TM-100355

STS-27R OV-104 ORBITER TPS DAMAGE REVIEW TEAM

SUMMARY REPORT

VOLUME I

FEBRUARY 1989

(NASA-TM-100355-Vol-1) STS-27R OV-104 ORBITER TPS DAMAGE REVIEW TEAM, VOLUME 1 Summary Report (NASA) 77 p CSCL 22B
N89-20178
Unclas
G3/16 0192816

STS-27R OV-104 TPS DAMAGE REVIEW TEAM

SUMMARY REPORT

VOLUME I

The STS-27R OV-104 TPS Damage Review Team, sometimes referred to as the Orbiter TPS Damage Review Team, submits this report consisting of Volume I through Volume X in response to the Director, NSTS letter of December 9, 1988. The report represents the consolidated views of all team members and associated contractors participating in this review.

John W. Thomas	Jay F. Honeycutt
JOHN W. THOMAS, CHAIRMAN	JAY F. HONEYCUTT, ALT CHAIRMAN
Robert D White	Judith A. Kersey
ROBERT D. WHITE, SYSTEMS	JUDITH A. KERSEY, LAUNCH OPS
	M C Coody
JAMES F. HESTER, JR., SRB/SRM	MARION C. COODY, ORBITER
Jack J. Nichols	Dewey B. Channell
JACK J. NICHOLS, ET	DEWEY B. CHANNELL, SRM&QA
Charles G. Stevenson	James M. Earle
CHARLES G. STEVENSON, ICE/DEBRIS	JAMES M. EARLE, PHOTO
Gary E. Coen	
GARY E. COEN, FLIGHT OPS	DONALD R. McMONAGLE, FLT CREW

ORBITER TPS DAMAGE REVIEW TEAM

VOLUME I

SUMMARY REPORT

TABLE OF CONTENTS

1.0 Introduction

- 1.1 Charter
- 1.2 Approach
- 1.3 Methodology
- 1.4 Organization
- 1.5 Schedule

2.0 General Observations

3.0 Data Review and Correlation

- 3.1 Previous Orbiter TPS Damage
- 3.2 Missing TPS from SRB
- 3.3 Statistical Treatment
- 3.4 Prelaunch and Flight Data
- 3.5 Ice Team Observations
- 3.6 Mission Events Timeline
- 3.7 Photographic Observations
- 3.8 C-Band Radar Observations
- 3.9 Crew Observations

4.0 Fault Tree Summary

5.0 Data Analysis and Tests

- 5.1 Laboratory Materials Testing
- 5.2 Debris Trajectory Analysis/Damage Flow Regime
- 5.3 MSA-1 Survivability Through Orbiter Nose Shock
- 5.4 Missing Tile Failure Scenario
- 5.5 Debris Quantity/Availability Assessment
- 5.6 MSA-1 Humidity Tests
- 5.7 MSA-1 Blister Test
- 5.8 External Tank PAL Ramp Test
- 5.9 C-Band Radar Testing
- 5.10 Crew Reported 4 Hz Vibration
- 5.11 BSM Performance

6.0 Failure Scenario

7.0 Findings

8.0 STS-29R Considerations

9.0 Concluding Remarks

LIST OF FIGURES

FIGURE	TITLE	PAGE
1-1	Team Membership	2
1-2	Methodology	5
1-3	Organization	6
1-4	Schedule	8
2-1	STS-27R Orbiter Post Landing Right Wing Lower Surface	9
2-2	STS-27R Orbiter Post Landing Left Wing Lower Surface	10
2-3	STS-27R Orbiter Post Landing Right Side Lower Surface	11
2-4	STS-27R Orbiter Post Landing Left Side Lower Surface	12
2-5	STS-27R Orbiter Post Landing Missing Tile/Region	13
2-6	STS-27R Orbiter Post Landing RH OMS Pod Locations	14
2-7	SRM Missing Cork	17
2-8	Orbiter TPS Damage Map Pictorial	18
2-9	Lower Surface Tile Damage Pattern	19
2-10	Major STS-27R Flight Parameters	20
3-1	Orbiter TPS Total Hits and Hits Greater than 1 Inch	22
3-2	Orbiter TPS Total Hits - Left Side and Right Side	23
3-3	Historical Orbiter TPS Damage - Distribution by Orbiter Zone	24
3-4	Missing TPS from SRB Frustums and Forward Skirts	25
3-5	Statistical Correlation - Orbiter TPS Damage History	27

LIST OF FIGURES (Cont'd)

FIGURE	TITLE	PAGE
3-6	STS-27R Flight Data Correlations	29
3-7	Ice Figure of Merit	31
3-8	Photographic Debris Observations on STS Flights	33
3-9	C-Band Radar Detections STS Particle Separations	35
4-1	Summary Fault Tree	38
5-1	Orbiter Locations for Material Identifications	43
5-2	Ascent Debris Trajectory Simulation	45
5-3	History of Elevon Hits from 19 Previous Flights	46
5-4	Probability of MSA-1 Debris Survival through Orbiter Nose Shock	48
5-5	C-Band Radar Materials Reflectivity Test	54
6-1	Failure Scenario	57

LIST OF TABLES

TABLE	TITLE	PAGE
1-1	Orbiter TPS Damage Review Team Report Contents	4
2-1	STS-27R SRB Inspection Results	16
3-1	Prelaunch and Flight Data - Parameters Assessed	28
4-1	Fault Tree Summary	39
5-1	Laboratory Material Testing	42
5-2	Debris Quantity/Availability Assessment	49
5-3	Samples Tested for C-Band RCS Signatures	53
6-1	Failure Scenario Assessment	58
8-1	STS-29R Assessment	66

Orbiter TPS Damage Review Team

Volume 1

Summary Report

1.0 Introduction

The NSTS mission STS-27R lifted off from the Kennedy Space Center on December 2, 1988, with Orbiter OV-104, Atlantis. Following the successful mission, the Atlantis returned to Earth at the Dryden Flight Research Facility. While inspecting Atlantis on the runway, it was observed that there was substantial Thermal Protection System (TPS) tile damage present on the lower right fuselage and wing. It was immediately evident that right side damage sites were more numerous than on previous flights and conversely, there was almost no damage present on Atlantis' left side. These unusual conditions led to the Director, NSTS establishing a review team to investigate the cause for this tile damage.

1.1 Charter

The STS-27R, OV-104 TPS Damage Review Team was established by the Director, NSTS in his letter of December 9, 1988. (See Appendix 1). Mr. John Thomas and Mr. Jay Honeycutt were named Chairman and Alternate Chairman, respectively. Several team members were initially named in the director's letter and others were appointed by the chairman to complete the organization.

The team's responsibilities as delineated in the director's letter are as follows:

a. Determine the cause(s) of the TPS damage to OV-104 on STS-27R.

b. Recommend design and/or procedural changes to reduce the potential for TPS damage for future flights.

1.2 Approach

In view of the damage severity and its unusual nature, the team chose to treat the review as a full investigation. To carry out this investigation, the team membership was established as depicted in Figure 1-1 and included representation from program management, engineering, operations, and safety, reliability, maintainability and quality assurance. It was necessary to fully involve and integrate the appropriate element contractors, Martin Marietta, Morton Thiokol, Rockwell, and USBI, into all facets of the team activities. Inasmuch as one team goal was to minimize

1-674-9-7T

FIGURE 1-1

ORBITER TPS DAMAGE REVIEW TEAM TEAM MEMBERSHIP

● CHAIRMAN	–	JOHN W. THOMAS	–	MSFC
● ALTERNATE CHAIRMAN	–	JAY F. HONEYCUTT	–	HQTRS
● MEMBERS	–	JACK J. NICHOLS	–	MSFC
	–	JUDITH A. KERSEY	–	KSC
	–	MARION C. COODY	–	JSC
	–	GARY E. COEN	–	JSC
	–	DONALD R. McMONAGLE	–	JSC
	–	DEWEY B. CHANNELL	–	MSFC
● OTHER MEMBERS SELECTED BY CHRMAN	–	VICTOR K. HENSON	–	MSFC
	–	JAMES M. EARLE	–	MSFC
	–	CHARLES G. STEVENSON	–	KSC
	–	ROBERT D. WHITE	–	JSC
	–	JAMES F. HESTER	–	MSFC
● GROUP AND CONTRACTOR MEMBERS	–	SEE VOLUMES II–VIII, ORGANIZATION SECTIONS	–	NASA, MMC, MTI, USBI, RI

the potential impact to STS-29R, many team members were housed in a central facility at MSFC to minimize distractions and expedite the review process. Similarly, to curtail interruptions in other important program work, team and group personnel were deployed at the various element contractor facilities to review flight hardware pedigree documentation.

Finally, it was deemed essential that all information, data, analyses, tests, and other team products be fully structured and documented for future reference. To this end, all team supporting data, actions, findings, and recommendations are documented in 10 individual volumes as listed in Table 1-1. Volume I summarizes the review activities covered in detail in volumes II through X and documents the damage cause(s), findings, and recommendations.

1.3 Methodology

The methodology employed to search for the damage cause is typical of most investigations. (See Figure 1-2.) The team began with a detailed inspection of the Atlantis TPS damage, and review of related inspection reports to establish an indepth anomaly definition. This was followed by an exhaustive data review to determine if there existed any common parameters between STS-27R and other damaged orbiters. Next, a fault tree was developed that comprised all conceivable components or conditions that could have led to the severe damage observed. There were then many data analyses and tests necessary to clear or confirm damage causes identified by the fault tree assessment and other sources. These results were used to postulate possible failure scenarios that could have resulted in the tile damage. Finally, after several iterations through the foregoing methodical steps, the failure scenarios were categorized as either not possible, possible but not probable, or probable. This and other information gained during the review formed the basis for the team's findings and recommendations.

1.4 Organization

The team members were organized into functional operating groups and support groups as shown in Figure 1-3. The functional groups--SRM/SRB, ET, Orbiter, Systems, and Launch Operations--were established to coincide with the major fault tree elements. The support groups' assignments and tasks cut across all the functional groups. A team member was assigned to lead each group with responsibility to fully carry out all activities implicit in each fault tree element and support area.

1-687-9-7T

TABLE 1-1

ORBITER TPS DAMAGE REVIEW TEAM

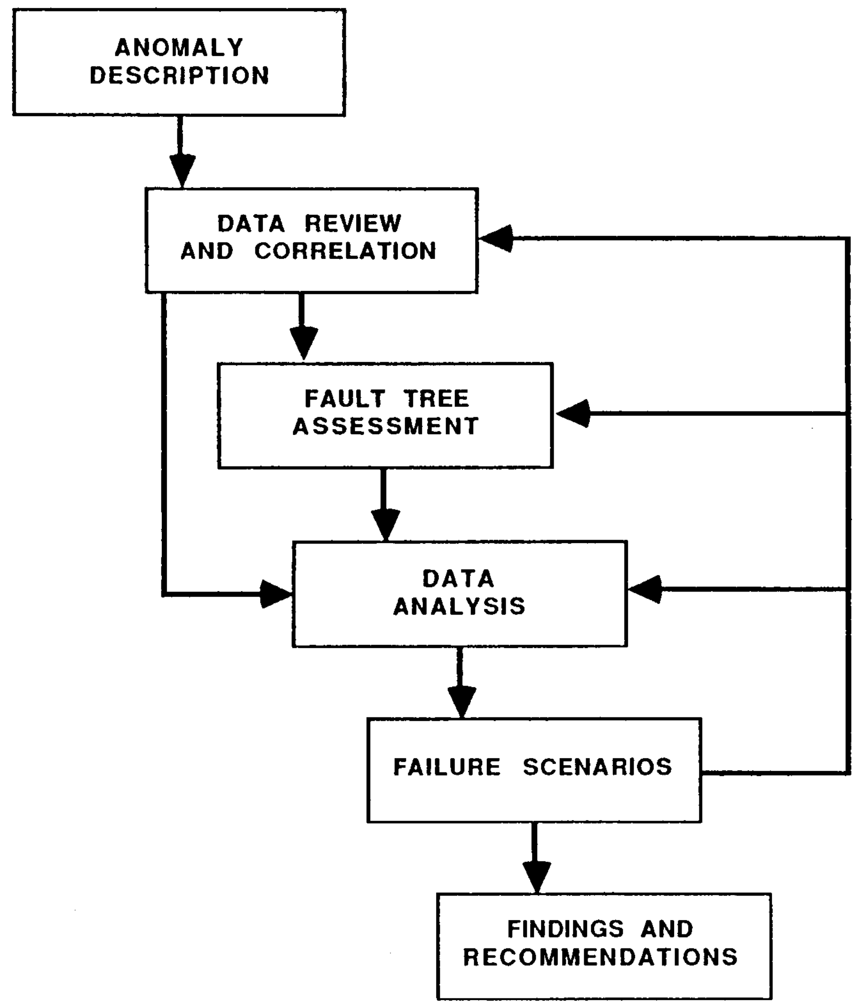
REPORT CONTENTS

VOLUME I	SUMMARY REPORT
VOLUME II	SYSTEMS GROUP (INCLUDING TIMELINE)
VOLUME III	LAUNCH OPERATIONS GROUP
VOLUME IV	ORBITER GROUP
VOLUME V	EXTERNAL TANK GROUP
VOLUME VI	SRB/SRM GROUP
VOLUME VII	LABORATORY TEST SUPPORT GROUP
VOLUME VIII	PHOTO SUPPORT GROUP
VOLUME IX	ACTION ITEMS
VOLUME X	PRESENTATION MATERIAL/MEETINGS

1-4462-9-5D

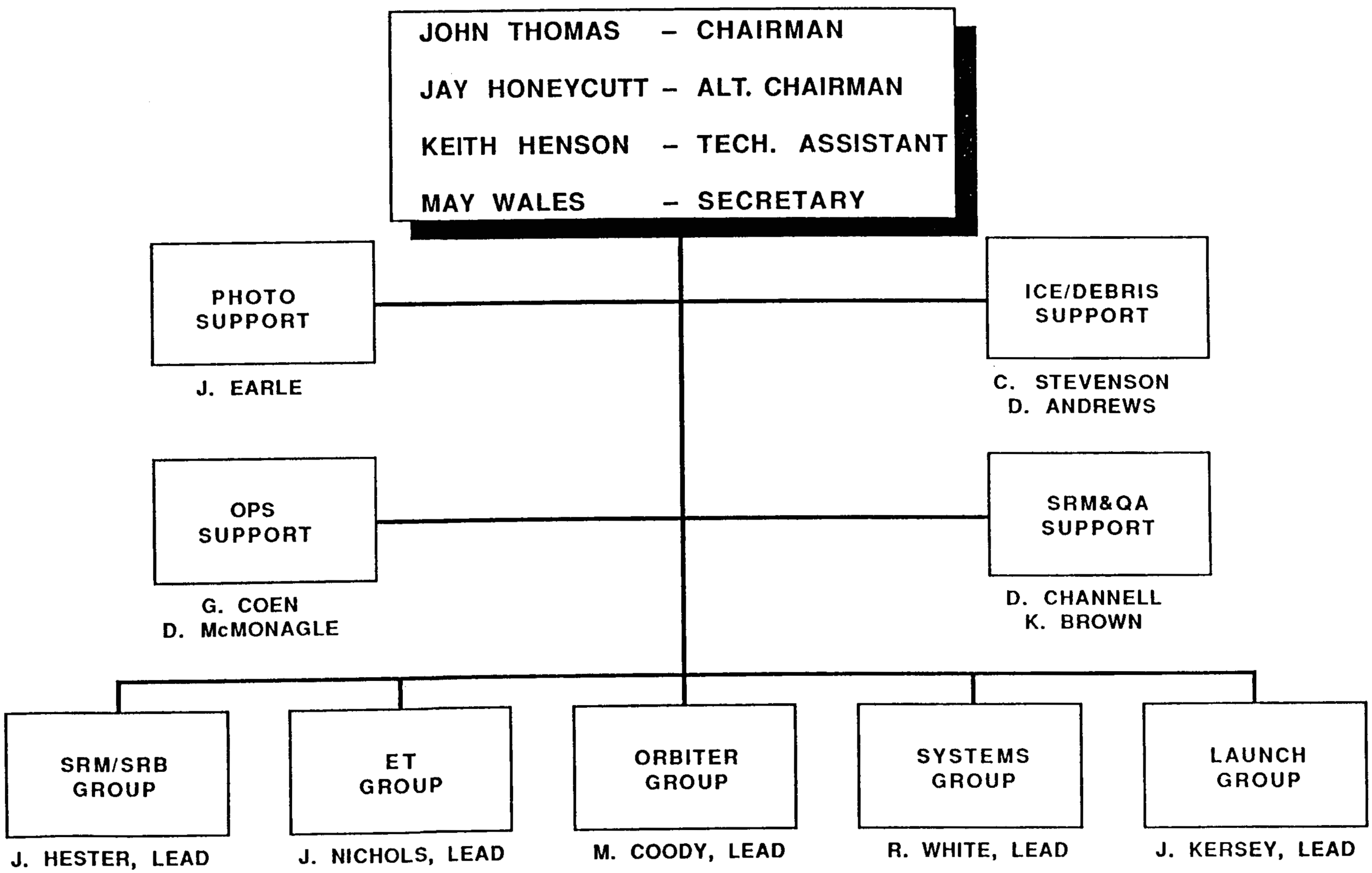
FIGURE 1-2

ORBITER TPS DAMAGE REVIEW TEAM METHODOLOGY



1-4477-9-5D

FIGURE 1-3
ORBITER TPS DAMAGE REVIEW TEAM ORGANIZATION



1.5 Schedule

The team's working schedule, Figure 1-4, was oriented to comply with the Director, NSTS letter instructing that the team's analyses were required by early January 1989. The first team meeting was held on December 9, 1988, and the oral report to the Director, NSTS was made, as originally scheduled, on January 23, 1989. During this period, the team met five times--at MSFC, MAF, KSC, JSC, and USBI-KSC, concluding with a telecon on January 20, 1989. The team also briefed the OSF Management Council and the NASA Administrator on January 25, 1989, and February 1, 1989, respectively.

2.0 General Observations

The Atlantis TPS was inspected at Dryden Flight Research Facility, and also after being ferried back to KSC. While it was at Dryden, the TPS damage was measured, mapped, and recorded. The damage severity and the contrast in right side versus left side damage is readily discernible in Figures 2-1, 2-2, 2-3, and 2-4. The inspection results and damage distribution are as follows:

a. Total recorded damage sites were 707, with 644 occurring on the lower surface.

b. Total recorded damage sites with any dimension greater than one inch were 298, with 272 occurring on the lower surface.

c. The left side had only two damage sites greater than one inch.

d. The elevon lower surfaces were undamaged.

e. The right OMS pod had 14 damage sites greater than one inch.

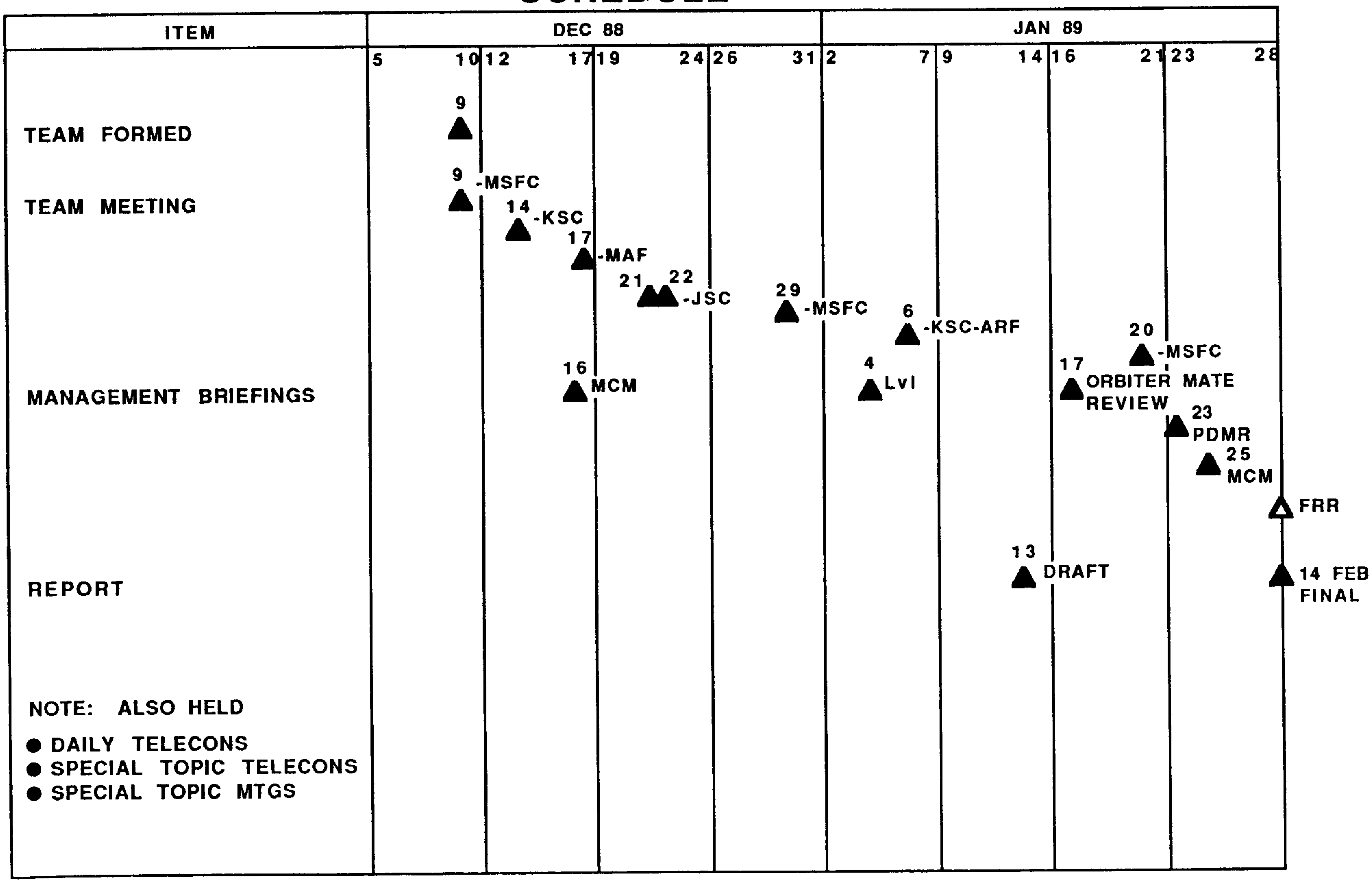
f. The right rudder speed brake had four damage sites greater than one inch.

