BAGGIE: A UNIQUE SOLUTION TO AN ORBITER ICING PROBLEM

L. J. Walkover*

ABSTRACT

Solving the orbiter icing problem that is located in two lower surface mold line cavities presented a challenging assignment on the Space Shuttle program. These two cavities are open during Shuttle ground operations and ascent, and are then closed after orbit insertion. If not protected, these cavities may be coated with ice, which may be detrimental to the adjacent thermal protection system (TPS) tiles if the ice breaks up during ascent, and may hinder the closing of the cavity doors if the ice does not break up. The problem of ice in these cavities was solved by the use of a passive mechanism called baggie, which is a purge curtain used to enclose the cavity and is used in conjunction with gaseous nitrogen as the local purge gas. The baggie, the final solution, is unique in its simplicity, but its design and development were not. This paper discusses the final baggie design and emphasizes its development testing. Also discussed are the baggie concepts and other solutions not used. This work was done under contract to NASA's Johnson Space Center (JSC) in Houston, Texas.

INTRODUCTION

The Space Shuttle consists of the reusable orbiter, expendable external tank (ET), and the reusable solid rocket boosters (SRB), which are protected from the various environments during ground operations, launch, orbit, and reentry (Figure 1). The environmental protection systems for the Shuttle elements vary, depending on the requirement, e.g., the TPS on the external surface of the orbiter, and the external spray-on foam insulation on the ET. On the orbiter, there are two local areas that are protected against the ground environments by the subject of this paper.

The mated Shuttle has two 17-inch diameter propellant feedlines that transfer liquid hydrogen (LH$_2$) on the left-hand side, and liquid oxygen (LO$_2$) on the right-hand side from the ET to the orbiter. The feedlines are connected and separated at the two interfaces between the two vehicles via each of the ET-to-orbiter umbilical separation disconnects. Each of these installations in the orbiter results in a local large-size mold line umbilical cavity that is open during ground operations and ascent, and is then closed by the respective left-hand and right-hand umbilical cavity doors after orbit insertion. Each cavity is approximately 50 inches by 50 inches wide by 6 inches deep. Figure 2 shows the location of the left-hand and right-hand cavities on the underside of the orbiter toward the rear of the vehicle.

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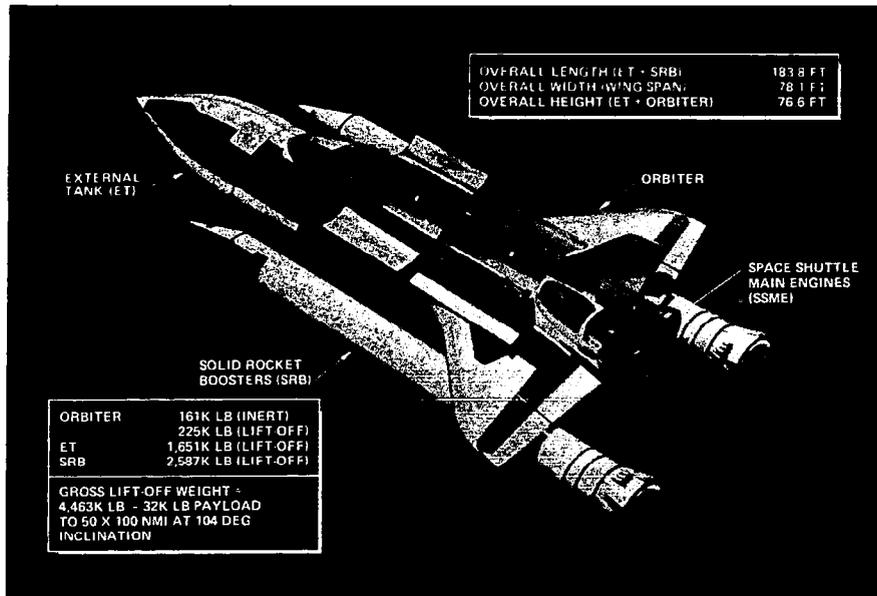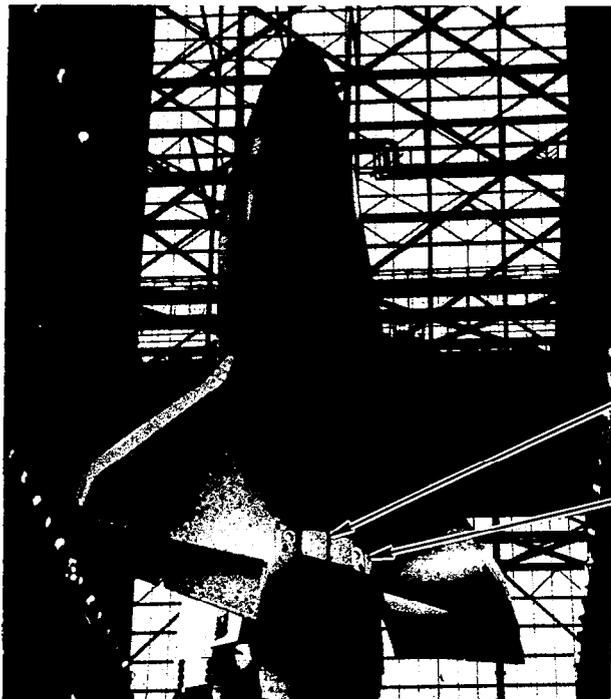
OVERALL LENGTH (ET + SRB)   183.8 FT
OVERALL WIDTH (WING SPAN)   78.1 FT
OVERALL HEIGHT (ET + ORBITER)   76.6 FT

EXTERNAL
TANK (ET)

ORBITER

SPACE SHUTTLE
MAIN ENGINES
(SSME)

SOLID ROCKET
BOOSTERS (SRB)

ORBITER	161K LB (INERT)
	225K LB (LIFT-OFF)
ET	1,651K LB (LIFT-OFF)
SRB	2,587K LB (LIFT-OFF)

GROSS LIFT-OFF WEIGHT =
4,463K LB - 32K LB PAYLOAD
TO 50 X 100 NMI AT 104 DEG
INCLINATION

Figure 1 — Space Shuttle Vehicle

PROBLEM
• PREVENT ICING IN CAVITY

ET UMBILICAL CAVITY DOOR
  • OPEN POSITION
  • LH AND RH SIDES

ET UMBILICAL CAVITY
  • LH$_2$ ON LH SIDE
  • LO$_2$ ON RH SIDE

• OPEN DURING
  GROUND OPERATIONS
  AND ASCENT
• CLOSED AFTER
  ORBIT INSERTION

Figure 2 — Space Shuttle Orbiter

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The local temperatures on the structure and the umbilicals in the cavity areas are influenced by the cryogenic temperatures of the local propellant feedlines and the payload when the payload contains cryogenic stages. The feedlines and payload cryogenic temperatures result in local, below-freezing temperatures that may cause icing because of condensation or rain on the structure at the cavity surface areas. The icing may be thick and dense enough to prevent the doors from closing by either jamming the door closure/locking mechanism or blocking the door/cavity interfaces. In addition, ice breakup during Shuttle ascent may damage the TPS tiles that cover most of the orbiter's exterior surface. It must be emphasized that the doors must be closed or a successful reentry will not be accomplished.

Many studies were made to solve the icing problem. The solutions had to be compatible with the orbiter's cost, schedule, manufacturing, weight, and installation. One of the main obstacles in finding a solution was that there was not much space available. This severely limited the design concepts and the details of any solution. In addition, the baggie design, as it matured during design, development, fabrication, and installation, required a step-by-step approach that was planned and executed in real time instead of being planned before the time of execution.

Because of its simplicity, the baggie design is a unique solution to a perplexing problem. It was developed from design efforts, expedient ground testing, and sophisticated transonic wind tunnel testing that yielded negative results until the final solution was determined.

REQUIREMENTS

The cavity icing solution was designed to satisfy, to various degrees, the listed requirements.

1. Prevent ice formation that could inhibit or harm ET umbilical separation, ET umbilical cavity door closure, or TPS tiles

2. No dedicated purge system: GN_2 vented from aft fuselage

3. Pad wind environment: 100 mph locally at ET umbilical cavity

4. Does not have to survive launch firing

5. Does not have to be reusable

6. Provide vision for cameras located in cavity, which are used on development test flights only, to record ET separation from the orbiter

7. No delta separation force requirement by orbiter or ET

8. Least impact on adjacent orbiter, ET, and launch facility structures and systems

9. Installation capability at Kennedy Space Center (KSC) both prior and subsequent to mating

10. Minimum weight and cost

DESIGN CONCEPTS

The icing problem in the cavities was determined late in the orbiter development program. At the time it was identified, the structure in and about the cavity had been designed, the door and its operating (closure and locking) mechanism were relatively complete, most of the local systems including the ET umbilical separation disconnect and its supporting closeout curtain were in their final stages, local TPS tile and TPS seals were far along in their design stages, and, most important of all, the size of the cavity and door was fixed. The late start, combined with the requirement that any icing problem solution have minimum impact on released or built orbiter structure and systems, and if possible, no impact on the ET or launch facilities, severely limited the scope and feasibility of any design solution.

Design concepts for the icing solution are listed in Table 1.

