degradation effect in α_s should occur almost immediately upon exposure to sunlight and that increases of the effect on OSRs with time may not be significant. Later flight data may prove or disprove this aspect.

More recently, flight data was obtained with the sun on the opposite side (-Y) of the S/C (inbetween times the sun was essentially on the High Gain Antenna or front of the S/C). The data matches quite closely predictions based on an α_s of 0.16 (the same as required to explain the Bay 3 Temperatures). This suggests a global effect such as might be expected with Shuttle or MGN S/C self-contamination.

Math modeling uncertainties examined for the Bay 3 OBC have included: OBC power higher than modeled; greater thermal interaction of the S/C bus with the S/C Aft end; greater interaction with the large shunt Radiators in the Forward Equipment Module (FEM); gaps in the thermal blankets around the bay 3 Louver; different thermal interactions with adjacent bays, and etc. The basic conclusion remains that the primary cause seems to be a degradation (increase) in the Bay 3 solar absorptance.

Other MGN Thermal Issues:

The Attitude Reference Unit (ARU) B Gyro 2 has been exhibiting some instabilities. There is some evidence that the temperature rises slightly every time the instability occurs (but then returns to normal). There has also been concern expressed that the Gyro temperatures are higher than expected. Based on the System Thermal Vacuum test data, these temperatures appear to be well within expected ranges. The ARU Flight Acceptance (FA) thermal cycle tests were apparently not conducted under vacuum conditions. The basic gyro units are hermetically sealed, so by themselves lack of vacuum is not particularly significant. However, heat transfer through all the interfaces of the ARU is affected by vacuum versus atmospheric test conditions. The presence of a gas (GN_2 or air) always increases heat transfer and results in smaller temperature gradients and cooler operating component temperatures. Thus the FA test measured rises would be less than flight vacuum conditions.

When the S/C was turned to sun on the -Y side recently, one of the battery temperatures fell to the low qualification level. This was not the result of a thermal control problem, but due to a software logic implementation that only monitors one of

the two batteries during flight. Modification of this logic to monitor both batteries, and thus turn on heaters based on the coldest of the two is under consideration.

Summary of the Lessons Learned:

- Thermal Control integration should remain the responsibility of the prime contractor.
- Subsystems involving complex thermal control elements should have developmental or protoflight Solar Thermal Vacuum testing at the subsystem level.
- S/C gimbal fixtures for System Thermal Vacuum tests should be designed for maximum altitude simulation flexibility.
- Thermal Control design changes must be verified by test, either at the subsystem or system level.
- External surface optical properties need proper inspection criteria to conclusively prove the desired values.
- The use of Iridite or (or Alodine) as an external structural surface conversion coating should be discouraged: Anodic coatings are preferred thermally.
- Degradation of S/C optical surfaces (especially critical OSR's) due to launch vehicle or S/C self contamination may be greater than currently assumed.
- Assembly protoflight or flight acceptance thermal tests should be performed under vacuum conditions in order to achieve proper internal temperature rises.

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Magellan Lessons learned

Set up environmental test and analysis tracking system with contractor early. It would amount to the applicable line of the Test and Analysis Configuration List for each assembly. Completion of this sheet (with waivers and PFRs and other applicable documents listed) would permit tracking of environmental programs progress and be usable for HRCRs and final consent to ship and launch reviews.

Get contractor to establish a single point of (environmental) contact. Current system contracts (and most companies) do not have the equivalent of an ERE requiring multiple contacts.

Put Environmental Program Policies and Requirements (document) in the RFP. At least then the contractors equivalent processes can be documented and understood in the contract as part of the proposal and negotiations process.

MAGELLAN - EMC LESSONS LEARNED

1. Thermal blanketing made of Astroquartz was found to be a likely source of particulate contamination. Laboratory experiments have demonstrated that ultraviolet energy can cause minute particles of this material to be released from the surface. Low level electrostatic potentials on non-conductive surfaces, such as lenses, can attract these particles. Incident light striking the particles may have contributed to the anomalous behavior of the star tracker. The use of Astroquartz on spacecraft with optical devices should be prohibited

2. It has been demonstrated in laboratory experiments that, upon ignition, the bridge wire in pyro devices can short to electrical ground. When this occurs a potentially harmful current surge is produced which can be propagated to sensitive circuitry. Methods to reduce the electrical noise effects from this source should be implemented. This was one of several sources considered as causes for Magellan anomalies but not verified.

3. All disengaged electrical connectors on a spacecraft must be covered with a conductive lid. Transition through the Earth's radiation belts, during active periods, can result in charge accumulation. Transients from subsequent ESD events can be coupled to sensitive circuitry by means of exposed inactive conductors in cable bundles. While this was of concern, because of the high level of magnetic field activity during the launch phase, no anomaly was verified as being caused by this source.

4. With respect to assemblies and/or subassemblies inherited from, or shared with, other flight projects (e.g. Galileo CDS), independent assembly level EMC testing must be performed. It cannot be assumed that the other flight project will have completed EMC testing prior to installation on the spacecraft. The Magellan subassembly only received EMC testing at the system level.

5. The thermal blanketing on the spacecraft adapter and booster rocket must be adequately grounded to assure that unacceptable levels of surface charging will not occur. Visual inspection by a qualified EMC engineer should be made prior to launch.

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
5217-91-44

January 15, 1991

TO: J. Clawson (301-466)

FROM: G. Murphy

SUBJECT: Magellan Lessons Learned

REFERENCES:
1) IOM 5135-87-023, Trummel to Parker "New Magellan Radiation Environmental Estimate with Potential Impacts."

2) IOM 5137-87-294, Dao-Gibner to M. Trummel, "Reviewing 1-10 MeV Solar Proton Fluence.

There are two specific lessons learned, one regarding the environment and our ability to estimate it, and the other regarding our investigation of subsystems sensitive to upset by particles.

1. The sun's behavior is statistical. Our observance of flares over a short 35 years or so is inadequate to give very reliable estimates of what a spacecraft may encounter and must design to. The Dao-Gibner/Feynman model showed that the concept of "anomalously large flare" had no basis statistically. New predictions for Magellan showed that the solar array had only a design margin of ~1. Subsequently Magellan experienced particle events which consumed much of its lifetime power margin early in the mission, lesson: the risk from solar event particles is real, our estimates involve a lot of error and low risk design demands adequate margin. There is no such thing as a "worst case" solar event.

2.) It is our responsibility in division 52 to assure reliability in S/C design. Any detector containing solid state devices such as CCD's will be sensitive to cosmic rays and solar events. The sensitivity of the Star Scanner to solar flare protons should have been anticipated and measures should have been in place before launch to assure reliable attitude control during solar events. In the past we have tended to treat radiation as only a total dose problem - we will find more and more in the future that radiation presents operational problems due to Single Event Effects and detector interference long before dose becomes an issue.

GM/jc

cc: T. Gindorf 301-456
E. Marian 301-456

ATTACHMENT 2

JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM
5214-90-99
November 6, 1990

TO: T. E. GINDORF

FROM: J. F. CLAWSON

SUBJECT: Effects of Higher-Than-Anticipated Temperatures on the Equivalent Life of Magellan Electronics

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SUMMARY

An evaluation of the temperatures experienced during the Magellan (MGN) mission to date, plus the expected temperatures during the "first extended mission" has been made. These have been correlated to the Voyager temperature experience, and a series of "equivalent life" ratios for piece part functions developed based on Arrhenius theory. The integral of these ratios represents a measure the extra "life" exposures of part junctions to date for MGN and the extra "life" exposure expected during the first extended mission.

The CDS and most of the power subsystem assemblies have seen the equivalent of about 1.2 (up to 3.1) years exposure in excess of the actual ≈ 1.5 years mission time to date (compared to equivalent Voyager experience for the same mission time). These same assemblies are expected to see ≈ 7 to 10 years equivalent life exposure in excess of the actual mission time for the first extended mission (about 8 months long). Mapping attitude sequence changes under consideration might reduce these to the 5 to 6 year range. The second extended mission should not be as severe.

INTRODUCTION

The Magellan (MGN) flight temperatures to date have been higher than anticipated. They are expected to reach even higher levels during the first extended mission. An evaluation of the effects of these high temperatures on spacecraft electronics has been made and is presented.

This report consists of several sections. These include flight data presentation, rationale for higher-than-anticipated temperatures, first extended mission predictions, excess equivalent life estimate approach (including junction temperature rise evaluation), a results section, and conclusions.

MAGELLAN/VOYAGER FLIGHT DATA

Flight data from the Magellan bus bay shearplates are shown in the attached Figures 1 thru 10 (for bays 1 thru 10 respectively). Figures 11 and 12 are the two measurements for the radar in the

Forward Equipment Module (FEM). This data was supplied by Mr. Joe Buescher of Martin/Denver on October 23, 1990. It is based on the daily mean values and thus misses certain peaks such as occurred during a four hour period at Venus Orbit Insertion (VOI). A summary of maximum long term values (and short term VOI levels where applicable) is shown in Table 1.

Voyager experience was essentially near room temperature (25°C ± 5°C) for most of its 10 bays for most of its 13 year mission to date. This is shown in Table 2.

Referring back to Table 1 and Figures 1 thru 10, many MGN bays have exceeded room temperature significantly (up to 60°C for Bay 10). The purpose of the evaluation reported in this IOM is to determine the excess equivalent life used by MGN to date compared to Voyager, and to estimate future effects on equivalent life.