The inspection also revealed that one complete tile was missing (Figure 2-5) from the forward right fuselage over the L-band antenna cover. A foreign object, later identified as Marshall Sprayable Ablator (MSA)-1 material, was found embedded in a right Orbiter Maneuvering System (OMS) pod Advanced Felt Reusable Surface Insulation (AFRSI) blanket as shown in Figure 2-6. This figure also shows the location of a right OMS pod TPS carrier panel that dislodged sometime during flight.

1-4479-9-5D

FIGURE 1-4

INTRODUCTION
ORBITER TPS DAMAGE REVIEW TEAM SCHEDULE



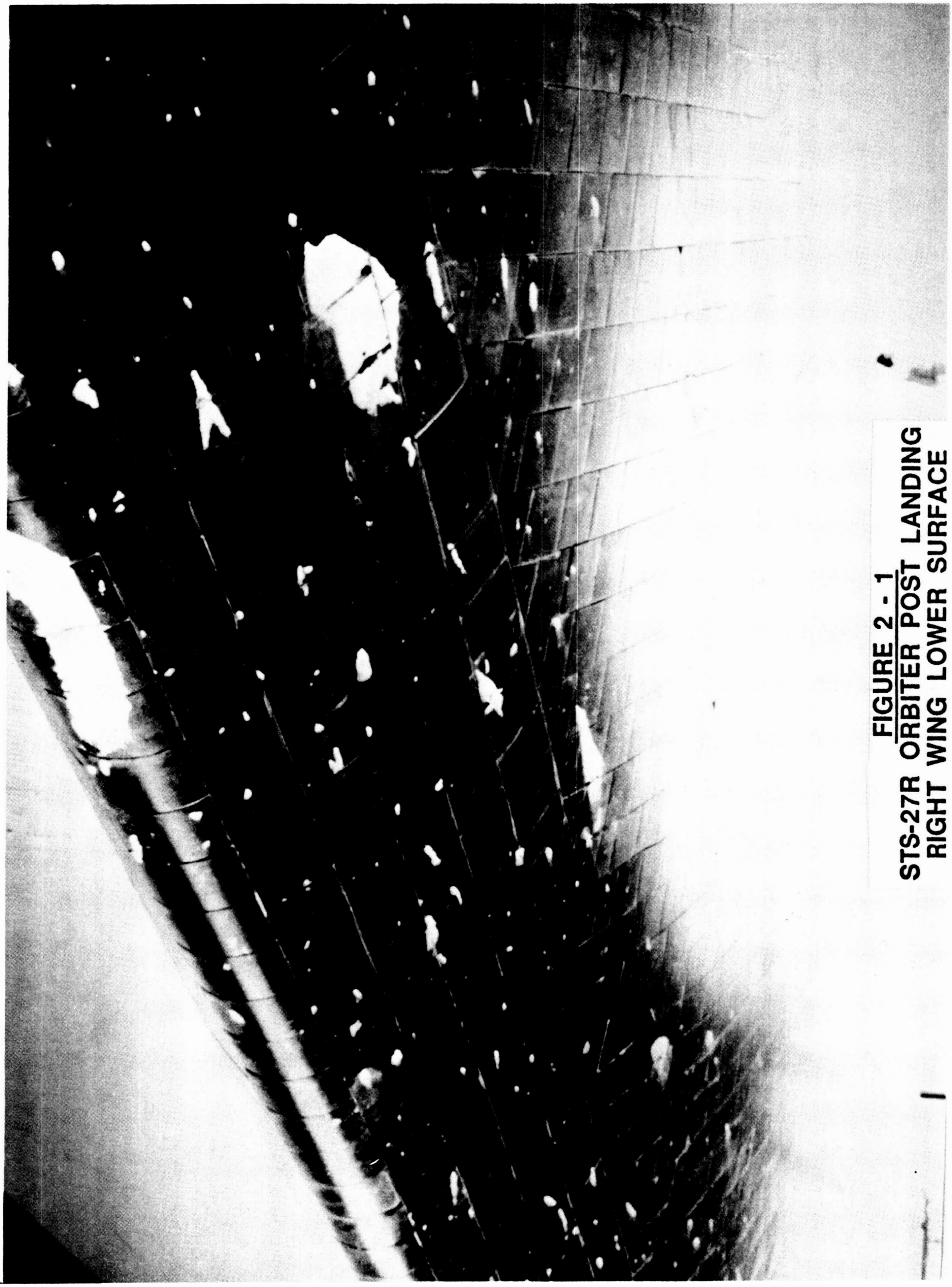


FIGURE 2 - 1
STS-27R ORBITER POST LANDING
RIGHT WING LOWER SURFACE

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

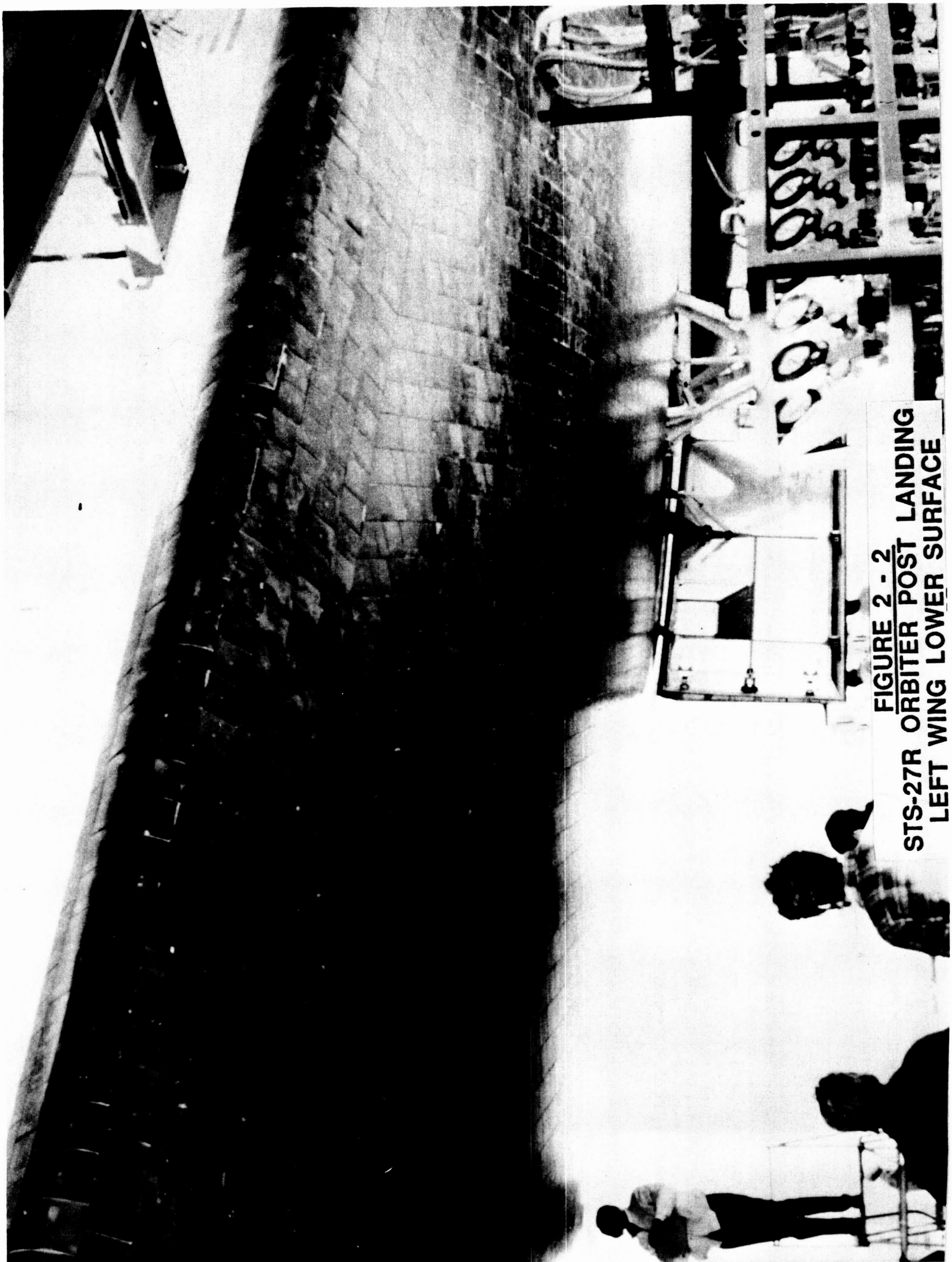


FIGURE 2 - 2
STS-27R ORBITER POST LANDING
LEFT WING LOWER SURFACE

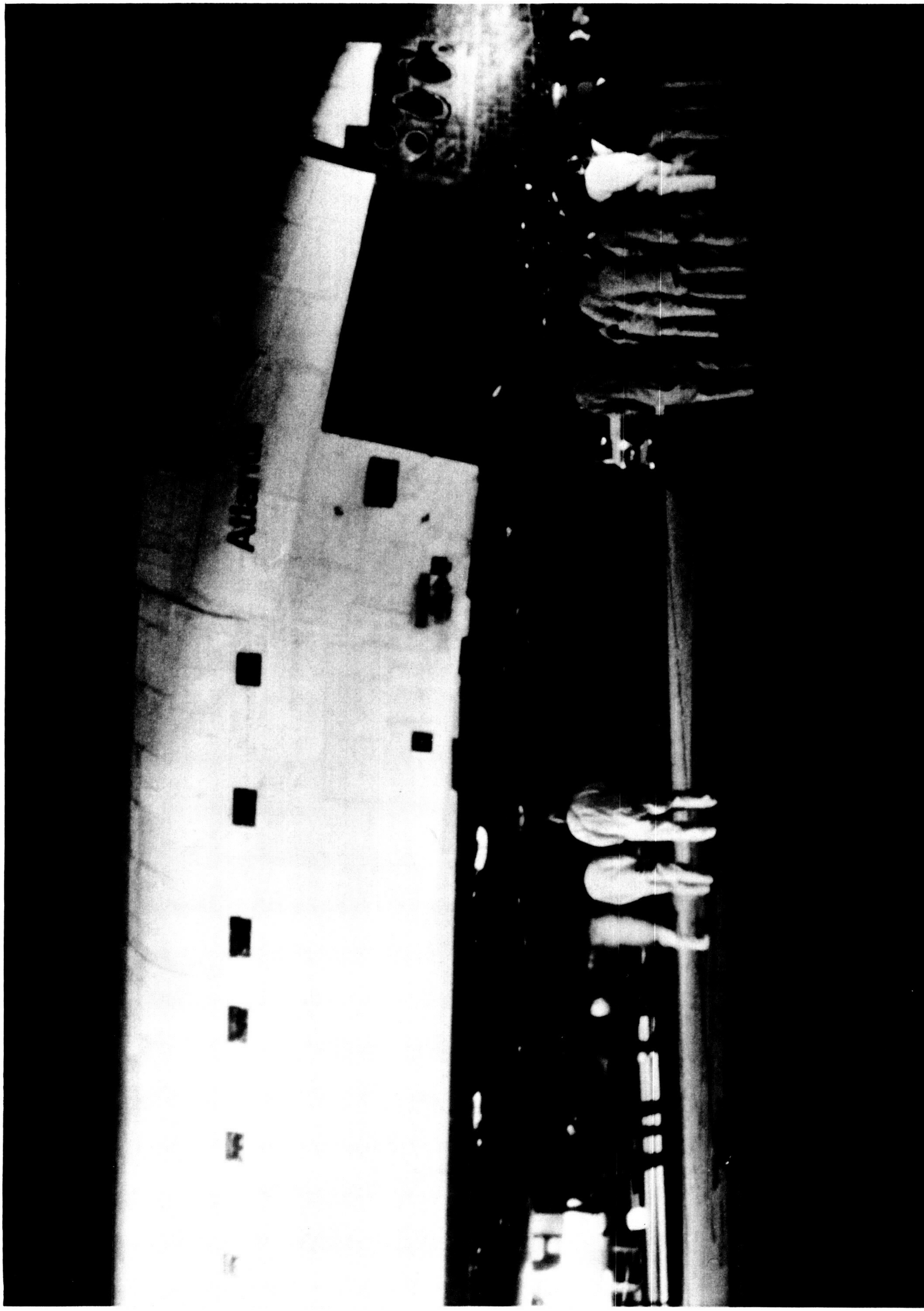


FIGURE 2 - 3
STS-27R ORBITER POST LANDING
RIGHT SIDE LOWER SURFACE

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

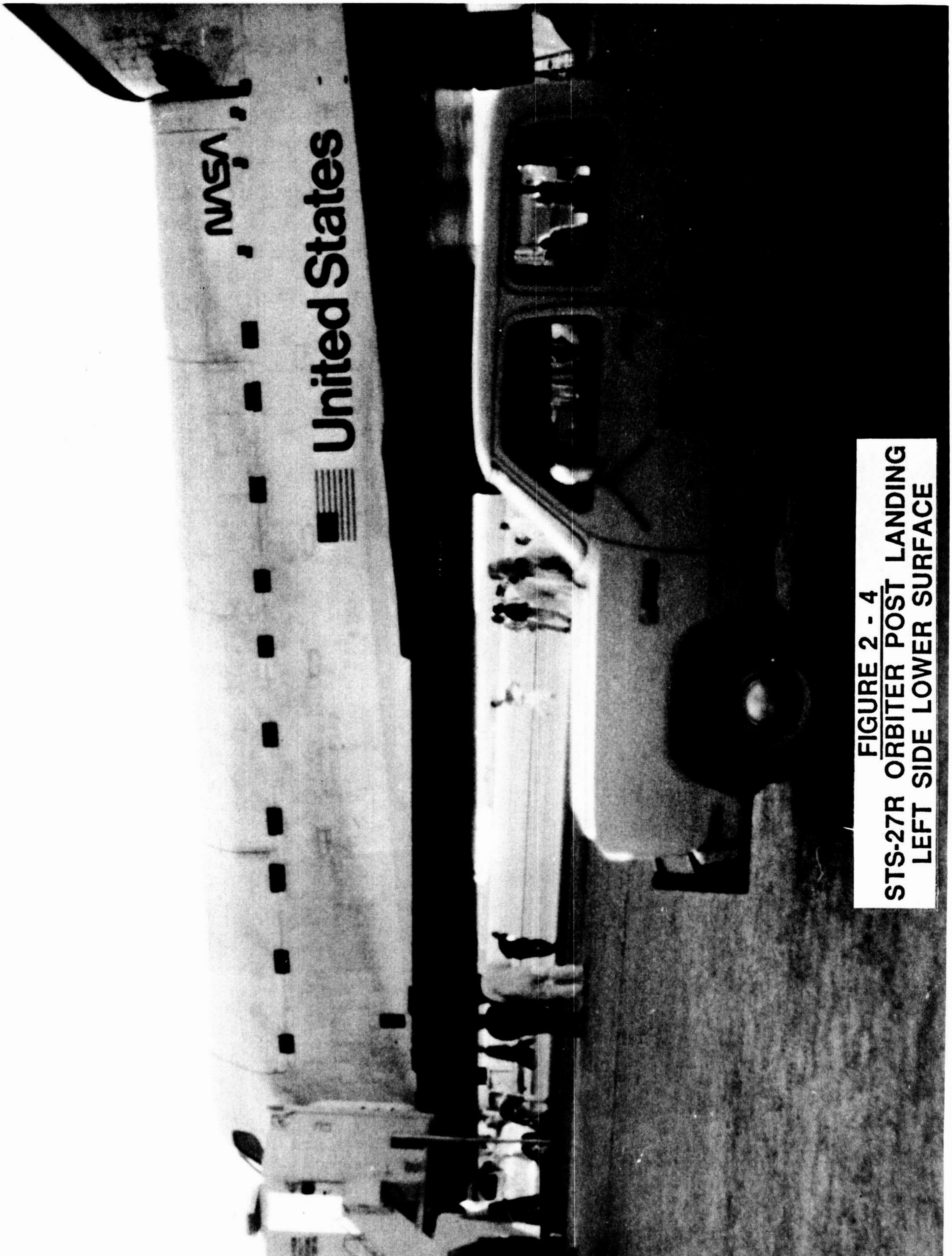


FIGURE 2 - 4
STS-27R ORBITER POST LANDING
LEFT SIDE LOWER SURFACE

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

National Aeronautics and
Space Administration

S27 (S) 029

Lyndon B. Johnson Space Center
Houston, Texas 77058

FIGURE 2 - 5
STS-27R ORBITER POST LANDING
MISSING TILE/REGION

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

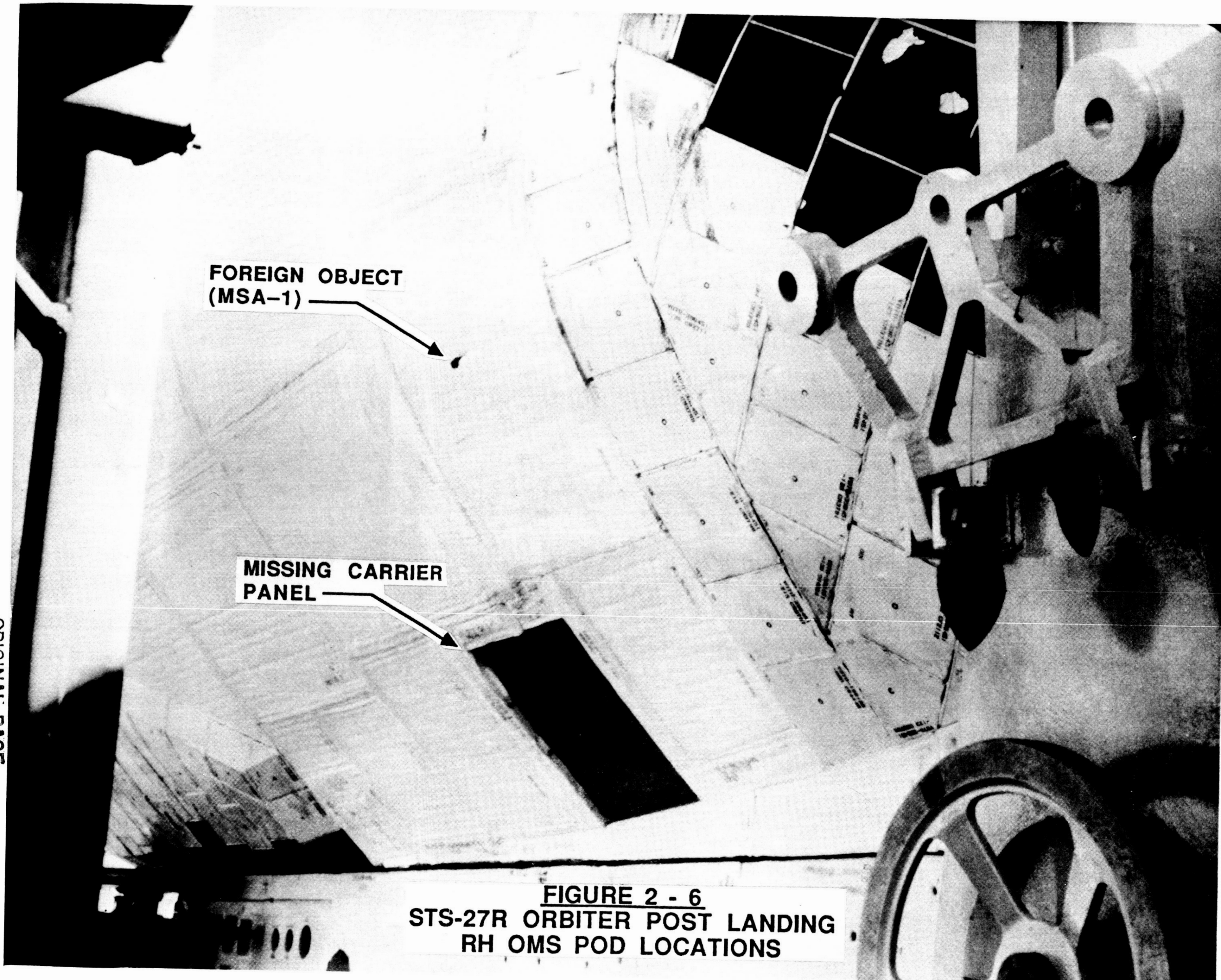


FIGURE 2 - 6
STS-27R ORBITER POST LANDING
RH OMS POD LOCATIONS

The STS-27R crew commented that white material was observed on the windshield at various times during ascent. On one occasion, the white material hit the window and slid off to the side into the frame. Inspection of this area was requested at Dryden, but the window had already been cleaned and covered for ferry flight. Nevertheless, the remaining residue from this white material was retrieved at KSC, and lab analysis showed it to be Room Temperature Vulcanizing (RTV) and Scotch Guard from the forward RCS nozzle moisture covers.

During orbiter inspection by the team at KSC, a small particle was discovered lodged between two tiles at the forward right OMS pod to fuselage intersection. This was later identified as Polymer Development Laboratories (PDL) foam covered with fire retardant latex paint.

The team reviewed the SRB Post Retrieval Inspection Reports prepared by the SRB Disassembly Inspection Team to ascertain if any debris came from those elements during flight. It was found that four small MSA-1 TPS pieces were missing from the left forward skirt and two pieces were missing from the right forward skirt. There were four small Marshall Trowelable Ablator (MTA)-2 repair material unbonds on the right frustum. Additionally, there were five small SRM Development Flight Instrumentation (DFI) cork pieces missing from the left SRM and one piece of cork missing from the right SRM center joint. The missing material sizes and locations are shown in Table 2-1 and Figure 2-7.