As shown in Table 1, the initial approach for the icing solution was to limit or raise the local temperatures to above the freezing temperature to simply prevent any ice formation. Two basic concepts used this method. One was to utilize insulation by coating local areas or, if required, the entire cavity. It was quickly determined that insulation by itself was not adequate. The next

TABLE 1 — DESIGN CONCEPTS

Method	Objective

1. Insulation and/or electrical heaters
   a. Complex
   b. Active system
   c. Heavy
 	
2. Hot gas blower
   a. Ground-supplied equipment (GSE)
   b. Removed before launch
   c. High pad reach (36 feet)
   d. Additional GSE disconnects
	• Increase local temperature above freezing

3. Hard enclosure
   a. ET supported
   b. Δ ET/orbiter interfaces
   c. Δ separation forces
   d. Heavy
 	
4. Purge barrier
   a. GSE
   b. Removed before launch (lanyard)
   c. High pad reach (36 feet)
   d. Additional GSE pad disconnects
 	
→ 5. Purge curtain
   a. Thin film/frangible
   b. Nonreusable
   c. Very lightweight
   d. Development requirements
	• Provide purge chamber
	• Keep moisture and rain out

attempt was to utilize electrical heaters, but the power requirements became excessive. Insulation was then combined with the use of local electrical heaters. This option was eliminated because of the complexity involved (insulation, heaters, and exposed mechanisms), the use of an active system (heaters), the lack of clearance room, the power requirements (approximately 622 watts), and the weight (approximately 110 pounds).

The second concept was to utilize a hot gas blower system supplied by GSE. This system used a blower feeding hot gas into two main ducts that reached approximately 36 feet up from the pad to each cavity. The ends of the blowers were fitted with either fixed or oscillating nozzles to direct the hot air to the required locations. This concept was quickly eliminated because the two main ducts had to be removed just prior to launch so as not to impede the vehicle launch. (KSC would not tolerate another ground separation system.) In addition, the excessive reach required and the limited clearance between the orbiter and the ET made this concept impractical.

The second approach to the icing problem (Table 1) was to provide a purge chamber that could be filled with a purge gas, and, at the same time, keep any rain or moisture out. One concept was to utilize a hard enclosure that would be mounted on the ET and enclose the cavity. This would be a typical structural approach utilizing a structural assembly. This design was eliminated because it required additional interfaces with and changes to the ET, required a change in the orbiter/ET separation force, and was relatively heavy. The next concept was to utilize a purge barrier that would essentially be a flexible external enclosure to the cavity (Figure 3). Covering the outer surface of the cavity essentially isolated all structures, systems, and mechanisms from the local
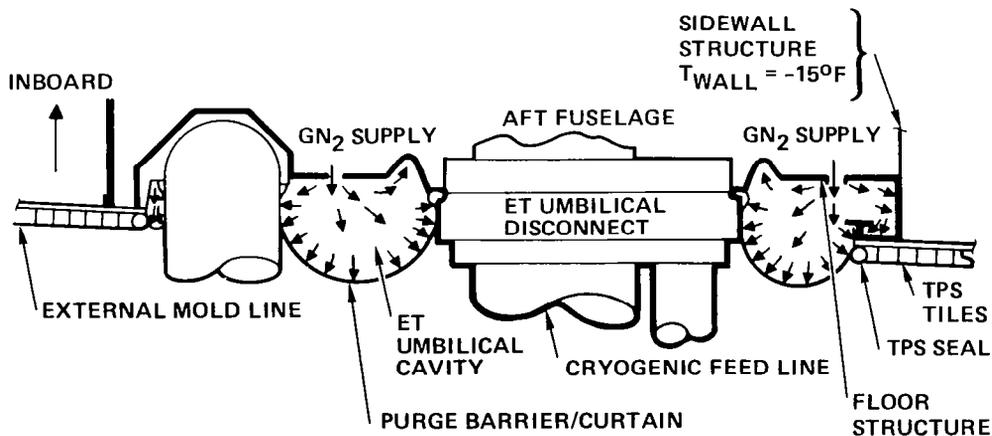
- PURGE CHAMBER ISOLATES COLD SOAKED STRUCTURE, SYSTEMS AND MECHANISM FROM PAD HUMID/RAIN ENVIRONMENTS

- GN$_2$ PURGE PREVENTS ICE FORMATION (BLOCKS AMBIENT AIR INTRUSIONS)

Figure 3 — Purge Chamber Concept

humid and rain environment. The enclosure was then filled with GN$_2$ purge gas, which prevents ice formation by blocking ambient air intrusion. The purge barrier was to be installed on the orbiter, and was to be removed immediately before or at launch by a GSE pad lanyard. This concept was dropped because of the required lanyard reach, approximately 36 feet. The limited clearance between the orbiter and the ET made it questionable as to whether the lanyard and purge barrier could be pulled free without damaging the Shuttle. And again, KSC was not in favor of another ground separation system.

The final concept was the frangible purge curtain, now called the baggie. (The basic concept is shown on Figure 3.) The concept was appealing because it was simple, lightweight, could be designed with the least impact on the adjacent structure and systems, and required no changes to the ET structure or separation force. The concept used a curtain made of a thin, frangible film material that did not have to survive the launch environment. It was accepted that new baggies would be installed for flight readiness firing and for each launch. It was also accepted that the material would be selected as the design progressed and that some development would be required, but how much development would be required to select and fabricate the material, the curtain shape, and the curtain attachments was not known. In addition, a major limitation was the cavity size, and the fixed door/cavity clearance, thus severely limiting the space for curtain attachments.

BAGGIE EVOLUTION

The evolution of the baggie is shown in Table 2, which lists the basic features that were changed during the design, development, and testing phases.

TABLE 2 – BAGGIE EVOLUTION

Item	Hemispherical Baggie ———	——▶ Flat Baggie
Shape	Hemispherical	Flat
Material	2 mil Kel F 800	2 mil Kapton
Fabrication	Spray-on mold	Cut from sheet stock
Attachment	• Tape to tiles, structure, umbilical • Zip lock • Zip lock + clips	• Zip lock + clips • Plate attached by screws (outer) • Drawstring (inner)) • Plate attached by screws (outer/inner)
Development	• Mold for shape • Material fabrication • Separation agent • Material reinforcement • Installation technique	• Assembly tool • Material assembly
Testing	• Door closure • AEDC transonic wind tunnel • Wind machine	• Wind machine • Door closure • AEDC transonic wind tunnel • Baggie/retainer integrity deviation test

Hemispherical Baggie

The original baggie (Figure 4) utilized a radial cross-section, which is the natural form to react to internal pressure, especially with a material with weak structural properties. The radius at various locations about the baggie periphery varied, depending on the distance between the umbilical and the cavity opening as defined by the cavity sill. The radial cross-section was tangent at the TPS thermal barrier (outer periphery) and to the umbilical (inner periphery). The baggie tangencies are to keep moisture and rain out of the cavity and away from the cavity edges (Figure 5). The actual shape of the LO_2 baggie is shown by Figure 6, which is the tool used for the baggie assembly. The material was 2 mil Kel F 800, which has a low tensile strength (1,500 psi), a low service temperature (+250°F), and was self-extinguishing; all characteristics picked to allow separation during boost. The baggie material is clear, which allows cameras to take separation pictures through the material.

Figure 7 indicates a possible baggie installation—if it survives the launch. There is no installation problem if the baggie is totally enclosed within the door. This was demonstrated by door closure tests, which proved the door mechanisms will penetrate through the baggie material, and by additional door closure tests in which the bunched baggie material was stuffed in and about the individual mechanisms without affecting door mechanism or closure. Thermal data indicated that there would be no problem if the baggie locally protrudes external to the door: the door closure will not jam, the baggie will not burn past the thermal barrier, and it will not trip the boundary layer. Figure 8 is an example of the problem of designing the baggie to fit about the door hinge mechanism when the door is open, but still not prevent proper hinge movement to allow the door to close.

The original thoughts on attaching the baggie to the structure and umbilical were to simply use tape of a suitable nature (Kapton tape). The tape attachment would be either external at the outer surface of the tiles or internal at the structure. These concepts were eliminated because no relatively smooth and uninterrupted surfaces (tiles or structures) were available for attachment, and, possibly more important, the pull action of the baggie tended to peel the tape off the surface it was attached to. The requirement for no delta separation forces meant that the baggie must be attached to the orbiter side of the umbilical disconnect.