RATIONALE FOR HIGHER MGN FLIGHT TEMPERATURES

The MGN mission profile requires transient and steady state exposures of most bays to a solar environment of ≈ 2 suns as well as reflected solar from Venus approaching a peak value in excess of 1.5 suns. The thermal control design of MGN (or any spacecraft) cannot accommodate these environments and maintain temperatures of 25°C (a la Voyager) without a significant increase in each bay's radiator/louver area. Thus, MGN was expected to be warmer than Voyager but not to the extent seen thusfar during its mission.

The most popular theories as to why MGN is warmer than expected tend to revolve around contamination of the Louver Cover surfaces. The Shuttle payload bay is known by JPL's contamination group (Dr. Jack Barengoltz in particular) to be "dirty" in terms of both particulates and organic molecules. Another source may be the MGN spacecraft itself, the solar panels in particular. During the TOPEX solar panel qualification test (which included about 120 hours at 106°C), significant outgassing and deposition of various bonding adhesives took place. The flight MGN solar panels only accumulated about 22 hours at 130°C, during their thermal vacuum acceptance test (which occurred over a year before the TOPEX qualification test). The same vendor (Spectrolab) is involved and the bonding adhesives are similar.

The basic concept is that continued ultraviolet exposure on deposited contaminates (organic compounds in particular) leads to continued breakage of chemical bonds which results in higher absorption. This trend could theoretically continue, slow, stop, (or perhaps reverse due to re-emission) but there is nothing in the flight data to indicate this yet. Two key unknowns are whether the MGN spacecraft is still outgassing, and whether or not the photolysis of the already deposited contaminates is complete or not.

The expected solar absorptance of the MGN louver covers was about 0.11 at start of mission and 0.16 at end of mission. However, data from bay 3 after only ≈ 4 months implied the absorptance was already up to 0.16. Currently, the data from most bays implies an absorptance of about 0.21 or more. Martin/Denver personnel have extrapolated the absorptance up to 0.25 (or more) for the peak of the first extended mission (about 9 months after VOI).

PREDICTIONS FOR MGN FIRST EXTENDED MISSION

Martin/Denver is still in the process of correlating certain portions of their thermal math model. However, Joe Buescher was kind enough to provide recent estimates for the first extended mission. He also provided estimates as to what changes would result from ongoing correlation efforts. The peak expected levels by bay, are shown in Table 1. The CDS and Power bays reach levels of ≈ 70°C to 78°C (again at the bay shearplate).

Temperatures above room temperature (i.e. 25°C) are expected to start about 100 days before the end of the primary mission and continue throughout the 243 day extended mission. This is shown pictorially for the CDS in Figure 13.

It must be noted that all these estimates are based on the assumption that the currently planned attitude timeline will be flown. Thermal issues (such as these high temperatures) thermal cycling concerns, Rocket Engine Module temperatures, and other mission constraints could result in different attitudes which could in turn result in different predictions.

Also note that these estimates include the assumption of solar absorptance having degraded to the 0.25 (or more), vicinity. As noted previously, the degradation might not be this severe.

EXCESS EQUIVALENT LIFE EVALUATION APPROACH

Most known wear-out mechanisms for electronic piece-parts (and other electronic assembly elements) can be mathematically described with the Arrhenius reaction rate equation as follows:

$$\lambda_{\frac{T_1}{T_{ref}}} = \bullet^{\frac{-E_a}{K}\left[\frac{1}{T_1} - \frac{1}{T_{ref}}\right]} \qquad (1)$$

where: $\lambda_{\frac{T_1}{T_{ref}}}$ is the reaction rate ratio at T_1 (in K) compared to a reference temperature (T_{ref} in K). This ratio can be integrated over time-at-temperature to provide a measure of the excess equivalent life used, compared to any given reference.

Ea is the activation energy for the mechanism of interest (in electron volts). For this study, Ea was assumed to be 0.7 e_v which is thought to be representative of an

average for most parts.

T_1 is the part junction temperature at any time of interest (in degrees Kelvin). T_{ref} is the part junction temperature of any desired reference. For this study, where Voyager is the reference, T_{ref} = 25 + 35 + 273 = 333K (60°C) (see below).

Junction Temperature Rise:

A brief study of electronic assemblies' temperature rise from shear plate to part internal junction was made for both VGR and MGN.

The normal JPL junction limit of 110°C is thought to have been more rigorously applied to VGR than MGN (with the exception of the Power subsystem). The VGR environmental program was very rigorous in requiring engineering subsystem electronics to be tested at a shearplate temperature of 75°C. Thus, the rise from shearplate-to-junction was generally limited to 35°C (i.e. 110°C - 75°C = 35°C).

The MGN program was somewhat less rigorous in both environmental test levels (i.e. some assemblies were tested at 65°C instead of 75°C), and junction temperatures were allowed to exceed 110°C in some cases. The MGN bays of interest (those that have exceeded 25°C significantly) include bay 3 (the On-Board Computer - basically the Galileo Attitude and Articulation Control Subsystem), Bay 7 (Command Data Subsystem - also Galileo hardware), and bays 8, 9 & 10 which are power subsystem elements. The qualification test level for all of these assemblies was 75°C (except for the shunt regulator in Bay 10 which was qualified at 80°C. Analyses are available for all of these assemblies and the temperature rises (shearplate-to-junction) are as follows:

Bay 3 (OBC - aka AACS):
Most Parts, ΔT = 25°C to 35°C
36 parts, $\Delta T \approx$ 45°C (Max = 48°C)

Bay 7 (CDS):
Most Parts, ΔT = 25°C to 35°C
some (few) parts, $\Delta T \approx$ 45°C

Bay 8, 9 & 10 (Power):

Low Power & Digital Parts, ΔT = 25°C to 35°C
High Power Transistors, $\Delta T \approx$ 45°C (50°C max)
Note that the junction limit for high power transistors in power subsystems is usually 125°C (versus the normal 110°C). Since these subsystems have not changed much

since VGR, it is assumed that both VGR and MGN used this higher derating limit.

The intent of this evaluation was to look at overall spacecraft equivalent life, not individual piece parts. Therefore, based on the above numbers, an average rise of 35°C shearplate-to-junction was assumed for both VGR and MGN. Since VGR operated at essentially room temperature (i.e. 25°C, see table 2), this assumption led to a reference junction temperature of 60°C (333K) (i.e. 25°C + 35°C = 60°C) for the Arrhenius reaction rate evaluation (equation 1).

RESULTS

The temperature vs. time flight data curves for the MGN bays with significant exceedances of 25°C (Figures 3, 7, 8, 9, & 10) were substituted into equation 1. These were then integrated (using a simple trapezoidal rule) to obtain excess equivalent life over and above the Voyager experience at 25°C. The effects of temperatures below 25°C were ignored since recent reliability expert opinion indicates that the Arrhenius relationship may not be valid at levels below about room temperature for electronic piece part junctions. In addition, such effects would be very minor compared to the high temperature exposure just due to the nature of equation 1.

Results are shown in Table 3. Excess equivalent life exposures to date range from only 0.6 years (Bay 3, OBC) to about 3 years for the shunt regulators in Bay 10.

The estimates for the first extended mission (from Joe Buescher, Martin/Denver) were integrated in a similar manner. Curves having the same shape as Figure 13, but for the different maximum values shown in Table 1 were used. These results are very dramatic as seen in Table 3. **The excess equivalent life exposures expected range from 7 to about 10 years.**

A similar integration for Bay 10 thru just the end of the primary mission (day 733 of Figure 13) yields up to about 1.4 years excess equivalent life beyond the 3.1 years excess already seen to date.

Martin/Denver is considering modified mapping attitudes for the hottest regions of the first extended mission. These could result in a 10°C reduction from the levels shown in Table 1 and Figure 13. The excess equivalent life exposure would be reduced to about 5 to 6 years (versus the 7 to 10 years above) if implementation were possible.

CONCLUSIONS

A method of comparing MGN high temperature exposures to the VGR experience base has been developed. It is based on the Arrhenius

reaction rate equation applied to electronic piece-part junction temperatures.

To date the excess equivalent life exposure ranges from about .6 years to ≈ 3 years. However, the first extended mission may use up 7 to 10 years of equivalent life. Modified mapping attitude sequences under consideration at Martin/Denver might reduce these very large exposures to about 5 to 6 years.