The Orbiter damage sites and missing hardware are shown in Figures 2-8 and 2-9 depicting their relationship to the integrated Shuttle vehicle. Also, Figure 2-10 is included to depict the STS-27R major flight parameters.

3.0 Data Review and Correlation

In anticipation that some parameter, event, or condition present on the STS-27R mission might signal the tile damage cause, all pertinent factors were compiled and reviewed. The same factors from previous flights were compiled and correlated with STS-27R to determine any STS-27R uniqueness, or to determine if STS-27R and prior heavily damaged flights exhibited any similarities. It should be noted that there are certain correlations between individual parameters and tile damage; however, these cannot be considered independent and absolute because there was no attempt to simultaneously correlate multiple parameters with damage. This necessitated that additional evaluation be performed to judge that correlation's influence on severe tile damage. The areas examined are described below.

1-675-9-7T

TABLE 2-1

ORBITER TPS REVIEW TEAM
STS-27R SRB INSPECTION RESULTS

- SRB FORWARD ASSEMBLY (LESS NOSE CAP) MISSING OR DEBONDED MATERIAL
  - LEFT FORWARD SKIRT – MSA 1 – FOUR PIECES AROUND +Y + BETWEEN .15" X .25" AND 1" X 2"
  - * RIGHT FORWARD SKIRT – MSA 1 – TWO PIECES – AROUND +Y AND +Z – .5" DIA AND 1" X 2"
  - RIGHT FRUSTUM – MTA 2 – FOUR PIECES – AROUND +Y – 1/2" TO 1" DIA
- SOLID ROCKET MOTOR – MISSING CORK
  - LEFT MOTOR –

**	① CAP CORK	CENTER JOINT	244°	POSITION	2.5" X 2"
**	② CAP CORK	CENTER JOINT	248°	POSITION	3" X 1.5"
**	③ CAP CORK	AFT JOINT	215°	POSITION	2.5" X 5"
	④ CAP CORK	AFT SEGMENT	218°	POSITION	1" X 5"
	⑤ CAP CORK	FORWARD JOINT	170°	POSITION	.75" X .75"

  - RIGHT MOTOR –

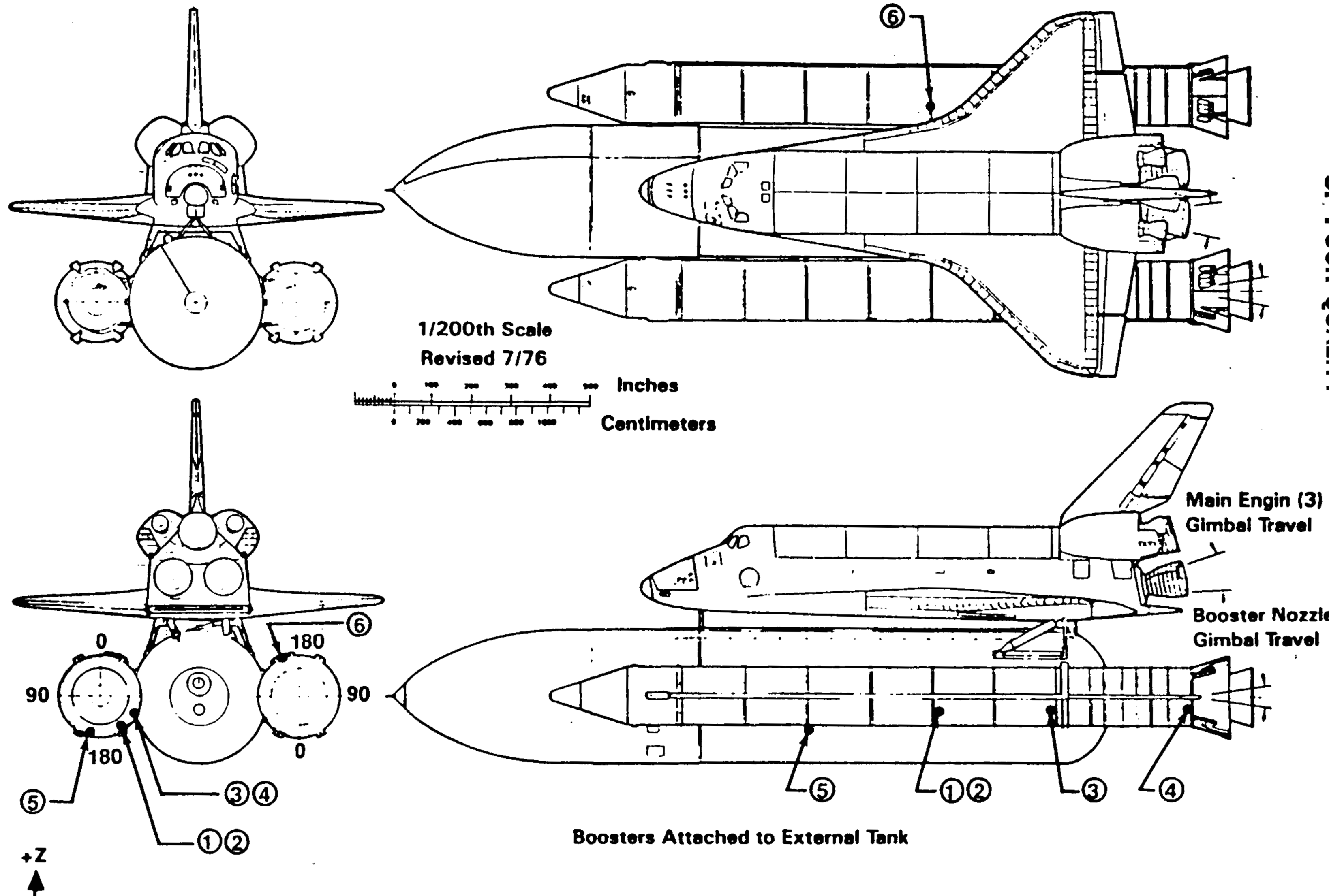
    ⑥ ONE PIECE JOINT PROTECTION CORK-CENTER JOINT – 185° LOCATION – 3.5" X 3.5"

* HANDLING DAMAGE
** IMPACTS FROM NOZZLE SEVERANCE

1-4469-9

FIGURE 2-7

ORBITER TPS DAMAGE REVIEW TEAM SRM MISSING CORK

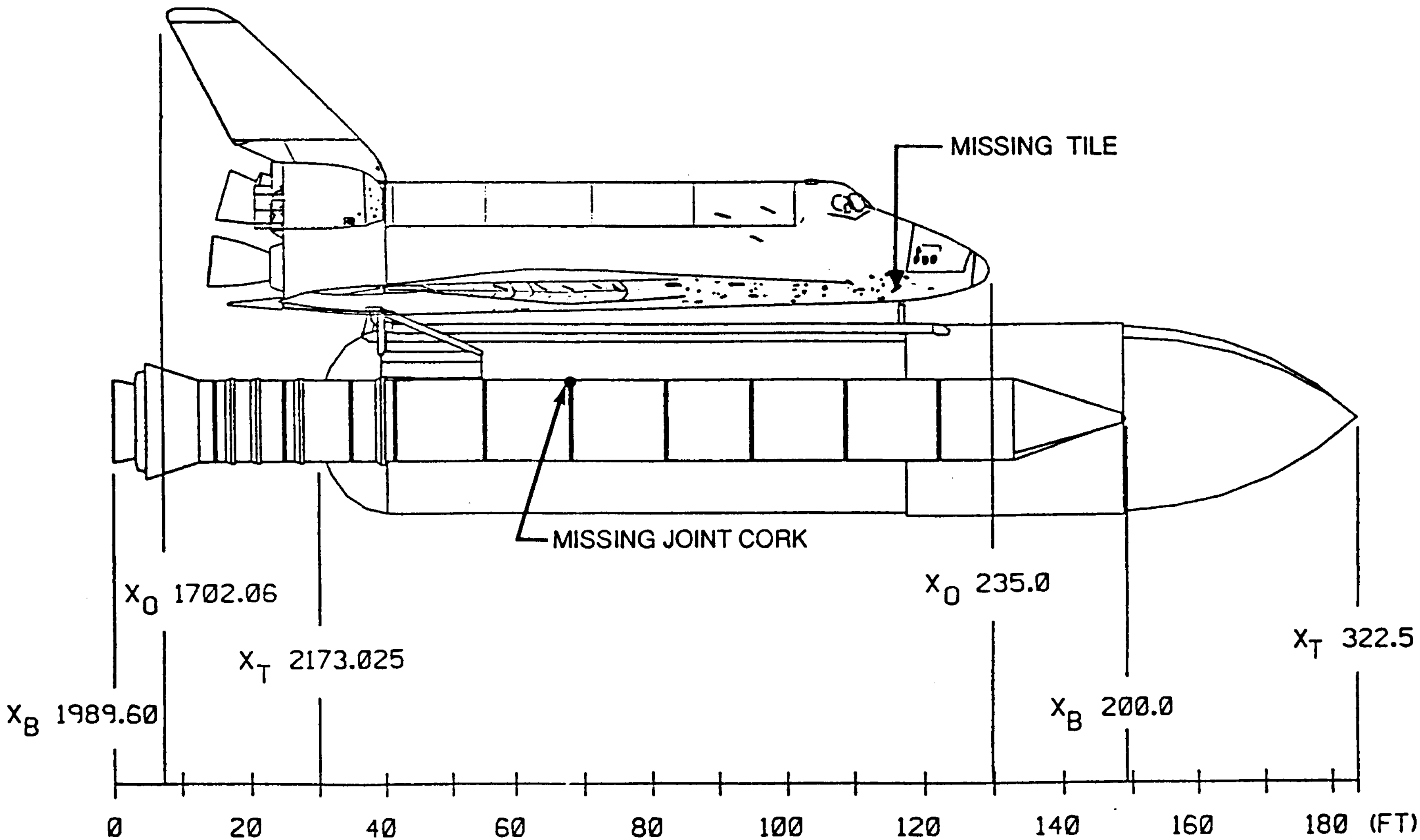


ORIGINAL PAGE IS OF POOR QUALITY

1-4470-9

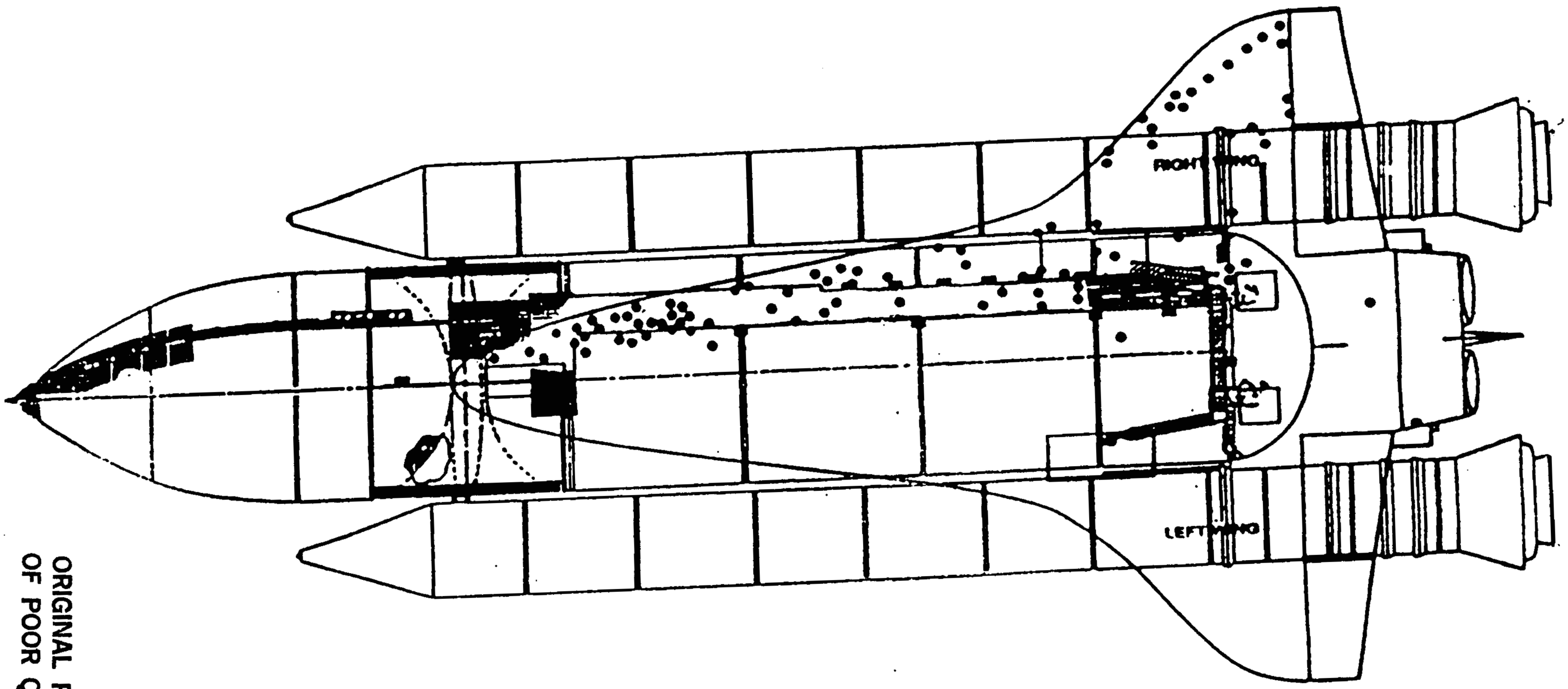
FIGURE 2-8

ORBITER TPS DAMAGE REVIEW TEAM
ORBITER TPS DAMAGE MAP PICTORIAL



1-4474-9

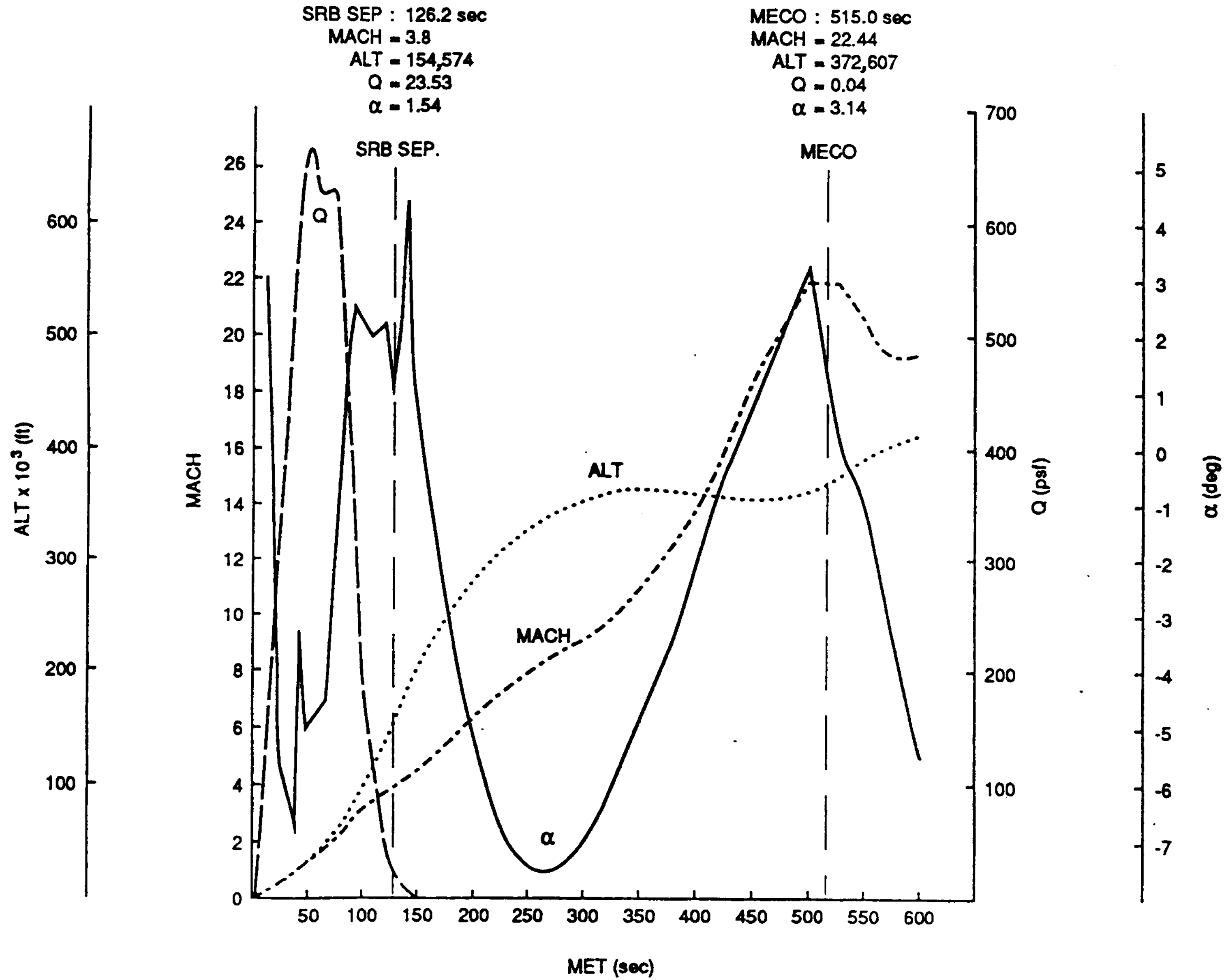
FIGURE 2–9
ET TPS LOCATION/DEFINITION RELATIVE TO ORBITER LOWER SURFACE TILE DAMAGE PATTERN



ORIGINAL PAGE IS
OF POOR QUALITY

1-4467-9

FIGURE 2-10
ORBITER TPS DAMAGE REVIEW TEAM MAJOR STS-27R FLIGHT PARAMETERS



3.1 Previous Orbiter TPS Damage

The lower surface tile damage inspections from 19 previous flights were entered into a computerized data base to facilitate assessing the damage sites by several selected attributes. The data base was arranged so that the Orbiter's lower surface was divided into four areas--forward and aft of main landing gear door for both left and right sides. The sites in the areas were sorted by total sites, lengths, depths, areas, and volumes. Three attributes, total, left/right sides, and those sites with any dimension greater than one inch are shown in Figures 3-1, 3-2, and 3-3. It should be noted the damage on STS-23, 24, 25, and 26 is known to have been caused by the ET intertank insulation defects stemming from anomalous Silmar resin, and that STS-26R damage was attributed to SRM DFI cap cork. A matrix correlating STS-XX flight designations with the STS-year/launch site/number designation is contained in Appendix 2.

Examining the various data plots evolved the following observations:

a. History does not reflect that damage is preferential to the Orbiter right side even though (a) Most ET protuberances are on the right side, and (b) permissible ET ice formation is on the right side.

b. Most Orbiter damage is forward of the main landing gear door.

c. Discounting STS-25, 26 and 27R, the number of large impacts appear to be controlled, but the total number of impacts are trending upward.

It is concluded from this data review that STS-27R damage is outside the experience data base, but history does not point to the damage cause.

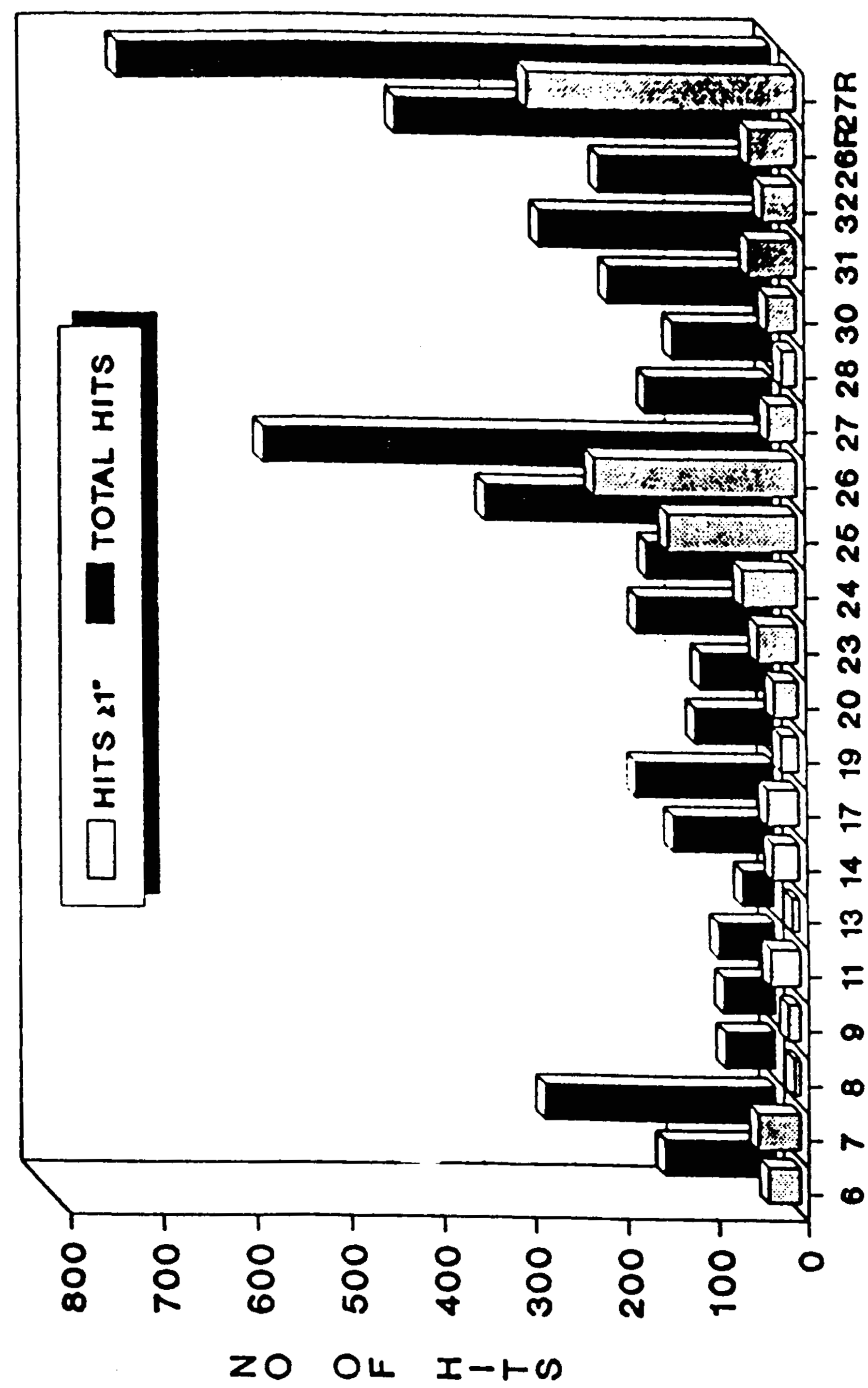
3.2 Missing TPS from SRB

The TPS missing from STS-27R and 19 previous SRB forward skirt and frustum flight sets--nose caps are not recovered--was reconstructed. The missing TPS data was tabulated alongside left and right side Orbiter tile damage site numbers (see Figure 3-4), to ascertain if large SRB TPS loss was accompanied by significant tile damage. It was concluded that there is no correlation between missing SRB TPS and tile damage.