The selected design used for baggie attachment to both the cavity structure (outer periphery) and the umbilical (inner periphery) is shown in Figure 9. It is similar to the zip-lock closure of commercial plastic bags by the same name. The outer periphery locking retainer (aluminum extrusion) is attached by No. 4-40 screws tapped into the adjacent structural aluminum skin. The inner periphery locking retainer uses No. 4-40 screws and nuts. The outer and inner periphery of the baggie were wrapped around a silicone rubber locking cord and reinforced with Kapton tape. The baggie cord assembly was hand forced into the preinstalled locking retainer. An interference fit at the retainer opening assured a positive retention force. The radial shape of the baggie resulted in a shear retention reaction rather than a direct tension pullout. The baggie was designed to tear and separate at the edge of the Kapton reinforcing tape. The zip-lock installation was also judged to be
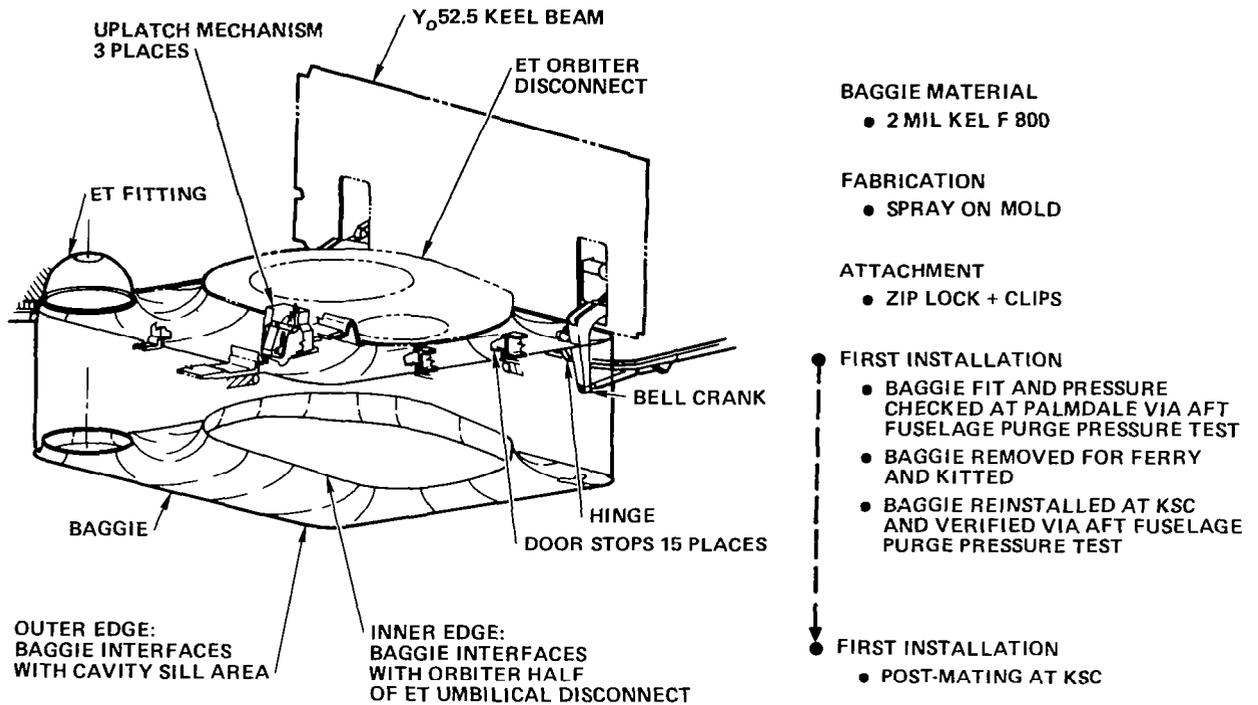
UPLATCH MECHANISM 3 PLACES

Y_o52.5 KEEL BEAM

ET ORBITER DISCONNECT

ET FITTING

BELL CRANK

BAGGIE

HINGE

DOOR STOPS 15 PLACES

OUTER EDGE: BAGGIE INTERFACES WITH CAVITY SILL AREA

INNER EDGE: BAGGIE INTERFACES WITH ORBITER HALF OF ET UMBILICAL DISCONNECT

BAGGIE MATERIAL
- 2 MIL KEL F 800

FABRICATION
- SPRAY ON MOLD

ATTACHMENT
- ZIP LOCK + CLIPS

FIRST INSTALLATION
- BAGGIE FIT AND PRESSURE CHECKED AT PALMDALE VIA AFT FUSELAGE PURGE PRESSURE TEST
- BAGGIE REMOVED FOR FERRY AND KITTED
- BAGGIE REINSTALLED AT KSC AND VERIFIED VIA AFT FUSELAGE PURGE PRESSURE TEST

FIRST INSTALLATION
- POST-MATING AT KSC

Figure 4 — Baggie Design; Hemispherical

CLOSEOUT STRUCTURE

STRUCTURE

CLOSEOUT CURTAIN

GN_2

PURGE AREA

TPS TILE

BAGGIE ATTACHMENT

THERMAL BARRIER

TANGENCY

UMBILICAL

BAGGIE

✓ IDEAL BAGGIE INSTALLATION
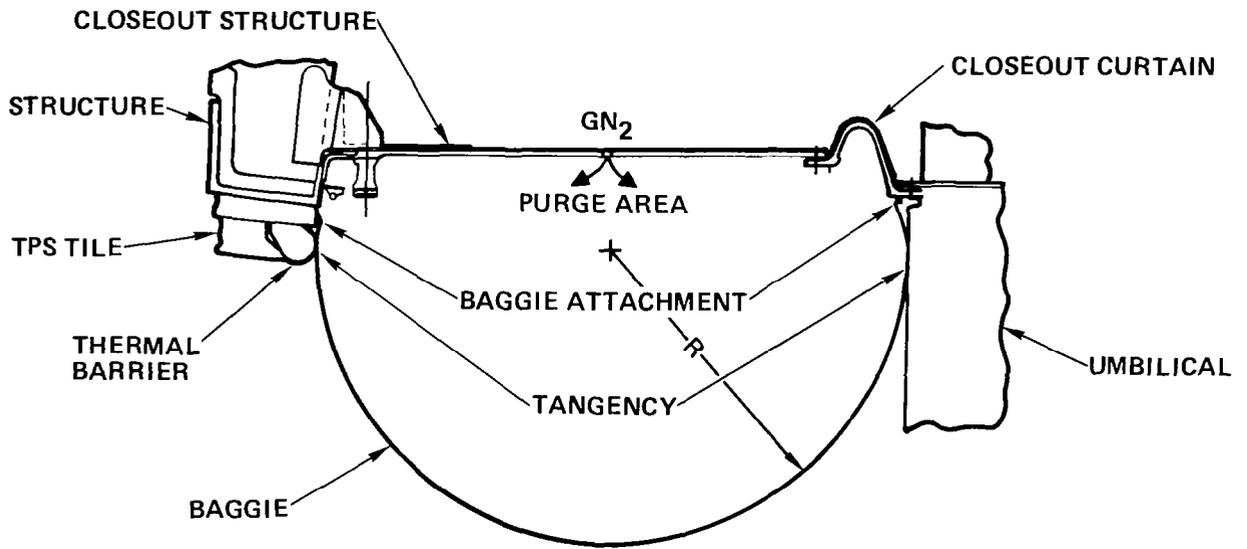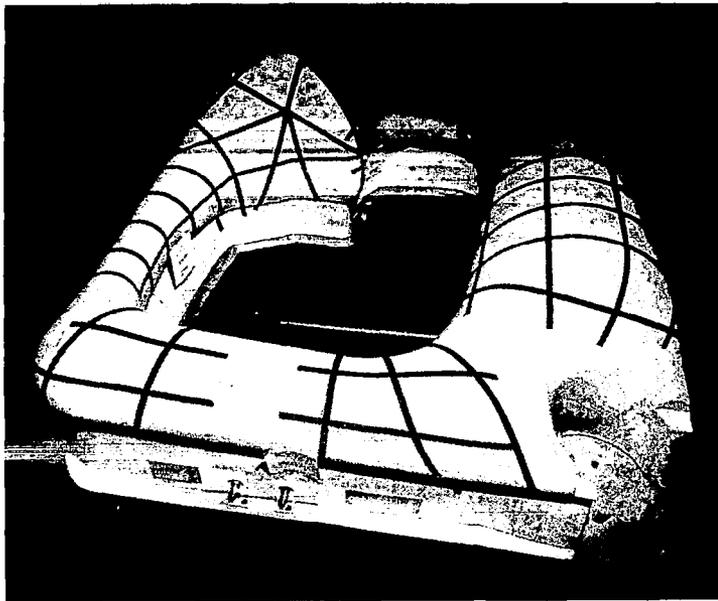PROVIDE PURGE CHAMBER AND
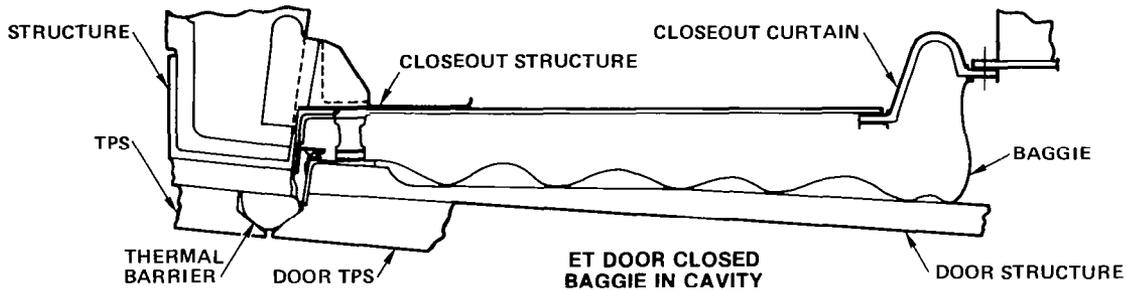KEEP MOISTURE AND RAIN OUT

