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RS-88 Pad Abort Demonstrator Thrust Chamber Assembly Testing at NASA Marshall Space Flight Center, November–December 2003

Rebecca A. Farr* and Timothy M. Sanders†
NASA Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

This paper documents the effort conducted to collect hot-fire dynamic and acoustics environments data during 50,000-lb thrust lox-ethanol hot-fire rocket testing at NASA Marshall Space Flight Center (MSFC) in November–December 2003. This test program was conducted during development testing of the Boeing Rocketdyne RS-88 development engine thrust chamber assembly (TCA) in support of the Orbital Space Plane (OSP) Crew Escape System Propulsion (CESP) Program Pad Abort Demonstrator (PAD). In addition to numerous internal TCA and nozzle measurements, induced acoustics environments data were also collected. Provided here is an overview of test parameters, a discussion of the measurements, test facility systems and test operations, and a quality assessment of the data collected during this test program.

I. Introduction

THE test program described in this paper was conducted during development testing of the RS-88 development engine TCA in support of the technology area-10 (TA-10) OSP CESP program PAD. Testing was performed under technical task agreement NRA8–30–C2–13, MSFC test project No. P2361.

The TA-10 PAD system-level objectives were to design, build, and test a vehicle to demonstrate components of a launch pad high-acceleration crew escape system. Lockheed Martin was awarded the contract under the above task agreement. The activity was originally awarded under the Space Launch Initiative and then subsequently supported the OSP program. Thus, this test program was often referred to simply as “OSP PAD.”

Figure 1. RS-88 OSP PAD thrust chamber assembly and nozzle.

Boeing Rocketdyne Propulsion and Power Division was subcontracted by Lockheed Martin to provide the PAD propulsion system. The design selected was based on the 60-kibf BANTAM engine, originally designed as a backup to NASA’s FASTRAC engine. The BANTAM baffled injector was a derivative of the injector developed by Rocketdyne as an upgrade to the ATLAS sustainer engine. Originally designed for lox/RP-1, the BANTAM TCA was adapted to use lox/ethanol, in order to meet crew escape propulsion system requirements, and was designated “RS-88.”

Figure 2. OSP PAD test 005, November 25, 2003.

II. Participants/Stakeholders

The main participants and stakeholders in the OSP PAD RS-88 Test program were as follows:

NASA Marshall Space Flight Center
Transportation Directorate
Test and Evaluation Department TD70
MSFC, AL 35812
Tim Sanders, Test Project Engineer

The Boeing Company
Rocketdyne Propulsion and Power
6633 Canoga Ave., P.O. Box 7922
Canoga Park, CA 91309–7922
Todd Roberts, Project Engineer

* Insert Job Title, Propulsion and Fluid Systems Test Division, ET11, Test Laboratory, Engineering Directorate.

† Test Project Engineer, Propulsion and Fluid Systems Test Division, ET11, Test Laboratory, Engineering Directorate.

Lockheed Martin Space Systems
Astronautics Operations
Mail Stop: L5070, P.O. Box 179
Denver, CO 80201
Tim Martin, Propulsion Module IPT Lead

Cambridge Collaborative, Inc.
689 Concord Ave.
Cambridge, MA 02138
Dr. Jerome E. Manning
Acoustics Analyst

III. Test Matrix

The tests were conducted in the 40-klbf test position at test stand 116 in the east test area of MSFC. Sixteen level 1 and mainstage test firings using lox/ethanol propellants were performed from November 21 to December 11, 2003. The test program, fully described in test plan TP-00330 RD03-283-1, included oxidizer and fuel blowdowns, ignition sequence development and demonstration of the combustion stability of the injector design, injector C* performance, specified thrust levels, thrust chamber life over flight duration, and measurement of potential TCA-induced environments on the PAD vehicle.¹

Table 1. RS-88 nominal operating conditions.

Table 2. RS-88 test matrix.

Table 3. Test article and facility instrumentation list.

IV. Acoustics Environments Data

In addition to the numerous internal pressure, strain, and temperature measurements in the RS-88 test article itself, listed above, Lockheed Martin and the OSP Project Office requested that acoustics and heating measurements be added to this Rocketdyne propulsion test program so that the PAD project could understand any induced environments that would potentially be created by the cluster of four RS-88 engines envisioned for the demonstrator vehicle. These requirements were then added to the test plan.¹

MSFC's Test and Evaluation Group worked with the test requestors to select sensors and design an acoustics data collection array, based largely on previous studies that had been done at the same test stand on similar engines in the past.²

The acoustics data were collected using an array of 10 PCB 112A22 pressure transducers at distances of 5, 50, and 100 ft from the nozzle exit plane. All sensors were ≈4 ft above ground level. The engine was tilted slightly downward at a 15° cant to allow excess ethanol to drain out following a test. The acoustics sensor array is shown in plan form in Fig. 6.