1-4473-9

FIGURE 3-1

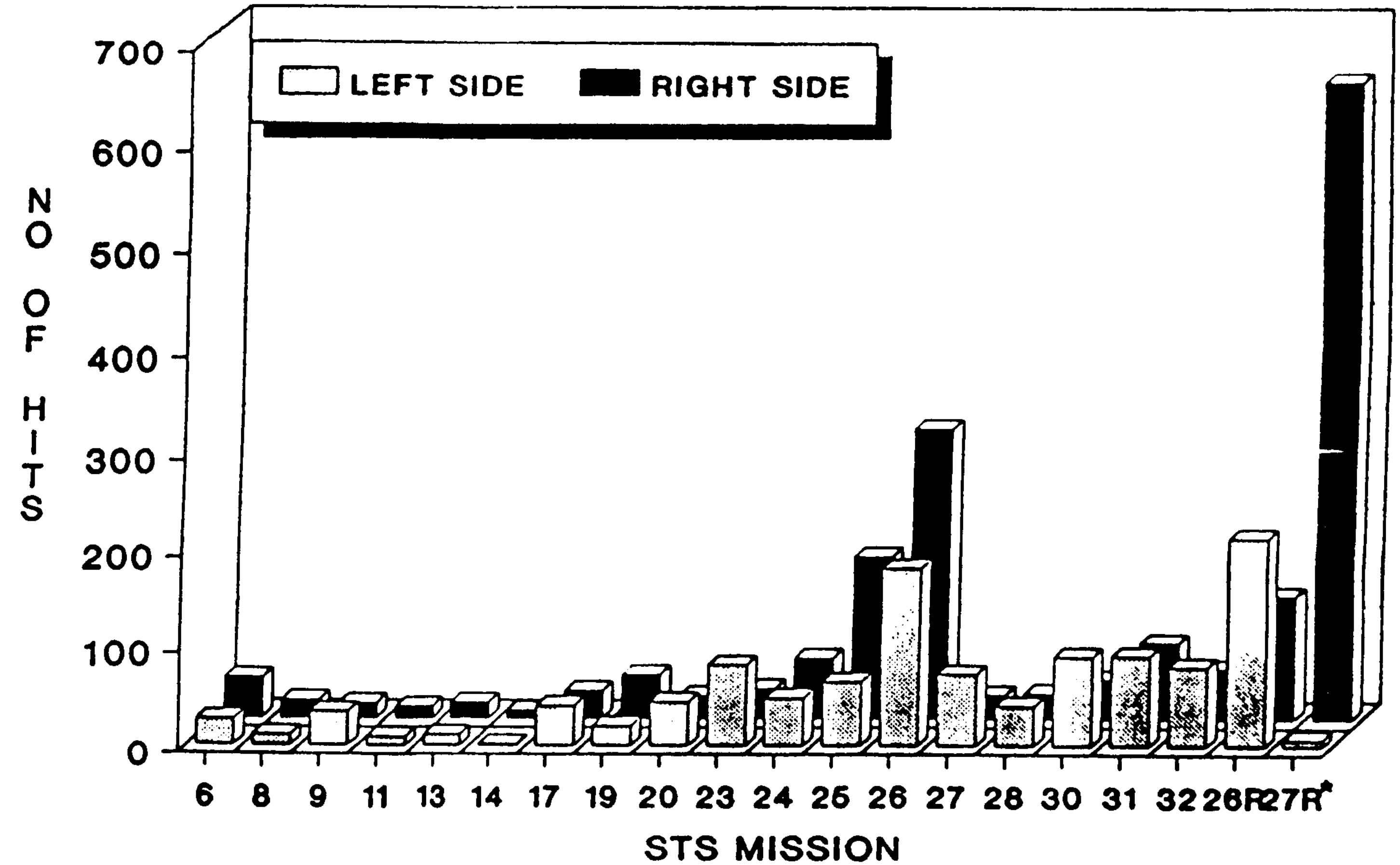
**ORBITER TPS
TOTAL HITS AND
HITS ≥1"**



1-4472-9

FIGURE 3-2

ORBITER TPS
TOTAL HITS
LOWER SURFACE



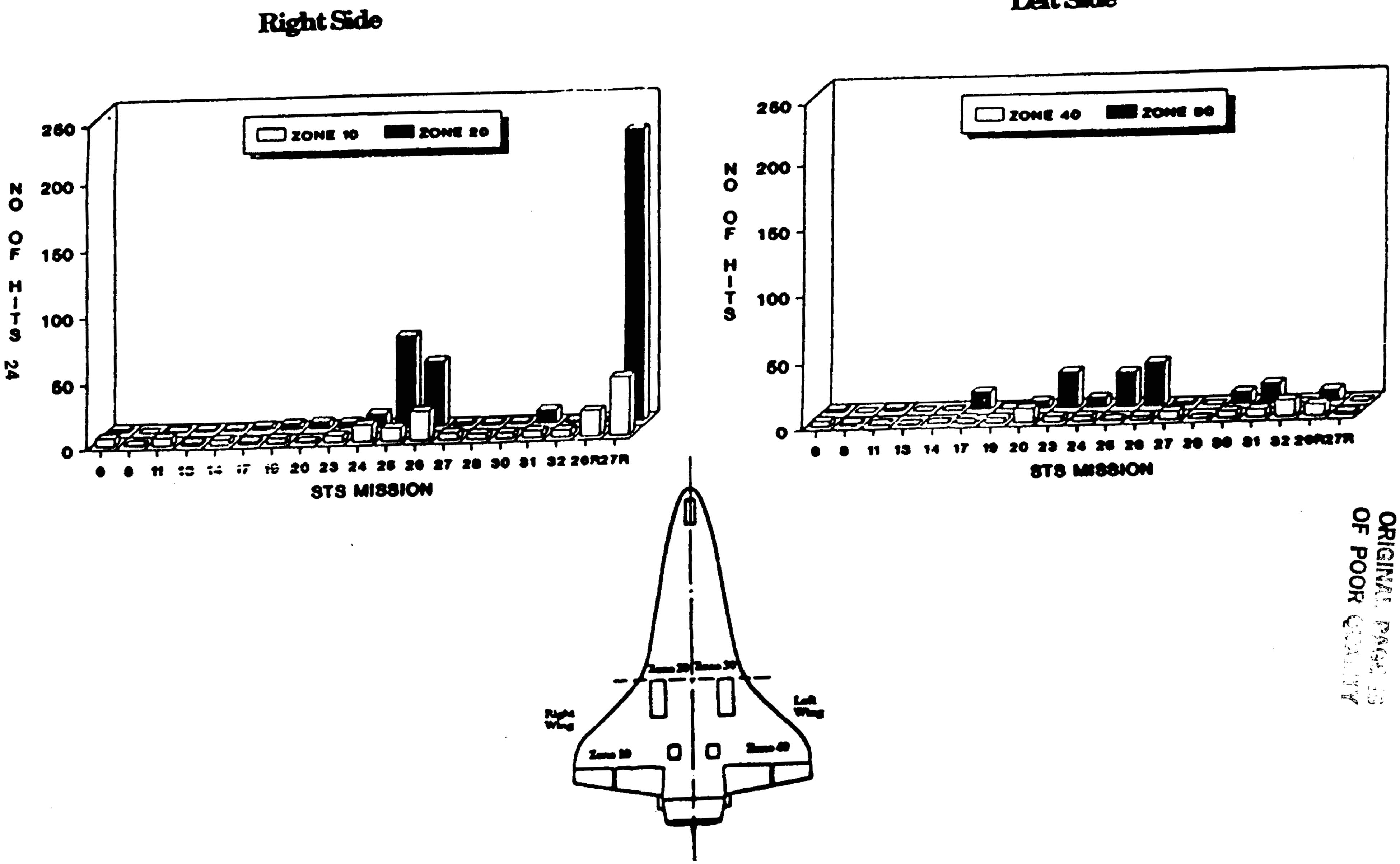
*NOTE: 372 hits on lower surface not annotated on debris map; all assumed to be on right side.

1-4471-9

FIGURE 3-3

HISTORICAL ORBITER TPS DAMAGE

NO. OF HITS WITH LENGTH ≥1 IN



1-684-9-7T

FIGURE 3-4
DATA REVIEW AND EVALUATION
ORBITER TPS DAMAGE REVIEW TEAM

– MISSING TPS FROM SRB FRUSTUMS AND FORWARD SKIRTS –

– DEBRIS ZONES –

FLIGHT	DATE	FRUSTUM		FORWARD SKIRT		TOTAL	ORBITER IMPACTS		
		LH	RH	LH	RH	SRB	LH	RH	TOTAL
STS-6	4/83	$\boxed{27}$	$\boxed{19}$	6	2	54	26	40	66
STS-7	6/83	0	0	0	1	1	22	19	41
STS-8	8/83	0	0	2	1	3	11	18	29
STS-9	11/83	2	0	0	2	4	34	15	39
STS-11	2/84	7	7	4	0	18	9	12	21
STS-13	4/84	12	5	4	6	27	11	16	27
STS-14	8/84	3	2	4	5	14	2	8	10
STS-17	10/84	2	7	5	3	17	40	28	68
STS-19	11/84	2	1	6	2	11	20	44	64
STS-20	1/85	5	16	10	$\boxed{27}$	58	44	23	67
STS-23	3/85	21	4	2	3	30	81	30	111
STS-24	4/85	18	3	$\boxed{21}$	24	$\boxed{66}$	48	61	109
STS-25	6/85	2	4	1	4	11	64	167	231
STS-26	7/85	2	1	13	11	27	182	296	478
STS-27	8/85	1	3	16	10	30	72	24	96
STS-28	10/85	11	2	14	7	34	40	26	66
STS-30	10/85	6	6	14	9	35	90	40	130
STS-31	11/85	4	7	4	1	16	91	78	169
STS-32	1/86	5	6	8	11	30	80	51	131
STS-26R	10/88	0	1	4	3	8	$\boxed{214}$	128	342
STS-27R	12/88	0	0	1	1	2	2	$\boxed{642}$	$\boxed{644}$

$\boxed{XX}$ MAX TPS LOSS OR DAMAGE

3.3 Statistical Treatment

The damage data base compiled to correlate previous tile damage, paragraph 3.1 above, was utilized to determine if STS-27R was within the prior damage population extremes. This statistical comparison used the damage attribute where any dimension is greater than one inch and was performed for both the Orbiter left and right sides. (See Figure 3-5.)

This assessment showed that the left side average damage has been ten sites whereas the right side average damage was just over eight sites. It further shows that the STS-27R right side damage represents a +50 sigma condition. From this, it is concluded that the STS-27R right damage side is not within the population which suggests an anomalous cause(s) peculiar to the STS-27R flight.

3.4 Prelaunch and Flight Data

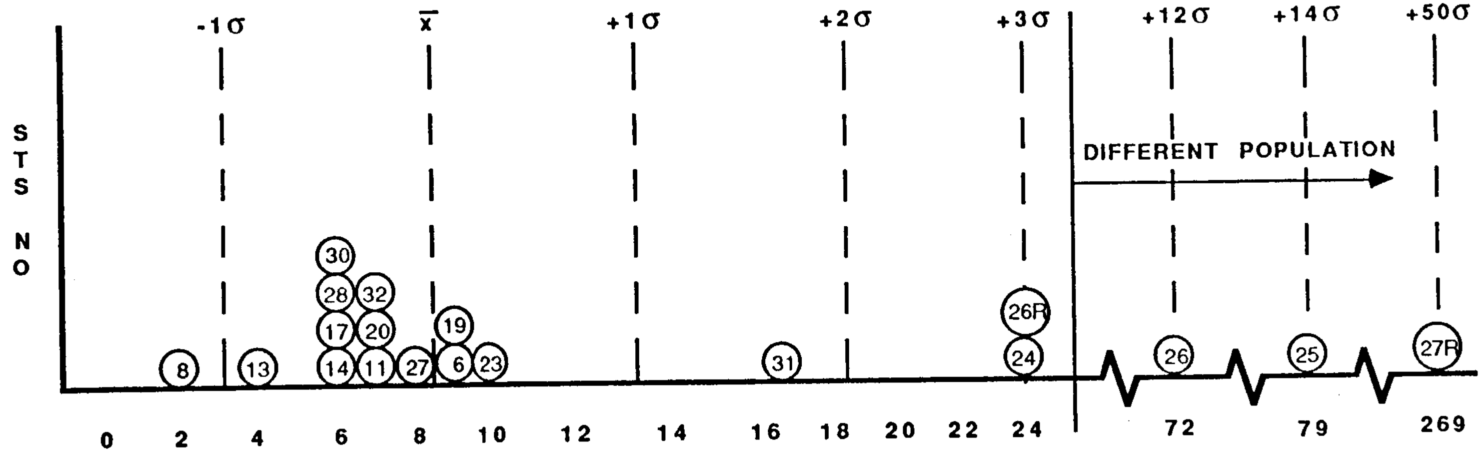
It was hypothesized that the tile damage cause was related to an unusual condition or environment not encountered on previous flights, and that this condition or environment would be detected by comparing STS-27R relevant prelaunch and flight data parameters with those from prior flights. The STS-27R parameters examined in detail and used for the comparisons described above were derived in part from a complete post-flight trajectory reconstruction. This entailed reconstructing the natural environment characteristics, the vehicle propulsion systems performance, and the vehicle flight mechanics and dynamics parameters. The reconstructed trajectory was then used to compute vehicle load and heating indicators, and protuberance loads. All this was evaluated against flight experience envelopes and design limits and no design exceedance was found; however, there were two parameters that slightly exceeded experience envelopes. The vehicle angle of attack and Beta angle were slightly beyond those previously experienced in the 20 and 50 seconds timeframe. Since these parameters were outside the experience envelope prior to the time that the tile damage occurred, and since they did not introduce excessive loading conditions, it was concluded that they were not instrumental in causing the severe tile damage.

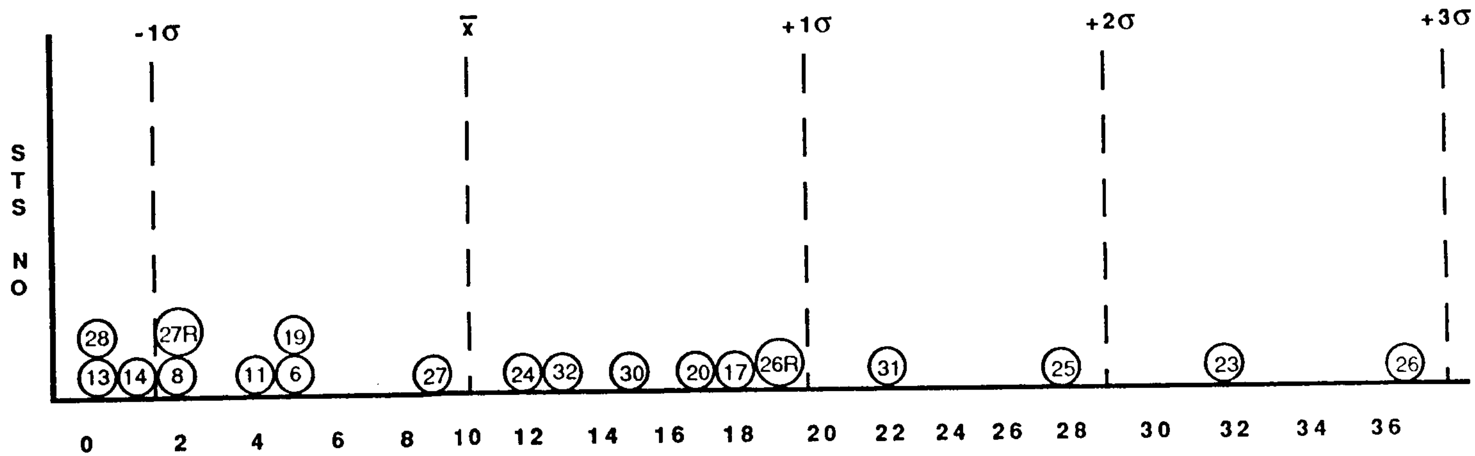
The total parameters compared with prior flights are shown in Table 3-1 and the data tables, and plots are contained in Volume II of this report. The comparison revealed only a slight right side total damage site correlation with minimum Q Alpha, and some correlation between large tile damage sites and Beta at SRB separation. (See Figure 3-6.) Even though there appears to be a slight correlation between total damage sites and minimum Q Alpha, the same is not true for large damage sites. It is

1-4478-9-5D

FIGURE 3-5

DATA REVIEW AND CORRELATION
ORBITER TPS DAMAGE REVIEW TEAM
STATISTICAL CORRELATION





1-192-9-2T

TABLE 3-1

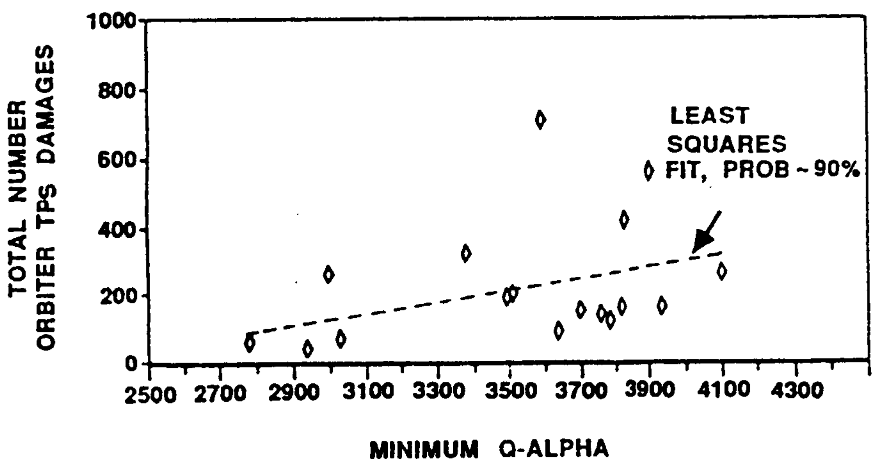
DATA REVIEW AND CORRELATION ORBITER TPS DAMAGE REVIEW TEAM PRELAUNCH AND FLIGHT DATA PARAMETERS ASSESSED

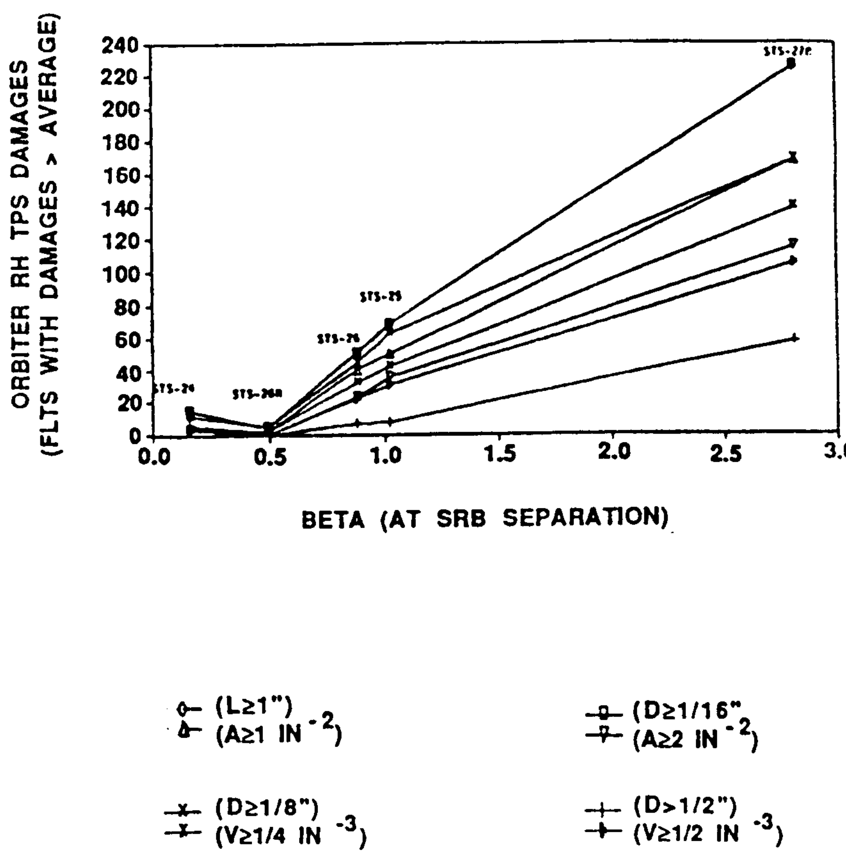
PRELAUNCH	FLIGHT
TEMPERATURE	INCLINATION/AZIMUTH
PRECIPITATION	DYNAMIC PRESSURE (Q)
WIND VELOCITY/DIRECTION	ALPHA-Q ALPHA
TIME/PRECIPITATION/WIND	BETA-Q BETA
LAUNCH TIME/DAY/YEAR	TIME AT 3G'S
NO. OF TANKINGS	SEP PARAMETERS
ORBITER/FLIGHTS	HEATING INDICATORS
ELEMENT AGE	

1–4476-9-5D

FIGURE 3-6

DATA REVIEW AND CORRELATION
ORBITER TPS DAMAGE REVIEW TEAM
FLIGHT DATA CORRELATIONS
STS-27R





therefore concluded that Q Alpha was not a potential cause for the STS-27R severe damage. It is further concluded that Beta was not related to the severe damage cause because it was well within design limits, and that if debris had been generated in the SRB separation flight regime, analysis shows that it could not have damaged the tiles.

