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Abstract:

Following the first **space shuttle** flight, the **shuttle** program established a team to identify and eliminate sources of debris which had caused serious **damage** to the **orbiter thermal protection** tiles. An approach was developed for debris identification which involved pre- and post-flight vehicle and pad inspections, analytic assessment of debris transport and impact phenomena, and analysis of various photographic records of the flight. Debris sources identified by this approach were classified as being either hazards to flight or sources of **damage** which increased vehicle refurbishment costs without having any safety implications. As a result of this assessment, all known hazardous debris sources on the launch vehicle and pad were eliminated; other sources are being removed in a cost effective manner as appropriate.

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SHUTTLE LAUNCH DEBRIS --
SOURCES, CONSEQUENCES, SOLUTIONS

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SUMMARY

Following the first space shuttle flight, the shuttle program established a team to identify and eliminate sources of debris which had caused serious damage to the orbiter thermal protection tiles. An approach was developed for debris identification which involved pre- and post-flight vehicle and pad inspections, analytic assessment of debris transport and impact phenomena, and analysis of various photographic records of the flight. Debris sources identified by this approach were classified as being either hazards to flight or sources of damage which increased vehicle refurbishment costs without having any safety implications. As a result of this assessment, all known hazardous debris sources on the launch vehicle and pad have been eliminated; other sources are being removed in a cost-effective manner as appropriate.

INTRODUCTION

The space shuttle vehicle is susceptible to the adverse effects of lift-off and ascent debris to a degree unknown on previous launch vehicles. This results from the fact that a significant portion of the launch vehicle, the orbiter, also serves as an entry vehicle and, as such, is covered with mechanically fragile thermal protection system (TPS) tiles. The shuttle program recognized this susceptibility early-on and instituted a program to minimize what was felt to be the chief launch debris threat, ice formation on the vehicle's external tank (ET). This effort was pursued with particular vigor on the nose region of the tank where analytic transport studies indicated a definite possibility that debris released in ascent would strike the orbiter windows and TPS tiles. The principal ice source on the nose was eliminated by covering the tank vent louvers in the nosecap with a facility vent hood, a "beanie cap," to duct away the cold vent vapors. The hood is retracted two minutes before launch to minimize ice and frost buildup. Analytic transport studies of the tank barrel section were inconclusive, but considerable effort was expended by the ET project to minimize ice formation on the tank lines and protuberances. The first shuttle flight, STS-1, was flown with this "minimum ice" configuration, although somewhat more ice than anticipated was located on the nosecap vent louvers due to a failure of the "beanie cap" dock seals. Following the flight, orbiter TPS damage was found to be significant in terms of both the number of debris impacts (hundreds) and in terms of the severity of the largest damage sites. To

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investigate the sources of STS-1 debris damage and to make recommendations to reduce damage on future flights, the Shuttle Program Manager established a Debris Assessment Team headed by the Johnson Space Center (JSC), with members from JSC, the Marshall Space Flight Center, the Kennedy Space Center, Rockwell International Corp., and the Martin Marietta Co. This paper will address the approach used by this team to assess debris sources and debris-related TPS damage, will present conclusions resulting from the team's effort, and will summarize vehicle and launch pad modifications undertaken to minimize damaging debris.

APPROACH

Methods available for identification of debris sources fall into three major categories: pre- and post-flight inspections of the launch pad and vehicle, analytic treatment of transport and impact damage phenomena, and analysis of flight film and crew voice records. Pre-launch inspections of the vehicle and pad are conducted to document the system configuration and to identify changes implemented since the previous flight. The final pre-launch inspection is conducted approximately two hours before launch, after the external tank has been filled, for the purpose of documenting ice/frost formations and tank insulation anomalies (if any). The principal ice/frost formations, to date, have been found on the ET feedline and protuberances and in the orbiter umbilical area. After launch, the pad is inspected after it has been safed (launch + 3 hours) to identify facility damage which may have produced debris. The pad grounds are searched for evidence of this debris as well as for evidence of vehicle damage which may have been sustained at launch. This inspection produced the first evidence on STS-3 that tiles had been lost at lift-off as several fragments were found on the pad apron. The SRB's are inspected for possible debris sources immediately upon their removal from the water after being towed to port. Loss of insulation from the nose frustrums has been the only debris source of concern identified on the SRB. The orbiter is inspected after it has been placed in the Mate-Demate Device at the landing site. Detailed maps of tile damage are made and the most significant damage sites are photographed and measured. The most significant concentrations of damage have been found on the upper nose surface and around the windows, on the right-hand wing chine and inboard wing and elevon underside, around the umbilical wells, on the body flap underside, and on the base between the engines. Samples of material imbedded in tiles and window wipes are taken for later chemical analysis.

