RHCTS-TP-1

Test Plan

SSD94D0221

Task 5, Subtask 5.2
Early On-Orbit TPS Debris Impact Tests

Cooperative Agreement NCC8-39

July 29, 1994

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1.0 Objective

The limitation of damage to, and survival of, the cryogenic tankage during the on-orbit stay despite potential impact of orbital debris, may be a significant discriminator in the RHCTS trade studies described in the TA-1 trade study plan (ref. RHCTS-TSP-1) dated July 29, 1994. The objective of this early phase of an overall debris impact test program is to provide the data to support assessment of the relative suitability of integral and non-integral tanks.

2.0 Background

The Rockwell SSTO baseline vehicle currently utilizes a composite hydrogen tank with externally-bonded Rohacell foam and with TPS materials bonded to the outer surface of the foam. There may also be a "bumper layer" of Nextel cloth between the TPS and the foam, depending upon our results in this test program and upon later trade studies and design requirements to be generated by the prototype design team.

3.0 General Requirements

3.1 Documentation

The following forms of documentation will be utilized for this program (and all programs to be conducted as part of the SSTO TAs in work at Rockwell):

3.1.1 Detailed Test Plan

All testing will be conducted in accordance with this detailed test procedure.

3.1.2 Laboratory Notebook

A laboratory notebook will be maintained by the Rockwell Responsible Test Engineer (RTE), depicting a complete test history. Test article configuration, instrumentation, test anomalies and all other pertinent data and information will be recorded in the notebook.

3.1.3 Test Report

The test agency will issue a Laboratory Test Report (LTR). The LTR will depict the complete test program, instrumentation, test procedures and results, test setup, photographs, test data, and any other pertinent information relating to the test.

3.2 Instrumentation

All measurement instrumentation shall be calibrated and have a decal showing a valid calibration due date. A list of all test instrumentation will be maintained in the Laboratory Notebook.

3.3 General Requirements for Impact Testing

The test matrix will include a variety of potential TPS materials, two different foam densities, and one average thickness of Graphite/Epoxy tank wall substrate. Some of the panels will also incorporate a "bumper" layer of Nextel cloth at the foam-to-TPS bondline in an attempt to further increase the impact resistance of the system. One sample representative of each TPS system will also be fabricated and tested with a configuration that simulates the "floating tank" design, with TPS on the outer vehicle skin and foam on the inner tank wall skin.

3.4 General Flow of Work

Specimens will be prepared by Rockwell-SSD and shipped to NASA-MSFC for impact testing and post-test examination. The impacted specimens will then be returned to Rockwell-SSD for final evaluation and documentation of results, and a test report will be issued by Rockwell.

4.0 Applicable Documents

Cooperative Agreement NCC8-39
Rockwell Material Specification for FRSI
Rockwell Specification MBO135-085 for AFRSI blanket material
AFRSI blankets fabricated per MAO605-315
MAO115-329, Rockwell specification for AFRSI heat cleaning
Rockwell Material Specification(s) for AETB tile materials - to be established during this program
Rockwell Material /Process Specification(s) for TUFI coating - to be established during this program
Rockwell Process Specification for Direct Bonding of Tiles using RTV 560 Adhesive - to be established during this program
NASA Document with Debris Impact Model for probability calculations

5.0 Detailed Requirements

The test conditions will simulate a variety of different TPS and foam insulation configurations, in combination with a range of anticipated debris particle sizes. All testing at this stage will be performed at the maximum gun velocity of 6.0 km/second. Since many of the planned SSTO TPS materials will not be available until later in the program, the panels to be impacted now will utilize existing materials that are similar to the proposed SSTO TPS materials, often the same as are currently being used for Shuttle, but in new configurations. The TPS materials included in this test will be FRSI felt insulation to be fabricated at Rockwell-SSD, AFRSI blankets to be fabricated by Rockwell-SSD, TUFI-coated AETB tiles to be fabricated by Rockwell-SSD, and Composite Flexible Blanket Insulation (CFBI) coupons which will be obtained from Demetrius Courtides at NASA-Ames (phone ##).