3.5 Ice Team Observations

It was evident from STS-27R data, observations, and photography that the only measurable ice/frost present at liftoff was confined to the so-called waived ice areas. Ice team reports and photography were reviewed to compare the STS-27R external tank ice/frost level with that of previous flights. From this review, the ice in each area was subjectively rated with respect to STS-27R--less than, same as, more than, and much more than. These adjective ratings were then assigned a numerical rating of -1, 0, +1, and +2, respectively. Summing the numerical ratings for all ice areas on each flight produced numerical, or figure of merit, ratings for all flights. A net positive rating for a flight means that it had more ice than STS-27R. A net negative rating means the opposite. These ratings were overlaid on the historical tile damage chart, Figure 3-7, from which the ice and tile damage correlation was examined. Unexpectedly, it was evident that those flights with more ice returned with fewer and less severe damage sites. The contrary was also true, i.e., those flights with less ice returned with more tile damage.

It was concluded from the STS-27R prelaunch ice team inspection results and the inverse ice/damage correlation that the severe damage was not caused by ice resident on the external tank.

3.6 Mission Events Timeline

All observations and data sources were reviewed to extract those events possibly related to the TPS damage. The Mission Events Timeline begins prior to launch and terminates immediately after Main Engine Cutoff (MECO). Included were flight events, flight dynamics sequences, crew observations, photographic observations, and C-band radar observations. The complete timeline is contained in Volume II, and the significant events were as follows:

a. Numerous photo particle sightings: T + 3, to T + 2:10.

b. Last confirmation of Orbiter TPS integrity: T + 4.

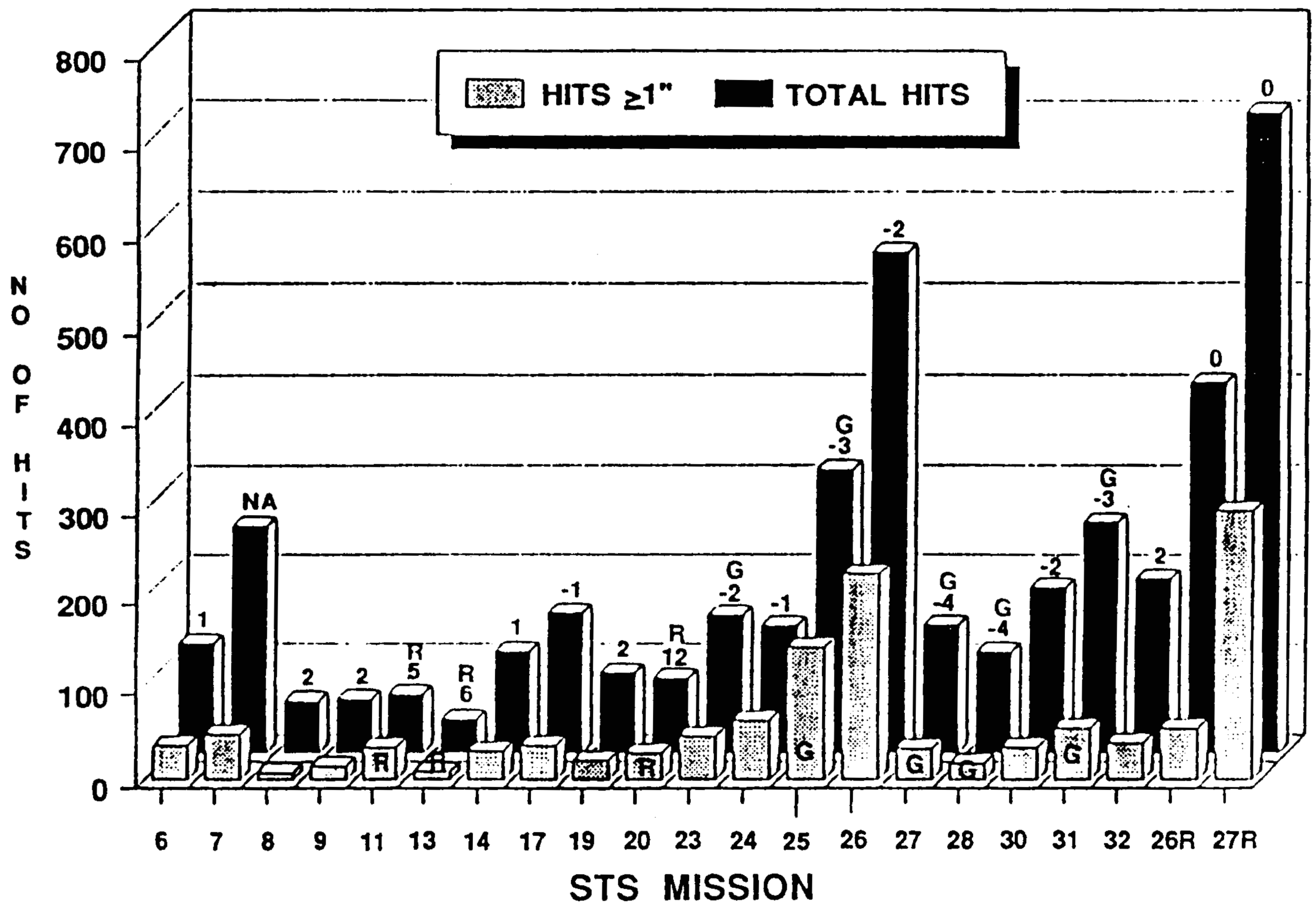
c. White particles impacting window: T + 27.

1-4468-9

FIGURE 3-7

DATA REVIEW AND CORRELATION
ORBITER TPS DAMAGE REVIEW TEAM

TOTAL HITS AND HITS ≥1"
AND ICE FIGURE OF MERIT (SHOWN ON TOP OF BLOCKS)



NOTE: FIGURE OF MERIT IS RELATIVE ORDER OF ICE FORMATION ON ET AT APPROX. T-3 HOURS. ALL NUMBERS ARE RELATIVE TO STS-27R.

R VEHICLES WITH THE MOST ICE

G VEHICLES WITH THE LEAST ICE

ORIGINAL PAGE IS OF POOR QUALITY

d. OMS pod carrier panel dislodged: T + 30.

e. Last confirmation of SRB-ET TPS integrity: T + 30.

f. Three-foot particle/streak in SRB plume: T + 52.47.

g. First C-band radar object sighted: T + 53.50.

h. Outboard elevons to 5^{o}: T + 67.8.

i. All elevons neutral: T + 84.6.

j. SRB separation: T + 126.

k. Objects separating from Orbiter/ET (C-band): T + 141 to T + 169.

3.7 Photographic Observations

Ascent photographic sources were reviewed in detail to determine if debris identification, debris sources, or tile damage could be detected. Generally, there were many debris particles/objects observed beginning at liftoff with the last one seen at SRB separation. Those observed are listed in the Mission Events Timeline along with their description and time observed. The only two objects tentatively identified were the OMS pod carrier panel, approximately T + 30 seconds, and slag from the SRMs at SRB separation. Six previous flights' photography were reviewed to ascertain if STS-27R particle/objects numbers were unusual. (See Figure 3-8.) It was concluded that the total number of particles/ objects appearing on STS-27R was not extraordinary; but, the time distribution from liftoff through SRB separation was different. There is no significance placed on this distribution because the severe tile damage occurrence has been placed at around T + 85 seconds.

Several unsuccessful attempts were made to identify SRB forward assembly photo or video scenes that could be enlarged or enhanced. This could have shown if there was TPS missing from the right nose cap. One crew photo containing a distant ET image was enlarged and enhanced. The enhancing organization pointed out two forward areas that were not as expected. The team identified one area as possibly light-reflected off the Gaseous Oxygen (GOX) pressurization line, but could not determine any reason for unusual color variations.

1-685-9-7T

FIGURE 3-8

ORBITER TPS DAMAGE REVIEW TEAM
PHOTOGRAPHIC DEBRIS OBSERVATIONS ON STS FLIGHTS

OBSERVED DEBRIS

FLIGHT PHASE SECONDS FROM T– ZERO	STS-9	STS-13	STS-20	STS-25	STS-26	STS-31	STS-27R	TOTAL
5 – 10	–	14	2	27	–	–	7	50
11 – 15	3	3	1	–	8	26	9	50
16 – 20	12	1	1	–	14	14	6	48
21 – 25	1	–	–	–	–	–	2	3
26 – 30	–	–	1	–	–	–	4	5
> 31	–	–	2	–	–	1	4	7
TOTAL	16	18	7	27	22	41	32	

3.8 C-Band Radar Observations

As the team began its review, there were reports that the Range Safety C-band radar had detected objects departing the ET/Orbiter following SRB separation. Meetings with Range personnel revealed that an object was observed at approximately T + 53 seconds, and eleven others appeared between T + 141 and 169 seconds. The signal strength was insufficient to be specific about shape, size, or possible material, except for possibly object number seven. Its physical characteristics may be postulated with further analysis.

The range provided some historical object observations as shown in Figure 3-9. The observations were compared to historical tile damage and no correlation could be discerned.

Further, C-band radar analysis and potential for debris identification are addressed in this report under Section 5.9.

3.9 Crew Observations

The following is a summary of STS-27R flight crew comments pertinent to Orbiter TPS damage.

3.9.1. Between throttle back and throttle up (less than Mach 0.95, intercom comment at T + 27), the Commander (CDR) noticed pieces of white material hitting windows W-3 and W-1. The material behaved like ice/frost and tended to be swept off the windows by the flow stream. A residual streak from this material was visible on W-1 through orbit and reentry.

3.9.2. SRB separation was described as "visible flame" by the CDR. The CDR recalled only seeing an "orange glow" and "lots of smoke" during SRB separation on previous flights (Pilot (PLT) on 41-B, CDR on 61-C). During both of the CDR's previous missions, SRB separation had occurred in daylight conditions. Mission Specialist 1 (MS1) described the SRB separation motor burn as longer in duration than he recalled form his previous flight (MS1 on 41-D). The separation motor burns looked symmetrical to Mission Specialist 2 (MS2).

3.9.3. All crew members felt a noticeable low frequency vibration/buffet during second stage that was not present after SRB separation on their previous flights. Crew members with previous flight experience described previous flights as "electric motor drive" during second stage. This included MS2's previous experience on Atlantis. The vibration was longitudinal (Orbiter x-axis) at approximately 3-4 Hz, and persisted to MECO.

1-686-9-7T

FIGURE 3-9

C-BAND RADAR DETECTIONS STS PARTICLE SEPARATIONS

FLIGHT	DATE	FL. AZ.	DETECTION TIMES (T+SEC)		SIGNAL STRENGTH (T > 138 SEC.)
			T < 138 SEC.	T > 138 SEC.	
STS-9	11-28-83	35.49°	112.5, 129, 131	147, 156, 162, 169.5, 176	FAINT
STS-13	4-06-84	88.108°	123–130	139, 141, 142, 143.5, 147	WELL DETECTABLE
STS-19	11-08-84	88.73°	121–131	144, 152, 157, 164.5	FAINT
STS-26	7-29-85	44.07°	120–131	149, 150.8, 154.5, 157.5	FAINT
STS-32	1-12-86	88.80°	125–130	144, 146, 169, 171, 172	FAINT
STS-26R	9-29-88	89.004°	124–130	147, 175, 186, 194	FAINT
STS-27R	12-02-88	35.––°	53.5, 120–138	141.3, 142.05, 142.85, 143.25, 146.75, 148.0, 148.3, 151.35, 154.0, 155.45, 158.0 168.75	WELL DETECTABLE

NOTES: DETECTIONS BEFORE T+138 SEC. REFER TO PARTICLES ORIGINATING FROM SRB/ET/ORBITER COMPLEX

DETECTIONS AFTER T+138 SEC. REFER TO PARTICLES ORIGINATING FROM ET/ORBITER ONLY

3.9.4. At Mach 8.8 (during second stage, approximately T + 4:26), MS2 made an intercom comment that more "stuff (white material) was coming off the front every once in a while" and passing by the windows.

3.9.5. The PLT moved his seat up and forward and watched the external tank separation. He was able to see only the tip of the tank and did not notice anything peculiar.

3.9.6. The crew took photographs of the external tank after separation as it was tumbling (approximately T + 26:00). Because of the long range from which these observations were made, the crew was unable to make a visual evaluation.

3.9.7. It was apparent to the crew during the Remote Manipulator System (RMS) survey that they had sustained considerable damage to the TPS. They noted approximately two dozen impact areas on the TPS, some of which covered several tiles. They felt that post flight inspection of tile damage correlated well with what they had seen during their on-orbit survey.

3.9.8. A review was made of crew flight reports from 19 previous STS missions. Crew members from five previous missions were also interviewed. The focus of this review was to compare crew comments from STS-27R with comments from previous missions to isolate any unique characteristics of STS-27R. The results are as follows:

a. The STS-27R crew noticed white material hitting/passing the window during ascent up to Mach 8.8. This has been a common occurrence on previous missions. Pieces of this white material have hit the windows in the past and left "chalky" stains/streaks. Most of these streaks were "burned off" during reentry although some have remained through landing. Several crews reported seeing this material during second stage, some throughout ascent. Two reports of interest highlighted activity at Mach 8.7 and 9.0. On mission 51-F, a large piece of this material passed the window at 8.7 Mach. On mission 51-B, the highest activity was reported at Mach 9.0.

b. Two members of the STS-27R crew commented that the SRB separation was different than their previous experience. (See Crew Observation 3.9.2.) That review brought out several SRB separation descriptions that enveloped those by the STS-27R crew. This indicates that although the crew noticed differences, the STS-27R separation may not have been unique.

c. The entire STS-27R crew reported a low frequency x-axis vibration/buffet of approximately 3-4 Hz during second stage. The experienced crew members recalled that second stage had been very smooth in their previous missions. Most previous flight reports indicated that second stage was very smooth. There were, however, two previous missions that encountered this vibration. These were STS-13 (41D) and STS-20 (51C), both with the Orbiter Discovery. These missions did not correlate to data of increased tile damage on the Orbiter.

4.0 Fault Tree Summary

In parallel with the data review and correlation, a comprehensive fault tree was constructed. It contained five major elements corresponding to each possible cause contributor, i.e., External Tank, SRB/SRM, Orbiter, Systems, and Launch Operations. These elements were further expanded until the tree contained over 250 elements that were subsequently evaluated. (See Volumes II-VI.) A condensed version is depicted in Figure 4-1 that reflects those legs that pointed toward damage cause. These fault tree causes and those derived from other sources are summarized in Table 4-1. All these possible causes required some level of analysis or test to resolve or confirm.

5.0 Data Analysis and Tests

The results established from the Data Review and Correlation Section (3.0), and the Fault Tree Section (4.0) necessitated further diagnostic analyses and tests. The objectives for these activities were either to evaluate data for potential cause identification, or to evaluate the Failure Tree causes. Some were necessary to absolve the potential cause or to confirm its contribution to the STS-27R anomaly. The following sections describe the analyses and tests, and relate the results to the area under investigation.

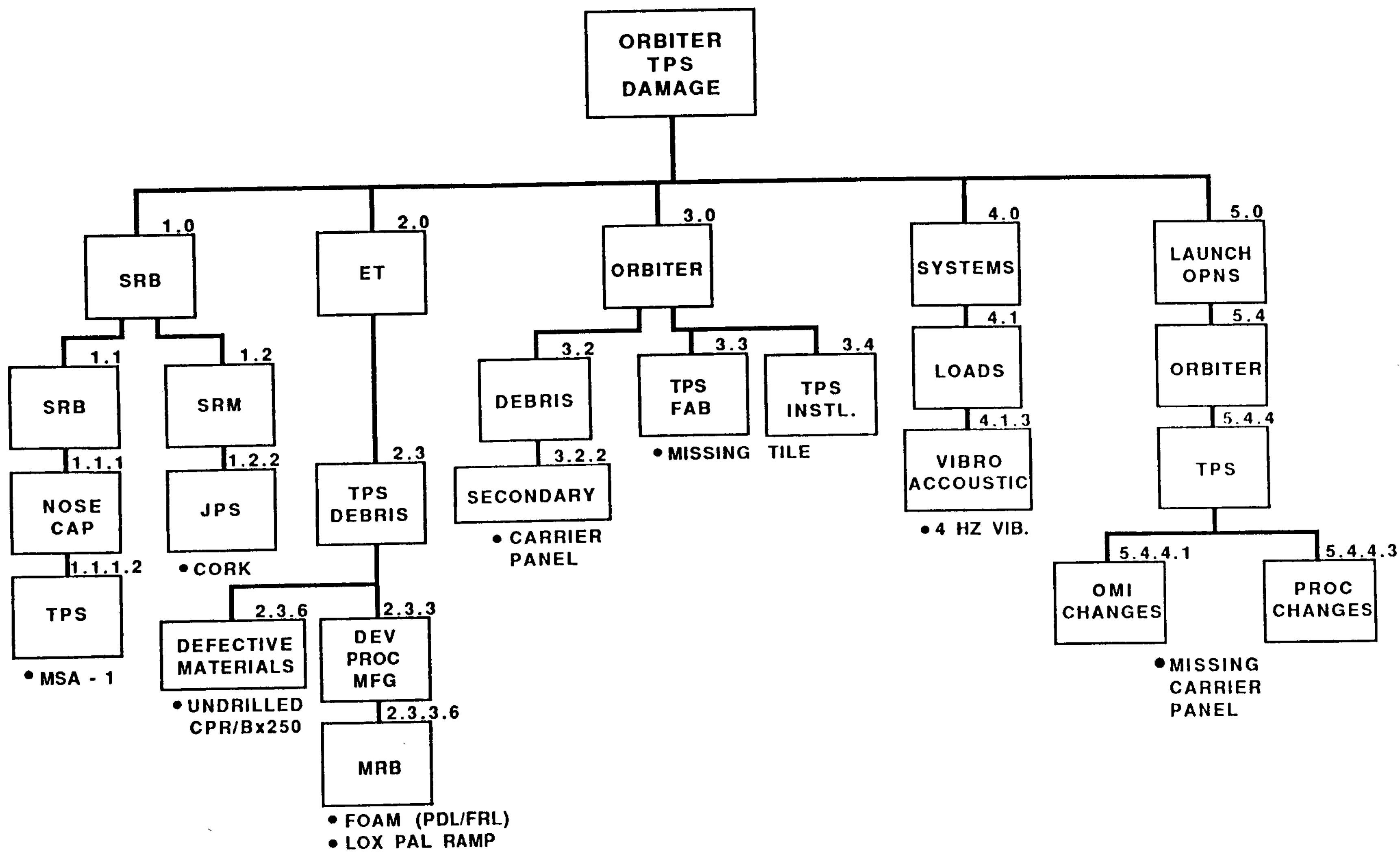
5.1 Laboratory Materials Testing

Initial inspection of the STS-27R Orbiter damaged tiles revealed contaminant and residual debris particulate. These early discoveries led to a concerted effort to specifically inspect the damaged areas for other possible debris samples. All the retrieved samples were subjected to laboratory materials analysis, test, and characterization. With this information, the material origin on the STS flight elements was established. These important evaluations, including the material tests and test organization, are presented in detail in Volume VII.

1-4481-9-5D

FIGURE 4-1

SUMMARY FAULT TREE
ORBITER TPS DAMAGE REVIEW TEAM



1-676-9-7T

TABLE 4-1

DATA ANALYSIS AND TEST
ORBITER TPS DAMAGE REVIEW TEAM
FAULT TREE SUMMARY

- EACH GROUP ESTABLISHED A FAULT TREE BASED ON ASSIGNED AREA
  - FIVE FAULT TREES
  - TOTAL ELEMENTS - 254
  - SRB/SRM SUBSTANTIALLY CLEARED EARLY - RETRIEVED HARDWARE INSPECTION
- CAUSE IDENTIFICATION SOURCE

POTENTIAL CAUSE	SOURCE	DESCRIPTION
• LOX PAL RAMP	• FAULT TREE ITEM 2.3.3.6 • CREW COMMENT	• REPAIR AT MAF PECULIAR TO STS-27R • FLAMES VS. ORANGE GLOW AT SEP • BSM BURN TIME LONGER
• LOX PRESS LINE BKT TPS – OR – PDL/FRL REPAIR	• POST FLIGHT INSPECTION • LAB TEST	• PARTICLE FOUND FORWARD OF RH OMS POD • PARTICLE IDENTIFIED AS PDL/FRL
• LH_2 PAL RAMP	• ACTION ITEM	• SOME TPS ACREAGE UNDRILLED SINCE SILMAR RESIN FIX

1-677-9-7T

TABLE 4-1 (CONT'D)

DATA ANALYSIS AND TEST ORBITER TPS DAMAGE REVIEW TEAM FAULT TREE SUMMARY

POTENTIAL CAUSE	SOURCE	DESCRIPTION
• SRB PROCESS VARIATION RH NC TPS DISLODGED	• POST FLIGHT INSPECTION	• PARTICLE FOUND IN RH OMS POD AFRSI PANEL
	• LAB TEST	• PARTICLE IDENTIFIED AS MSA-1 • MSA-1 OR HYPALON PAINT MATERIAL RESIDUE IDENTIFIED IN 16 OF 38 LOCATIONS EXAMINED ON ORBITER TPS
	• FAULT TREE 1.1.1.2	• PROCESSING CONCERNS
• RADAR OBSERVED OBJECT	• C-BAND RADAR - PATC	• RADAR REFLECTIVITY PLOTS SHOWED OBJECTS AT T + 53 SEC AND POST SRB SEP
• 4 Hz VIBRATION	• CREW COMMENT	• LOW FREQUENCY VIBRATION THROUGHOUT SECOND STAGE OPERATION
• CARRIER PANEL RH OMS POD	• POST FLIGHT INSPECTION	• MISSING CARRIER PANEL

Table 5-1 and Figure 5-1 summarize the Orbiter locations where the debris/residue samples were found, the resulting material identifications, and the probable STS vehicle origins for the noted material. The most prevalent material found exhibited a paint signature. Sixteen of 38 TPS location samples showed either Hypalon paint or MSA-1 TPS traces. Although this signature, titanium in combination with aluminum, has other potential sources on the STS elements (Volume 6.a, Section 3.2.2.6), those other sources were either found intact during STS-27R post flight inspection or did not have a path or transport mechanism to the lower Orbiter surface. Therefore, the identified probable origin for the noted Hypalon paint debris is the SRB RH Nose Cap. Hypalon paint is applied to the SRB forward and aft assemblies primarily as moisture protection for the MSA-1 TPS. Since the aft assemblies are located so that debris transport to the Orbiter is not reasonable, and all the forward assembly but the Nose Cap was found essentially intact by post flight assessment, it has been concluded that the most probable origin was the SRB Nose Cap. Based on the STS-27R Orbiter sustaining most severe damage on its right side (Section 2), the source is further restricted to the SRB RH Nose Cap.