JC:sw

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TABLE 1: MGN FLIGHT TEMPERATURES (°C)

BAY	EQUIPMENT	FLIGHT TO DATE MAX SHORT TERM @ VOI	FLIGHT TO DATE MAX LONG TERM	1ST EXTENDED MISSION MAX LONG TERM EXPECTED (CYCLIC AVERAGE WHERE APPLICABLE)	
1	SA DRIVE ELECT.	≈ 51	≈ 32	≈ 34	
2	IODA	≈ 35	≈ 33	≈ 24	
3	OBC (AACS)	-	≈ 50	≈ 35	
4	DMS B	--	≈ 35	≈ 23	
5	DMS A/PORTION OF CDS	--	≈ 15	≈ 23	
6	EMPTY	--	12	--	
7	CDS	≈ 50	≈ 50	≈ 70	RESULTS FROM CURRENTLY PLANNED ATTITUDES
8	PWR (PRE REG, RELAY BD)	≈ 55	≈ 55	≈ 76	
9	PWR (PDU, FUSE BD, INVERTER, PYRO SWITCH)	≈ 68	≈ 55	≈ 72	OTHER OPTIONS BEING EXAMINED TO REDUCE THESE LEVELS
10	PWR (SHUNT REGULATORS)	≈ 75	≈ 60	≈ 78	

NOTE: ALL TEMPERATURES ARE AT THE SHEARPLATE OF THE RESPECTIVE BAY

TABLE 2: VOYAGER BUS SHEARPLATE FLIGHT DATA - °C

BAY/EQUIP	LAUNCH 0 DAYS	NEAR EARTH ≈100 DAYS	JUPITER ≈700 DAYS	SATURN ≈1500 DAYS	URANUS ≈3100 DAYS	NEPTUNE ≈4300 DAYS
1/RFS	32	30	36	30	27	27
2/DSS	30	26	27	23	23	21
3/CCS	31	26	23	21	20	19
4/FDS	27	23	20	19	18	17
5/HYPACE	29	28	28	27	26	26
6/DRIRU	31	29	33	33 (CYC 26/34)	32 (CYC 24/33)	25 (CYC 24/32)
7/PWR	32	30	30	29	28	28
8/PSU	26	24	23	21	20	21
9/RFS	26	25	26	24	23	23
10/MDS/MAG	27	25	27	25	25	24

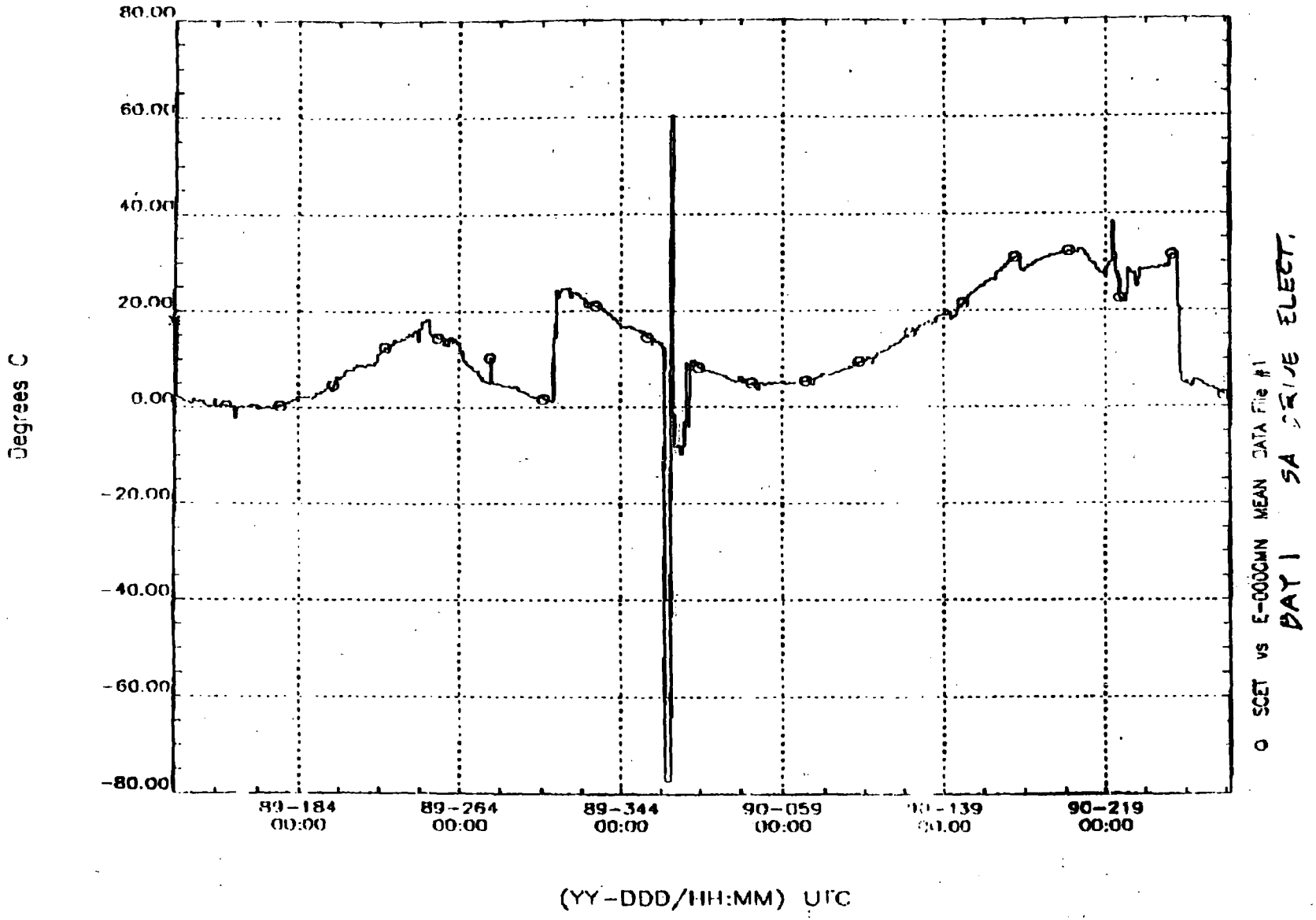
JFC 12/7/89

TABLE 3: MGN EXCESS EQUIVALENT LIFE DUE TO HIGH TEMPERATURE EXPOSURE (COMPARED TO VGR EXPERIENCE)

BAY	EQUIPMENT	FLIGHT TO DATE	END PRIMARY & FIRST EXTENDED MISSION
1	SA DRIVE ELECT.	NON SIGNIFICANT	NON SIGNIFICANT
2	IODA	NON SIGNIFICANT	NON SIGNIFICANT
3	OBC (AACS)	0.6 YEARS	NON SIGNIFICANT
4	DMS B	NON SIGNIFICANT	NON SIGNIFICANT
5	DMS A/PORTION OF CDS	NON SIGNIFICANT	NON SIGNIFICANT
6	EMPTY	N/A	N/A
7	CDS	1.2 YEARS	**6.8 YEARS**
8	PWR (PRE REG RELAY BD)	2.1 YEARS	**9 YEARS**
9	PWR (PDU, FUSE BD, INVERTER, PYRO SWITCH)	2.2 YEARS	**7.5 YEARS**
10	PWR (SHUNT REGULATORS)	3.1 YEARS	**10.5 YEARS**

E-0000

FIGURE 1, MGN BAY 1

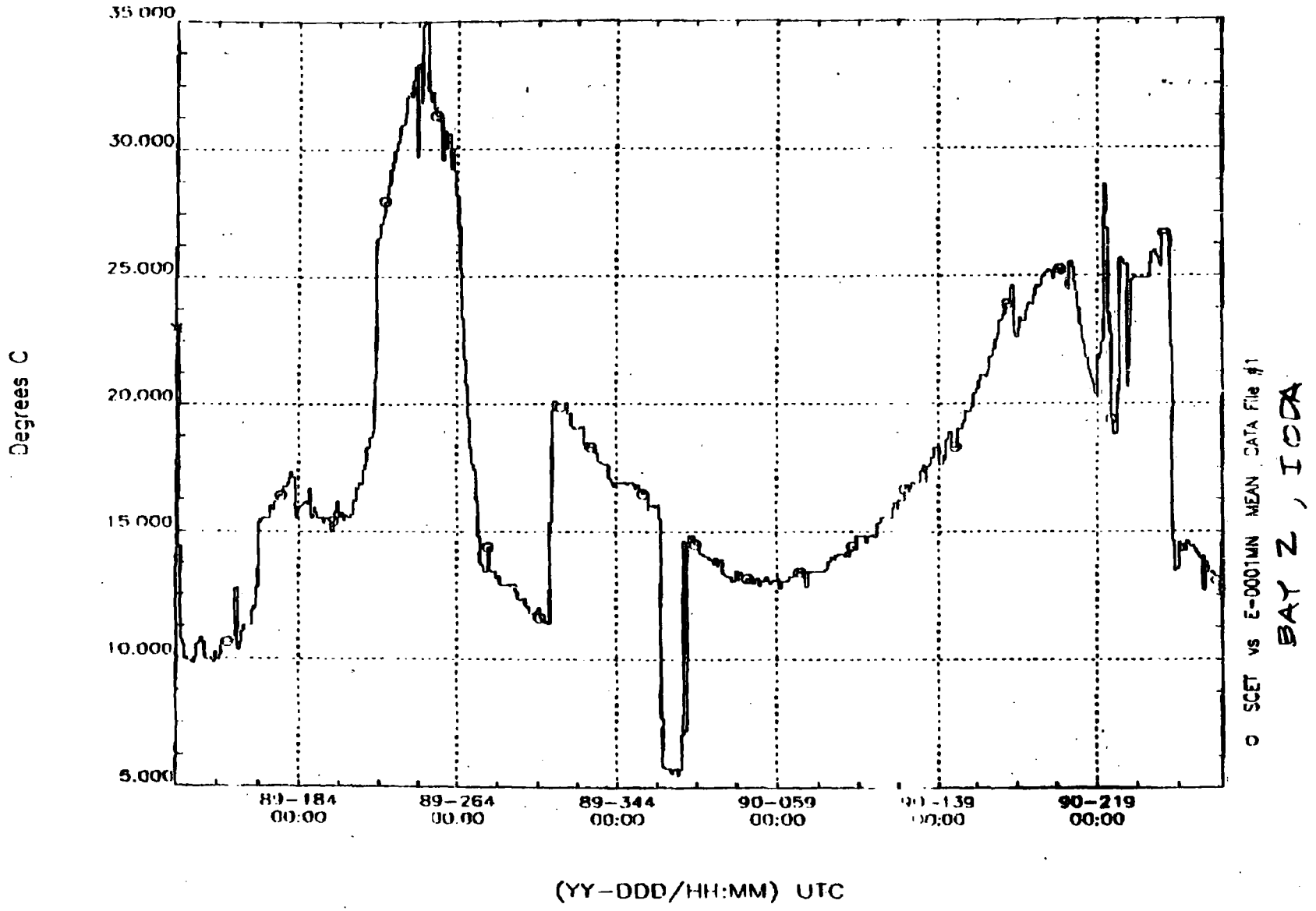


DATE: Tue Oct 23 18:24:06 1990
DATA File Number 1: E-0030.trend Tue Oct 9 21:07:09 1990
VMPLOT CPCI REV003 11/17/89