Figure 5 — Typical Baggie Cross-Section; Hemispherical

- BAGGIE SHAPE SHOWN BY TOOL CONTOURS

- STRIPS INDICATE CRISSCROSS KAPTON TAPE REINFORCEMENT

- TOOL USED TO ASSEMBLE BAGGIE TO INNER AND OUTER PERIPHERY ZIP LOCK LOCKING CORD

Figure 6 — Hemispherical Baggie (LO₂) Assembly Tool

Figure 6 — Hemispherical Baggie (LO_2) Assembly Tool

STRUCTURE

CLOSEOUT STRUCTURE

CLOSEOUT CURTAIN

TPS

BAGGIE

THERMAL BARRIER

DOOR TPS

ET DOOR CLOSED
BAGGIE IN CAVITY

DOOR STRUCTURE

ET DOOR CLOSED;
BAGGIE PROTRUDING
PAST DOOR

✔ BAGGIE WILL NOT
- PREVENT DOOR CLOSURE
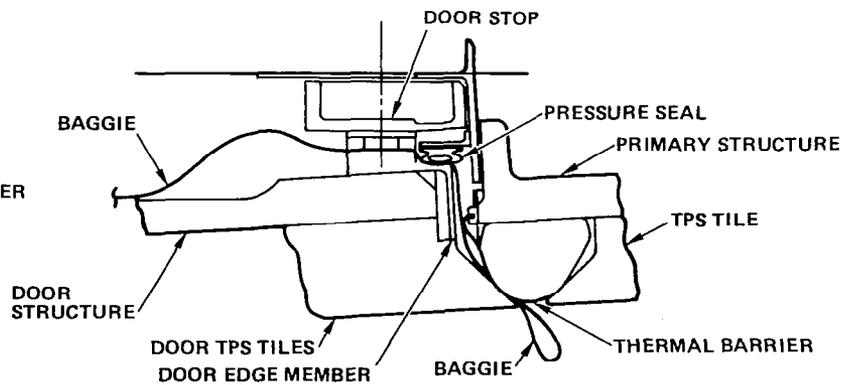- BURN PAST THERMAL BARRIER
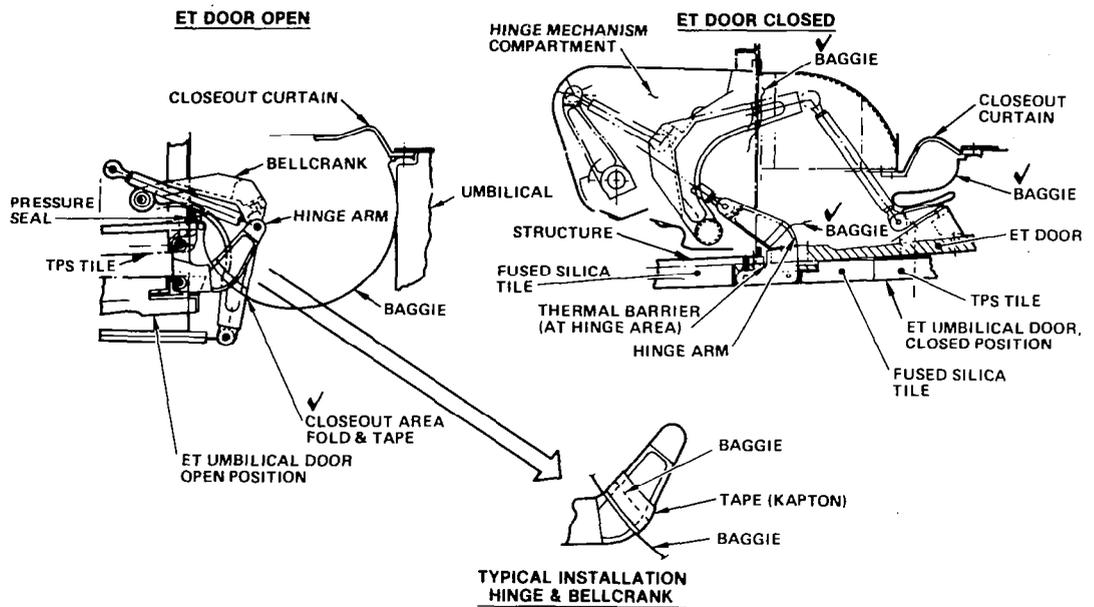- TRIP BOUNDARY LAYER

DOOR STOP

BAGGIE

PRESSURE SEAL

PRIMARY STRUCTURE

TPS TILE

DOOR
STRUCTURE

DOOR TPS TILES

DOOR EDGE MEMBER

BAGGIE

THERMAL BARRIER

Figure 7 — If Baggie Survives Launch

ET DOOR OPEN

HINGE MECHANISM
COMPARTMENT

ET DOOR CLOSED

BAGGIE

CLOSEOUT CURTAIN

BELLCRANK

CLOSEOUT
CURTAIN

PRESSURE
SEAL

UMBILICAL

BAGGIE

HINGE ARM

STRUCTURE

ET DOOR

BAGGIE

TPS TILE

FUSED SILICA
TILE

TPS TILE

THERMAL BARRIER
(AT HINGE AREA)

ET UMBILICAL DOOR,
CLOSED POSITION

BAGGIE

HINGE ARM

FUSED SILICA
TILE

CLOSEOUT AREA
FOLD & TAPE

BAGGIE

ET UMBILICAL DOOR
OPEN POSITION

TAPE (KAPTON)

BAGGIE

TYPICAL INSTALLATION
HINGE & BELLCRANK

Figure 8 — Hemispherical Baggie Installation;
Hinge Area

LOCKING RETAINER ⟹ RETAINER INSTALLATION ⟹ ZIP LOCK ⟹ SNAP CLIP
INSTALLATION   INSTALLATION

0.150

0.280

0.103 ± 0.003   0.080 ± 0.005

MATERIAL
● 6063 T
● ALUMINUM EXTRUSION

LOCKING CORD

0.100 ± 0.005
CORD

MATERIAL
● SILICONE RUBBER

LOCKING
RETAINER

LOCKING CORD

LOCKING RETAINER

ATTACHMENT
SCREWS
● NO. 4-40
● 6 IN. CENTERS
● TAPPED
● LOCKED

CAVITY SKIN
STRUCTURE
● ALUMINUM

BAGGIE CORD ASSEMBLY

LOCKING CORD

KAPTON TAPE
● 1 IN. WIDE
● 2 MIL THICK

TEAR LINE

BAGGIE
● 2 MIL
● KEL F 800

SNAP
CLIP

INSTALLATION METHOD

INSTALLED
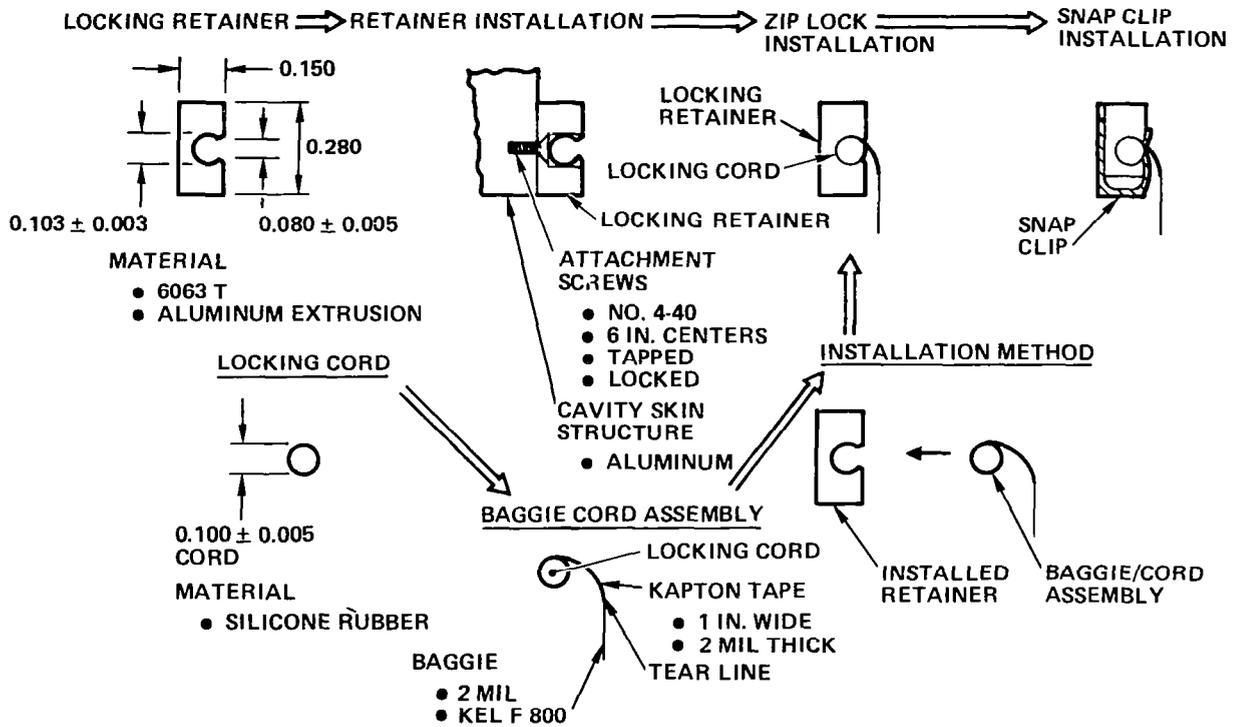RETAINER

BAGGIE/CORD
ASSEMBLY

Figure 9 — Hemispherical Baggie Attachment

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reasonably easy to do. A special hand tool was developed to help install the baggie and cord into the retainer.

Because of the unusual shape of the baggie (Figure 6), Kel F 800 sheet stock could not be used because there was not a way to transform the flat sheet stock to fit the complicated shape of the baggie. Instead, a spray-on mold technique was selected. Kel F 800 is adaptable to spraying, which is one of the reasons it was chosen. The procedure for spray-on mold is to spray 0.5 mil on the mold, and cure at 425°F. This is repeated four times. The result is a 2 mil Kel F 800 baggie of the correct shape, which is then peeled off the mold and assembled on an assembly tool (Figure 6) with the locking cord at both the inner and outer peripheries.