In addition to the noted Hypalon/MSA-1 debris, other signatures were found as presented on Table 5-1. The other potentially significant debris particle was PDL foam/Fire Retardant Latex (FRL) paint. This material was traced to either the External Tank "rabbit ears" (located in the ET nose area), or a TPS repair in the ET nose area. The final particularly interesting debris was the Reaction Control System (RCS) nozzle cover (RTV/butcher paper/Scotch Guard) residue found on the Orbiter W-1 window. This is not a damage concern but it could be a potential vision impairment to the crew.

5.2 Debris Trajectory Analysis/Damage Flow Regime

Analyses were conducted to determine the plausibility of suspected ET/SRB debris impacting the Orbiter at the observed damage locations. The suspected ET debris at that time was the Liquid Oxygen (LOX) PAL Ramp and PDL/FRL from the Nose Cap area. The SRB Debris analyzed was MSA-1 from the nose cap. Analyses were also performed to confirm the reasonableness of these impacts causing damage to the Orbiter tiles (i.e., confirm sufficient impact energy for incipient damage), and to determine the probable flight regime (time) for such an occurrence. The tools and techniques contributing to this overall assessment were (1) STS launch vehicle wind tunnel oil flow correlations to the Orbiter tile damage pattern, (2) debris transport trajectory parametric analyses using STS aerodynamic computational fluid dynamic codes, (3) candidate debris energy as functions of flight

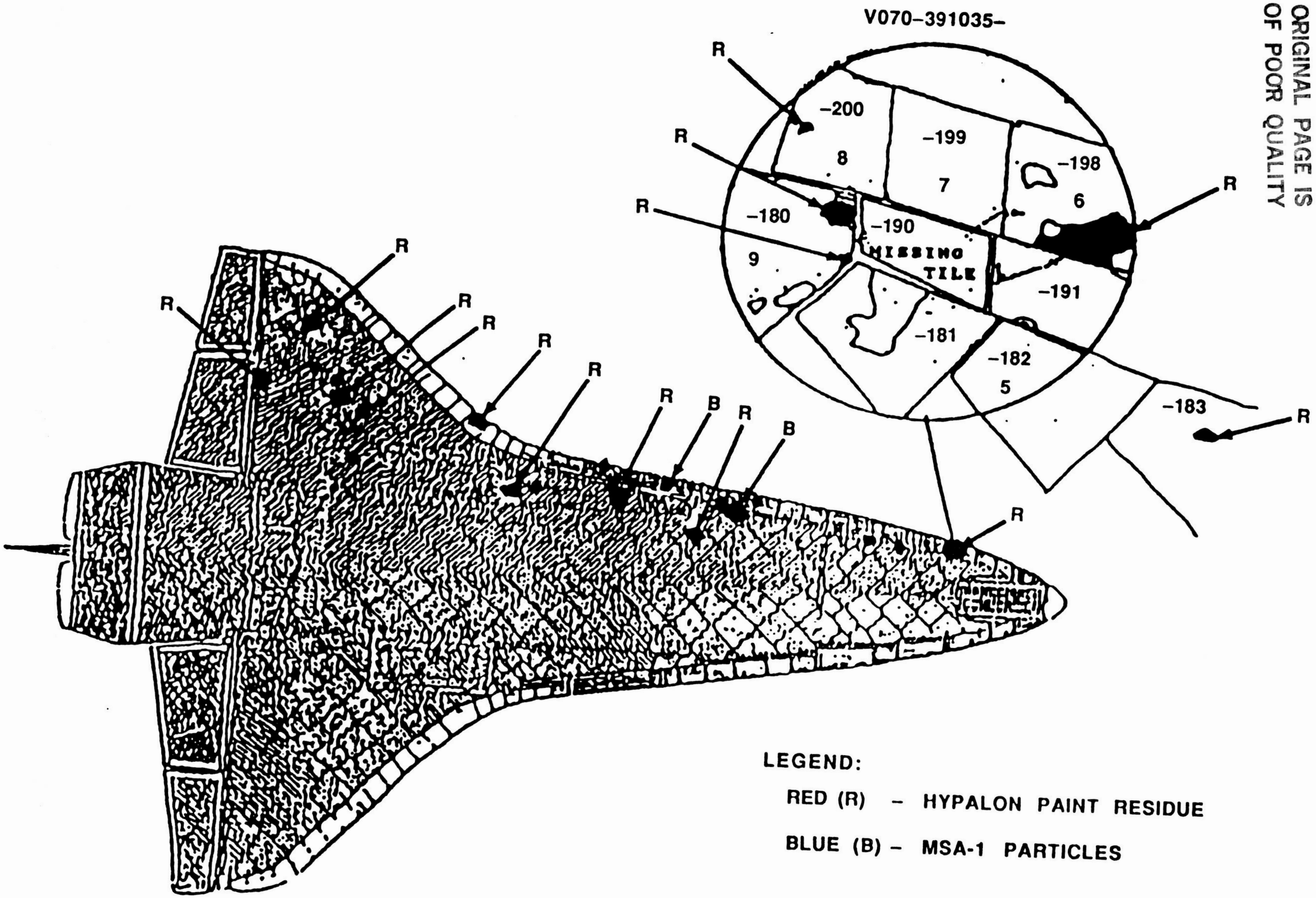
1-678-9-7T

TABLE 5-1

DATA ANALYSIS AND TEST
ORBITER TPS DAMAGE REVIEW TEAM
LABORATORY MATERIAL TESTING

WHERE FOUND	MATERIAL FOUND	PROBABLE ORIGIN
W-1 CDR WINDOW	SILICA, RTV, SCOTCHGUARD	RCS NOZZLE COVERS
ORBITER LOWER SURFACE	HYPALON PAINT SIGNATURE	SRB NOSE CAP AREA
MISSING TILE AREA RIGHT CHINE AREA RIGHT GLOVE AREA FORWARD OF MLGD AFT OF MLGD RIGHT WING	MSA-1 ECCOSPHERES	SRB NOSE CAP AREA
	PHENOLIC BALLOONS (FROM MSA-1)	SRB NOSE CAP AREA
	GREY-WHITE STREAKS	RECONDENSED SILICA FROM TILES
	RTV, NOMEX FIBERS, SIP	TILE ADHESIVE, GAP FILLER
RCC PANEL RIGHT ORBITER WING	HYPALON PAINT SIGNATURE	SRB NOSE CAP AREA
RIGHT OMS POD	MSA-1 W/HYPALON TOPCOAT	SRB NOSE CAP AREA
	PDL FOAM W/FRL PAINT	ET NOSE CAP REPAIR OR "RABBIT EARS"
ORBITER MID-BODY	IRON FIBER (1.0MM X 0.05MM D)	UNKNOWN
MISSING TILE CAVITY	FILLER BAR, SIP, RTV	NORMAL MATERIAL

FIGURE 5–1 ORBITER LOCATIONS FOR MATERIAL IDENTIFICATIONS



LEGEND:

RED (R) – HYPALON PAINT RESIDUE

BLUE (B) – MSA-1 PARTICLES

regime and Orbiter station compared with tile damage threshold values (to determine damage flight regimes), and (4) Orbiter elevon damage vs. position historgram (to assess significance of the STS-27R no-elevon-damage post flight condition).

Figure 5-2 graphically depicts the assessment results leading to the most probable flight regime. Based on debris energy calculations versus tile damage energy thresholds, it was established that SRB Nose Cap debris can damage the Orbiter between Mach 0.4 and 3.75, and for ET Nose Cap debris between Mach 0.4 and 2.5. It is also shown that between Mach 1.0 and 2.5, the STS oil flow results correlate well with the Orbiter damage pattern. Further, it reflects that the Orbiter inboard elevon moves to neutral (i.e., out of the direct flowfield) at Mach 2.5. Therefore, since elevon damage history (Figure 5-3) shows damage on all flights prior to STS-27R, it is apparent that the STS-27R damaging debris event occurred after Mach 2.5.

It was noted from parametric debris transport analyses that the Orbiter tile damage probability increases substantially for positive vehicle angles of attack. Figure 5-2 also shows this condition exists after Mach 2.25. It is therefore concluded that the most likely flight regime where the STS-27R damage occurred is in the Mach 2.5 flight regime.

It was confirmed by analyses using the tools and techniques discussed above that the suspected ET/SRB debris could reach the STS-27R Orbiter damage sites. More detail on this subject is contained in Volume 2 (section 3.3). The cases analyzed included several ET and SRB TPS debris sizes, and encompassed the Max Q to SRB separation flight regime. Results were that all the ET and SRB suspect TPS sources do have the capability to reach the damaged Orbiter regions with sufficient energy to inflict severe damage.

5.3 MSA-1 Survivability Thru Orbiter Nose Shock

For the SRB Nose Cap MSA-1 material to damage the tile, a relatively large piece must traverse the Orbiter nose aerodynamic shock wave. The Orbiter missing tile failure scenario assessment (reference Volume IV) established the MSA-1 impacting debris size, .25 x 5 x 10 inches, necessary to fracture the tile. An assessment was made to determine if this MSA-1 particle size could be expected to traverse the Orbiter nose shock and retain its structural integrity.

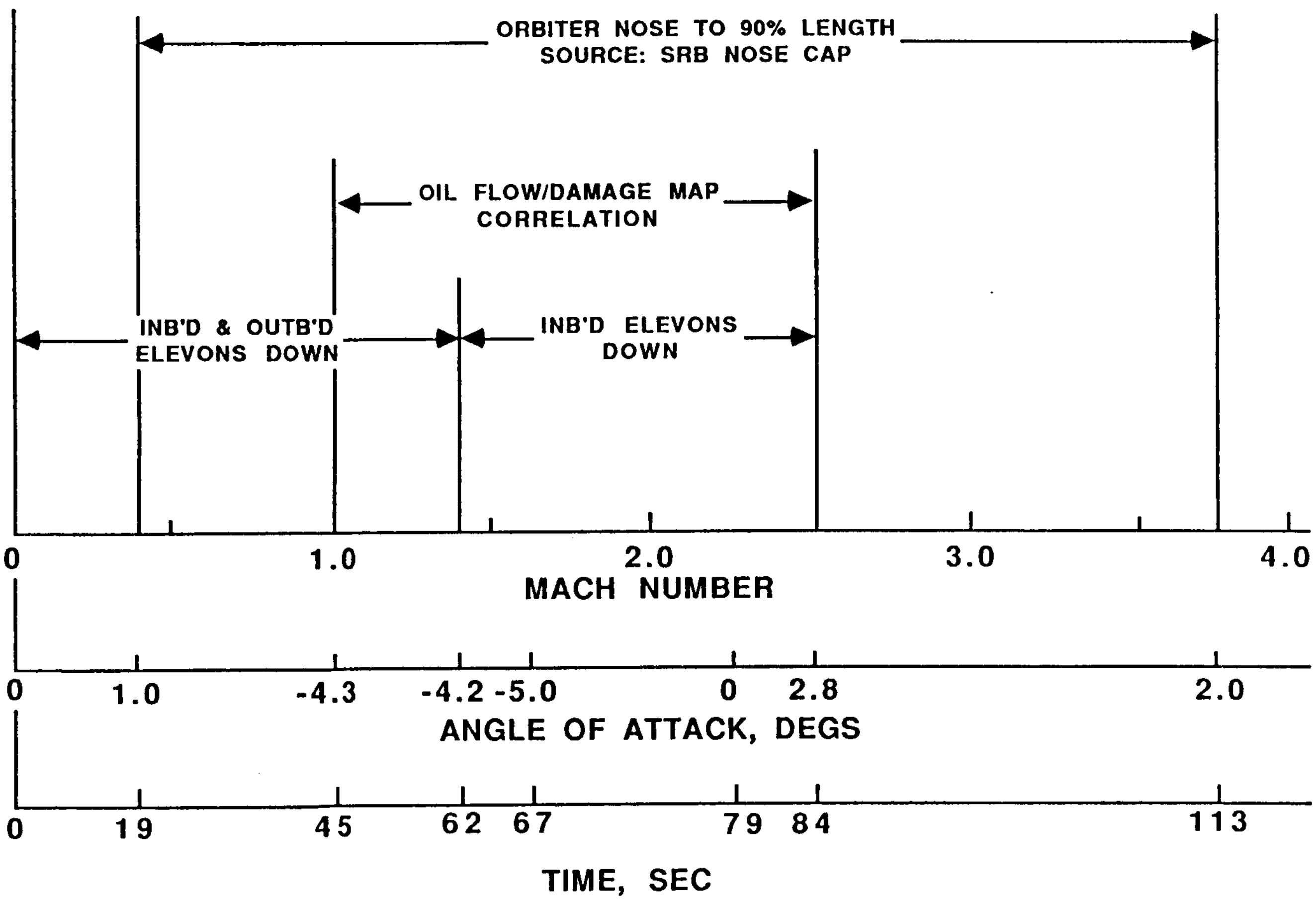
Debris that traverses the nose shock is subjected to asymmetric aerodynamic forces which induce moments, and therefore stresses, into the debris. The asymmetric aerodynamic loading due to the

1-4480-9-5D

FIGURE 5-2

ORBITER TPS DAMAGE REVIEW TEAM ASCENT DEBRIS TRAJECTORY SIMULATION

POSSIBLE DAMAGE FLIGHT REGIME



1-679-9-7T

FIGURE 5-3

ORBITER TPS DAMAGE REVIEW TEAM
HISTORY OF ELEVON HITS FROM NINETEEN PREVIOUS FLIGHTS

	FLIGHT	ELEVON HITS			
		INBOARD		OUTBOARD	
		L	R	L	R
1	STS-6	3	4	1	2
2	STS-8	-	2	-	1
3	STS-9	1	3	-	-
4	STS-11	-	2	-	-
5	STS-13	-	4	-	-
6	STS-14	1	1	-	-
7	STS-17	1	4	1	-
8	STS-19	2	12	-	-
9	STS-20	-	2	2	-
10	STS-23	-	2	1	-
11	STS-24	2	2	1	2
12	STS-25	-	9	2	1
13	STS-26	2	11	-	-
14	STS-27	-	5	-	-
15	STS-28	3	8	-	1
16	STS-30	5	7	1	-
17	STS-31	-	5	1	-
18	STS-32	7	11	5	5
19	STS-26R	-	12	-	6
20	STS-27R	-	-	-	-

differences in the flow field before and after shock wave. These stresses are debris size and orientation dependent. A range of debris sizes and orientations was evaluated to determine the debris survival probabilities.

Debris passing through the shock wave is exposed to the two separate forces, which produce uneven loading or moments about the debris center of gravity (CG). Bending moments about the debris CG were calculated using a distributed lump mass approach. If the bending stresses were greater than 50 percent of the allowable MSA-1 tensile strength, a failure was assumed. The survival of each debris size for a given orientation was calculated using the methodology described above. The survival probability was calculated for each debris size as a function of pitch ($0-90^{o}$) and roll ($0-90^{o}$) combinations. Figure 5-4 presents the debris survival probability results versus debris planform size. It is noted from these data that a piece of MSA-1 .25 x 5 x 10 inches has a 70 percent probability of surviving transition through the Orbiter nose shock. Therefore, it is considered reasonable that this size debris could move from the SRB nose area to the Orbiter damage site without losing its structural integrity.

5.4 Missing Tile Failure Scenario

An assessment to provide the failure scenario and technical rationale for the Orbiter missing tile was performed by the Orbiter team, and is reported in detail in Volume IV, Action Item 37 and Appendix J. In summary, it was concluded that failure resulted from ascent debris impact which initially caused partial tile loss. Subsequent reentry heating led to overheating of the remaining tile bondline and its complete loss prior to post landing inspection. Thermal reconstructions by analyses show compatibility of the noted scenario with the post flight condition of the tile cavity and surrounding structure. A primary by-product of this assessment was the estimated .25 x 10 x 5 inches MSA-1 particle size necessary to fracture the tile. The estimated size was derived based on empirical correlations from tile threshold damage test results.

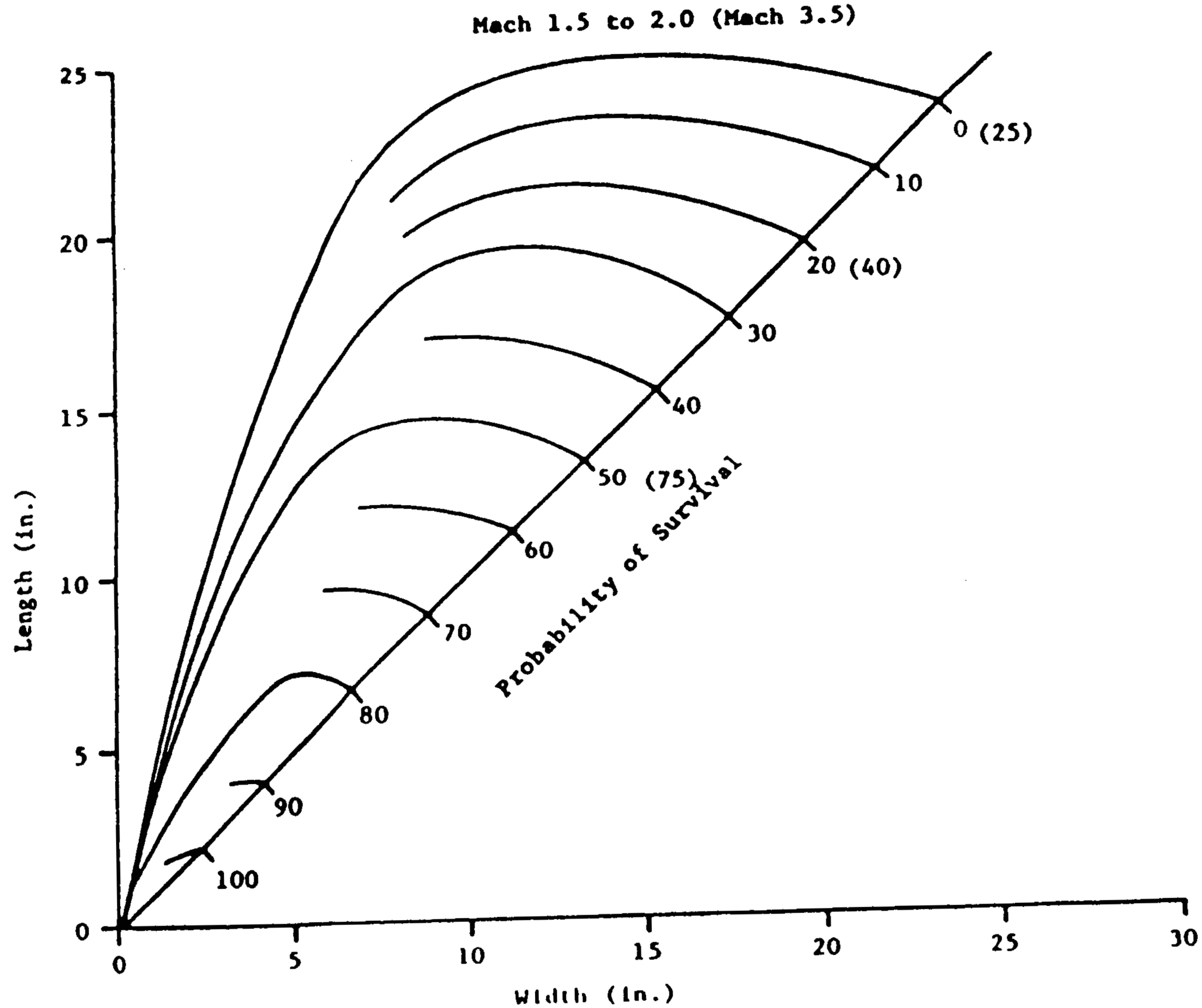
5.5 Debris Quantity/Availability Assessment

An assessemnt was conducted to determine if adequate material was available in the suspected ET and SRB regions to have caused both the missing tile damage and the total STS-27R Orbiter tile damages. As established in Section 5.4, the estimated debris size which was required for the missing tile site was 1 x 5 x 10 inches assuming PAL ramp material as the cause, and .25 x 5 x 10 inches assuming MSA-1 as the cause. (See Table 5-2.) Similar calculations were made for the 17 largest damage craters with

1-4475-9

FIGURE 5-4

ESTIMATED PROBABILITY OF MSA–1 DEBRIS SURVIVAL THROUGH ORBITER NOSE SHOCK



1-680-9-7T

TABLE 5-2

DATA ANALYSIS AND TEST
ORBITER TPS DAMAGE REVIEW TEAM
DEBRIS QUANTITY/AVAILABILITY ASSESSMENT

RESULTS

	PAL RAMP	MSA-1
● MISSING TILE SITE		
● VELOCITY – FPS	1050	900
● IMPACT ANGLE – DEG.	11.4	19.0
● DENSITY – LB/FT^3	2.3	16.0
● THICKNESS – INCHES	2.25	0.25
● DEBRIS SIZE – INCHES	1 X 5 X 10	.25 X 5 X 10
● TOTAL DAMAGE SITES		
● DEBRIS VOLUME REQUIRED – IN^3	3400	80
● DEBRIS VOLUME AVAILABLE – IN^3	4900	750*
		100**

* ONE QUADRANT OF NOSE CAP
** ONE QUADRANT OF DOME

● CONCLUSIONS – SUFFICIENT MATERIAL EXISTS TO CAUSE OBSERVED DAMAGE depth greater than 3/4 inch. The remaining smaller damage sites were evaluated by using an averaging technique. These assessment results are presented in Table 5-2. It was concluded that adequate ET PAL ramp material was available to have produced the STS-27R damages, and that adequate MSA-1 material was available from one SRB Nose Cap (or Nose Cap dome) quadrant.