Two areas of analytical effort have been useful in understanding the debris source and damage data obtained from these inspections. Transport studies were undertaken for the nose and barrel sections of the ET to identify probable debris impact locations on the orbiter. The results of ET nose transport studies have shown that debris striking the orbiter upper nose surface and around the windows must have originated ahead of ET station 500. ET barrel transport studies have indicated that it is unlikely that debris originating on the ET barrel will strike the orbiter as the result of inter-vehicle pressure gradients. Debris from the barrel which does strike the orbiter must, therefore, do so as the result of other localized effects (SRB bow wave impingement, ET drag strut upflow). Impact studies were undertaken to identify incident energy thresholds corresponding to tile coating cracking for various debris materials. These studies have shown that the ET acreage foam insulation, with a density of about 2 lb/cu. ft., will not damage tiles under any but the most severe impact conditions. The ET nosecap insulation, at 19 lb/cu. ft., will damage the tiles over a wide range of impact conditions. Impact studies also indicated that high velocity ice impacts on the orbiter windows were sufficient to cause catastrophic damage.

Review of the flight film and crew voice records has been very useful in establishing a correlation between debris sources and vehicle damage. Film from cameras in the immediate vicinity of the launch pad has identified the ablative insulation applied to the hold-down posts as a prime source of severe vehicle damage. These films have also aided in the definition of pad flow phenomena which direct debris objects back toward the orbiter. On-board films of SRB and ET separation taken from the orbiter umbilical wells have aided in establishing debris sources on both vehicles. Much of the ice on the ET lines and protuberances survives ascent intact without becoming debris. On several flights large pieces of air-load reduction ramps on the ET have been lost in flight. All flight crews have reported seeing a large quantity of debris throughout ascent, much of it striking the windows. All of it has been reported as being white in color.

STS-1 AND STS-2 DEBRIS EXPERIENCE

TPS Damage Due to Debris

Debris damage to the orbiter TPS tiles on STS-1 was significant in terms of both the number of debris impacts (hundreds) and in terms of the severity of the largest damage sites. The most alarming damage was located on the right-hand nose gear door and consisted of a gouge approximately 12 inches long and 1 inch deep in several damage-resistant, high density TPS tiles (figures 1 and 2). Severe damage was also inflicted on a low density tile on the underside of the body flap (figures 3 and 4); this damage site was enlarged significantly by melting of the tile substrate material during entry. Extensive, though less severe, damage was observed on the right-hand inboard elevon near the hinge line (figure 5); approximately 25 sq. in. of tile coating was removed by an impact with very little loss of depth. These large damage sites were very atypical. The average impact damage size was less than 1/8 inch and exhibited no depth other than that associated with loss of the tile coating. This type of damage was particularly evident on the nose upper surface and right-hand side.

Although no severe damage was sustained on the orbiter nose, STS-2 experienced debris damage which was similar to STS-1. Damage to the body flap was significant and exhibited the substrate melting as before. The number of damage sites was roughly comparable to STS-1. The only area which was damaged in a different fashion was the base tile array between the three main engines (figure 6). A number of small damage sites were present as on STS-1 but, in addition, on STS-2 there was a long scrape or compression which damaged seven adjacent tiles. A summary of the locations of noteworthy TPS damage due to debris on flights STS-1 and STS-2 is presented in figures 7 and 8.

The role of entry heating in modifying impact damage characteristics can be dramatic. As noted above, this effect has been observed on both STS-1 and STS-2 at body flap damage sites. Figure 9 presents a summary of TPS tile sensitivity to damage incurred before entry. Flight and arc-jet experience has revealed that on regions of the vehicle where surface temperatures exceed approximately 2200°F (figure 10) significant growth of larger damage sites can be expected due to shrinkage of the substrate silicon matrix. This knowledge is useful in both reconstructing the appearance of the original damage, which aids in identifying the damage source, and in anticipating the consequences of damage. Body flap temperatures on STS-1 and STS-2 were relatively low (2300°F) compared to their design values (2500°F). This was fortunate in that the higher temperatures may well have resulted in a burn-through. Shrinkage of the STS-1 nose gear door tile damage was minimal because of the higher density of the tiles, even though the temperatures were also higher (2400°F).