Fabrication development was required for the actual spraying, the mold materials, and the parting agent. The spraying techniques had to be developed to control the actual thickness of each spray and the total final thicknesses. (Technicians were trained as to this technique.) The original mold was made of glass epoxy from a plaster master. The glass epoxy molds would not take the repeated high temperature required during each spray curing cycle—they deteriorate. The glass epoxy molds were replaced by electro-formed nickel molds, which were also made from the plaster masters. These latter molds were successful in that they stood up to repeated temperature usage. Various parting agents (to allow the baggie to be peeled off the mold without tearing) were utilized and did not work satisfactorily. It was found that a Teflon coating sprayed on the electro-formed nickel molds allowed the baggies to be successfully peeled off the molds.

The baggies were tested for proper separation from the orbiter. The testing was done at the transonic wind tunnel at the Arnold Engineering Development Center (AEDC) in Tullahome, Tennessee. The baggie testing was piggy-backed to the planned aerodynamic flow tests used in the development testing of the TPS tiles. Figure 10 shows the baggie test bed for the LO$_2$ right-hand side, which included the cavity structure, the adjacent TPS tiles, the ET structural crossbeam, the umbilical, and the installed baggie. The baggie shown is not the hemispherical baggie, but the flat baggie to be discussed later. Five runs were made: one with strips of Kel F 800 and four runs with the installed baggie. Problems were encountered when a long section of the locking cord separated from the locking retainer, slapped, and damaged some downstream TPS tiles before total baggie separation occurred. Snap clips (Figure 9) were designed to slip about the locking retainer and the locking cord. These were installed approximately six inches on center and the locking cords, after installation, were slit at each snap ring to limit the length of cord that could separate from the retainer (if it were to come out) and possibly damage the adjacent tiles. The last runs were successful in that the baggie separated properly (at approximately 0.25 Mach) and the locking cord did not come out of the locking retainer.

The original plan was to install the baggies on Orbiter 102 during manufacturing operations at Palmdale. This would verify the installation (fit and pressure check), provide training for manufacturing personnel, and turn up any required changes or installation difficulties. It was not done because certified baggies were not available, i.e., the baggie was not designed, developed, and tested in time; therefore, two complete sets of baggies (one set plus one spare set) were sent to KSC

to be installed on the mated Shuttle. The two field splices (per cavity) were in a difficult location to reach. They were relocated by cut and fit with baggie material segments and Kapton tape. Numerous tears occurred in the baggies during handling and installation, which were spliced by Kapton tape. There were problems in closing out and taping the baggie in the hinge areas, and the baggies did not fit properly (tangency) about the inner and outer periphery. The baggies were finally installed and the installation accepted for the first flight of Orbiter 102—space transportation system flight 1 (STS-1).

The following day, the local winds at KSC increased in velocity. This resulted in one of the baggies being torn away. It was estimated that the ground winds were at 50 mph, but the local cross wind in the vicinity of the cavities was as high as 80 mph. Higher cross wind velocities (relative to the vertically oriented Shuttle) are expected in the cavity area because of the maze of structures surrounding the cavity and the reduced area between the orbiter and the ET as the winds pass crosswise between the two vehicles. Immediately, the spare set of baggies was installed, but a few days later they also failed in a moderate wind.

An immediate program was set up for ground testing of the hemispherical baggies. A limited number of spare LO2 baggies were available for the tests. As time (the launch schedule) was a major factor, ground testing had to be as expeditious as possible. The thought was to mount the baggie test bed (Figure 10) on a flat bed truck with a long ground run to attain the required velocity. The test runs were to be done on either the long runways or the flat test salt bed available at Palmdale and Edwards Air Force Base. This was reluctantly discarded as being too unreliable, and probably too dangerous.

Ground testing was done at the Downey plant facilities utilizing a wind machine owned by Controlled Airstreams, Inc. (See Figure 11.) The machine was immediately available, and would provide controlled air flow over the baggie test bed (Figure 10). The wind machine utilized a Continental gasoline engine mounted behind a flow screen; the combination adjustable for flow orientation and installed on a trailer for mobility. The machine normally is used by various fire services for agricultural spraying and for creating special effects for television and the movies.

During the first run, the baggie failed at approximately 50 mph. Another baggie was immediately reinforced by crisscross strips of Kapton tape spaced four to six inches apart (Figure 6). This baggie assembly also failed. It was planned to then increase the thickness to provide more material strength, but this was nullified because it would take approximately three weeks to fabricate the baggie, and, more important, it was realized that the basic material, shape, and retention had to be changed. The final plan for GSE ground protection of the baggie from the winds was not considered because 36 feet of access stands and GSE protection would have to be removed before launch. Figure 12 is a summary of the problems with the hemispherical baggie and the reasons for stopping work on this design.
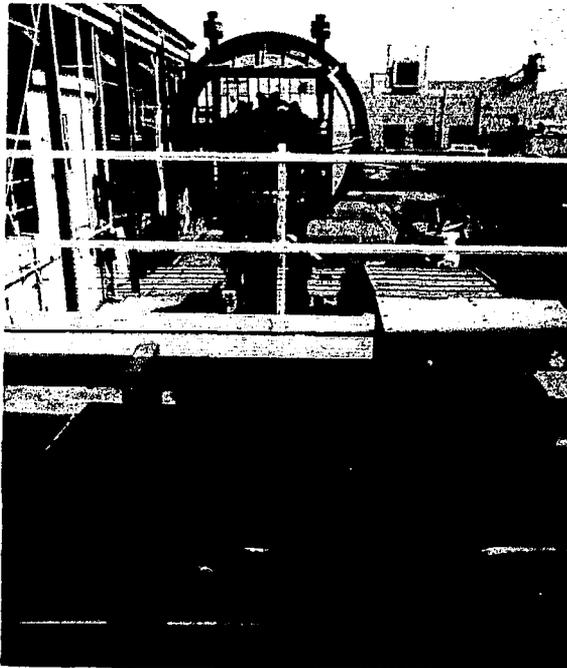
The first flight of the Shuttle did not contain baggies because baggies of proper design and certification were not available in time for the launch. Additional thermal analysis also indicated that there would be no ice in the ET umbilical cavity at launch unless it rained after the propellant tanks had been filled. During previous tanking tests and launch tanking, there had been no rain and
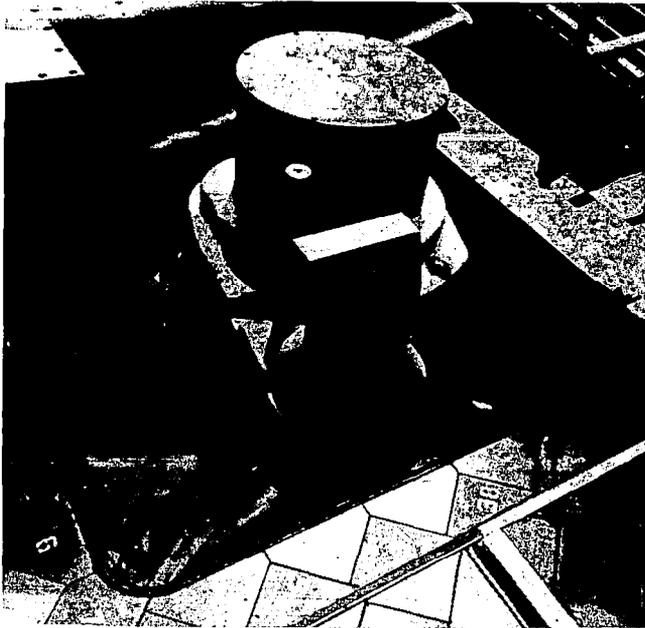
- USED FOR
  - GROUND TESTING WITH WIND MACHINE AT DOWNEY, CA.
  - WIND TUNNEL TESTING AT AEDC SUPERSONIC TUNNEL
- ASSEMBLY OF
  - CAVITY STRUCTURE   • LO_2 UMBILICAL
  - UMBILICAL
  - ET CROSS BEAM   • RH SIDE
  - ADJACENT TPS TILES
  - BAGGIE
- ORIGINALLY USED FOR
  - AERODYNAMIC FLOW TESTS FOR TPS TILES

Figure 10 — Baggie Test Bed

- WIND MACHINE, WHICH IS OWNED BY CONTROLLED AIRSTREAM INC., IS USED FOR
  - FIRE SERVICE
  - AGRICULTURAL SPRAYING
  - SPECIAL EFFECTS FOR TV AND MOVIES
- BAGGIE TESTING
  - CROSS WIND FLOW
  - MAXIMUM VELOCITY AT BAGGIE = 100 MPH
  - AT DOWNEY CA.