5.6 MSA-1 Humidity Test

A potential cause identified in the SRB fault tree assessment was RH SRB Nose Cap MSA-1 material loss. TPS build records evalaution for the STS-27R Nose Caps and five prior flights produce some concern with several processing parameters. One was the time lapse between the RH SRB Nose Cap MSA-1 spray event and the subsequent Hypalon paint application. This hiatus for STS-27R RH Nose Cap was 45 days, whereas historical average was approximately 15 days. The Hypalon paint's primary function is to provide a humidity barrier for the hygroscopic MSA-1 insulation. The bare MSA-1 exposure to the uncontrolled environment in the KSC Vertical Assembly Building could have degraded the material.

Therefore, a MSA-1 strength evaluation test was conducted with varied humidity levels prior to Hypalon application. A full test report is in Volume 6, Section 3.2.2.4; but in summary, MSA-1 strength decreased by 30-40 percent after a 7-day exposure to 75 percent humidity. This, in all probability, was a contributing factor to the low average acceptance test portapull results for the RH Nose Cap, STS-27R average failure strength of 36 psi versus normal average greater than 100 psi.

5.7 MSA-1 Blister Test

The Laboratory Materials Testing, Section 5.1, showed Hypalon paint traces on several Orbiter damaged tiles. Prior SRB forward assembly post flight assessments have consistently revealed small "blistered" MSA-1/Hypalon, some of which were missing post flight. Since it has been determined that small MSA-1/Hypalon chips can damage Orbiter tiles during ascent (see Volume IV, Section 4 and Action Item 32), and, since it was hypothesized that these small blistered paint chips could be deposited on the Orbiter, a test (Volume VI, Section 3.2.2.6) was conducted to evaluate the potential for losing Hypalon blisters during ascent. It was determined by thermal vacuum test that Hypalon paint blisters as large as 2-inches in diameter can be created due to the STS ascent heat load. Although the thermal vacuum test did not result in the loss of any Hypalon blisters, the aerodynamic shear force simulation was unconservative, leaving open the possibility for blister loss under actual ascent flight dynamic pressures. It should be noted that the size blisters produced by the test have not been observed during any post-flight inspection, nor did MSA-1 humidity test panels blister when subjected to the same heating profile. Although the assessment concluded that the potential exists for Hypalon blisters with MSA-1 attached to damage the Orbiter tiles, it exists only for worst case impact angles and velocity and does not result in damage characteristics as severe as that exhibited by the STS-27R Orbiter.

5.8 External Tank PAL Ramp Test

The STS-27R ET as-built records review revealed that an approved full length axial repair had been made to the LO_2 PAL Ramp. This resulted in a unique flight configuration in the critical debris zone which had not been validated by test prior to flight. On this basis, a test was initiated to demonstrate the required ultimate safety factor (reference Volume V, Section 2.3.3.6, paragraph 8, and Appendix E).

The flight induced structural loading conditions for the LO_2 ramp established the following two design drivers: (1) 3.0 psi BSM plume impingement aerodynamic load which occurs during SRB separation, and (2) induced deflections resulting from cryogenic temperature LO_2 tank pressure considerations. Since analysis for the 3.0 psi impingement pressure established a very large predicted safety factor (greater than 21), the only test objective undertaken was to verify the PAL ramp structure for the deflection condition.

The deflection condition results in PAL ramp bending along its longitudinal axis. This bending is quantified by an equivalent bend radius which at the defined limit load condition is 200 inches. The test subjected the ramp to this limit load condition with no apparent structural anomalies. In subsequent test-to-failure, the ramp reached a 160 inch radius which corresponds to a 1.25 equivalent safety factor.

Therefore, based on these test results, the PAL ramp repair implemented on STS-27R was not deemed a flight debris threat.

5.9 C-Band Radar Testing

As described in Section 3.8, STS-27R C-band radar data revealed objects departing the STS ascent vehicle both before, and just after, SRB separation. It was thought at the time that identifying these objects could aid in understanding the cause for tile damage. With full cooperation by the Eastern Test Range, action was initiated to characterize the C-band signal signature for potential STS debris materials to pursue possible object identification.

Table 5-3 lists the STS debris samples, their sources, and sizes provided for C-band characterization. Figure 5-5 presents signal strength characterization for 20 of the noted samples overlayed with the C-band Radar signal strength range for the STS-27R observed objects. The various debris types have been annotated to present a qualitative probability-of-detection (high, good, low). It was determined that four of the 20 samples tested, at the size tested, could not have been the STS-27R objects. Any of the remaining samples could potentially have been the source. Closer discrimination could not be made because the object signal returns were so faint.

The overall C-band observations significance was established, based primarily on the conclusions reached in Section 5.2, Debris Trajectory Analysis/Damage Flight Regime. Because the potential for damaging the Orbiter tiles by the suspected SRB or ET debris sources diminishes rapidly beyond the Mach 3.8 timeframe (Figure 5-2), it is not likely that the several unidentified C-band objects which were observed subsequent to SRB separation (T + 141 to 169 seconds) contributed to the STS-27R Orbiter tile damage. Although the single object observed at T + 53.5 seconds is in flight regime of potential damage, it is not consistent with the Mach 2.5 most probable flight regime, in particular, the no-elevon-damage consideration.

Therefore, although it was not possible to identify the C-band radar observed objects, the established damage flight regime rules out their complicity in the severe tile damage.

5.10 Crew Reported 4 Hz Vibration

The STS-27R post flight crew comments, Section 3.9, revealed that a 4 Hz vibration was experienced throughout the second stage burn. The Systems Group reported that this phenomenon has occurred on previous flights, but it was noted that the phenomenon was stronger on STS-27R than on previous flights. The vibration was observed in the flight control system and migrated from approximately 3 Hz at SRB separation to approximately 3.8 Hz near MECO.

The vibration amplitude was low, and induced vehicle loads were negligible. Each Shuttle element reviewed their structural, component, and system certification and concluded that this low amplitude could not have dislodged damaging debris.

The team reviewed this phenomenon with the narrow view as to how it might have influenced the potential for debris. There was no attempt to assess other ramifications introduced into the Shuttle system.

1-4465-9-5D

TABLE 5-3

DATA ANALYSIS AND TESTS ORBITER TPS DAMAGE REVIEW TEAM SAMPLES TESTED FOR C-BAND RCS SIGNATURES

- ORBITER
  - –BLACK TILE
- ET
  - –PDL
  - –CPR
  - –SLA
  - –NCFI
  - –MA25
  - –BX250
  - –INSTAFOAM**
  - –ICE SHEET
- SRM
  - –JOINT CLOSEOUT
  - –INHIBITOR
- BOOSTER ASSEMBLY
  - –MSA-1
  - –MSA-2
  - –CORK 1/4*
  - –CORK 1/2*
  - –AFT BSM COVER
  - –SRM SLAG
- THERMAL CURTAIN
  - –VITON-COATED BALLISTIC NYLON
    - UNMARKED
    - WITH DIAGONAL STRIPE
  - –QUARTZ CLOTH FIBERFRAX BLANKET

* HYPALON PAINT ONE SIDE ONLY

NOTE: NOMINAL SIZE 6 IN. X 6 IN.

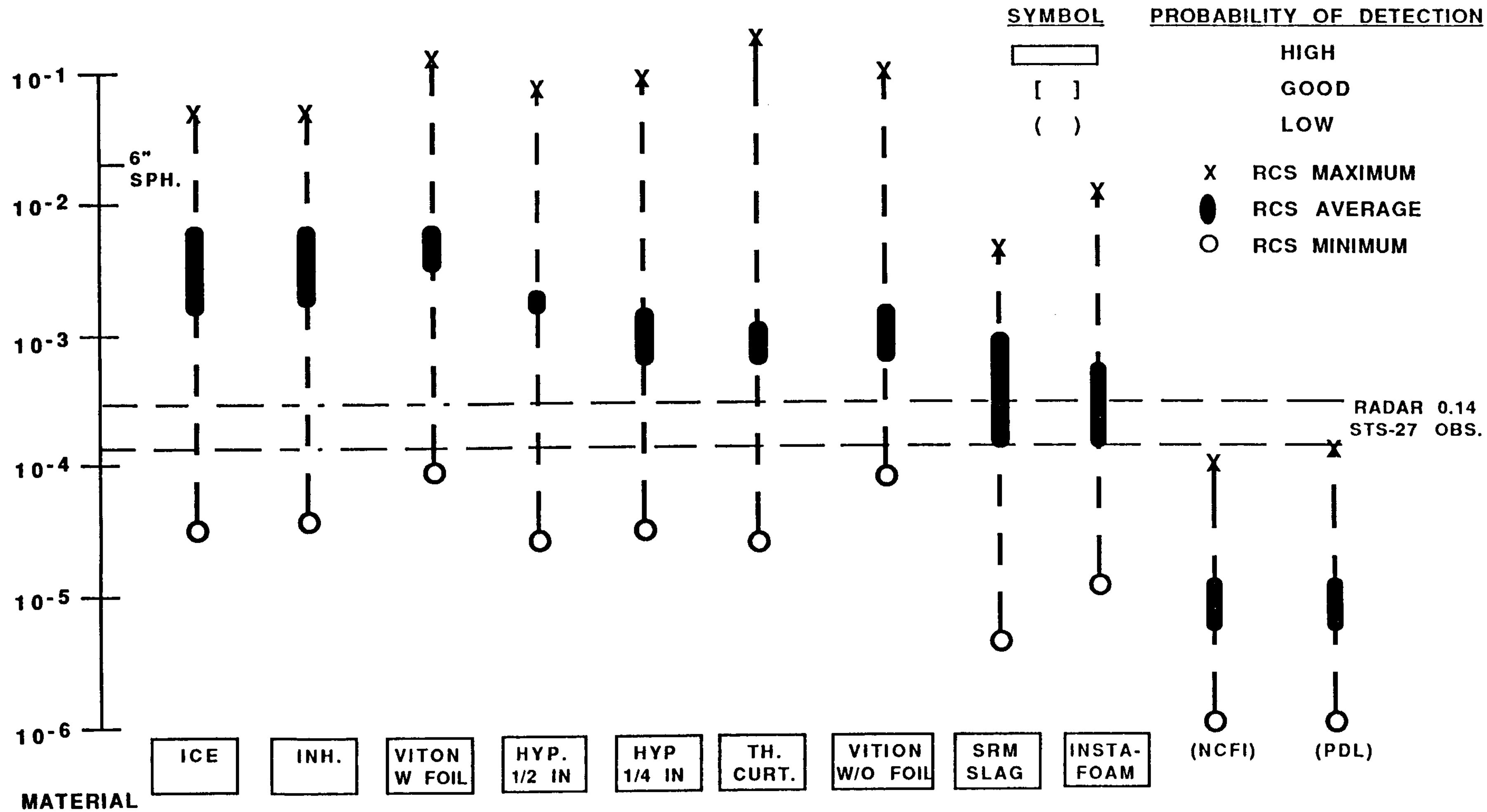
** RCS VALUE INDICATES HIGH P_d FOR 6 IN. X 6 IN.

1-4466-9-5D

FIGURE 5-5

ORBITER TPS DAMAGE REVIEW TEAM
C-BAND RADAR MATERIALS RELECTIVITY TEST

PAFB, DATE: 12-29-88

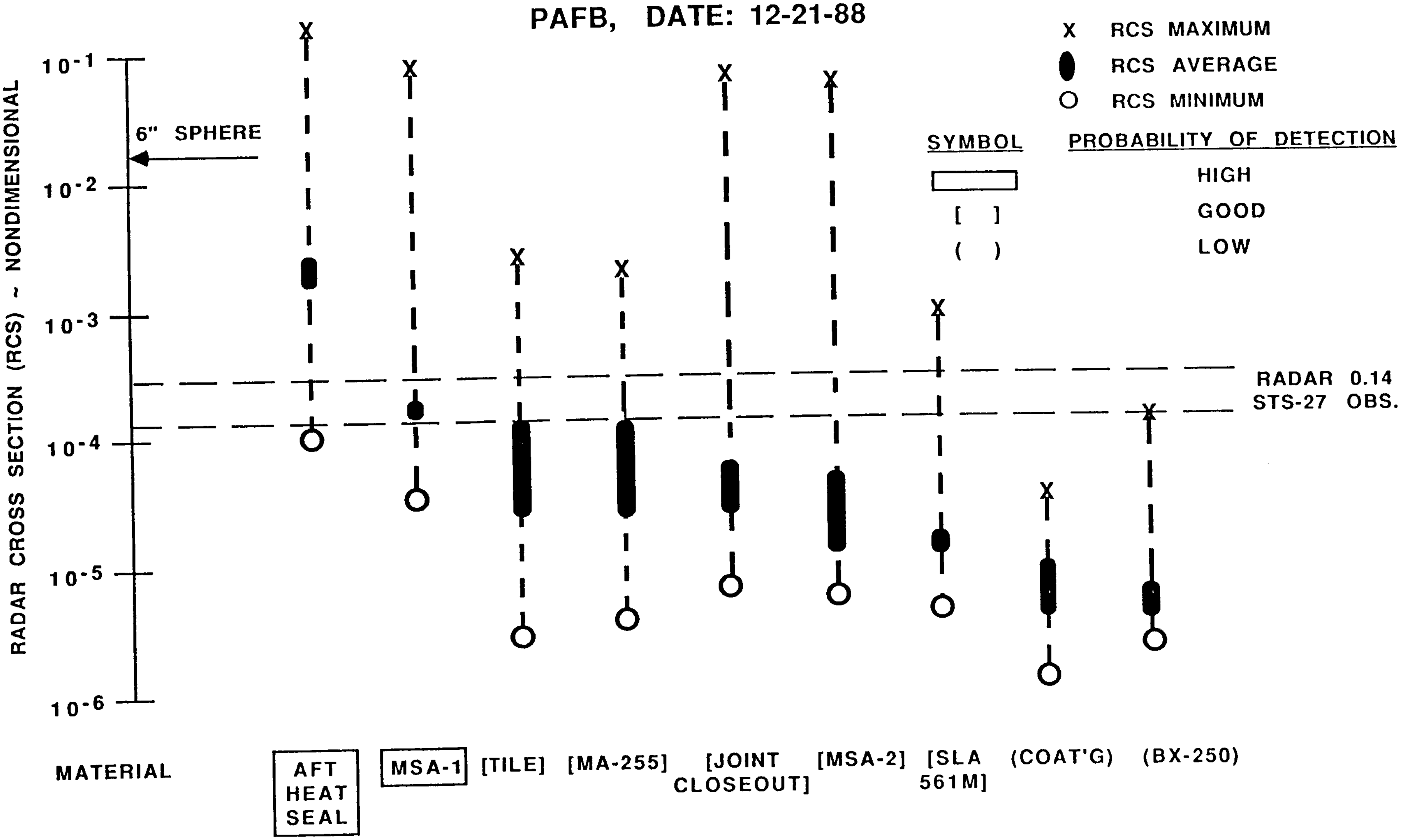


1-4464-9-5D

FIGURE 5-5 (CONT'D)

ORBITER TPS DAMAGE REVIEW TEAM
C-BAND RADAR MATERIALS RELECTIVITY TEST

PAFB, DATE: 12-21-88



5.11 Booster Separation Motor (BSM) Performance

The crew commented, Section 3.9.2, that the BSM seemed to produce "visible flames" rather than an "orange glow" and that they seemed to have burned longer. These observations led to the suspicion that the BSM performed anomalously and possibly dislodged ET insulation that impacted the Orbiter tile. To resolve this suspicion, the retrieved BSMs were thoroughly inspected and the SRB separation dynamics were examined.

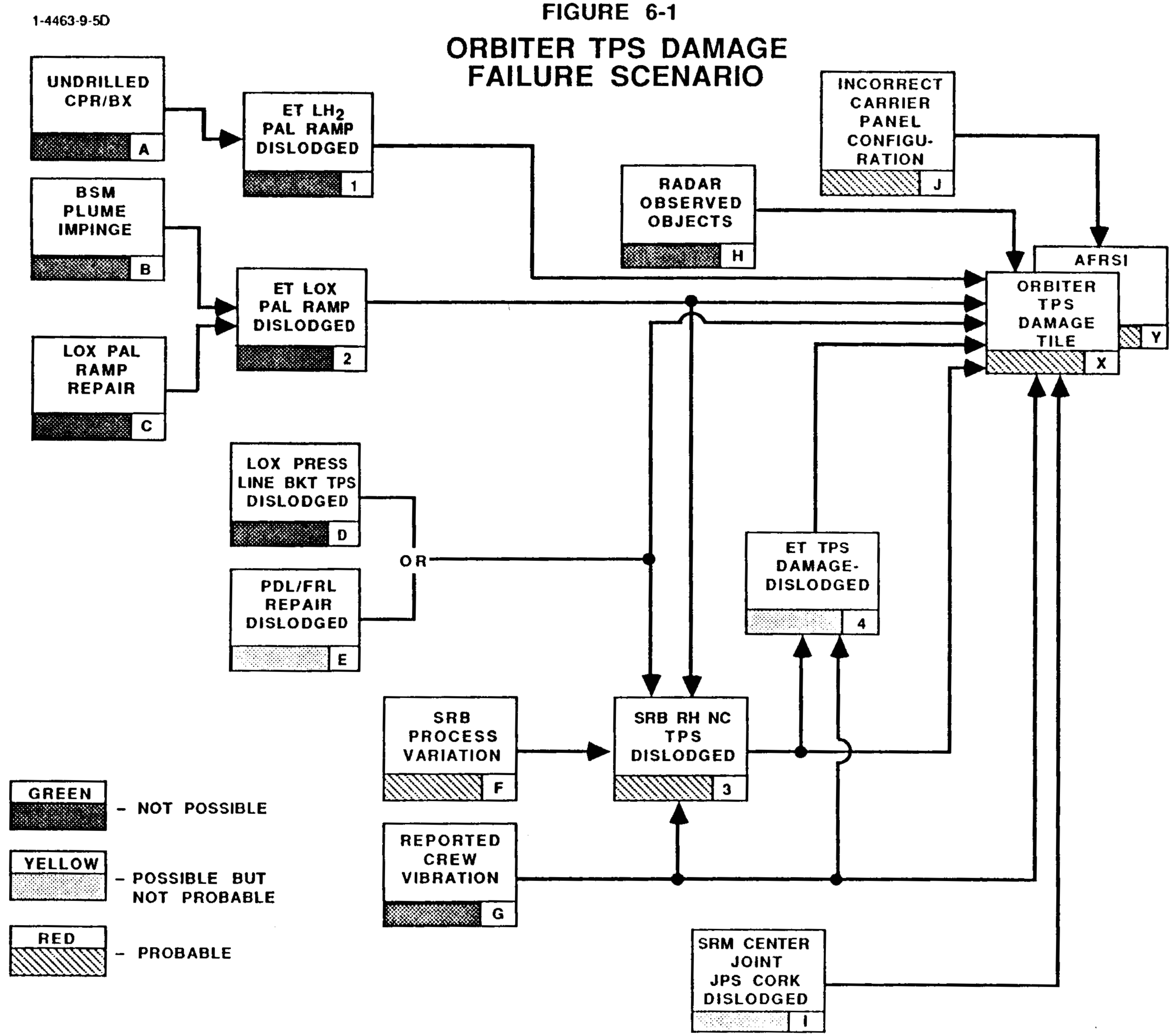
The BSM inspections, performed at the manufacturer's plant (Chemical Systems Division of United Technologies Corporation) with NASA's participation, indicated normal performance. This was based primarily on examining the residual propellant slivers always present after normal firings. An unusual sliver shape is indicative of uneven burning as would be the case should propellant chunks be dislodged and expelled during the firing. The right SRB dynamic performance parameters--roll rate, linear acceleration, and acceleration vector--were retrieved and compared to those from other right boosters. It was determined that the right booster did not exhibit any unusual behavior during separation.

Based on these inspections and the performance evaluation, it is concluded that the STS-27R SRB BSMs performed normally. The detailed SRB dynamic performance evaluation and BSM post flight inspections are presented in Volume II, Action Item 18, and Volume VI, Appendix E, respectively.

6.0 Failure Scenario

Several failure scenarios were developed from the fault tree potential cause summary and other relevant data. Each scenario was evaluated using the data analysis and test results along with data coming from the fault tree assessment. The scenarios were categorized as not possible, possible but not probable, and probable as shown in Figure 6-1. Each scenario is numbered by combining the numbers and letters in the lower right corner of each logic block. Table 6-1 contains all the failure scenarios, their category, and the rationale for their categorization. The failure scenario dealing with the OMS pod carrier panel is treated alone because it was not a cause for lower surface tile damage. Tabulated rationale is provided as to why the scenarios were cleared, retained as possible, or listed as most probable. Even though the evidence is predominantly circumstantial, the MSA-1 from the SRB right Nose Cap is judged the most probable cause.