File #1 * Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E -0001

FIGURE 2, MGN BAY 2

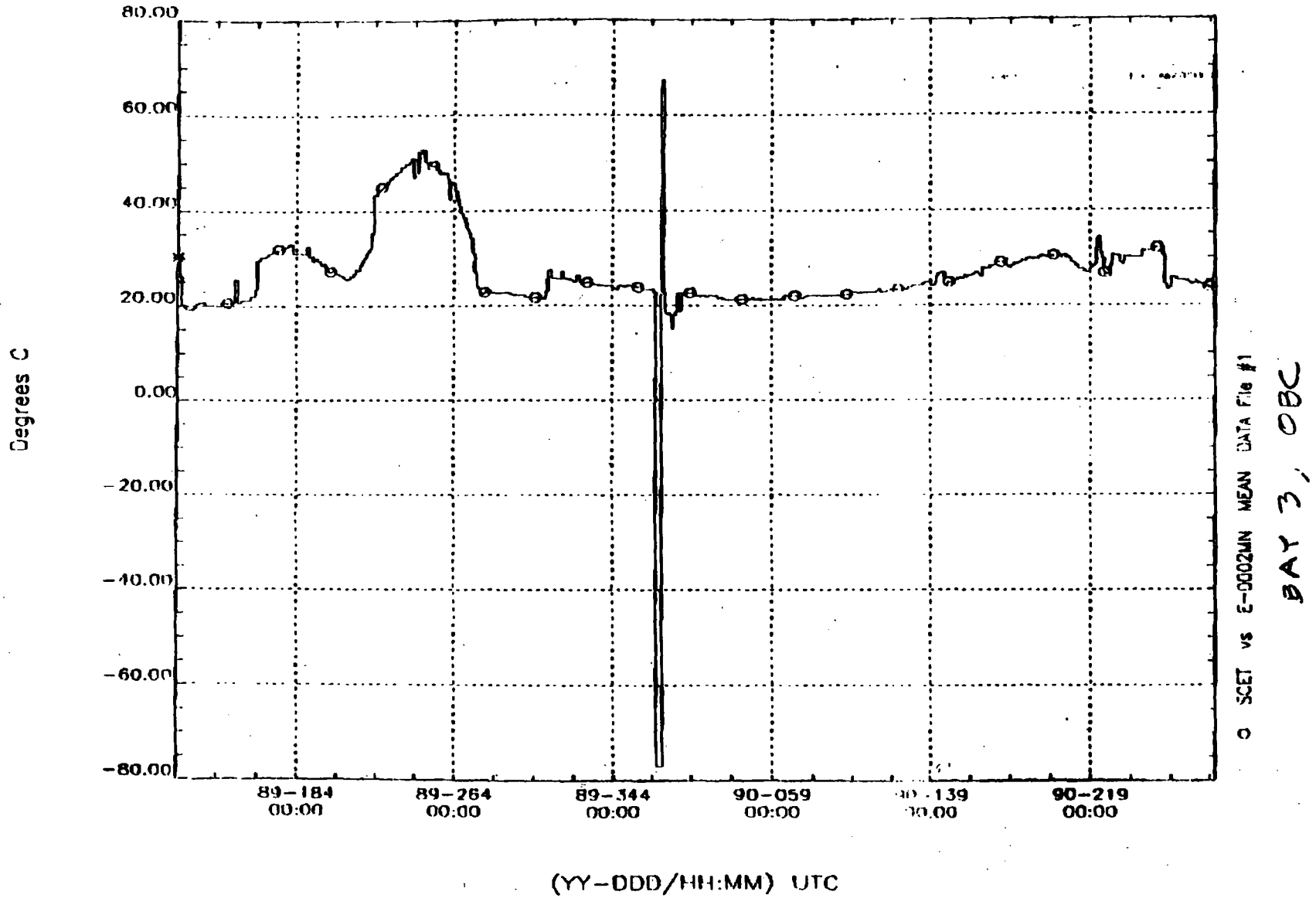


DATE: Tue Oct 23 18:24:38 1990
DATA File Number 1: E-0001.trend Tue Oct 9 21:07:11 1990
VMPLOT CPGI REV003 11/17/89

File #1 x Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0002

FIGURE 3, MGN BAY 3

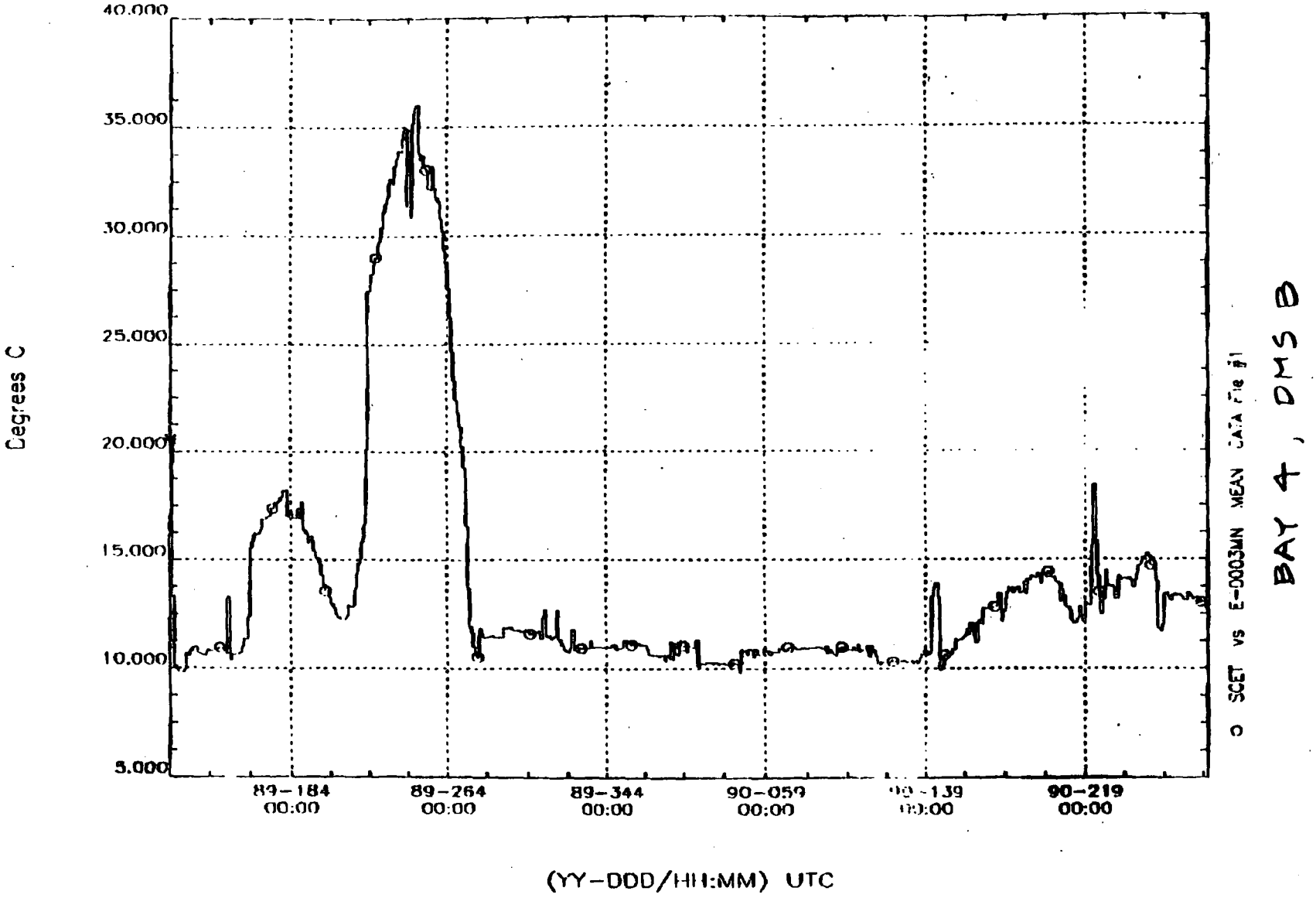


DATE: Tue Oct 23 18:25:04 1990
DATA File Number 1: E-0002.trend Tue Oct 9 21:07:13 1990
VMPLOT CPGI REV003 11/17/89