- CONTINENTAL GASOLINE ENGINE
- FLOW SCREEN
- ADJUSTABLE FLOW DIRECTION
- ON TRAILER FOR MOBILITY

Figure 11 — Ground Testing

13

only frost was indicated in the ET umbilical cavities. By itself, humidity is not an icing problem; therefore, management decided to launch STS-1 without baffies. Figure 13 is a summary of the basic development sequence for the hemispherical baggie.
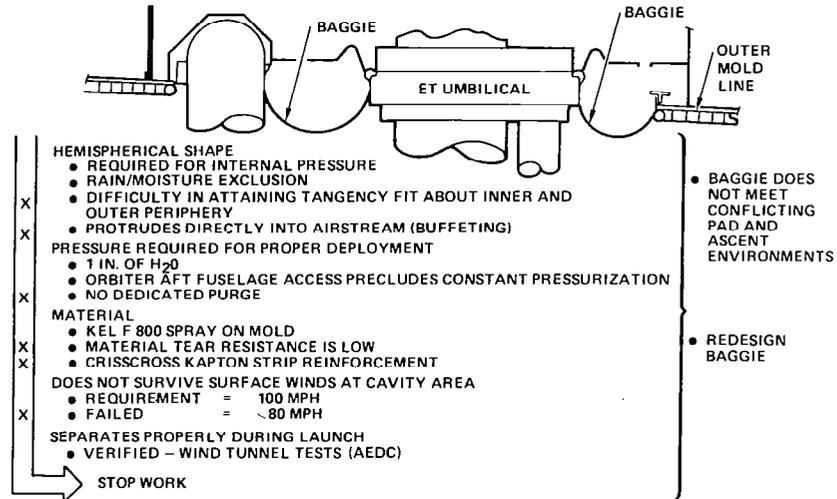

HEMISPHERICAL SHAPE
- REQUIRED FOR INTERNAL PRESSURE
- RAIN/MOISTURE EXCLUSION
- X DIFFICULTY IN ATTAINING TANGENCY FIT ABOUT INNER AND OUTER PERIPHERY
- X PROTRUDES DIRECTLY INTO AIRSTREAM (BUFFETING)

PRESSURE REQUIRED FOR PROPER DEPLOYMENT
- 1 IN. OF H₂0
- ORBITER AFT FUSELAGE ACCESS PRECLUDES CONSTANT PRESSURIZATION
- X NO DEDICATED PURGE

MATERIAL
- KEL F 800 SPRAY ON MOLD
- X MATERIAL TEAR RESISTANCE IS LOW
- X CRISSCROSS KAPTON STRIP REINFORCEMENT

DOES NOT SURVIVE SURFACE WINDS AT CAVITY AREA
- REQUIREMENT = 100 MPH
- X FAILED = ∿80 MPH

SEPARATES PROPERLY DURING LAUNCH
- VERIFIED – WIND TUNNEL TESTS (AEDC)

STOP WORK

- BAGGIE DOES NOT MEET CONFLICTING PAD AND ASCENT ENVIRONMENTS

- REDESIGN BAGGIE

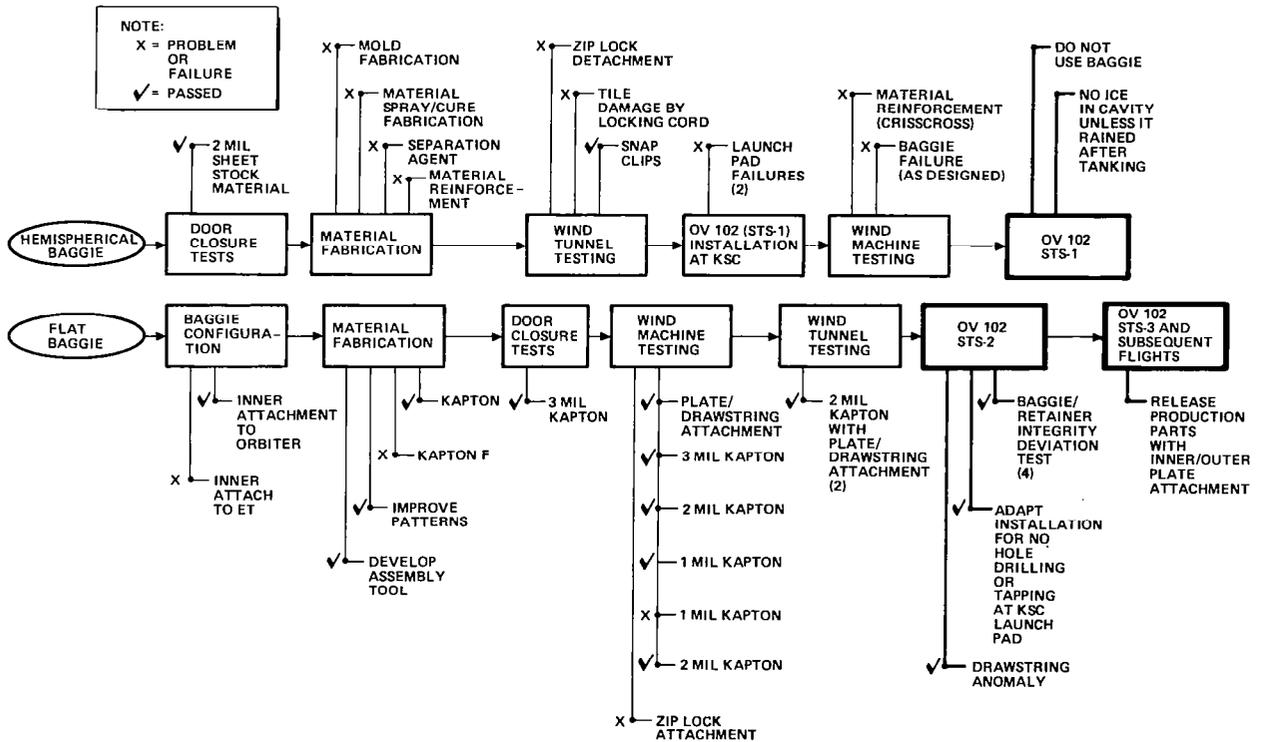*Figure 12 – Hemispherical Baggie; Problem Summary*

Figure 13 – Basic Development Sequence

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Flat Baggie

The failure evaluations of the hemispherical baggies indicated the configuration should be changed from hemispherical to flat to remove the baggie from the direct effects of the wind velocity coming across the cavity. The hemispherical baggie extends beyond the mold line and was being buffeted by the wind; a flat baggie would be within the mold line and be semiprotected within the cavity. The hemispherical baggie required constant internal pressure (1 inch of H_2O) to sustain its shape and minimize buffeting in the wind. The internal pressure was not always available, especially when the aft fuselage access doors were open. The flat baggie did not require internal pressure, but it did require a controlled minimum inner pressure in the cavity to absolutely reduce the tension pull loads on the locking retainer; therefore, the baggie leak rate was increased. This was done by not closing out the hinge area, which both simplified the installation at the hinge and reduced the retainer load. In addition, a flat baggie could be made from flat sheet stock, and cut and fit to form the total assembly, which was an improvement over the spray-on mold technique.

The flat baggie configuration (Figure 14) was a flat sheet of material retained at the outer periphery of the cavity by a newly designed retainer system (plate attached by screws) and at the inner periphery about the orbiter side of the umbilical by a drawstring contained in a channel. A skirt was added to limit rain on the exposed umbilical separation attachment structure. This
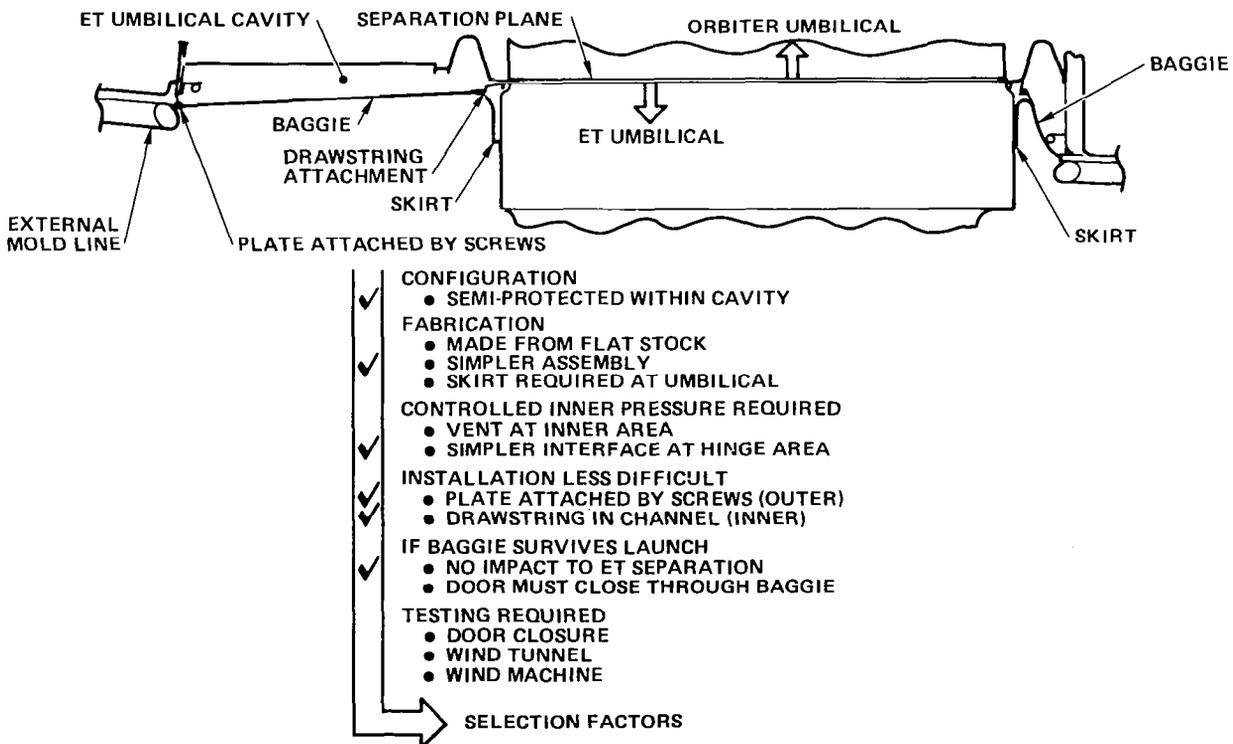