Debris Sources

Three potential sources of the debris causing the nose gear door tile damage (figure 2) were hypothesized. The first, and most likely, was that a section of the ET lightning band had dislodged and been transported to the orbiter. The lightning band consists of a graphite-loaded epoxy material which is applied on the external surface of the tank insulation in a strip about 6 inches wide; it can be seen circling the tank nose in figure 11. Photographs taken of the ET immediately after its separation from the orbiter revealed that large sections of the band were missing. At a density of over 100 lb/cu. ft., the lightning band material certainly would have caused significant tile damage on impact. Another potential source of the damage was ice on the ET nose. As was mentioned earlier, the facility "beanie cap" failure resulted in the formation of ice on the ET liquid oxygen (LOX) dump vent louvers; figure 12 shows a typical build-up observed during a tanking test. These louvers are within 10° of the ET lateral plane, though, so that transport to the orbiter is unlikely. Several thermal shorts which produced frost balls at the nosecap/insulation interface (the forward lightning band) can also be seen in figure 12. This frost certainly would have been transported to the orbiter (to the right but not shown in figure 12) but probably would not have had the density required from the unique characteristics of the damage. As can be seen in figure 2, the damage had a V-shaped cross section which is maintained along its entire length. Near the end of its course, one would expect the cross section to moderate as damage inflicted on the debris by the tile increased. Because this did not happen the debris would appear to have been very hard with a square corner to form the "V." Some problems had been experienced in tank operations with the retention of phenolic spacer blocks in the cable tray running up the right-hand side of the ET nose (figure 11). Although no proof exists that any blocks were lost, they must also be considered a candidate for causing this damage.

The severe damage to the body flap (figure 4) was conclusively shown to have been the result of impacts by an ablative insulation applied to the pad SRB hold-down posts. Significant amounts of this insulation were observed in launch films to be released in the first few seconds after SRB ignition. The loss of this material can be observed in figure 13. The north posts, those on the left, experience a much more severe environment than do the south posts because they are overflown by the very abrasive SRB exhaust plumes as the vehicle heads initially north. The south posts, for all extents and purposes, represent the pre-ignition configuration of insulation on the north posts. Several films revealed that pieces of this material were caught in plume flow reflected upward from the top of the structure supporting the posts and impacted the orbiter body flap and aft fuselage. The calculated impact velocity was 100 fps; the density of the material is over 100 lb/cu. ft.

The damage area on the inboard elevon (figure 5) was probably the result of an impact by a large piece of ET insulation since it exhibited little depth. The damage mechanism involved only the shattering of the tile coating. Many of the small tile damage sites were also a result of ET insulation impacts; on-orbit photos revealed that the insulation surface contained many inch-size divots. Several large pieces of insulation (1-2 feet) were observed to be missing from load alleviation ramps in proximity to external lines.

The remainder of the damage was caused by ice released from the ET feedline and anti-geyser line which run down the right side of the tank (figure 11). This ice, which is produced at exposed cold-points along the lines, was anticipated and waived as acceptable prior to flight. Typical damage resulting from ice consisted of long, shallow grooves which would be expected from high velocity, low angle impacts (figure 5).

Modifications to Reduce Debris

Following STS-1, several steps were taken to reduce the debris hazards discussed above. The lightning bands which had been installed on the ET were removed for STS-2 and all subsequent vehicles pending identification of a material which would not generate debris (figure 14). The dock seals on the facility "beanie cap" were modified to eliminate leaks and prevent ice formation on the vent louvers (figure 14). Although no direct evidence of loss existed, provisions were made in the ET cable tray design to physically constrain the phenolic spacer blocks. In addition to these changes, updated aerodynamic load analyses indicated that some of the insulation used in load alleviation ramps could be eliminated. About 70 running feet of these ramps were removed from the hydrogen tank.

Debris experience gained from STS-2 resulted in several changes to the launch pad. The most significant change was the removal of a substantial portion of the SRB hold-down post ablative insulation; material was retained on the base of the posts but was stripped from other areas. An attempt was also made to improve the procedure by which the material was bonded to the post to assure its retention. During several inspections the debris team found evidence of loose material on the launch platform immediately before launch. Detailed inspection and clean-up procedures were initiated to alleviate this problem. On the external tank, thermal shorts which had existed at the nosecap/insulation interface were eliminated to preclude the formation of frost balls. Two debris-producing agents on the orbiter on STS-2 were also eliminated. A more secure method of retaining orbiter umbilical well baggie fragments was found to prevent these fragments from damaging tiles immediately behind the umbilical well opening on the underside. In addition, tire pressure monitoring wires which sever on landing at tire spin-up were provided with quick-disengage connectors to prevent the wires from being thrown up into underside tiles.