Table 1 shows a matrix of test conditions to be included in this impact program, for a total of thirty-three panels.

Panel ID	TPS Material System	TPS Depth (in)	Foam Density (pcf)	Foam Depth (in)	IM7/977 Thickness (in)	Impact Particle Dia. (in)	Bumper Layer ?
1	FRSI	0.25	3.2	0.75	0.075	0.125	NO
2	FRSI	0.25	3.2	0.75	0.075	0.250	NO
3	FRSI	0.25	3.2	0.75	0.075	0.375	NO
4	FRSI	0.5	3.2	0.5	0.075	0.125	NO
5	FRSI	0.5	3.2	0.5	0.075	0.250	NO
6	FRSI	0.5	3.2	0.5	0.075	0.375	NO
7	FRSI	0.5	3.2	0.5	0.075	0.125	YES
8	FRSI	0.5	3.2	0.5	0.075	0.250	YES
9	FRSI	0.5	3.2	0.5	0.075	0.375	YES
10	AFRSI	0.5	3.2	0.5	0.075	0.125	NO
11	AFRSI	0.5	3.2	0.5	0.075	0.250	NO
12	AFRSI	0.5	3.2	0.5	0.075	0.375	NO
13	AFRSI	0.50	3.2	0.5	0.075	0.125	YES
14	AFRSI	0.50	3.2	0.5	0.075	0.250	YES
15	AFRSI	0.50	3.2	0.5	0.075	0.375	YES
16	AFRSI	1.00	3.2	0.75	0.075	0.125	NO
17	AFRSI	1.00	3.2	0.75	0.075	0.250	NO
18	AFRSI	1.00	3.2	0.75	0.075	0.375	NO
19	AETB	2.00	3.2	0.75	0.075	0.125	NO
20	AETB	2.00	3.2	0.75	0.075	0.250	NO
21	AETB	2.00	3.2	0.75	0.075	0.375	NO
22	AETB	2.50	3.2	1.00	0.075	0.125	NO
23	AETB	2.50	3.2	1.00	0.075	0.250	NO
24	AETB	2.50	3.2	1.00	0.075	0.375	NO
25	AETB	3.00	3.2	1.25	0.075	0.125	NO
26	AETB	3.00	3.2	1.25	0.075	0.250	NO
27	AETB	3.00	3.2	1.25	0.075	0.375	NO
28	CFBI	1.00	3.2	0.50	0.075	0.125	NO
29	CFBI	1.00	3.2	0.50	0.075	0.250	NO
30	CFBI	1.00	3.2	0.50	0.075	0.375	NO
31	CFBI	1.00	3.2	0.75	0.075	0.125	NO
32	CFBI	1.00	3.2	0.75	0.075	0.250	NO
33	CFBI	1.00	3.2	0.75	0.075	0.375	NO

Table 1: Specimens for Preliminary On-Orbit Debris Impact Testing

In addition to the basic test matrix of 33 coupons, we have proposed that the following eight specimens be added to this preliminary impact series in order to evaluate the floating tank concept for input to the trade study and requirements definition activities.

Panel ID	TPS Material System	TPS Depth (in)	Foam Density (pcf)	Foam Depth (in)	IM7/977 Thickness -inner/ tank wall- (in)	Gr/BMI Thick. - outer wall - (in)	Impact Particle Dia. (in)
34	FRSI	0.25	3.2	0.75	0.075	0.040	0.375
35	FRSI	0.25	3.2	0.75	0.075	0.040	0.375
36	AFRSI	0.25	3.2	0.75	0.075	0.040	0.375
37	AFRSI	0.5	3.2	0.5	0.075	0.040	0.375
38	AETB	0.5	3.2	0.5	0.075	0.040	0.375
39	AETB	0.5	3.2	0.5	0.075	0.040	0.375
40	CFBI	0.5	3.2	0.5	0.075	0.040	0.375
41	CFBI	0.5	3.2	0.5	0.075	0.040	0.375