CONFIGURATION
- SEMI-PROTECTED WITHIN CAVITY

FABRICATION
- MADE FROM FLAT STOCK
- SIMPLER ASSEMBLY
- SKIRT REQUIRED AT UMBILICAL

CONTROLLED INNER PRESSURE REQUIRED
- VENT AT INNER AREA
- SIMPLER INTERFACE AT HINGE AREA

INSTALLATION LESS DIFFICULT
- PLATE ATTACHED BY SCREWS (OUTER)
- DRAWSTRING IN CHANNEL (INNER)

IF BAGGIE SURVIVES LAUNCH
- NO IMPACT TO ET SEPARATION
- DOOR MUST CLOSE THROUGH BAGGIE

TESTING REQUIRED
- DOOR CLOSURE
- WIND TUNNEL
- WIND MACHINE

SELECTION FACTORS

Figure 14 — Selected Flat Baggie Design

design completely enclosed all the critical icing areas. The cavity outer edge was now not as critical for moisture or rain freezing, and the flat baggie protection was considered adequate. Complete testing was required for this design.

A series of new designs was investigated for retaining both the outer and inner baggie attachments. The zip-lock and snap clip attachment used for the hemispherical baggie (Figure 9) were not adequate for the flat baggie, which would apply loads to the retention device in a tension direction. This was demonstrated during wind machine ground testing of a 1 mil flat baggie with zip-lock outer and inner attachment. During testing, some of the locking cord came out of the locking retainer, and part of the locking retainer moved away from the attachment structure.

As noted before, a major limitation for the design of the retention device was the fact that the cavity size and door/cavity clearances were fixed. The volume available for the retention devices was limited, and attachments to the adjacent primary structure (primarily the structural skin) were also limited. To complicate matters further, on Orbiter 102 the TPS thermal barrier about the outer periphery of the ET umbilical cavity was not exactly as per the released drawing, but it was still acceptable, and no changes to the actual location of the thermal barrier would be tolerated. Figure 15 indicates some of the designs that were not used, primarily because of impractical installations.
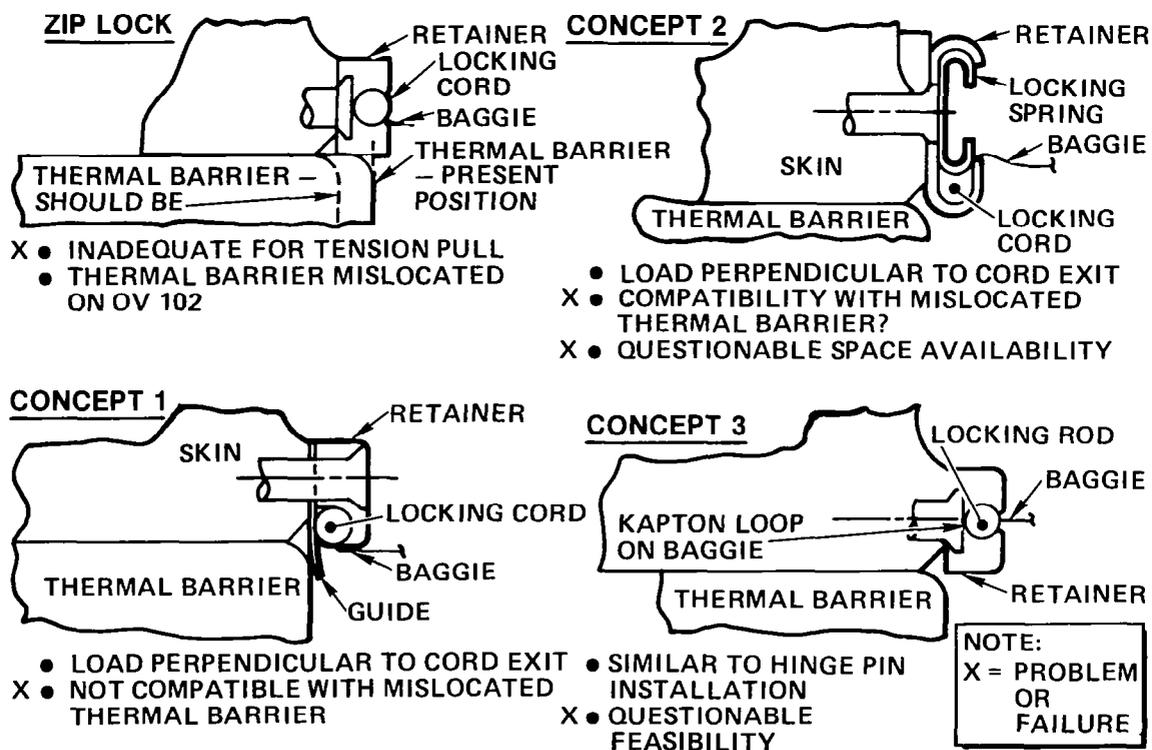

Figure 15 — Not Utilized Flat Baggie Attachment

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The selected design for the flat baggie retainer is shown in Figure 16. For the outer periphery, the selected retainer system utilizes a plate attached by screws, and for the inner periphery, a drawstring enclosed in a retainer channel. The drawstring provided a very simplified final attachment method, which was well received by KSC. To provide reusability for the outer periphery retainer, a fixed ring is attached by tapped No. 4-40 screws (3-inch spacing) into the adjacent aluminum skin. The baggie is held by the removable ring that, in turn, is attached to the fixed ring by tapped No. 4-40 screws at 3-inch spacing. The fixed ring becomes the steel tapping ring that provides the reusability. Tapped screws into aluminum are not recommended for reusability. Both rings are 718 Inconel. The use of Inconel rings and more screws increased the strength of the retention design. The retainer channel supporting the drawstring is attached by No. 4-40 screws and nuts (6-inch spacing) to the orbiter side of the separation plate structure. The drawstring was made of lacing tape.

The materials considered for the flat baggie are listed in Table 3. Kel F 800 was immediately eliminated as being too weak. Kapton F was seriously considered until it was realized that the material has a memory, e.g., a piece cut from rolled stock would roll up again, making it hard to work with this material. Reinforced Kapton with its extremely high tear strength (internal mesh cord) would only be considered as a last resort. Kapton was selected as the material, but the thickness would be determined from the test results. The testing philosophy was to start with the
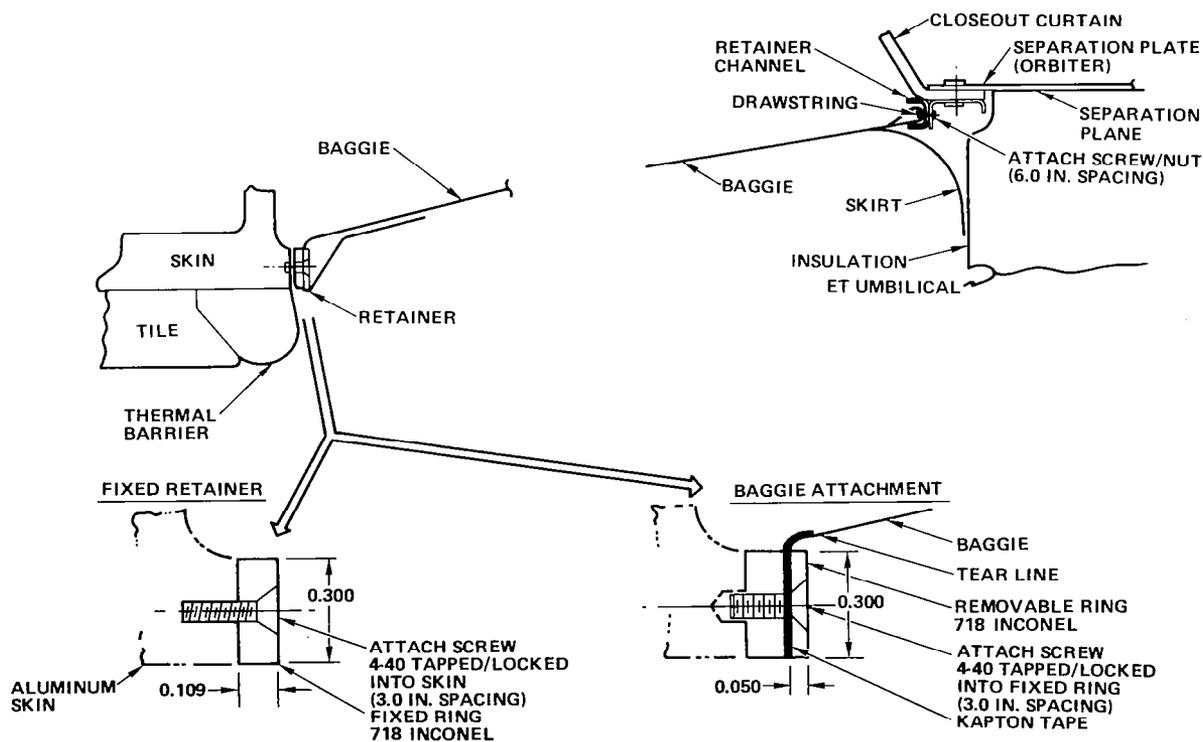