STS-3 DEBRIS EXPERIENCE

As a result of the vehicle and pad modifications described above, no hazardous debris damage was experienced on STS-3. The number of debris damage sites, though, was comparable to those on STS-1 and STS-2. The only new damage characteristic was observed on the orbiter upper nose surface (figure 15) and around the windows (figure 16). In this area six large shallow gouges about 1 inch wide and 4 inches long were found on the left-hand side. One gouge of this type was found in this area on STS-1. No connection could be found between this impact damage and the loss of a number of tiles from the upper nose surface. The tile loss, which was caused by bondline failures, did result, however, in some impact damage around the windows.

The damage to the nose upper surface was particularly enigmatic because transport studies showed that the only possible source was the forward portion of the ET nose. On the ET nose, however, there are no protuberances on the left-hand side to serve as debris generators. It was finally concluded that the most probable source was an area of hand-packed insulation on the nosecap which had demonstrated bond problems during ET build-up operations. The density of this hand-pack (20 lb/cu.ft.) is more than adequate to have caused the observed damage. STS-3, for the first time, afforded a good opportunity to assess the extent of ice sources on the ET protuberances because the insulation was no longer painted white but allowed to retain its

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natural brown color. Figure 17 shows the ice formations on the anti-geyser line rainshields and the LOX feedline brackets and line bellows. Although much of this ice remains in place throughout ascent, a significant portion is dislodged and impacts the orbiter nose and wing chine (because of SRB bow wave impingement) and the wing and elevon (because of upflow at the aft orbiter/ET attachments). A debris source noted on STS-3 continued to be the hold-down posts. The pre- and post-launch configurations of post M-3 are shown in figures 18 and 19, respectively. Large amounts of insulation were again lost from the base although, fortunately, no vehicle impacts were observed. Also missing after launch were the box covers placed over the tops of the post struts. These were found at great distances from the pad. For the first time a significant debris source was noted on the SRB's in that large sections of nose frustrum insulation were missing upon recovery. No specific tile damage sites could be attributed to this debris, however.

Several modifications to the vehicle and pad were undertaken to eliminate these debris sources. On the external tank, a small thermal short which formed a button of ice on a line mount at the ET nosecap was foamed over. Efforts were again made to reduce the amount of insulation on the hold-down posts and to improve application techniques to assure retention of the material during launch. In addition, some insulation was added to the tops of the post strut covers to protect the bolts holding them in place. On the SRB, the frustrum insulation application technique was revised to prevent material debond.

STS-4 DEBRIS EXPERIENCE

Debris damage to TPS tiles on STS-4 was roughly comparable to that on STS-3 in terms of number of impacts. STS-4 did not experience significant damage on the left-hand side of the nose and the damage on the upper nose was less severe. There were, however, several large damage sites on the right-hand underside of the vehicle (figure 20). A gouge about 9 inches long and 2 inches wide was induced on the right side wing chine by the impact of a fairly large object (figure 21). A series of scrapes was formed on the aft wing and inboard elevon underside by the high velocity, low angle impact of a number of objects (figure 22). Several of the scrapes line up and indicate that the major dimension of the impacting debris was about 1 inch.

Sources of damaging debris were similar to those encountered on previous flights. The gouge on the right-hand wing chine was caused by a piece of ET insulation about 18 inches long which was lost during ascent from a load alleviation ramp on the hydrogen tank (figure 23). Several such pieces were lost and may also account for the damage to the wing and inboard elevon. Another candidate for the wing damage is ice from the anti-geyser line. Most of this ice, however, as seen in figure 23, has been retained to orbit insertion. Ice observed on acreage areas of the insulation in this photo is air ice produced by foam venting in second stage flight; it is not believed to represent a debris hazard. The hold-down posts continued to generate debris but, fortunately, none of the material hit the orbiter. Figures 24 and 25 present a pre- and post-launch view of north post M-7. Note that substantial amounts of the white insulation material are missing in figure 25 from the post base. One such piece (figure 26) was observed on film moving up out of the flame hole but away from the orbiter at approximately 1 second after ignition when the vehicle had risen about 5 feet. Figure 25 shows a clear view of the post support structure and the flat top plate which deflects SRB plume flow, and debris, upward toward the vehicle. The post strut covers survived launch intact due to the application of insulation over their placement bolts (figure 24) but many were loose and could be lifted off without resistance.

Two modifications were made to the pad as a result of STS-4 debris experience. Hold-down post insulation was reduced to minimal levels. The insulation which was packed at the post base was replaced with a steel belly band and that on the base webs was eliminated. The strut covers were modified to accept internally penetrating bolts and were faired so as to lower the incident flow heating induced as the SRB plumes passed overhead. An important change was made to the ET following STS-4 in that the principal source of ice on the launch vehicle, the anti-geyser line, was eliminated. Studies had shown that propellant geysering would not occur in its absence, so it was removed to reduce ET weight and eliminate an important debris source.

