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J Kahn 10/24/69*

SNAP-27 SHOCK OVERPRESSURE TEST
(SHOCK TUBE FACILITY)

MASTER

AEROSPACE
NUCLEAR
SAFETY

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AEROSPACE NUCLEAR SAFETY DEPARTMENT 9510

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SC-DR-69-65

SNAP-27 SHOCK OVERPRESSURE TEST
(SHOCK TUBE FACILITY)

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ABSTRACT

The SNAP-27 was subjected to an explosive shock tube test simulating the shock overpressure resulting from a near maximum explosive abort of the S-IVB stage of the Saturn V launch vehicle. This test demonstrated that the beryllium secondary thermal shield and fuel capsule assembly can withstand the simulated environment without fuel release.

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SUMMARY

The SNAP-27 graphite lunar module fuel cask (GLFC) with the fuel capsule assembly (FCA) is attached to the descent stage of the Apollo lunar module. The GLFC/FCA is mounted on the descent stage of the lunar module and is positioned directly above (about seven feet) the dome of the hydrogen tank of the S-IVB stage of the Saturn V launch vehicle. An explosive abort of the launch vehicle will subject the GLFC/FCA to the severe environments of overpressure, fragment impact, fire-ball thermal flux, and afterfire thermal flux. To realistically test the GLFC/FCA to an abort environment would require successive exposure to the above-listed environments. However, facility limitations require testing each environment separately. This document reports the results of subjecting a simulated GLFC/FCA and a real GLFC/FCA assembly to a shock overpressure environment.

The shock overpressure environment was produced in a steel tube two feet in diameter by 60 feet in length. The shock was explosively driven and produced two test conditions: (1) a static overpressure of 600 psig, with a static impulse of 2.2 psi-seconds, and (2) a static overpressure of 187 psig, with a static impulse of 0.84 psi-seconds; these environments are believed to simulate a near maximum explosion and a near minimum explosion, respectively.

Simulated GLFC/FCA test items were exposed to both environments, but the lack of real hardware allowed only a near maximum overpressure test of the realistic GLFC/FCA.

The near minimum overpressure test on the simulated GLFC/FCA produced minimum damage. However, the near maximum overpressure test on the simulated GLFC/FCA destroyed the primary thermal shield. No damage was inflicted on the secondary thermal shield, but this was expected because the structure was solid aluminum.

The one test of the realistic GLFC/FCA in a near maximum overpressure environment revealed that the graphite primary thermal shield was destroyed completely. The beryllium secondary thermal shield and fuel capsule assembly were damaged, but not sufficiently to cause fuel release. Sufficient protection remained to protect the FCA from fragments and the subsequent thermal fluxes.

Comparing the damage inflicted on the simulated GLFC/FCA test items at the near minimum and near maximum overpressure environments indicates that the real GLFC/FCA will withstand a near minimum overpressure environment with minimum damage to the graphite primary thermal shield and no damage to the internal components.

ACKNOWLEDGEMENT

An expression of sincere appreciation is extended to all who assisted in the planning, preparation, and performance of these shock tube tests. Special thanks is extended to J. H. Biffle, 1542, for his assistance in the interpretation of the data acquired.

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SNAP-27 SHOCK OVERPRESSURE TEST (SHOCK TUBE FACILITY)

Introduction

The sequence of events which can occur during the explosive abort of a launch vehicle system is important to the analysis of the capability of the graphite lunar module fuel cask (GLFC)/fuel capsule assembly (FCA) to withstand the resulting environment. The generally accepted sequence for the explosive abort environment is: (1) shock overpressure, (2) fragment impact, and (3) fireball. Accepting this sequence of events dictates a very strong interest in the effects of the shock overpressure on the GLFC/FCA. Removal of the graphite primary thermal shield decreases the fragment impact resistance and increases the fireball temperature effects. The removal by the shock overpressure of both the graphite primary thermal shield and the secondary thermal shield is considered to be sufficient damage to result in fuel release sometime during the duration of the fireball.