Table 2: Additional Specimens for Floating Tank Configuration (dual-wall)

6.0 Detailed Test Specimen Description

The basic test specimens will consist of 6x6 inch square TPS panels bonded onto 6x6 inch foam blocks, bonded onto 10x10 inch square composite panels. The composite panels will be fabricated by a fiber placement process and will be provided by Hercules under subcontract to Rockwell - NAAD Tulsa. Material will be IM7/977 approximately 0.075 inches thick (nominally an 8-ply $[0/\pm45/90]_S$ layup). The adhesives to be used to assemble the system may change as the vehicle prototype design concept becomes more developed, but this plan initially requires that the TPS-to-foam bondlines be RTV 560 silicone adhesive and the foam-to-tank-wall bondline be PR1660 urethane adhesive. Both bonds will require a full-footprint 6x6-inch bonded area, pending trade study, requirements, and test data results.

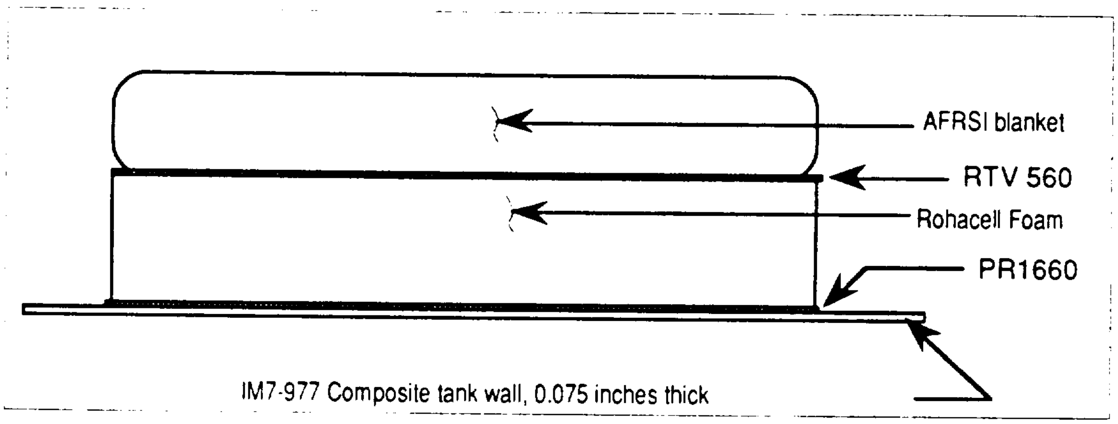

Figure 1: AFRSI/foam panel structural arrangement

Some of the panels to be tested will include a "bumper" layer of Nextel cloth, which will be placed into the bondline between the TPS and foam layers. The purpose of the Nextel layer is to absorb and distribute impact loading when an incoming particle is encountered. The bumper cloth will be incorporated in two different configurations (for six specimens total) for the preliminary impact test program.

