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A PROGRESS REPORT ON THE ADVANCED REUSABLE TECHNOLOGIES PROJECT

J.E. Turner and U. Hueter
NASA Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

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James E. Turner * and Uwe Hueter **
NASA- Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Abstract

The National Aeronautics and Space Administration has formed the Advanced Space Transportation Program (ASTP) at the Marshall Space Flight Center to address advanced space transportation technologies. The main focus of the ASTP Office is directed to those technologies that will be needed to reduce the cost of both Earth-to-orbit and in-space transportation. The current focus of the advanced reusable technologies (ART) Project is the development of those critical technologies required to enable a rocket-based combined-cycle (RBCC) engine and ultimately an RBCC-based reusable launch vehicle. Additional effort is also being expended to address those associated technologies that would be required to not only support an RBCC-based vehicle but other advanced reusable transportation systems as well. This paper will describe the work that has been performed since the last project status was presented to the 1997 Joint Propulsion Conference.[1]

Currently, NASA and its industry partners are performing ground testing of hydrogen-fueled rocket-based combined-cycle flowpaths. Successful ramjet and scramjet testing at Mach 6 and scramjet testing at Mach 8 have been performed. Cold flow mixing tests have also been successfully performed as have inlet operability tests. Additional testing of RBCC flowpaths at air augmented rocket and rocket only modes is underway.

Additional work will be performed on technologies that will support an RBCC-powered launch vehicle and will be focused in the following areas: structures and materials; avionics and operations; propulsion turbomachinery; and thermal protection systems.

* Chief Engineer, Advanced Reusable Technologies Project, NASA/MSFC, Senior Member AIAA

** Project Manager, Advanced Reusable Technologies Project, NASA/MSFC, Member AIAA

Introduction

The National Aeronautics and Space Administration (NASA) Advanced Space Transportation Program (ASTP), part of the Space Transportation Program (STP) Office at the Marshall Space Flight Center (MSFC), is focusing on those technologies that will be needed to reduce the cost of both Earth-to-orbit and in-space transportation. NASA's strategy is to advance innovative space transportation technology development through the X-33, X-34, ASTP, and the Future-X programs to enable reduction of these costs. The ASTP consists of three major technology areas: focused, core, and research technologies.

The ART project currently manages the work that is covered under NASA Research Announcements 8-16 and 8-21. The project's primary focus over the last 2 years has been on rocket-based combined-cycle (RBCC) technology development activities awarded under NRA 8-16. The current aerospace and academic organizations listed in Figure 1 are performing testing and analysis supporting the RBCC propulsion activities. The engine contractors, Aerojet, Pratt & Whitney, and Rocketdyne are currently either testing or preparing to test their RBCC engine flowpaths. Direct connect testing has been performed at Mach 6 flight conditions in both ramjet and scramjet modes and at Mach 8 flight conditions in the scramjet mode. Testing has also been performed at sea-level static conditions and at Mach 3.4 ramjet conditions.

- Aerojet(GenCorp)
- Astrox
- GASL, Inc.
- Georgia Institute of Technology
- Pennsylvania State University
- Pratt and Whitney (United Technologies)
- Rocketdyne (Boeing Aerospace)
- University of Alabama in Huntsville

Fig. 1. Current ART contractors.

The University of Alabama in Huntsville (UAH) has initiated testing to determine the mixing characteristics of two supersonic, parallel jets representative of RBCC hardware.

The Pennsylvania State University (PSU) is currently performing Raman spectroscopy experiments in determining the mixing/combustion characteristics of the RBCC flowfield. Also, using a highly instrumented nozzle, PSU is working with MSFC to assess the accuracy of several heat flux methodologies that have been proposed.

Recently, the ART project has also funded technology work outside of the RBCC propulsion arena. Funding in this fiscal year has gone to the areas of structures and materials, TPS and avionics/operations. Current efforts in structures and materials include investigation into the aluminum lithium alloy C458. Funding for avionics/ operations is currently supporting investigation into an advanced video-based rendezvous sensor for automatic rendezvous and docking technologies and for development of super capacitors. Also, NRA8-21 recently selected technology efforts in both airframe and propulsion systems focusing on those technologies that would support the year 2000 Reusable Launch Vehicle (RLV) decision to establish if the RLV program is ready to transition from a technology effort into a development program.

Test Efforts

The engine flowpaths from Aerojet, Rocketdyne, and Pratt & Whitney are either in test or are undergoing installation into their respective test stands. All direct connect and freejet testing is being conducted at the General Applied Science Laboratories, Inc. (GASL) facilities on Long Island, New York. Direct connect testing of one of the flowpaths at Mach 6 ramjet and scramjet conditions and Mach 8 scramjet operations has been completed. Rocket only mode testing and air augmented rocket mode testing are underway on another flowpath. Trajectory simulation testing is scheduled in Leg 5 of the GASL facility in July 1998.