Figure 6. Acoustics data collection location 5 ft from the nozzle (highlighted).

A 4-ft-tall steel post was anchored at each data collection location shown in Fig. 7. Data collection locations were determined on the concrete apron adjacent to the test position via simple geometry using a tape measure and chalk. Sensors were mounted on the posts.

Figure 7. Acoustics array data collection locations relative to the test stand and nozzle (drawn to scale).

PCB pressure transducers—designated DPS for dynamic pressure sensors—were located at every position, but in some cases, other sensors were also co-located at the same location on some tests. Thermocouples were added to some locations and also had use of two Larsen Davis 2200B microphones. In addition, at some locations, PCB

transducers were added to the bottom of the posts attached acoustically by 4 ft of tygon sense line to the top of the posts. The data collected at each location in the array are described in detail in the RESULTS section.

Figure 7 shows a closeup of a representative acoustics data collection location. The PCB transducers were mounted in L-brackets bolted to the posts with the sensors' face oriented parallel to the ground, facing upwards. They were directly exposed to heat, shock, and water spray. The microphones were attached to the posts with clamps and oriented towards the engine. The thermocouple probes were taped to the tops of the posts with electrical tape as was any tygon tubing. When using tygon tubing, the PCB sensor was wedged down in the post near the ground. The whole post and sensor assembly was then usually wrapped in heat-resistant tape that protected the sensors from most of the pad flush water spray.

Figure 8. Sensors located at position 2, 5 ft from the nozzle: Larsen Davis microphone, PCB pressure transducer, tygon tubing to PCB transducer lower in post, test 016.

V. Acoustics Data System Configuration

The PCB transducer and Larsen Davis microphone data were collected at 100,000 samples per second with a 20-kHz low-pass filter, using the high-speed NEFF 490 system located in the basement of test stand 116. The thermocouple data were collected on some tests using the same high-speed NEFF 490 data system; on others, the adjacent low-speed NEFF 495 data system was used. The data system components are shown in Fig. 9 while Table 4 describes the high-speed data system configuration for tests 010 through 016.

Figure 9. Acoustics data capture setup for OSP PAD tests 8–16.

Table 4. OSP PAD acoustics array high-speed data system configuration.

VI. Results

Nineteen successful RS-88 tests were completed between November 18 and December 11, 2003, including three cold-flow tests and 16 hot-fire tests.

The objectives of the test matrix were satisfied. Specific impulse (I_{sp}) ranged between 218 and 222 s. Axial thrust ranged between 52,000 and 56,000 lbf. Chamber pressure ranged between 650 and 686 psia. The secondary fuel injection manifold performed as predicted for boundary layer cooling of the combustion chamber. The igniter squibs performed successfully.

Figure 10. Typical mainstage test data profile showing six parameters.

Acoustics data collection commenced with the first mainstage hot-fire test on December 3. In total, ~471 MB of acoustics environments data were collected during eight OSP PAD RS-88 hot-fire tests. These data have been archived and are available to authorized users on CD-ROM from MSFC ET13 upon request. Figure 11 is a composite image of representative acoustics data collected during test 016.

Figure 11. Graphical representation of pressure transducer data collected at location 12 during test 013, showing ignition overpressure pulse, thermal effects, shutdown transient, and posttest facility purge, December 9, 2003.

Following the conclusion of this test program, copies of the acoustics data collected were provided to Lockheed Martin, CO, and to their acoustics analyst, Dr. Jerry Manning, Cambridge Collaborative, Inc., MA. Data collected during this test program were used to update acoustic model predictions provided to the OSP project and Lockheed Martin.

With these tests, the development phase of the OSP PAD test program was completed. Planned subsequent flight acceptance tests were cancelled with OSP project termination.

References

1. *NASA MSFC RS-88 TCA Test Plan TP-00330 RD03-283-1*, Marshall Space Flight Center, AL, November 11, 2003.
2. Frendi, K.; Nesman, T.; and Wang, T.-S.: "Computational and Experimental Study of Linear Acrospike Engine Noise," *AIAA Journal*, Vol. 39, No. 8, pp. 1478–1484, August 2001.