STS-5 DEBRIS EXPERIENCE

The damage patterns established on STS-5 are important because they reflect representative damage for future flights unless additional modifications are made to reduce debris sources. STS-5 was also important because it allowed five flights worth of tile damage to be viewed simultaneously in that the gray tile repairs are easily visible. The most extensive damage was experienced on the right-hand lower side of the nose (figure 27). Those damage repairs seen in this figure which are essentially circular are associated with hail damage experienced by the vehicle on the pad immediately prior to STS-4. New debris damage sites are easily visible, though, as are many repaired debris impact streaks. An area that exhibited substantially less debris damage on STS-5 was the right wing and onboard elevon underside. This can be attributed directly to the removal of the ET anti-geyser line and its associated ice (compare figure 28 to figure 17). All other debris damage was representative of that experienced on previous flights.

The debris damaging the orbiter right-hand nose was ET insulation from either the intertank/upper hydrogen tank areas or from the nose of the LOX tank. Intertank debris is transported to this region by flow resulting from impingement of the SRB bow shock on the ET. Nose debris receives sufficient momentum to cross streamlines and reach the orbiter as the result of being accelerated over the ogive of the LOX tank. No significant insulation degradation on the ET can be observed

Figure 6.- BSM plume-on test configuration.

in these areas (figure 29) which is consistent with the fact that the maximum debris dimension as inferred from the damage is approximately 1 inch. Pad debris cannot be shown to have produced any tile damage on STS-5. The amount of hold-down post insulation applied for this flight was greatly reduced and was placed in an area where the majority of it would be physically retained (figure 30). Post-flight inspection, however, revealed that several inch-sized pieces were lost during launch. The major pad debris source which remains unresolved is the hold-down shoe shim material. The epoxy-based shim is poured around the SRB support pads after they have been installed in the shoe; the shim is designed to be retained firmly in the shoe, but this has not always occurred (figure 31). Because the shoe serves as a source of upward plume reflection the shim material has the potential of impacting the orbiter if it is released.

The only major debris-reducing modification to the vehicle undertaken after STS-5 was an improvement of the insulation placed over the thermal short on a line mount at the ET nosecap. This short had been foamed over initially for STS-4 but that was not totally effective in preventing ice formation. An effort has also been made to improve the retention characteristic of the hold-down shoe shim material by improving the application procedure.

CONCLUDING REMARKS

Figure 32 presents a summary of the principal orbiter TPS tile debris damage regions experienced on each of the first five space shuttle flights. The only potentially catastrophic damage was encountered on flights STS-1 and STS-2 as the result of ET lightning band or cable tray debris and pad hold-down post insulation debris. The elimination of these sources as well as the principal source of ice on the launch vehicle, the ET anti-geyser line, has resulted in a fairly repeatable and well understood debris damage pattern. STS-5 was typical of debris damage which can be expected on future flights unless spallation of the ET insulation can be eliminated. Five flights worth of repaired debris damage can be observed on the left-hand side of the orbiter nose (figure 33) where hail damage was minimal and around the right-hand umbilical well (figure 34). Debris moving near the lower surface of the vehicle is brought into impact with the orbiter just forward and outboard of the umbilical wells by upflow around the aft orbiter/ET attach structure.

A summary of potentially damaging debris produced by the launch vehicle and pad is presented in figure 35. The debris is categorized by its potential damage severity which may or may not coincide with damage which it has actually caused to date. "Safety of flight" severity is assigned to debris which potentially could damage the orbiter windows or TPS tiles to the point that either the mission or the vehicle was lost. All known "safety of flight" debris sources have been eliminated. "Significant" severity is based on either the size or extent of damage. Figure 36 summarizes steps taken to date to eliminate these sources.

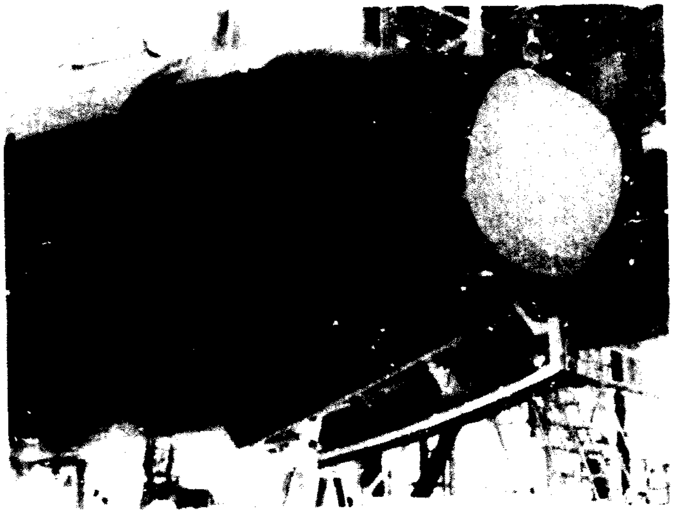

Figure 1.- Nose gear door tile damage (STS-1).