File #1 * Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0003

FIGURE 4, MGN BAY 4

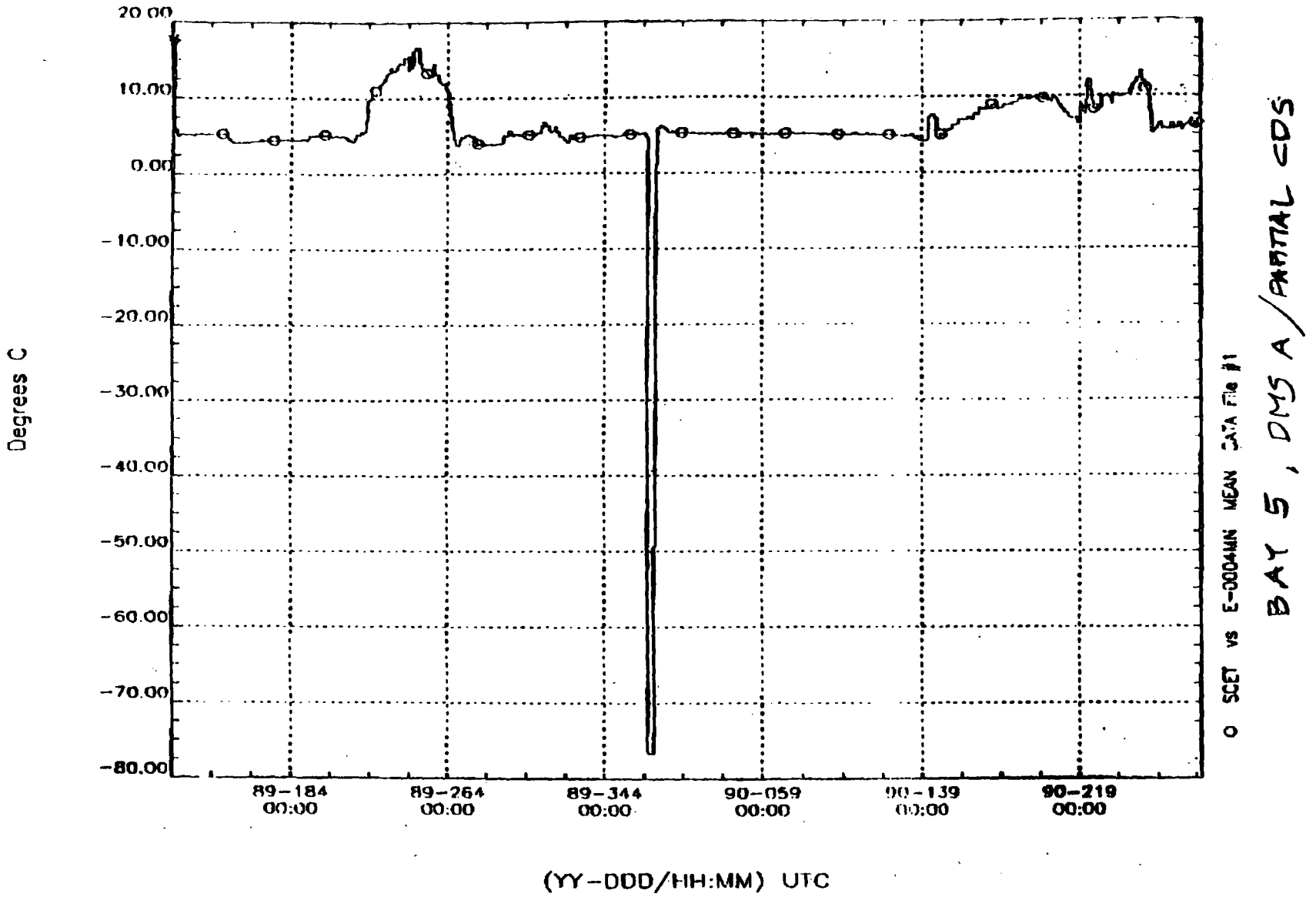


DATE: Tue Oct 23 18:25:31 1990
DATA File Number 1: E-0003.trend Tue Oct 9 21:07:15 1990
VMPLOT CPCI REV003 11/17/89

File #1 * Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0004

FIGURE 5, MGN BAY 5

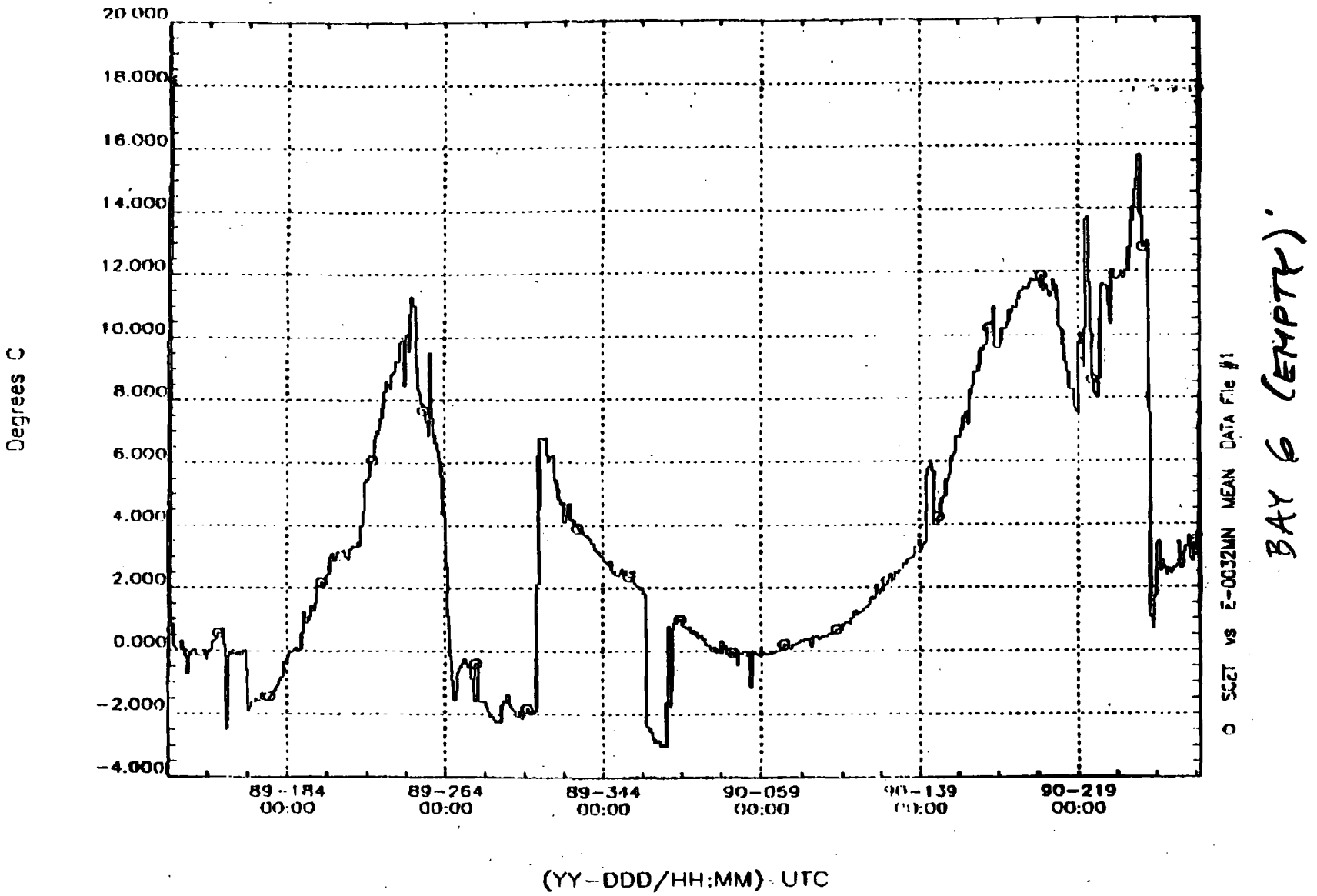


DATE: Tue Oct 23 18:25:58 1990
DATA File Number 1: E-0004.trend Tue Oct 9 21:07:17 1990
VMPLOT CPCI REV003 11/17/89