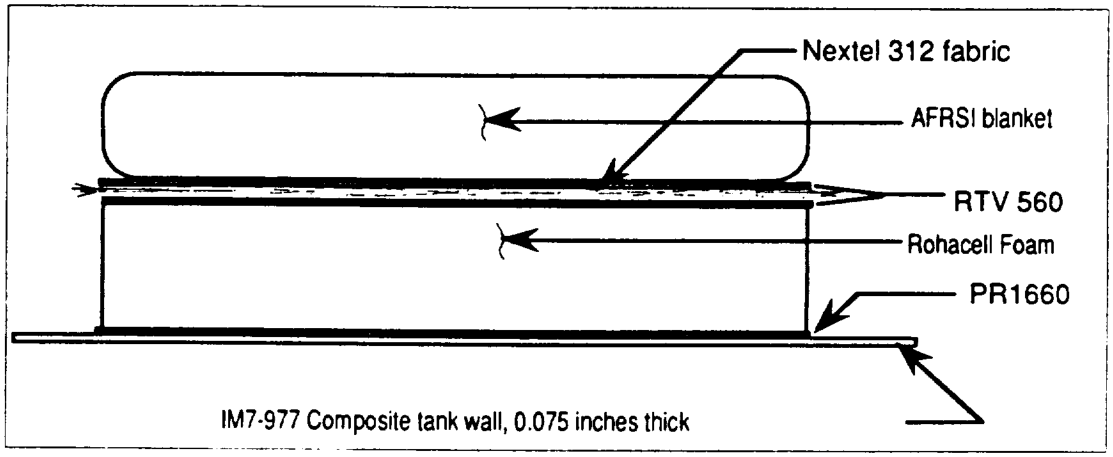

Figure 2: AFRSI/foam panel with "Bumper" layer

The third type of specimen (for floating tank designs) will utilize an additional Gr/BMI composite panel approximately six inches in front of the IM7/977 tank wall. The configuration is shown in Figure 3.

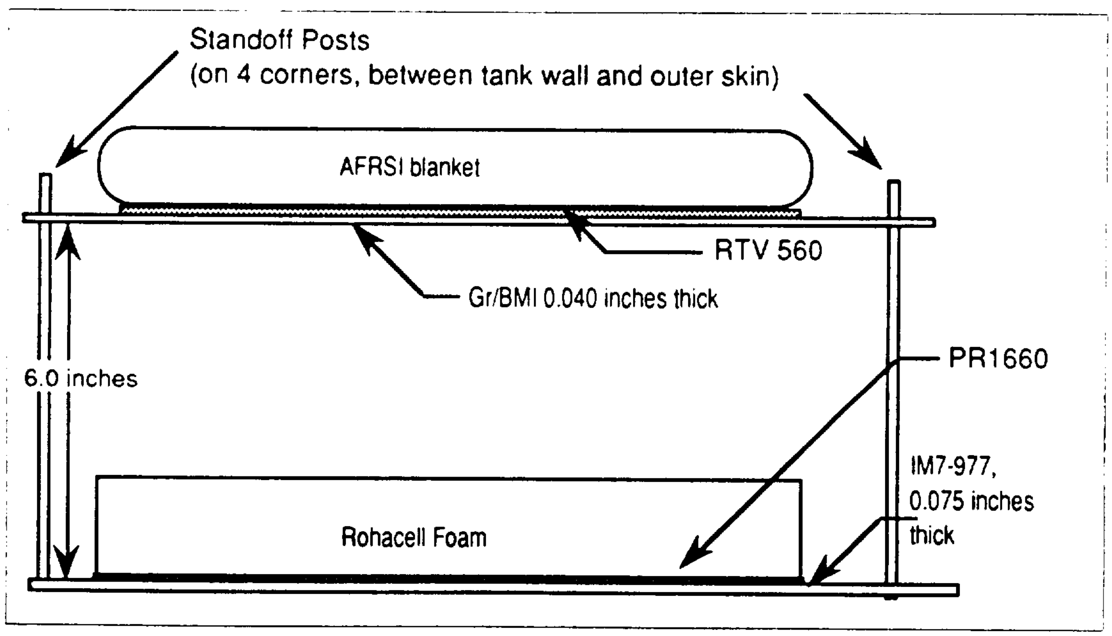

Figure 3: AFRSI Panel with Floating Tank Configuration
(Double-Wall Construction)

The TPS to be evaluated will include AFRSI blankets (Rockwell configuration, fabricated per MAO605-315), AETB tiles with TUFI coating, and conventional FRSI insulation. The foam layer will consist of low-density (approx. 3.2 pcf) Rohacell foam in a variety of depths ranging from 0.5 inches to 1.25 inches. The TPS thickness will range from 0.25 inch FRSI to 3.0 inch TUFI tiles. Completed panels will be shipped to NASA-MSFC for testing, to the attention of Ms. Angela Nolen.