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Figure 2.- Close-up of nose gear door tile damage (STS-1).

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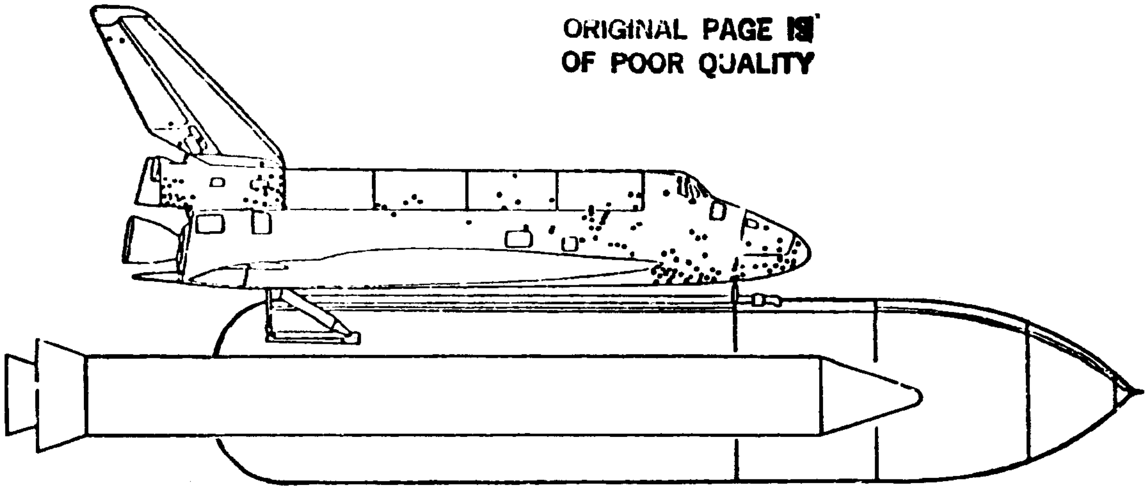


Figure 7.- STS-1 and STS-2 right-side debris damage composite.

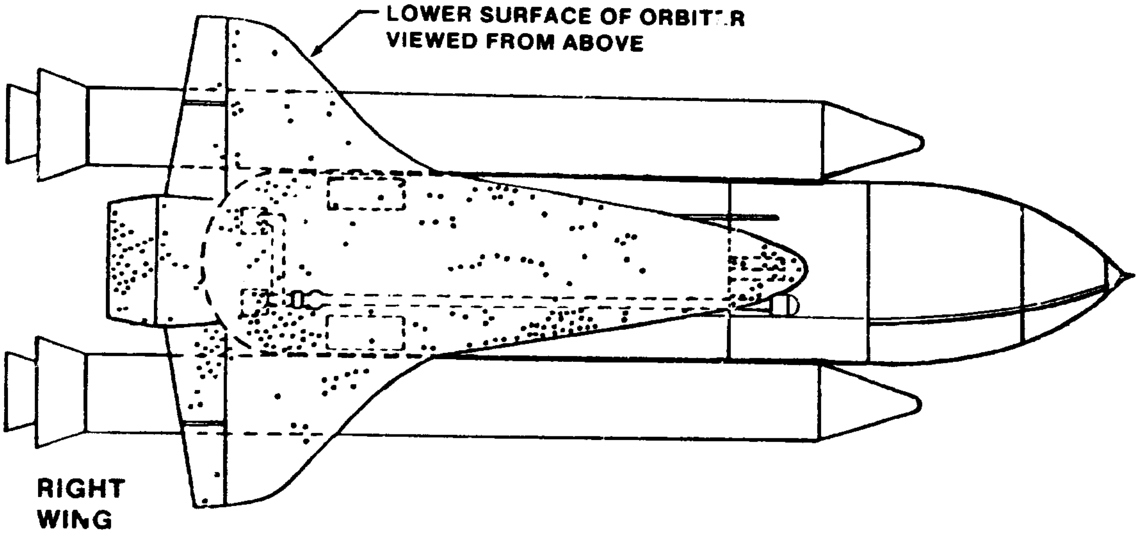


Figure 8.- STS-1 and STS-2 lower surface debris damage composite.