e #1 ■ Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0032

FIGURE G, MGN BAY 6

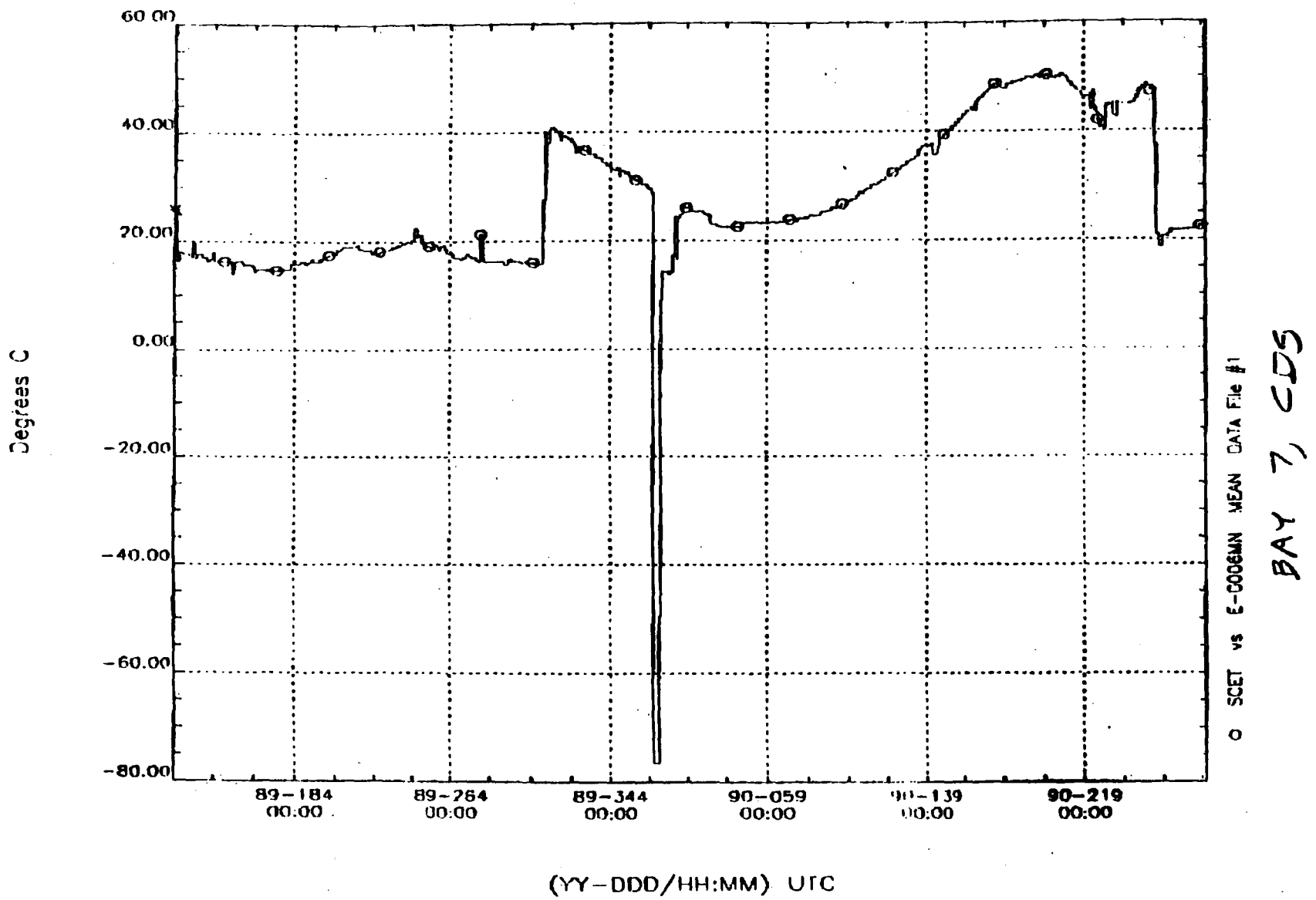


DATE: Tue Oct 23 18:26:25 1990
DATA File Number 1: E-0032.trend Tue Oct 9 21:08:17 1990
VMPLOT GPCI REV003 11/17/89

File #1 * Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0006

FIGURE 1, MGN BAY 7



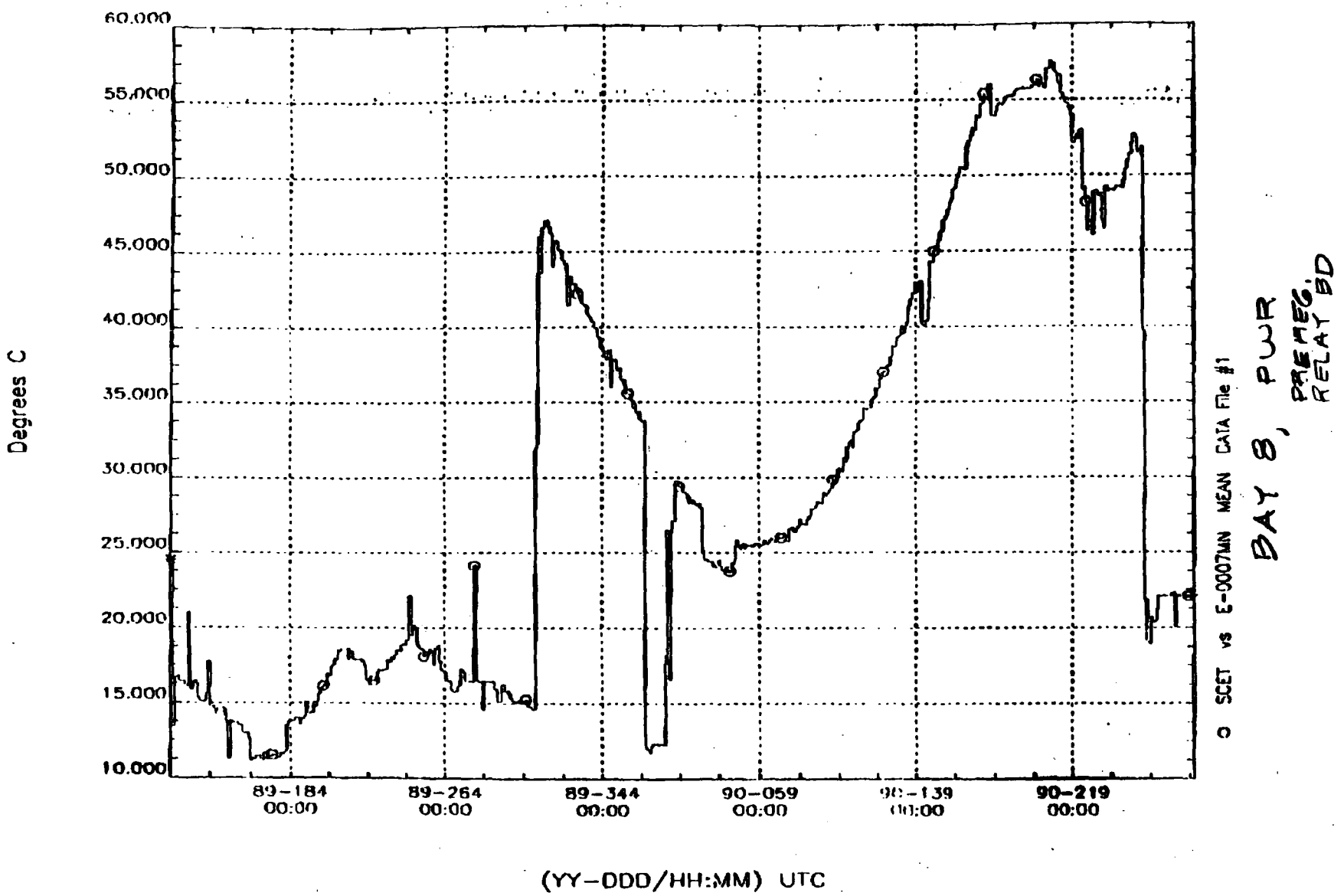
BAY 7, CDS

DATE: Tue Oct 23 18:26:52 1990
DATA File Number 1: E-0006.trend Tue Oct 9 21:07:19 1990
VMPLOT CPCI REV003 11/17/89