FIGURE 6-1
ORBITER TPS DAMAGE FAILURE SCENARIO



1-681-9-7T

TABLE 6-1
FAILURE SCENARIO
ORBITER TPS DAMAGE REVIEW TEAM ASSESSMENT

SCENARIO		FAILURE CATEGORY			RATIONALE
NO.	TITLE	NOT POSSIBLE	POSSIBLE-NOT PROBABLE	PROBABLE	
A.1.X	UNDRILLED CPR/BX	√			• ANALYSIS SHOWED GOOD SAFETY FACTOR (1.7) • STS-27 TANK HAS STABILIZED SILMAR RESIN • NOT UNIQUE TO STS-27
B.2.X	BSM PLUME IMPINGEMENT	√			• PRIOR FLIGHTS POST SEP PHOTOS DO NOT SHOW TPS LOSS • BSM/ET CONFIGURATION NOT CHANGED • BSM/ET PLUME IMPINGEMENT PRESSURE LOW (~ 2.8 PSF) • BSM OPERATION NORMAL • POST FLIGHT BSM INSPECTION • SRB SEP DYNAMICS
C.2.X	LOX PAL RAMP REPAIR	√			• REPAIRED PAL RAMP TEST RETAINED INTEGRITY THROUGH WORST FLIGHT CONDITION
D.X	LOX PRESS LINE BRACKET TPS DISLODGED	√			• NO REPAIRS PERFORMED • ANALYSIS SHOWS POSITIVE MARGINS • INSUFFICIENT SIZE TO CAUSE MAJOR DAMAGE
E.X	PDL/FRL REPAIR DISLODGED		√		• SMALL PARTICLE RECOVERED FROM RIGHT OMS POD AREA • REPAIR SIZE INSUFFICIENT TO CAUSE OBSERVED ORBITER TPS DAMAGE (2.4 x 2.6 INCHES) • COULD CAUSE MINOR ORBITER TPS DAMAGE
E.3.X	PDL/FRL REPAIR DISLODGED	√			• ANALYSIS SHOWED PDL COULD DAMAGE MSA-1 • JUDGED MSA-1 DAMAGE WOULD NOT BE SUFFICIENT TO CAUSE OBSERVED ORBITER TPS DAMAGE
F.3.X	SRB PROCESS VARIATIONS			√	• MSA-1 PARTICLE RECOVERED FROM RIGHT OMS POD • HYPALON OR MSA-1 SIGNATURE RESIDUE IDENTIFIED IN 16 OF 38 PLACES EXAMINED ON ORBITER. FIVE NEAR MISSING TILE • SEVERAL SRB RIGHT NOSE CAP PROCESS VARIABLES WERE NEAR OR OUTSIDE EXPERIENCE BAND • PLUG PULL TEST VALUES WERE LOWEST IN EXPERIENCE POPULATION, TWO FAILED AND REPAIRED. • ADEQUATE QUANTITY OF MATERIAL AVAILABLE TO PRODUCE DAMAGE

1-682-9-7T

TABLE 6-1 (CONT'D)

FAILURE SCENARIO
ORBITER TPS DAMAGE REVIEW TEAM ASSESSMENT

SCENARIO		FAILURE CATEGORY			RATIONALE
NO.	TITLE	NOT POSSIBLE	POSSIBLE-NOT PROBABLE	PROBABLE	
F.3.4X	SRB PROCESS VARIATIONS		√		• SAME AS ABOVE • DEBRIS TRAJECTORY ANALYSIS SHOWED MSA-1 COULD STRIKE INTERTANK • VELOCITY OF INTERTANK TPS DISLODGED PROBABLY NOT SUFFICIENT TO CAUSE OBSERVED ORBITER TPS DAMAGE • COULD POSSIBLY CAUSE MINOR ORBITER AFT TPS DAMAGE
G.X G.3.X G.4.X	CREW REPORTED VIBRATIONS	√			• AMPLITUDE WELL BELOW ALL TPS CERTIFICATION LIMITS • PREVIOUS REPORTS (3) OF PRIOR OCCURANCE DOES NOT CORRELATE TO ORBITER TPS DAMAGE
H.X.	RADAR OBSERVED OBJECTS	√			• FIRST OBJECT OBSERVED BEFORE SUSPECTED DAMAGE FLIGHT REGIME • OTHER OBJECTS OBSERVED PAST FLIGHT REGIME THAT CAN PRODUCE TILE DAMAGE
I.X	SRM CENTER JOINT JPS CORK DISLODGED		√		• DISCOVERED 3" X 3" PIECE MISSING AT RECOVERED RIGHT MOTOR CENTER FIELD JOINT • DEBRIS TRAJECTORY ANALYSIS SHOWED POSSIBILITY OF WING CONTACT • COULD NOT CAUSE SEVERE OBSERVED DAMAGE
J.Y	INCORRECT CARRIER PANEL CONFIGURATION			√	• WAS NOT RELATED TO TILE DAMAGE • DID CAUSE SOME DAMAGE TO ADJACENT PANEL TPS • POST FLIGHT INSPECTION AND DOCUMENTATION REVIEW SHOW PANEL ATTACHING HARDWARE IMPROPERLY CONFIGURED.

7.0 Findings and Recommendations

The team has completed its assigned responsibilities as reflected in Finding Number 1 and Recommendation Number 1 listed below. The team has also submitted other findings and recommendations that are believed pertinent to minimizing the potential for inflight debris. The findings and recommendations are as follows:

Finding 1:

a. The most probable cause of the severe STS-27R Orbiter tile damage is that the ablative insulating material covering the RH SRB Nose Cap dislodged and struck the Orbiter tile near 85 seconds into flight.

b. It is possible that debris from other sources, including repaired ET insulation and SRM joint cork, caused minor tile damage.

Recommendation 1: Recognizing that the evidence leading to the most probable damage cause is predominantly circumstantial and that other debris is routinely photographically observed beginning at liftoff, it is recommended that:

a. In the immediate future, equipment, systems, procedures, and resources be put in place to gather sufficient data to understand the causes for and to propose changes to eliminate the damage to the Orbiter TPS. Specifically, this effort should include the following:

(1) A detailed reassessment of the systems design criteria influencing potential debris for all elements.

(2) A review of design and certification methodology for all element debris sources.

(3) Additional testing and/or analysis if certification is lacking.

(4) An increase in photo and television coverage, both photo and video cameras should be installed in the Orbiter umbilical door area. The use of airborne cameras and cameras located in the ET and SRB should be considered.

(5) Allocation of the necessary resources to accelerate refinement of debris transport mechanism analytical tools and RI (Orbiter TPS) penetration equations to assist in the analyses of future TPS damage.

b. Specifically for flight STS-29R, it is recommended that:

(1) Additional TPS plug pull tests be performed on the external tank encompassing all possible materials and combinations of materials.

(2) Additional TPS plug pull tests be performed on the SRB Nose Caps in the quadrant bounded by the ET and Orbiter, on the right Frustum, and on the right Forward Skirt.

(3) Vent holes be drilled in the SRM field joint cork bounding locations of Kevlar band buckles and pin retainer band trunnions--the same cork should be inspected for internal low density inclusions and repaired where detected.

(4) Additional cameras be positioned in the crew cabin to view the ET and SRBs where permitted by window/position field of view.

(5) A detailed test objective be implemented to maneuver the Orbiter to facilitate crew photography of the ET after separation.

(6) Ground based imagery equipment be augmented to improve resolution, increase frame rate, increase coverage, and record data.

(7) Assign photography equipped low (2 each) and high (1 each) altitude aircraft to view the Space Shuttle during ascent for debris particles and sources.

c. For those flights following STS-29R, it is recommended that:

(1) Those SRB Nose Cap plug pulls performed on STS-29R be implemented on all future flights.

(2) The SRM joint cork be thoroughly inspected for low density inclusions before installation.

(3) The vent holes drilled into the SRM joint cork be continued until negated by other design solutions.

(4) Photographic and video cameras be installed in the Orbiter umbilical well door area.

(5) The post separation detailed test objective for crew photographing the ET be continued through one flight that incorporates the requested photographic and video cameras in the Orbiter umbilical well door area.

(6) Augmented ground based imagery be continued through STS-28R (three flights total).

(7) Photography-equipped aircraft be continued through STS-30R.

Finding 2: It is observed that program emphasis and attention to tile damage assessments varies with severity and that detailed records could be augmented to ease trend maintenance.

Recommendation 2: It is recommended that the existing Shuttle Debris Team be chartered as the Shuttle Debris Assessment Team. The team chairman and membership representing each NSTS project and materials engineering should be formally appointed by the Deputy Director, NSTS Program Office, and provided with capabilities to fulfill the following responsibilities.

a. Perform pre-flight ice/frost assessment.

b. Perform pre- and post-launch pad debris assessments.

c. Brief Mission Management Team (MMT), Mission Day 1 (MD-1) on liftoff and ascent debris assessment-inspection, photography and radar.

d. Perform pre- and post-landing runway walkdowns.

e. Inspect Orbiter at the landing site and specify those tile and/or debris samples to be removed for laboratory analyses.

f. Document inspection results on Orbiter tile maps and other appropriate tables to include damage site characterization.

g. Sign Orbiter ferry CoFR stating acceptability for return to launch site.

h. Perform post-flight SRB debris assessment.

i. Maintain all TPS damage assessment records.

j. Provide post mission report to Level I with recommendations, if appropriate.

k. Perform statistical, correlation, and trending analyses.

l. Perform TPS pre-flight assessment and recommendations for upcoming flight.

m. Document flight readiness rationale.

Finding 3: The SRB forward assembly TPS records review revealed recording inconsistencies and incomplete data entries. There were also some uncontrolled process variables, which in hindsight, should have been controlled.

Recommendation 3: Even though we believe that these conditions have been substantially corrected with later documentation improvements, it is recommended that SRM&QA and materials engineering witness a complete TPS application cycle to ensure that the process is adequate, fully documented, and controlled as a critical process.

Finding 4: The SRB and ET records review revealed a large number of TPS repairs.

Recommendation 4: It is recommended that:

a. The criteria for repair, rework, and "remove and replace" be reassessed with the objective of:

(1) Eliminating nonessential repair or rework.

(2) Emphasizing "remove and replace" rather than permitting extensive repair and rework.

(3) Assuring that all processes and procedures used to correct discrepant TPS are fully certified by test.

b. The discrepancy disposition approval process be reviewed with the intent of ensuring that:

(1) The discrepant item receives sufficient management visibility prior to closure.

(2) There is a consistent closure process across all program elements.

Finding 5: There are no general standards nor guidelines dealing with ET/SRB plug pull test location/density for large surface thermal protection acreage. The tooling, equipment, and procedures also differ among users and these differences appear to result in varying test values.

Recommendation 5: It is recommended that each project in concert with the SRM&QA and materials engineering organizations:

a. Evaluate each type TPS, its usage, standard repairs, etc., and provide general guidelines or criteria, if possible, for testing application and technique.

b. Evaluate the tooling, equipment, and procedures with the objective of combining the best features of each into operator friendly test apparatuses.

c. Evaluate other methods to verify material and process integrity.

Finding 6: The crew comment regarding the white material deposits on the cabin window led directly to determining that it emanated from the RCS nozzle covers. It was still present after return to KSC even though the window had been cleaned. The presence of this material on the Orbiter windows could impair crew vision during critical mission phases.

Recommendation 6: It is recommended that:

a. A short post-launch debrief with the flight crew be performed during mission day 1 of each flight. This debrief should emphasize out-the-window observations and any perceived systems differences.

b. Alternative designs be pursued to eliminate this material from the RCS nozzles.

Finding 7: There have been adequate analyses and tests of the Orbiter windshield glass tolerance to ice and bird strikes. There are, however, no such data for other objects such as ET TPS resident on the Nose Cap area. Cursory assessment of this latter condition did not surface undue concern.

Recommendation 7: It is recommended that TPS debris emanating from the ET Nose Cap area be analyzed for window damage potential.

Finding 8: It is apparent that all Shuttle elements have made great progress in eliminating debris sources as evidenced by comparing early and recent ascent photography. There remains other areas for product improvements that could further reduce debris potential, particularly in the External Tank.

Recommendation 8: It is recommended that the program actively solicit design improvements directed toward eliminating debris sources or minimizing damage potential.

Finding 9: The flight heating profile experienced by the SRB forward assembly typically is in the range of 40% of the design case. Preliminary analyses indicate that reducing the heating design conditions to 50 - 70% could potentially result in eliminating most external TPS from the SRB forward assembly.

Recommendation 9: In concert with recommendation 1.a, it is recommended that the systems design criteria be assessed to determine the possibility of reducing the design requirements sufficiently to permit a detailed SRB evaluation of eliminating external TPS.

Finding 10: It is the team's view that there is a general lack of awareness on the Orbiter tile susceptibility to damage by debris. The same applies to the care and critical nature of the Shuttle elements and operations process so necessary to minimizing damaging debris. It is essential that all involved employees, both Government and contractor, understand that loose objects or materials coming off the elements will cause tile damage at the speed encountered during ascent.

Recommendation 10: It is recommended that descriptive material, photos, video tape, debris sample and other appropriate matter be assembled and provided to the proper organizations for dissemination to their employees. It should emphasize that the tiles perform outstandingly in their debris-free design environment; but are extremely sensitive to any particle damage, particularly large debris that could lead to Criticality 1 conditions.

8.0 STS-29R Considerations

The team was requested to participate in the STS-29R Orbiter Rollout Review on January 17, 1989, to present any constraints derived from the review team activities that would affect mating Discovery to the SRB/ET stack. The Rollout Review occurred before the team arrived at the most probable TPS damage cause and thus each potential cause listed in the Fault Tree Summary, Section 4.0, was addressed.

The STS-29R assessment is summarized in Table 8-1 and is formatted to list the failure consideration, its applicability to STS-29R, and any special action required. If no special action was necessary, the rationale clearing STS-29R was listed.

The actions for STS-29R dealing with plug pull tests on the ET and SRB have been successfully accomplished. The drilling operations to vent potential voids under the SRM field joint cork, adjacent to Kevlar band buckles and pin retainer band trunnions, are complete. The inspections on the same joint cork

TABLE 8-1
ORBITER TPS DAMAGE REVIEW TEAM
STS-29 ASSESSMENT

STS-27 FAILURE CONSIDERATION	APPLICABILITY TO STS-29	SPECIAL STS-29 ACTION

● UNDRILLED CPR/BX - INTERTANK	● SAME DRILL PATTERN
	● INCORPORATES KOPPERS RESIN
	● THIS CONFIGURATION FLOWN FIVE TIMES
	  ● FLIGHTS STS-28, 30, 32, 33,26R
	  ● TILE DAMAGE LOW EXCEPT 26R
		● TWO PLUG PULLS - SUCCESSFUL

● BSM PLUME IMPINGEMENT AND LOX PAL RAMP REPAIR	● NO CHANGE IN BSM'S ● PAL RAMP NOT REPAIRED AS ON STS-27	● PLUG PULL PAL RAMP - SUCCESSFUL
● LOX TANK PRESS LINE BRACKET TPS AND PDL/FRL REPAIR	● SAME POTENTIAL AS FOR STS-27	● PARTICULAR ATTENTION TO REPAIRS DURING WALK-DOWN

● SRB PROCESS VARIATION IN NOSE CAP TPS (MSA-1)	● NEW TPS SYSTEM MSA-2 ON STS-29
	  ● FULLY CERTIFIED
	  ● HIGH STRENGTH
	  ● IMPROVED PROCESS AND CONTROLS
	  ● MORE NDE
		● REVIEWED SYSTEM IMPROVE-MENTS AND CERTIFICATION
		● PLUG PULLS ON STS-29 NOSE CAPS - SUCCESSFUL
		● PLUG PULLS ON RIGHT FRUSTUM - SUCCESSFUL

● SRM JOINT CORK	● SAME POTENTIAL AS FOR STS-27	● HOLES DRILLED INTO POTENTIAL VOID AREAS
		  ● KEVLAR BAND BUCKLES
		  ● PIN RETAINER BAND TRUNIONS
		● RAMP AREA IN CORK AT ALL JOINTS INSPECTED VISUALLY AND BY TAP TEST - THREE ADDITIONAL REPAIRS REQUIRED.
		● BULGED CORK DETECTED REMOVED AND REPLACED WITH K5NA

1-256-9-3T

TABLE 8-1 (CONT'D)
ORBITER TPS DAMAGE REVIEW TEAM
STS-29 ASSESSMENT

STS-27 FAILURE CONSIDERATION	APPLICABILITY TO STS-29	SPECIAL STS-29 ACTION

• 4 Hz VIBRATION	• COULD BE OBSERVED ON STS-29
	  • PAYLOAD CONFIGURATION
	  • DISCOVERY VEHICLE
		• RECOMMEND ASSESSMENT AND CREW BRIEFING

• RADAR OBSERVED OBJECTS	• SAME POTENTIAL AS FOR STS-27	• C-BAND RADAR SYSTEM WILL BE ADJUSTED TO ENHANCE OBJECT REFLECTIVITY
• CARRIER PANEL	• SAME POTENTIAL AS FOR STS-27	• ALL APPLICABLE PANELS TO BE INSPECTED PRIOR TO FLIGHT
• GENERAL DEBRIS POTENTIAL	• EXTERNAL TANK	• PEDIGREE ASSESSMENT PERFORMED ON ALL DEBRIS POTENTIAL ITEMS IN DEBRIS ZONE - NO CONCERNS • PLUG PULLS OF ALL MATERIALS AT APPROPRIATE LOCATIONS - SUCCESSFUL

	• SRB FORWARD ASSEMBLY	• PEDIGREE ASSESSMENT RESULTS
		  • ADDITIONAL PLUG PULLS PERFORMED ON LEFT FRUSTUM DUE TO 30 DAY TIME BETWEEN SPRAY AND PAINT - SUCCESSFUL
		  • STRENGTH TEST OF FASTENER CAPS - SUCCESSFUL
		  • PLUG PULLS AROUND SPLIT IN MSA-2 ON RIGHT FORWARD SKIRT SUCCESSFUL AND REPAIRED
		  • NO ADDITIONAL CONCERNS

to detect and repair low density inclusions have also been completed. The program is currently evaluating the crew-reported 4 Hz vibration for a more indepth understanding of its origin and potential presence on STS-29R. There is also proper documentation in place at KSC requiring that the AFRSI carrier panels be inspected for proper fastener configuration. Finally, MSFC is updating the appropriate Program Requirements Document (PRD) to permit the Range to adjust their C-band radar for better object characterization.

In addition to the special actions, the team also reviewed the STS-29R ET and SRB manufacturing records for the debris sources in the critical debris zones. This was accomplished by having those ET and SRB group members already at the contractor's facility reviewing STS-27R records to also review STS-29R and present their findings to the team. There were no ET concerns identified, but the SRB review led to three actions. It was learned that the left Frustum was not painted with Hypalon until 30 days had elapsed following MSA-2 application. Additional plug pull tests were performed and the results showed no significant strength reduction. The same type tests were also performed on either side of a split discovered in the right Forward Skirt MSA-2 near the tunnel fairing. The tests showed that the surrounding material was acceptable and the split was repaired. The remaining action was to check the MSA-2 adhesion to the fastener covers on both Frustums. These checks showed good adhesion.

Finally, the team reviewed the new MSA-2 TPS material properties, manufacturing process, and certification. It was found that the MSA-2 material has increased strength, the manufacturing process is superior to that for MSA-1, and the certification program was comprehensive and successful. The MSA-2 is superior principally because the manufacturing facility is temperature and humidity controlled, the tooling is modernized and is monitored and controlled automatically, the manufacturing specifications are more stringent, and the verification/repair latitude is more restrictive.

Based on this review, and having successfully completed all the identified work, the Orbiter TPS Damage Review Team considered the STS-29R ET and SRB ready to launch, which was the recommendation at the Rollout Review.

9.0 Concluding Remarks

The Orbiter TPS Damage Review Team has fulfilled its assigned responsibilities. The most probable cause for the OV-104 STS-27R TPS damage is reflected in Finding No. 1; and those recommended design and/or procedural changes to reduce potential future flight TPS damage are contained in Recommendation No. 1.

Recommended hardware actions have been successfully accomplished; thus, the team has no reservation, relative to debris, with flying STS-29R.

The team submits herein other findings and recommendations that are considered pertinent to minimizing the potential for inflight debris.

The program is encouraged to continue to devote a high level of attention to this important matter. To this end, this team will be pleased to examine the STS-29R OV-103 post flight tile condition and update its recommendations, if appropriate.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

ORIGINAL PAGE IS OF POOR QUALITY

Reply to Attn of M

TO: Distribution

FROM: M/Director, National Space Transportation System

SUBJECT: STS-27 Thermal Protection System (TPS) Damage Review Team

Effective immediately, an STS-27 TPS Damage Review Team is established. The primary responsibility of this team is to determine the cause(s) of the TPS damage to OV-104 on STS-27. The team will review the OV-104 damaged areas in detail, review the prelaunch ice inspection requirements and procedures, assess in-flight optical, tracking and other data, and review the design and build records of the flight hardware to determine potential sources of debris, and recommend design and/or procedural changes to reduce the potential for TPS damage for future flights. All program elements will support the team as required. The results of the team's analysis are required by early January 1989. Team membership is as follows:

Chairman	-	John Thomas, MSFC
Alternate Chairman	-	Jay Honeycutt, NSTS Program Office
Members	-	Jack Nichols, MSFC
		Judith Kersey, KSC
		Marion Coody, JSC
		Gary Coen, JSC
		Don McMonagle, JSC
		Dewey Channell, MSFC

Arnold D. Aldrich
Director, National Space
Transportation System

NSTS LAUNCH INFORMATION
CORRELATION OF MISSION-DESIGNATOR WITH STS-DESIGNATOR

MISSION	STS	LAUNCH DATE	ORBITER
	STS-01	04/12/81	102
	STS-02	11/12/81	102
	STS-03	03/22/82	102
	STS-04	06/27/82	102
	STS-05	11/11/82	102
	STS-06	04/04/83	099
	STS-07	06/18/83	099
	STS-08	08/30/83	099
41-A	STS-09	11/28/83	102
41-B	STS-11	03/02/84	099
41-C	STS-13	04/06/84	099
41-D	STS-14	08/30/84	102
41-G	STS-17	10/05/84	099
51-A	STS-19	11/08/84	103
51-C	STS-20	01/24/85	103
51-D	STS-23	04/12/85	103
51-B	STS-24	04/29/85	099
51-G	STS-25	06/17/85	103
51-F	STS-26	07/29/85	099
51-I	STS-27	08/27/85	103
51-J	STS-28	10/03/85	104
61-A	STS-30	10/30/85	099
61-B	STS-31	11/26/85	104
61-C	STS-32	01/12/86	102
51-L	STS-33	01/28/86	099
	STS-26R	09/29/88	103
	STS-27R	12/02/88	104