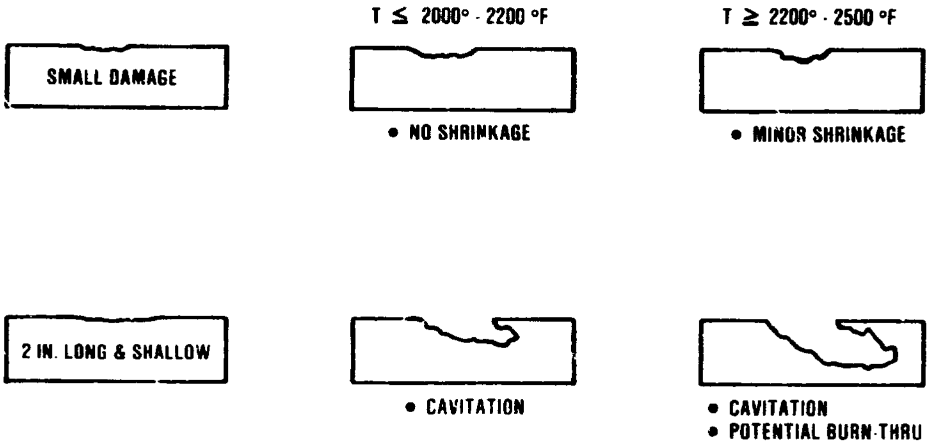


Figure 9.- TPS tile sensitivity to debris damage.

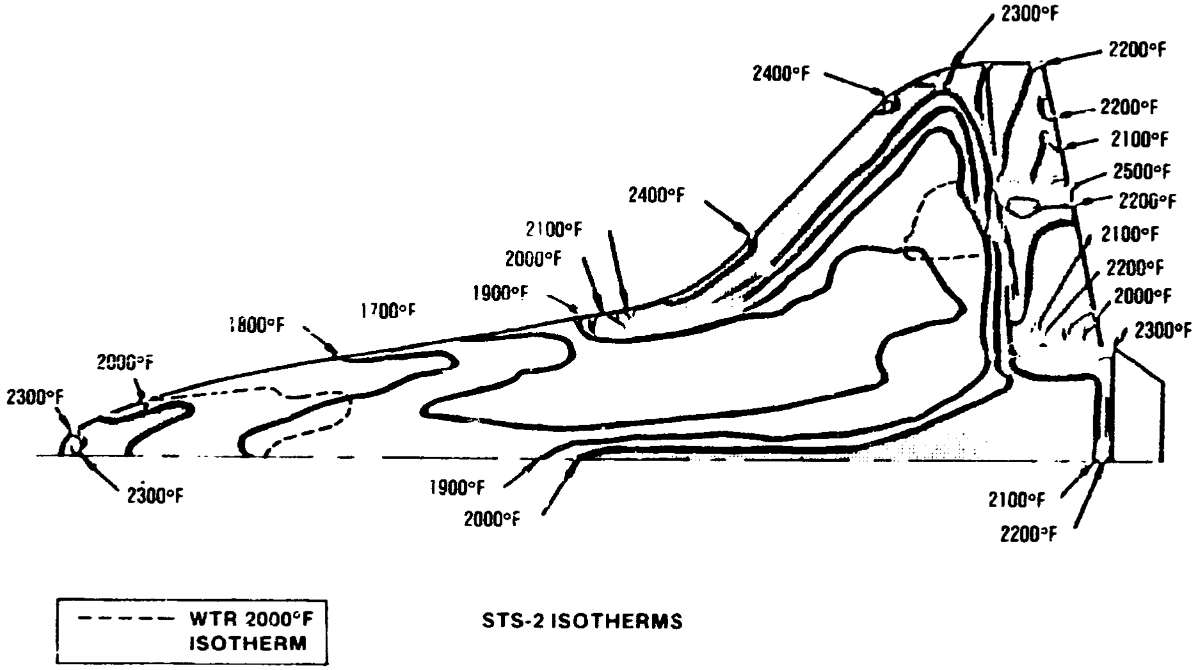
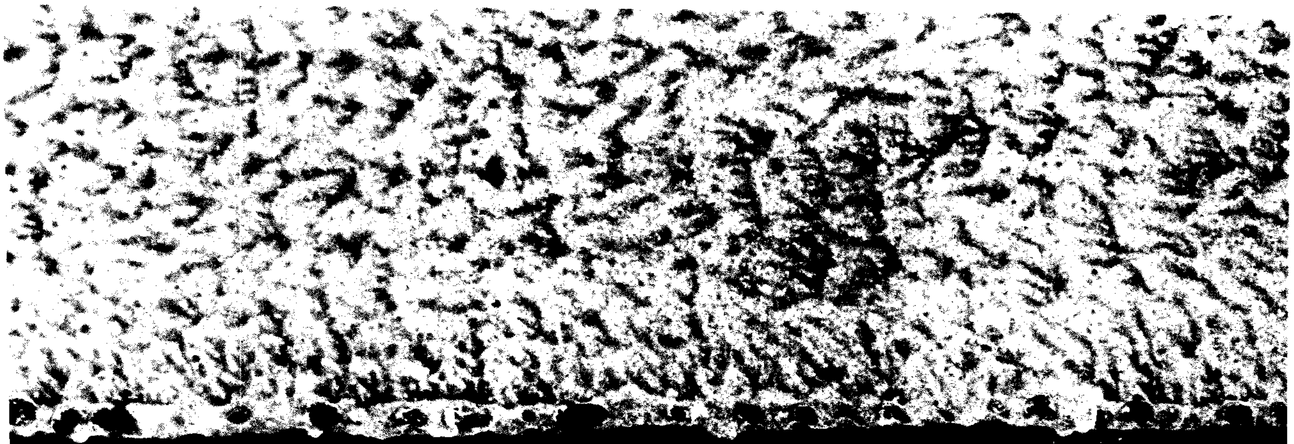