File #1 ■ Start Time: 89-124/00:02:01.327
♦ End Time: 90-280/00:53:25.800

E-0007

FIGURE 8, MGN BAY 8

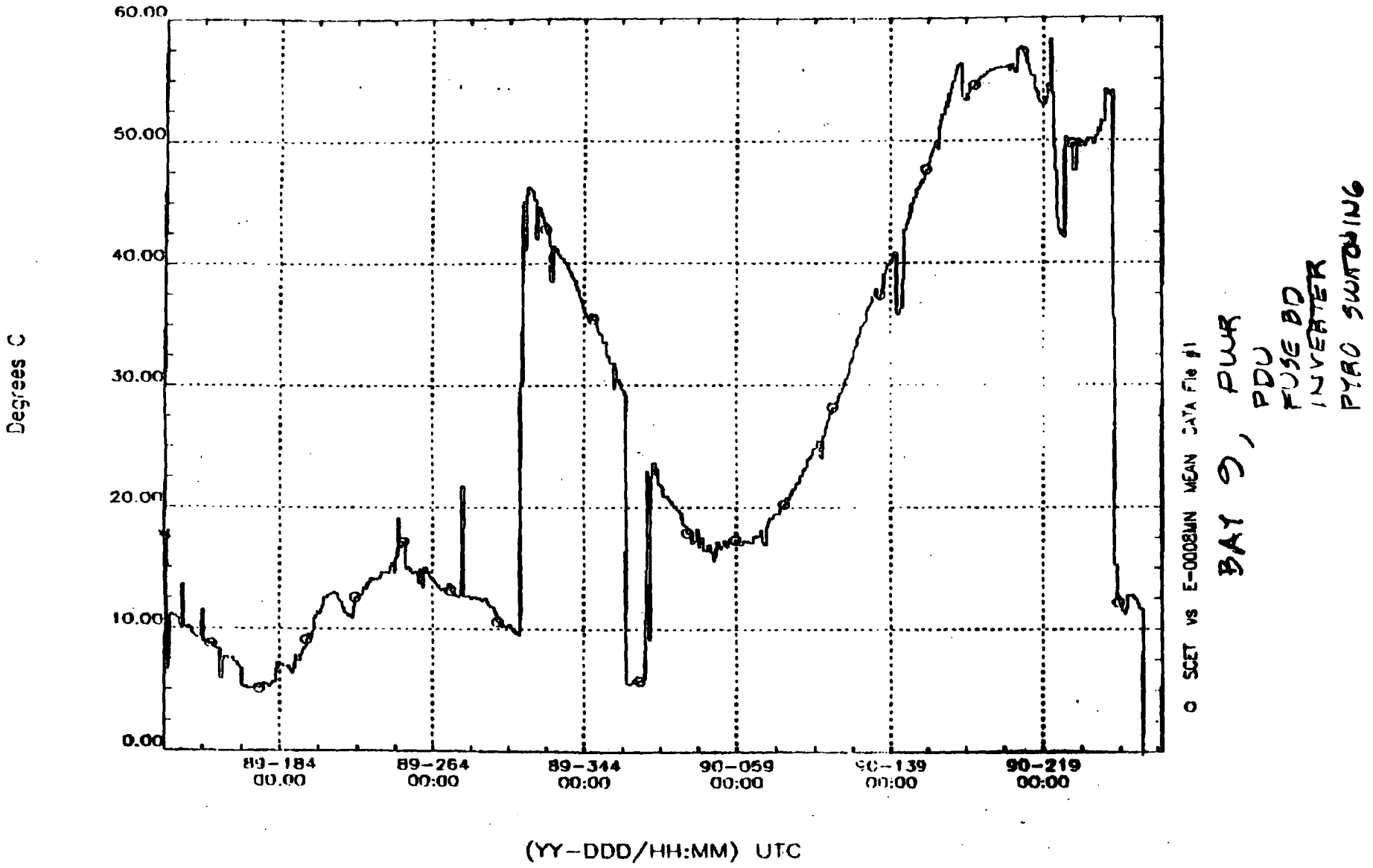


DATE: Tue Oct 23 18:27:19 1990
DATA File Number 1: E-0007.trend Tue Oct 9 21:07:21 1990
VMPLOT CPCI REV003 11/17/89

File #1 ✱ Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0008

FIGURE 9, MGN BAY 9

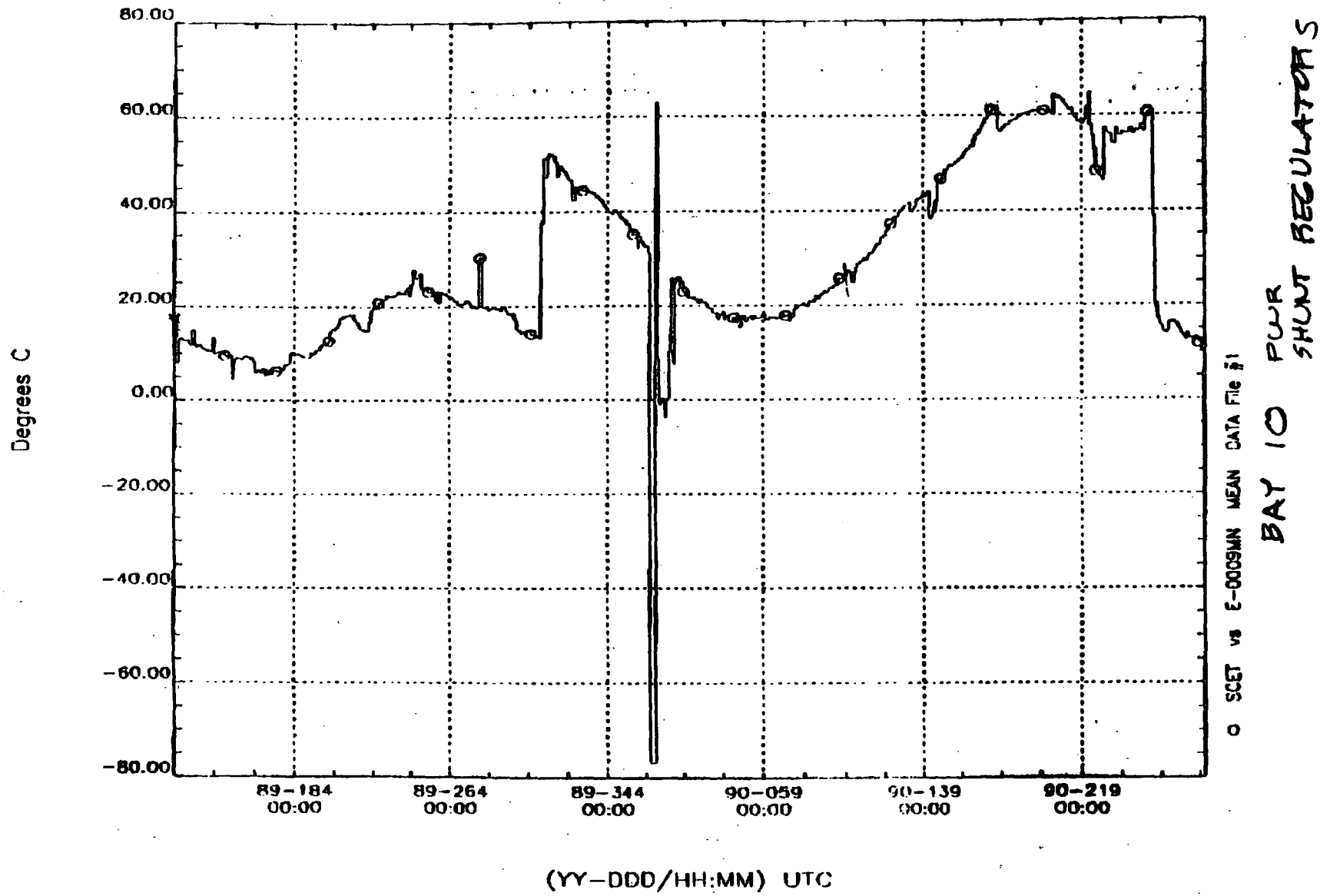


DATE: Tue Oct 23 18:27:47 1990
DATA File Number 1: E-0008.trend Tue Oct 9 21:07:23 1990
VMPLOT CPCI REV003 11/17/89

File #1 * Start Time: 89-124/00:02:01.327
+ End Time: 90-271/00:55:02.324

E--0009

FIGURE 10, MGN BAY 10

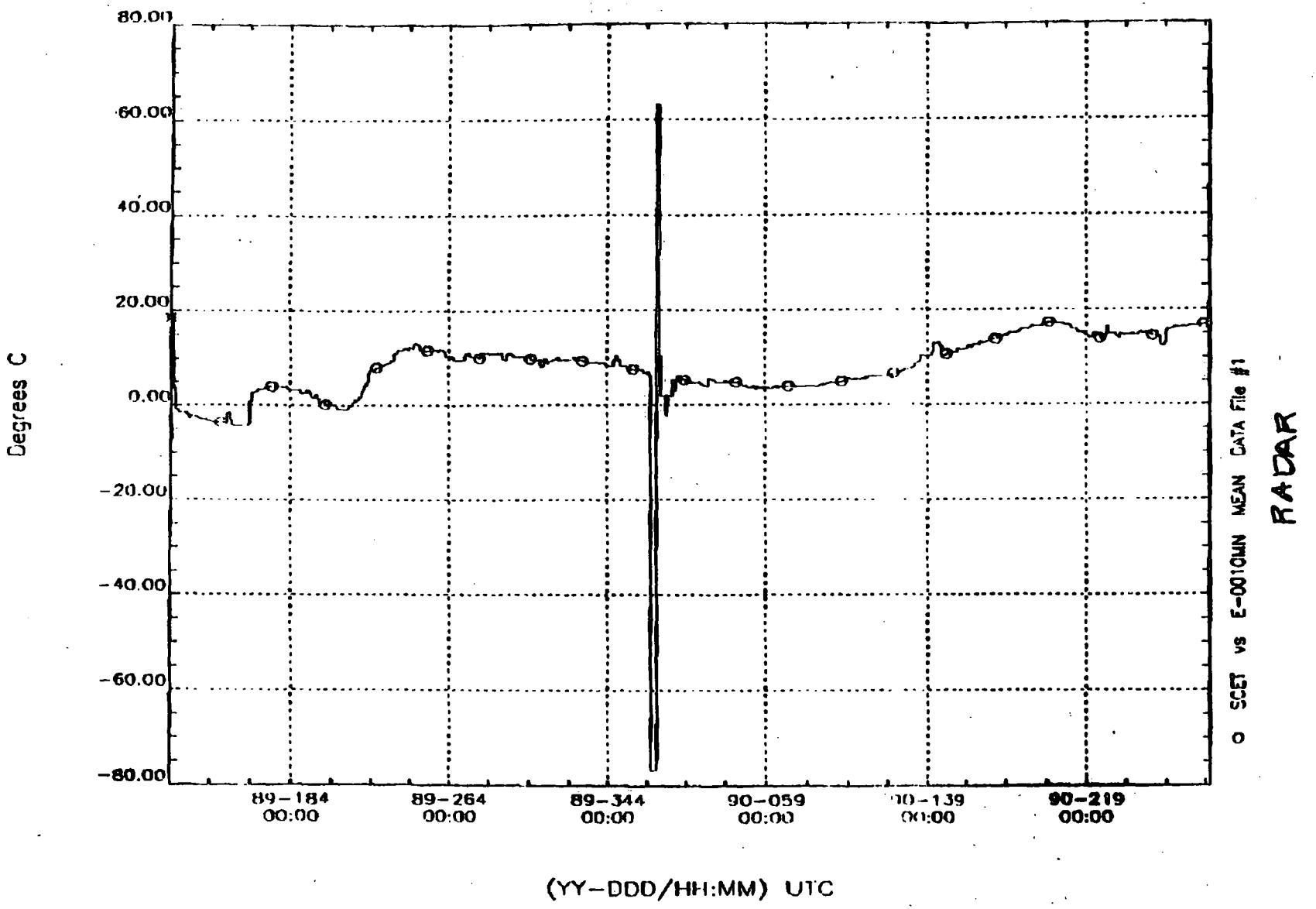


DATE: Tue Oct 23 18:28:13 1990
DATA File Number 1: E-0009.trend Tue Oct 9 21:07:25 1990
VMPLOT CPCI REV003 11/17/89