7.0 Test Procedure

7.1 System Alignment

The NASA light gas gun will be aligned prior to test using dummy samples placed into the sample holder. Alignment will be adjusted so that particles fired from the gun will consistently impact near the center of the panel. The angle of impact for all tests will be 90°, normal to the surface. After alignment is complete, the dummy panels will be removed and TPS specimens will placed into the sample holder and bolted in place. The selected particle will be loaded into the gun according to the test matrices in Tables 1 and 2, and a data sheet will be prepared with the specimen identification number and name of operator.

7.2 Description of Light Gas Gun System at NASA MSFC

The two-stage light gas gun housed in the 4612 building and illustrated schematically in Figure 5 is used to launch payloads simulating meteoroids and space debris up to velocities of 3 to 7 kilometers per second. The payload will be an 1100-O aluminum sphere 1/8 to 3/8 inches in diameter. The payload is supported by a cylindrical sabot made of Lexan to enable the payload to survive the launch acceleration.

7.3 Description of Gun Operation

The first stage of the gun uses up to 200 grams of gun powder to launch a 1.3 kg piston. The piston compresses a quantity of hydrogen gas (initially at 95 psi) contained in the second stage of the gun. The hydrogen is normally contained between the breech and the high pressure section of the gun. The projectile initially rests at a position just past the high pressure section (to the right, in figure 5) and is separated from the hydrogen by a rupture disk. The disk is designed to rupture at preselected values between 1.5 and 15.0 ksi, with different disks selected to achieve different launch velocities.

7.4 Firing Procedure

The projectile is selected by the compressed gas down the launch tube, where it meets the sabot stripper at the muzzle of the gun. The sabot stripper is made of four tungsten rods which protrude into the bore of the gun far enough to touch the sabot, but not far enough to touch the payload. The sabot is slowed and fragmented by the tungsten pins and eventually stopped by a trap plate spaced a short distance from the tungsten pins. The trap plate has a hole in it 0.1 inch larger in radius than the payload. Thus the payload and not the sabot fragments are allowed to travel down range toward the target.

7.5 Measurement of Velocity

Nineteen feet from the small test chamber a flash x-ray radiograph of the payload is taken at two different times. The velocity of the payload can be calculated from the known time interval between the two radiographs and distance traveled by the payload during the time interval. A by-product of the velocity measurement will be radiographs of the projectile shape after sabot separation.

7.6 Post-Test Analysis

After the impact is complete, a brief visual inspection will be performed to identify any gross damage to the TPS, foam and composite substrate layers. Any visible damage and measurements of damage will be noted in the space provided on the data sheet, and the specimen will be removed from the sample holder and returned to its original package. Additional analysis and documentation will be performed by the ED52 analysis group as deemed appropriate. After all impacts and analyses are completed for a particular specimen group, the specimens will be returned to Rockwell-Downey for detailed examination and photo-documentation. The composite substrates will be examined using ultrasonic NDE (B-scan or C-scan) to identify any internal damage such as fiber breakage, cracking or delamination which may not be visible on samples which appear to be otherwise intact. Significant results will be reported in the LTR. Additional testing beyond the thirty-three specimens identified in Table 1, may be performed as deemed necessary and/or possible based upon available materials and funding.

7.7 Rockwell POC for Testing and Hardware

The Rockwell point of contact for these tests is David Wittman, (310) 922-4619. Specimens and other test-related hardware should be directed to Rockwell Space Systems Division, 12214 Lakewood Boulevard, Downey California, 90241, Attention D. Wittman at Mail Code DA33.