This test was designed to produce data which would help in the evaluation of the resistance of the GLFC/FCA to the fireball after the GLFC/FCA was subjected to shock overpressure. An independent test series was performed to evaluate the effects of fragment impact on the GLFC/FCA.*

The test facility selected to produce the shock overpressure was a shock tube two-feet in diameter by sixty-feet in length. Tests were performed to establish the proper flow conditions of 600-psig static overpressure and 2.2-psi-seconds positive phase static impulse. Two calibration tests using simulated test assemblies, were performed before the actual test assembly was placed in the shock tube. The conditions to be simulated in the tube were the expected maximum conditions for an abort explosion of the S-IVB stage of the Saturn V launch vehicle. The explosion was assumed to occur along the missile centerline and at the common bulkhead between the liquid hydrogen and the liquid oxygen.

*SC-DR-69-64, SNAP-27 Fragment Impact Tests, R. E. Berry, Sandia Laboratories, Albuquerque, New Mexico, June 1969.

Shock Tube Description and Flow Tests

The shock tube is constructed from two-foot diameter, schedule 80 steel pipe. Two different configurations were used during the flow and calibration phases of the test program. Figure 1 shows the configuration selected initially. The large six-foot diameter section was installed to allow the GLFC/FCA to rotate without impacting the steel pipe. Problems with tube instrumentation dictated a change to the second tube configuration (Figure 2); this configuration was used for the final test of an actual GLFC/FCA.

Figure 3 is a schematic showing the gage locations for determining the tube characteristics. These gages gave sufficient information to establish shock wave velocity, static overpressure, stagnation pressure, static impulse, and stagnation impulse. The values for overpressure and impulse were established ahead of, at, and behind the GLFC/FCA.

The shock tube was sealed and pressurized to ambient sea level conditions to better simulate the launch conditions. Figure 4 shows pressure and impulse curves three inches ahead of the nose of a simulated GLFC/FCA; these curves established the flow conditions and demonstrated that the shock tube was capable of producing the required pressure and impulse conditions. More shock tube characteristic curves are included in Appendix A. Figure 5 shows the same type of information for a reduced pressure and impulse environment; more data are included in Appendix B.

Calibration Test Assembly Description

Two calibration tests were performed to prepare the way for proper tube characteristics, camera alignment, and down range field preparation. The original intent was to perform two tests to show repeatability, but trouble with the first test required changing the tube for the second test. Both tests were performed using test assemblies that simulated those parameters considered most important, i. e., shape, weight, and CG were correct for the GLFC used. The Bendix mounting structure was simulated with 4130 steel, heat treated to 160,000 psi. This structure was bolted together for a realistic simulation of the expected failure mode. No attempt was made to produce the correct weight, CG, or strength of the members. As stated before, the joints were simulated as closely as possible.

Figure 6 shows a cross-section of the simulated GLFC/FCA used for these tests. Figure 7 shows the GLFC/FCA mounted in the simulated Bendix support structure. The thermal shield shown in Figure 7 was changed when more realistic information about the construction was received. A 0.060-inch thick material was used instead of the 0.250 material shown in the illustration.

A third test was performed using this type of hardware to acquire information about the relative effects of a high overpressure environment and a low overpressure environment.

Calibration Test Assembly Instrumentation

The internal components of the simulated GLFC/FCA were not suitable for internal instrumentation. Therefore, only external instrumentation was used on these tests. Ten strain gages and four break wire gages were used. Figure 8 shows the location of the strain gages and the break wire gages for the first two calibration tests. The third low pressure test was not instrumented because of poor data collection on the first two tests.

GLFC/FCA Test Assembly Description and Instrumentation

The shock tube test was performed on an actual GLFC/FCA except that the fuel was simulated and the center of the capsule assembly was bored to accept a silicon carbide electric heater. Figure 9 shows a quarter section of the GLFC/FCA; this figure does not show the modifications or instrumentation necessary for test purposes. Figure 10 is a full cross-section and shows the type and location of the instrumentation. The instruments shown are duplicated 90° from those illustrated. There were 14 strain gages, 5 thermocouples, and 2 accelerometers installed on the GLFC/FCA test assembly. Figure 11 shows the GLFC/FCA during various stages of assembly after all instrumentation had been installed.

Note the hole along the centerline in Figure 11b. This hole is not part of a functional assembly. This hole was bored in the fuel capsule to accept the silicon carbide electric heater. Figure 11c shows the heater installed. Figures 12, 13 and 14 show the same assembly after the instrumentation leads were routed and epoxy bonded for overpressure protection. Note that the astronaut guard was partially

removed to facilitate proper mounting in the shock tube. Figures 15 and 16 show the assembly mounted in the shock tube in preparation for final instrumentation hookup and calibration.