File #1 * Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0010

FIGURE 11, MGN FEM (SAR)

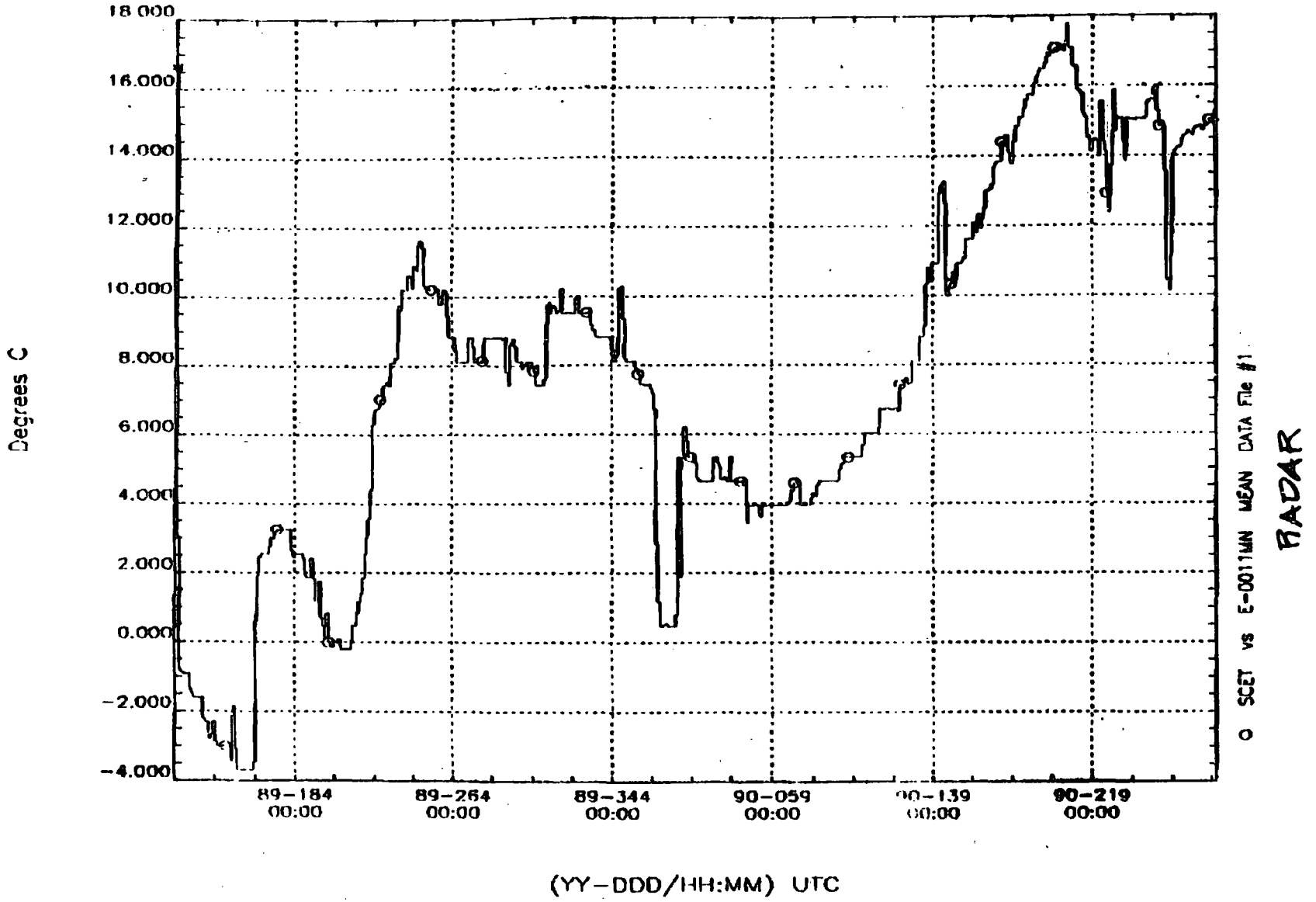


DATE: Tue Oct 23 18:28:40 1990
DATA File Number 1: E-0010.trend Tue Oct 9 21:07:27 1990
VMPLOT CPCI REV003 11/17/89

File #1 ■ Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

E-0011

FIGURE 12, MGN TEM (SAR)

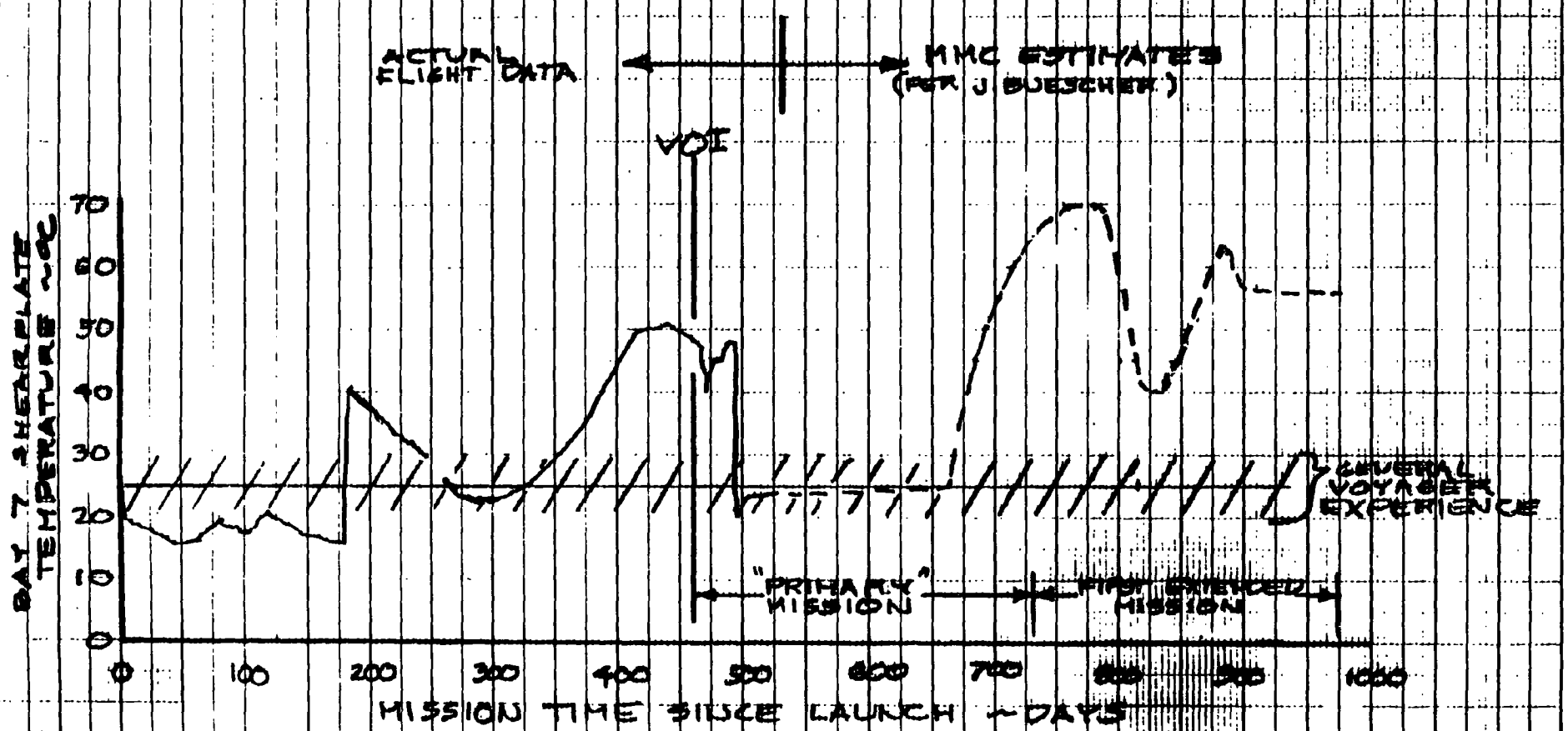


DATE: Tue Oct 23 18:29:06 1990
DATA File Number 1: E-0011.trend Tue Oct 9 21:07:29 1990
VMPLOT CPCI REV003 11/17/89

File #1 ■ Start Time: 89-124/00:02:01.327
+ End Time: 90-280/00:53:25.800

FIGURE 13

MGN BAY 7 (CDS) SHEARPLATE TEMPERATURE HISTORY



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11/1/90