An area that has caused a large amount of difficulty in the testing efforts is the means of initiating the rocket combustion process. All three of the engine contractors above were, or are, planning to use a combination of oxygen and silane (SiH_4) as the ignition source for the thrusters. This follows from past successful use of silane in hypersonic flowpaths. However, difficulties were immediately encountered when an 80/20 volumetric mixture of hydrogen and SiH_4 was used for rocket ignition. After a lengthy test series at MSFC Test Stand 115, one of the engine RBCC thrusters could be lit with SiH_4 repeatedly, but one of the combustion products, silicone dioxide, caused major operational difficulties. The silicone dioxide formed a hard coating on the thruster injector face as well as on the chamber walls which required lengthy operations to remove. Due to the unpredictability of ignition and the operational impacts of cleaning the thrusters after every test, SiH_4 was dropped as a candidate for ignition for this particular engine.

A second engine contractor tested their injector at MSFC Test Stand 115 and had acceptable ignition using SiH_4. A thruster was then manufactured and SiH_4 ignition testing was performed at the engine contractor location. By manipulating such variables as temperature and mixture ratio a curve was developed that was used to define required parameters to assure combustion using SiH_4. Also, silicone dioxide contamination was not a large issue.

When a different set of engine thrusters were delivered to GASL for testing, problems were once again encountered with SiH_4 ignition. The GASL facility had been modified to mimic as closely as possible the test facility that was used by the contractor. However, parameters for ignition previously assumed correct were repeatedly used and ignition was not achieved. It has been postulated that a minor physical variation in the first thruster, alignment of the injector face to the thruster, was a probable cause for the different results. A decision was then reached that 100-percent SiH_4 should be used for ignition purposes. Pure SiH_4 has been used for ignition for the rocket tests with success. However, contamination remains a problem, as unused pressure ports that are not purged have been obstructed.

In both of the above cases, the contractors have decided to use a combustion wave ignition (CWI) system as their method for ignition. This system has been previously described in detail by Larry Liou of the NASA Lewis Research Center.[2] This system uses a combustion chamber in which an oxidizer and fuel, in this case oxygen and hydrogen, are introduced and detonated. The detonation wave is then directed to each of the thrusters by means of a small dedicated line which feeds into the thrusters, typically from an original chamber pressure port. This system has proved to be reliable. Since the system uses only hydrogen and oxygen there are no contaminating combustion by-products to contaminate the thruster hardware. The system is also fairly inexpensive and simple.

There has been one failure using the CWI system. During a sea level static test with rocket operation, a small fire was seen during transition from ignition to main stage. After test termination and review of the data and the hardware, it was determined that several of the CWI tubes supplying the combustion wave front had failed. Purge pressures in the tubes were below the combustion pressures, thereby allowing backflow into the tubes, thus inducing a failure. Repairs to the system have been made and test operations have resumed without any further incidents.

Inlet testing has been performed on two of the engine contractor's inlets. Testing was successfully completed at the Lewis Research Center's 1×1 variable Mach wind tunnel. Parameters that were varied during the testing included simulated flight Mach numbers, which varied from 3.6 to 8.1, throat bleed, cowl positions, and contraction ratio. Testing on one of the engines revealed that throat bleed was a critical parameter. The inlet could be unstarted by simply turning off the bleed flows and restarted by turning them back one. The inlet tests proved to be very beneficial in the design and ultimate configuration of the freejet test engines. Figure 2 shows the Aerojet inlet in testing at Lewis.

PSU has performed Raman Spectroscopy Experiments to determine the mixing/combustion characteristics of an RBCC flowfield. Figure 3 shows the location of the oxygen/hydrogen thrusters and the optical window locations. Measurements have been completed at locations 1, 2, 3, 4 and 5. Thermal choking CFD analyses have also been performed. For a straight duct mixer followed by a diverging duct, the computational results have indicated that thermal choking takes place near the starting point of the diverging section of the duct. However, the flow field tends to be highly unsteady. Ultimately this leads to a large amplitude fluctuations in the flow field. Also, a shock wave exists near the exit plane of the duct which further accentuates the unsteadiness of the flow field. The presence of the downstream shockwave is a result of the atmospheric back pressure being too high to sustain supersonic flow through the exit.

One area of interest throughout the ART project has been the throats of the small rocket thrusters. The concern has been that the throats are so small that there may be inadequate cooling to prevent burnout. A separate paper is currently being prepared by Kevin Tucker of MSFC to address the analytical methods that were used to address this problem. In summary, there have been different methodologies applied to the problem which have yielded throat heat fluxes that were widely different. In response to this, PSU has designed, fabricated, and tested a highly instrumented RBCC rocket nozzle to accurately measure hot gas wall temperatures. The testing of this nozzle has been completed up to a chamber pressure of 500 psi. Data analysis is currently under way. Results from the PSU testing will be presented at the annual meeting of the Policy Advisory Board of the Propulsion Engineering Research Center this fall.