Calibration Test Results

The first calibration test was performed in the two-foot diameter tube, with the six-foot diameter exit section attached (Figure 1). The reflected shock from the diaphragm seal on the six foot section of the shock tube destroyed all the two-foot shock tube instrumentation, and therefore no tube characteristics data were recorded.

Some information was acquired from time of arrival data and photographic film. The shock velocity was 7300 feet per second, and data from the high speed camera film indicated a velocity of 255 feet per second and an exit angle of 48 degrees from the tube's longitudinal axis for the simulated STS/FCA test assembly. The STS/FCA test assembly impacted 935 feet from the exit end of the shock tube. The strain gages and the break wire gages were destroyed by the passage of the shock, and therefore no data were acquired when the overpressure impinged on the GLFC/FCA/Bendix structure. Figure 17 shows the impact location of the simulated STS/FCA, with the shock tube in the background. Figure 18 shows the simulated STS/FCA with a piece of mahogany primary thermal shield on one end. The shock overpressure caused no apparent damage to the simulated STS/FCA. Figure 19 shows the parts of the simulated Bendix support structure. As was expected, bolt failure allowed disassembly of the various components.

The second calibration test was performed in the two-foot shock tube without the six-foot exit section (Figure 2). The results from this test were superior to the previous shot because complete tube data were recovered. However, strain gage data were not available because the shock again destroyed either the gages or the wiring prior to overpressure loading of the structure. The shock velocity was 6900 feet per second, and data from the high speed camera film indicated a velocity of 227 feet per second and an exit angle of 55 degrees from the shock tube longitudinal axis for the simulated STS/FCA test assembly. The STS/FCA test assembly impacted 840 feet from the shock tube.

Figure 20 shows the STS/FCA test assembly at the impact location, with the shock tube in the background. Figure 21 is a close-up of the simulated STS/FCA. No damage to the simulated STS/FCA was apparent. Figure 22 shows the simulated Bendix support structure. Apparently there was some structural differences in the two simulated structures because this structure sustained less damage than did the previous structure. The simulated STS/FCA had about the same exit characteristics, indicating similarity between the two tests even though the tube configuration was changed and the simulated Bendix structure sustained less damage.

The third test in the calibration series was performed in the two-foot shock tube to provide data for comparing the damage sustained at lower pressure and impulse levels with the damage sustained at high pressure and impulse levels. No strain gages were installed on this test assembly. The results were quite different from those obtained under the high pressure and high impulse conditions. The simulated GLFC/FCA test assembly was torn from the Bendix support structure, but the support structure remained in the shock tube (see Figure 23a). Figures 23b, 23c, and 23d show the test assembly in flight; there is no indication of damage due to overpressure. Only two bolts were sheared on the support structure (Figures 23e and 23f). The other damage to the structure is illustrated in Figure 23g.

The shock velocity was 3460 feet per second, and the GLFC/FCA exited from the tube at 23 degrees from the horizontal and acquired a velocity of 25 feet per second. First impact occurred at 19 feet, and the GLFC/FCA came to rest at 32 feet (Figure 23h). A crack was observed in the cylindrical portion of the simulated graphite primary thermal shield, but the photographic coverage does not show the crack and, therefore, the crack is assumed to have occurred at ground impact (Figure 23i).

GLFC/FCA Test Results

The shock tube test of an actual GLFC/FCA demonstrated the capability of the GLFC/FCA to withstand these simulated overpressure conditions. The shock tube conditions are believed to simulate a near maximum yield explosive abort of the S-IVB stage of the Saturn V launch vehicle. The shock tube test conditions actually acquired were a 620-psig overpressure and a 2.6-psi-millisecond impulse. Figures 24 and 25 show the pressure and impulse curves for a point 3 inches ahead

of the GLFC/FCA test assembly. Additional tube characteristics data are included in Appendix C.

The various components of the test assembly had peak temperatures of:

Forward fuel capsule	1200°F
Center fuel capsule	1150°F
Aft fuel capsule	1325°F
Titanium (thermal cover)	825°F
Beryllium secondary thermal shield	850°F
Bendix forward support band	450°F
Bendix aft support band	Instrument Failure

For complete temperature-time information see the traces in Appendix D.