Figure 10.- Orbiter lower surface isotherms (STS-2).



DEBRIS SOURCES	POTENTIAL DAMAGE SEVERITY		
	SAFETY OF FLIGHT	SIGNIFICANT	MINOR
ORBITER		TILE FRAGMENTS UMBILICAL H_2O ICE	TIRE STRAIN GAUGE WIRE UMBILICAL BAGGIE REMNANTS TILE SPACER SHIMS
ET	LIGHTNING BANDS VENT LOUVER ICE LOX PRESS LINE MOUNT ICE NOSECAP/OGIVE INTERFACE ICE	NOSECAP SLA PAL RAMP FRAGMENTS FEEDLINE & A/G LINE ICE* SOFI FRAGMENTS	TUMBLE VALVE COVER
SRB		FRUSTRUM INSULATION THROAT PLUG FRAGMENTS	STRUT BAGGIES* ET/SRB CONNECTOR PIECES*
PAD	HOLD-DOWN POST RTV POST STRUT COVERS	SHOE LINER MATERIAL	WATER TROUGH FRAGMENTS

***WAIVED FROM NO DEBRIS REQUIREMENT AS ACCEPTABLE**

Figure 35.- Debris source summary.

- **FOR STS-2 AND SUBS**
  - ET LIGHTNING BANDS REMOVED
  - ET CABLE TRAY PHENOLIC SPACERS REDESIGNED TO ASSURE RETENTION
  - FACILITY BEANIE - CAP MODIFIED TO PREVENT ICE ON ET VENT LOUVERS
  - LH_2 PRESS LINE LOAD ALLEVIATION RAMPS REMOVED
- **FOR STS-3 AND SUBS**
  - USE OF HOLD-DOWN POST ABLATIVE INSULATION DRASTICALLY REDUCED
  - THERMAL SHORTS FORMING ICE AT ET NOSECAP/OGIVE INTERFACE ELIMINATED
  - ORBITER UMBILICAL BAGGIES RETAINED BY CLIPS RATHER THAN DRAWSTRING
  - TIRE PRESSURE STRAIN GAUGE WIRES MODIFIED TO ASSURE CLEAN RELEASE AT SPIN-UP
  - RIGOROUS PAD CLEAN-UP PROCEDURE INSTITUTED
- **FOR STS-4 AND SUBS**
  - THERMAL SHORT ON LOX PRESSURIZATION LINE MOUNT FOAMED OVER
  - SRB FRUSTRUM INSULATION APPLICATION TECHNIQUE REVISED TO PREVENT SPALLATION
- **FOR STS-5 AND SUBS**
  - HOLD-DOWN POST STRUT COVERS MODIFIED TO ELIMINATE EXPOSED BOLTS TO ASSURE RETENTION
  - HOLD-DOWN POST RTV INSULATION MINIMIZED
  - ET ANTI-GEYSER LINE REMOVED
- **FOR STS-6 AND SUBS**
  - THERMAL SHORT ON LOX PRESSURIZATION LINE MOUNT FOAMED OVER

Figure 36.- Summary of modifications to reduce debris.