8.0 Sample Data Sheets

Preparation of test samples will be documented in a Rockwell Engineering Laboratory Notebook, and test data reported by NASA will be documented using standard data sheets as shown in Figure 4. Data to be reported include impact particle material, particle diameter, impact velocity, sample identification, and a description of any visible damage resulting from the impact event.

SSTO On-Orbit Debris Impact Data Sheet

Operator ________ Date______

Specimen ID______
Velocity ______
Particle Diameter ______
Particle Material ______
Angle of Impact ______

Describe any visible damage immediately following test :

Figure 4: Format for Sample Data Sheet

In addition to written descriptions prepared by the NASA test agency, photographs will be taken by the Rockwell failure analysis laboratory of all specimens before and after testing from front, back and side view locations to help identify damage. These will be included in the final test report. The results of NDE scans performed on the composite panels will also be included in the report.

9.0 Test Equipment

Testing will be performed at NASA Marshall Space Flight Center, Huntsville, using the two-stage light gas gun located in room 1000 of building 4612, and the test facility will be operated by NASA personnel under the direction of Ms. Angela Nolen (205) 544-9245. A schematic of the gun is shown on the following page, in Figure 4, section 10.0 of this test plan. Rockwell analysis and examination of specimens will be performed in the Failure Analysis Laboratory in Building 4 of the Rockwell SSD Downey facility.

10.0 Sketches and Schematics

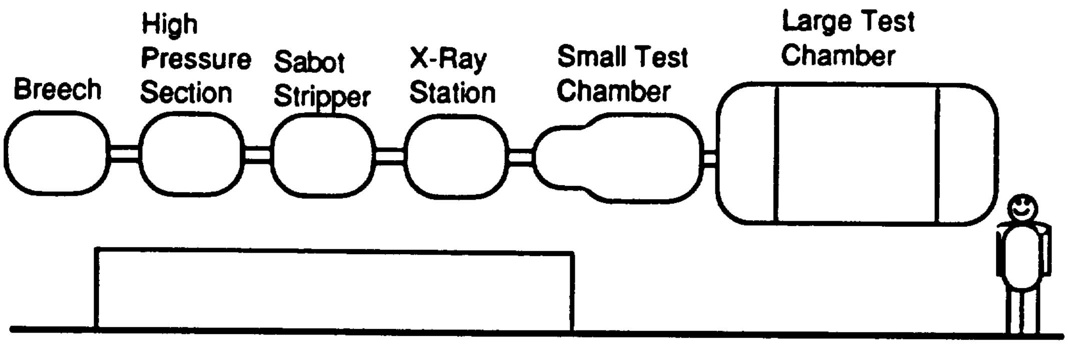

Figure 5: Light Gas Gun System at MSFC

11.0 Schedule

Preliminary Impact Testing:

Begin Specimen Fabrication at Rockwell:	8 August 1994
Begin Impact Testing at MSFC:	29 August 1994
Specimens prepared for test:	9 September 1994
Specimens received at NASA-MSFC:	16 September 1994
Impact testing complete:	7 October 1994
Specimens received at Rockwell-Downey:	14 October 1994
Documentation complete:	4 November 1994

A later test program will also be conducted to perform on-orbit debris impact testing using the NASA-MSFC light gas gun, as well as smaller guns for lower velocity impacts. The following are proposed dates for the later series of tests, subject to change. This program will evaluate some of the TPS materials that are being developed specifically for SSTO, such as TABI and CFBI, in configurations that more accurately represent the prototype vehicle design. The number of shots required for the later program is currently 72, depending upon TPS selection and prototype configuration. The schedule is tentatively as follows:

Integrated TPS/Insulation/ Tank Wall Micrometeoroid/ Debris Impact Testing:

Begin Specimen Fabrication at Rockwell:	16 January 1995
First Specimens received at NASA-MSFC:	6 February 1995
Begin Impact Testing at MSFC:	13 February 1995
Impact testing complete:	14 April 1995
Specimens received at Rockwell-Downey:	21 April 1995
Documentation complete:	5 May 1995