The combination of high temperature, shock overpressure, and premature firing of a cable cutter prevented the acquisition of strain gage and accelerometer data. The premature firing of the cable cutter was not as disastrous as might be expected because the high temperature had caused excessive drift in the strain gages prior to test performance. There were only two accelerometers still functional at the time of explosive firing.

The STS/FCA exited the shock tube in a manner similar to that observed in the calibration tests. The exit conditions were 157 feet per second at 42 degrees from the shock tube longitudinal axis. The shock wave velocity was 6500 feet per second. The STS/FCA impacted 750 feet from the shock tube.

Figure 26 shows the simulated Grumman support structure and the damage caused when the test hardware was torn loose; the Bendix structure mounting holes were torn out on the upstream fittings, and the Grumman structure was deformed on the downstream fittings. Figure 27 shows all that was recovered of the Bendix thermal shield. Figure 28 shows the forward graphite end cap and the rear end cap support structure. Figures 29 and 30 show the damage sustained by the Bendix support structure. Figure 31 shows the STS/FCA at its impact point; the hole in the ground is the point of first impact, and there was very little translation after impact. Figures 32 through 35 show the STS/FCA from various angles to show the damage sustained by this body. Figure 35 shows the aft end of the structure; the material damaged in the center ring is the ceramic insulator used to isolate the electric heater and is not a part of a functional fuel capsule assembly. Figures 36

and 37 show the aft graphite end cap after test; the insulation hold-down ring is sheared, and there are other minor abrasions and cracks. Figures 38 through 44 show the damage to the internal surface of the beryllium STS and to the surface of the fuel capsule assembly. Based on previous stress analyses of the Bendix structure and with expected failure points established, the response of the GLFC to the shock overpressure appears to have taken place in the following manner. Very early in time when the pressure wave reached the GLFC, the forward graphite end cap sheared at a diameter of approximately 4.5-inches and/or the graphite cylinder collapsed. This action allowed the pressure to be applied to the forward capsule support structure and the titanium thermal cover. The force applied caused the forward capsule support ring to wedge onto the fuel capsule.

The force was transmitted to the Bendix structure through the latch fitting, the rear graphite end cap, and the rear trunnions on the Bendix support structure. All three latch locations on the fuel capsule back plate were bent forward, thus substantiating this loading action. The Bendix support structure remained tied down during this first phase.

The second phase consisted of a rotation of the GLFC about the rear trunnions of the Bendix support structure. The forward GLFC band failed first, and the quick release pins at the rear trunnions failed later. The release pins failed in such a manner that the GLFC assumed an almost vertical position with a small amount of rotation. An alternative to the trunnion pins failing is the titanium straps failing on the rear of the Bendix support structure.

The motion pictures show the STS/FCA flying side-on stable after exiting the shock tube.

In Figure 37 note the sheared graphite ring inside the graphite end cap. This indicates the force with which the latch fitting impacted the structure. In addition the graphite end cap was recovered about 150 feet farther down range than was the STS/FCA.

The shock tube demonstrated the capability of the STS/FCA to withstand a overpressure and impulse environment which it is believed could be associated with a near maximum abort condition.

The final calibration test on simulated hardware at conditions simulating a near minimum abort environment (180 psig and 0.57 psi-seconds) demonstrated that the simulated GLFC/FCA will survive intact. Without performing a low

pressure test on an actual GLFC/FCA, one can only assume that the actual hardware will react in a manner similar to that shown by the test on the simulated test assembly. Therefore, it is assumed that the actual GLFC/FCA will withstand at least a 4 percent centerline explosion of the S-IVB stage of the Saturn V launch vehicle without graphite primary thermal shield damage. Probably, the yield necessary to cause graphite primary thermal shield damage is nearly twice that used in the simulated test assembly test.

Conclusions and Recommendations

Three simulated GLFC/FCA test items and one realistic GLFC/FCA were subjected to a shock overpressure environment. This environment is believed to simulate the shock overpressure produced during a launch vehicle explosive abort.

Two test conditions were simulated in a 2-foot diameter by 60-foot long explosively driven shock tube. Condition one simulated a near minimum explosion and condition two simulated a near maximum explosion.

The near maximum overpressure environment destroyed the primary thermal shield on the GLFC but inflicted insufficient damage to the secondary thermal shield and fuel capsule assembly to cause fuel release.

The near minimum overpressure environment did not damage the simulated GLFC/FCA, and it is assumed it would not damage the real GLFC/FCA.