Figure 16 — Selected Flat Baggie Attachment

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TABLE 3 — FILM MATERIAL OPTIONS FOR FLAT BAGGIE

Property	Film Materials						
	Kel F 800	Kapton	Kapton F	Tedlar	Aclar	Fep	Reinforced Kapton
Tensile (psi)	1,500	25,000	25,000	7,000	7,000	2,500	25,000
Elongation (%)	350	70	105	150	15	300	5-9
Tear gm/mil							
Initiation	–	510	500	620	450	270	1,800
Propagation	–	8	38	40		125	
Service Temperature							
Maximum	250	750	450	225	350	450	250
Minimum	-200	-400	-400	-100	-320	-400	-320
Flammability		SE	SE	SE		SE	
Color	Clear	Clear Amber	Clear Amber	Clear	Clear	Clear	Amber Opaque

Kel F 800 used for hemispherical baggie • Low tensile • Low tear resistance	• Do not use for flat baggie
Kapton F • High tear resistance • Rolled material has memory	• Not usable for flat baggie
Reinforced Kapton • Integral mesh cord • Too high tear strength	• Not usable for flat baggie
→Kapton	• Selected for flat baggie

estimated thickest material and work toward the thinner materials until one of the materials failed. The preceding thicker material test would then be repeated.
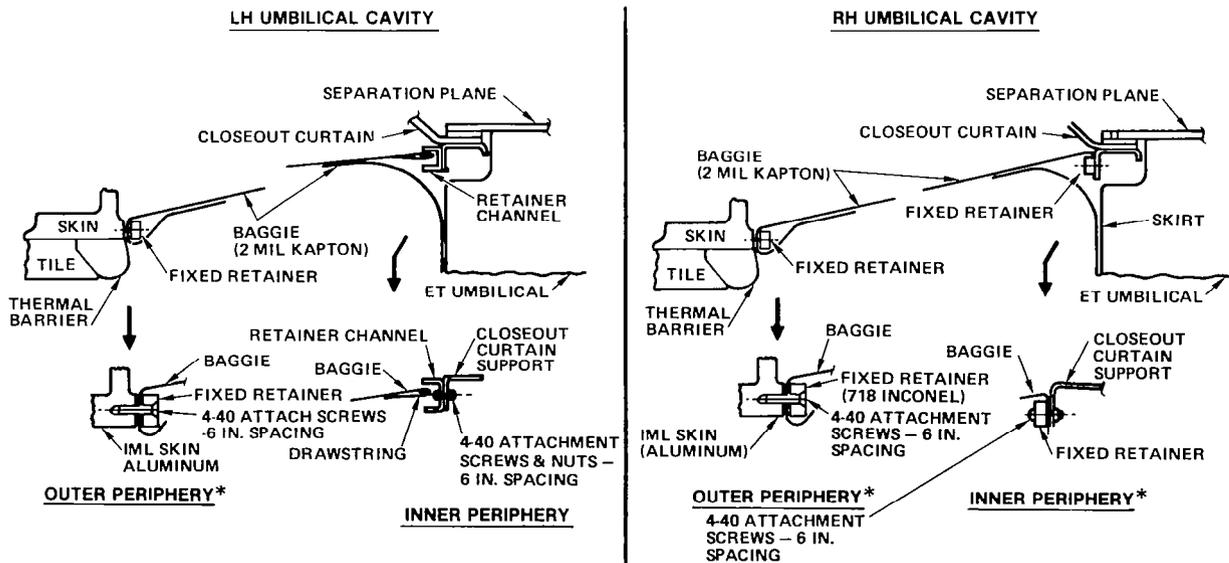
Individual LO_2 baggies were made of various thicknesses of Kapton 1 mil through 3 mil. The baggies were cut from sheet stock to a pattern that was developed during the assembly operations. The assembly tool was a simple, flat tool fabricated in the model shop mostly of wood and some metal. The flat baggie assembly was much easier than the previous hemispherical baggies.

Door closure tests were repeated using 3 mil Kapton, which were successful. The ground wind tests (baggie test bed shown in Figure 10, and the wind machine in Figure 11) using the wind machine were again activated with the following results: 3 mil Kapton passed, 2 mil Kapton passed, 1 mil Kapton passed, 1 mil Kapton failed, 2 mil Kapton passed, and 2 mil Kapton was selected to be tested at the AEDC wind tunnel with the baggie test bed shown in Figure 10. Two tests passed. No further work was done with any of the thicker Kapton materials or with reinforced Kapton.

The flat baggie was released for installation on STS-3. Meanwhile, a compromise retention installation was designed and released for STS-2, as noted in Table 4 and in Figure 17.

TABLE 4 — BAGGIE INSTALLATION FOR ORBITER 102 (STS-2)

Item	Deviation
1. Requirements	
a. No additional drilling or tapping on the vehicle	
b. Utilize existing attachment holes	
c. Minimize possibility of vehicle damage	
d. Installation post-mating	
• Reduced access to cavity	
• Tight schedule to launch	
2. Baggie retention modifications	
a. LH umbilical cavity (LH$_2$ umbilical); outer periphery	Certified by baggie retainer integrity test
• Fixed retainer only	
• Traps baggie	
• Attachment screws 6.0 inch spacing	
b. LH umbilical cavity (LH$_2$ umbilical); inner periphery	
• Drawstring attachment in retainer channel	
c. RH umbilical cavity (LO$_2$ umbilical); outer periphery	Certified by baggie retainer integrity test
• Fixed retainer only	
• Traps baggie	
• Attachment screws 6.0 inch spacing	
d. RH umbilical cavity (LO$_2$ umbilical); inner periphery	Certified by baggie retainer integrity test
• Fixed retainer only	
• Traps baggie	

Figure 17 — Baggie Installation; OV-102 (STS-2) Only

The baggie installation in STS-2 would be done after the mating. Access to the ET umbilical cavity combined with installation just prior to launch did not involve any additional hole drilling or tapping operations on the vehicle to install the baggie. The compromise did not violate the baggie design, testing, or certification. A final baggie and retainer integrity test, which was repeated four times, certified the STS-2 installation deviations. Figure 13 summarizes the basic development sequence for the flat baggie.

SUMMARY

In summary, the late start of the design, the space limitations, the real time testing (using sophisticated and expedient facilities), and the use of materials for purposes never utilized before created a challenging assignment that led to a unique solution to an orbiter icing problem, which was successfully used on STS-2.

The baggie performed successfully on this mission (including the prolonged ground stay capability because of the launch delay), except for one flight anomaly: the left-hand baggie drawstring broke, hung up, and slightly damaged some adjacent tiles.

A design review of the anomaly determined that the drawstring about the umbilical (inner periphery) be replaced by a positive mechanical retention similar to the retainer design used at the outer periphery (plate attached by screws). Figure 18 shows the final attachment design as released for Orbiter 102 (STS-3) and subsequent Shuttle flights.
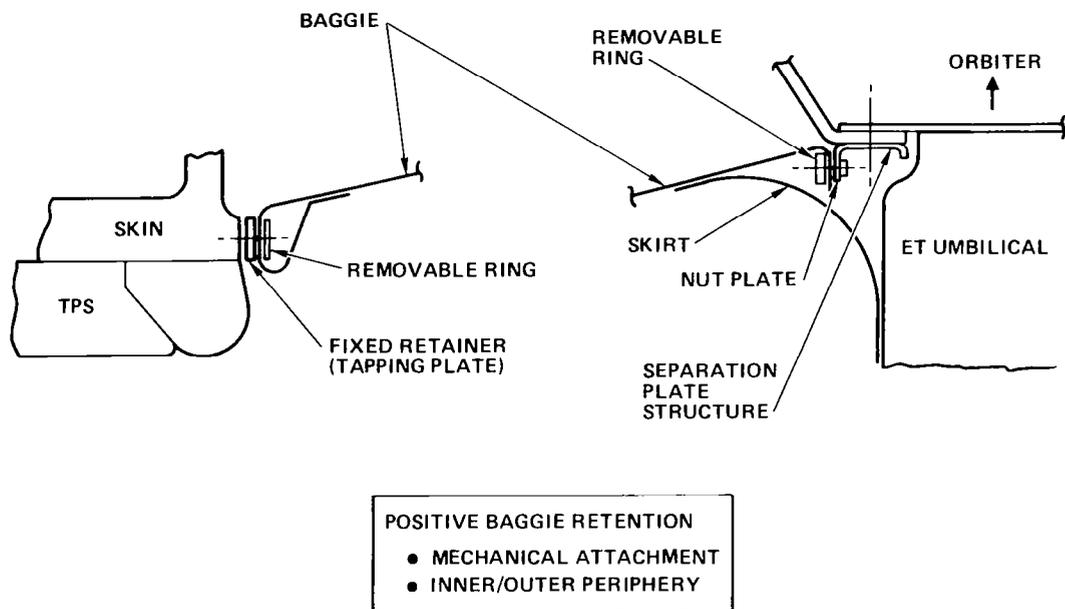

Figure 18 — Flat Baggie Attachment—Final Selection;
OV-102 (STS-3) and Subsequent Vehicles

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