The low velocity imparted to the GLFC/FCA by the shock overpressure is not expected to cause any problems because impact tests have been completed at significantly higher velocities.

Probably the most useful addition to testing of the GLFC/FCA would be a more complete definition of the entire launch abort environment and the interactions between the various individual environments experienced within the explosion and fireball.

Figure 1a. Shock tube set-up for SNAP-27 simulated GLFC/FCA and Bendix structure

Figure 1b. Simulated SNAP-27 GLFC/FCA and Bendix structure

Figure 2. Simulated GLFC/FCA/Bendix structure installation

Figure 3. GLFC/FCA Bendix structure installation

Figure 4a. Simulated GLFC/FCA shock tube pressure data
(near maximum pressure expected)

Figure 4b. Simulated GLFC/FCA shock tube impulse data
(near maximum impulse expected)

Figure 5a. Simulated GLFC/FCA shock tube pressure data
(near minimum pressure expected)

Figure 5b. Simulated GLFC/FCA shock tube impulse data
(near minimum impulse expected)

Tolerances: Wood - $\pm 1/32$
 Aluminum - $\pm .010$

Figure 6. Simulated GLFC/FCA

Figure 7a. Simulated GLFC/FCA in simulated Bendix support structure

Figure 7b. Simulated GLFC/FCA in simulated Bendix support structure

Figure 8. Strain gage locations on simulated Bendix structure

Figure 9. SNAP-27 graphite LM fuel cask with beryllium secondary thermal shield incorporated

Figure 10. Instrumentation locations in GLFC/FCA

(a)

(b)

(c)

Figure 11. Assembly of the GLFC/FCA

Figure 12. GLFC/FCA/Bendix support structure

Figure 13. GLFC/FCA/Bendix support structure

Figure 14. GLFC/FCA/Bendix support structure with instrumentation

Figure 15. GLFC/FCA/Bendix support structure
in the two-foot shock tube

Figure 16. GLFC/FCA/Bendix support structure
in two-foot shock tube

Figure 17. Simulated GLFC/FCA shock tube test

Figure 18. Simulated STS/FCA

Figure 19. Simulated Bendix support structure

Figure 20. Simulated GLFC/FCA/shock tube test

Figure 21. Simulated STS/FCA

Figure 22. Simulated Bendix Support Structure

Figure 23a. Low overpressure test of simulated GLFC/FCA

b.

c.

d.

Figure 23. Overpressure test of unrelated GLFC/FCA

Figure 23e. Simulated Bendix support structure after low overpressure test

Figure 23f. Simulated Bendix support structure after low overpressure test

Figure 23g. Simulated Bendix support structure after low overpressure test

Figure 23h. Low overpressure test of simulated GLFC/FCA

Figure 23i. Low overpressure test of simulated GLFC/FCA

Figure 24. GLFC/FCA shock tube pressure data
(near maximum pressure expected)

Figure 25. GLFC/FCA shock tube impulse data
(near maximum impulse expected)

Figure 26. Simulated Grumman support struts

Figure 27. Bendix thermal shield debris

Figure 28. GLFC/FCA test debris

Figure 29. Bendix support structure

Figure 30. Bendix support structure

Figure 31. Impact point for STS/FCA

Figure 32. STS/FCA

Figure 33. STS/FCA

Figure 34. STS/FCA

Figure 35. STS/FCA

Figure 36. Aft graphite end cap

Figure 37. Att graphite end cap

Mounting structure cut from fuel capsule
to facilitate removal from beryllium STS

Forward fuel capsule support ring
wedged onto capsule

Figure 38. Fuel Capsule assembly

Figure 39. Fuel capsule assembly

Figure 40. Beryllium secondary thermal shield

Figure 41. Beryllium secondary thermal shield

Figure 42. Beryllium secondary thermal shield

Figure 43. Beryllium secondary thermal shield

Figure 44. Beryllium secondary thermal shield

APPENDIX A

FLOW CALIBRATION TEST DATA
(HIGH YIELD EXPLOSION)
FOR SIMULATED GLFC/FCA TEST ASSEMBLY
(600 psig, 2.2 psi-seconds desired)

Figure A-1. FT1 stagnation pressure, 2 inches from wall, 9 inches ahead of nose, 315 degrees.

Figure A-2. IT1 STAG. Impulse from FT1, 2 inches from wall, 9 inches ahead of nose, 315 degrees.

Figure A-3. P8 wall static pressure 9 inches aft of nose, 90 degrees.

Figure A-4. I8 static impulse from P8, 9 inches aft of nose, 90 degrees.

Figure A-5. P6 wall static pressure 15 inches ahead of nose, 90 degrees.

Figure A-6. I6 static impulse from P6, 15 inches ahead of nose, 90 degrees.

Figure A-7. P9 wall static pressure 19 inches aft of nose, 90 degrees.

Figure A-8. I9 static impulse from P9, 19 inches aft of nose, 90 degrees.

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APPENDIX B

FLOW CALIBRATION TEST DATA
(LOW YIELD EXPLOSION)
FOR SIMULATED GLFC/FCA TEST ASSEMBLY
(187 psig, 0.84 psi-seconds desired)

Figure B-1. P8, wall static pressure 9 inches aft of nose, 90 degrees.

Figure B-2. I8, static impulse from P8, 9 inches aft of nose, 90 degrees.

Figure B-3. P6, wall static pressure 15 inches ahead of nose, 90 degrees.

Figure B-4. I6, static impulse from P6, 15 inches ahead of nose, 90 degrees.

Figure B-5. P9, wall static pressure 19 inches aft of nose, 90 degrees.

Figure B-6. I9, static impulse from P9, 19 inches aft of nose, 90 degrees.

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APPENDIX C

GLFC/FCA TEST ASSEMBLY TEST DATA
(600 psig, 2.2 psi -seconds desired)

Figure C-1. P4 wall static pressure 3 inches ahead of nose, 0 degrees.

Figure C-2. I4 static impulse from P4, 3 inches ahead of nose, 0 degrees.

Figure C-3. P3 wall static pressure 15 inches ahead of nose, 0 degrees.

Figure C-4. I3 static impulse from P3, 15 inches ahead of nose, 0 degrees.

Figure C-5. P6 wall static pressure 15 inches ahead of nose, 90 degrees.

Figure C-6. I6 static impulse from P6, 15 inches ahead of nose, 90 degrees.

Figure C-7. P9 wall static pressure 19 inches aft of nose, 90 degrees.

Figure C-8. I9 static impulse from P9, 19 inches aft of nose, 90 degrees.

Figure C-9. P11 wall static pressure 3 inches ahead of nose, 180 degrees.

Figure C-10. I11 static impulse from P11, 3 inches ahead of nose, 180 degrees.

Figure C-11. P12 wall static pressure 9 inches aft of nose, 180 degrees.

Figure C-12. I12 static impulse from P12, 9 inches aft of nose, 180 degrees.

Figure C-13. P10 wall static pressure 15 inches ahead of nose, 180 degrees.

Figure C-14 I10 Static impulse from P10, 15 inches ahead of nose. 180 degrees.

Figure C-15. P1 wall static pressure 19 inches aft of nose, 180 degrees.

Figure C-16. I1 static impulse from P1, 19 inches aft of nose, 180 degrees.

Figure C-17. P16 wall static pressure 3 inches ahead of nose, 270 degrees.

Figure C-18. I16 static impulse from P16, 3 inches ahead of nose, 270 degrees.

Figure C-19. P17 wall static pressure 9 inches aft of nose, 270 degrees.

Figure C-20. I17 static impulse from P17, 9 inches aft of nose, 270 degrees.

Figure C-21. P18 wall static pressure 19 inches aft of nose, 270 degrees.

Figure C-22. I18 static impulse from P18, 19 inches aft of nose, 270 degrees.

Figure C-23. PT1 stagnation pressure, 2 inches from wall, 9 inches ahead of nose, 315 degrees.

Figure C-24. IT1 stagnation impulse from PT1, 2 inches from wall 9 inches ahead of nose, 315 degrees.

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APPENDIX D

GLFC/FCA TEST ASSEMBLY TEMPERATURE DATA

Figure D-1. Thermocouple No. 1, forward fuel capsule

Figure D-2. Thermocouple No. 2, center fuel capsule

Figure D-3. Thermocouple No. 3, aft fuel capsule

Figure D-4. Thermocouple No. 4, titanium dome

Figure D-5. Thermocouple No. 5, beryllium heat shield

Figure D-6. Thermocouple No. 6, forward band

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