UAH is conducting tests to experimentally determine the mixing characteristics of the Aerojet strutjet rocket and turbine exhaust gases. A model of the strutjet device has been built and is undergoing testing at the UAH

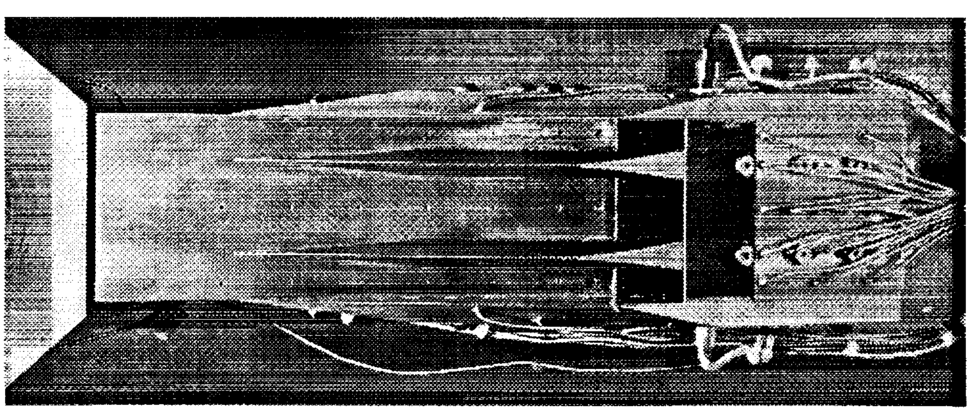

Fig. 2. Aerojet inlet in the NASA-Lewis 1×1 facility.

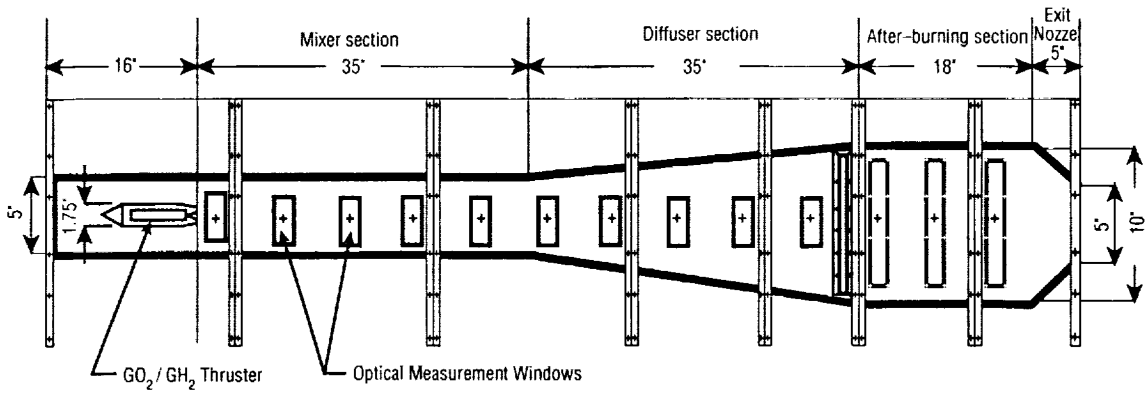

Fig. 3. PSU RBCC test article.

Parameter	Range
♦ Rocket	
– O/F ratio	4 → 8
– Chamber pressure	200 and 500 psia
♦ Secondary/primary flow ratio	2.3 → 3.4
♦ Mixer section lengths	0, 14, 35 inches
♦ Diffuser lengths	35 and 14 inches
♦ Diffuser outlet cross section	10×3 inches (adjustable)
♦ Afterburner area	10×3 inches (adjustable)
♦ Exit nozzle convergent	7.0×3.0 and 5.0×3.0 inches (adjustable)
♦ Exit nozzle convergent/divergent	6.5×3.0 inches (adjustable throat area)

Fig. 4. PSU test parameters.

campus. The experiment design utilizes hot air as a rocket exhaust simulant and hot carbon dioxide as the turbine exhaust gas simulant. The carbon dioxide is seeded with Acetone to permit tracing of the mixing processes through Laser- Induced Fluorescence (see Fig. 5).

NASA's Lewis Research Center has completed work on a statistical experimental design to study the performance of RBCC thruster nozzles in the all-rocket mode of operations. Axisymetric Navier-Stokes simulations were performed using NPARC. Detailed results of this study have been published in references 3 and 4. The authors of these references report that the free expansion process, directly downstream of the rocket nozzle, can influence the overall RBCC nozzle performance. Also, the following results were based on the design space of the study: increasing the mixer-ejector duct inlet area ratio hinders performance; long mixer-ejector duct hinders performance; a large primary rocket exit area improves performance up to a point; a large mixer-ejector exit area ratio improves performance up to a point; high chamber total pressure slightly improves performance; and the effect of secondary flow can either be beneficial or detrimental depending on configuration.

Advanced Technologies

Several areas of advanced technologies have been funded in fiscal year 1998 by the ART project office: structures and materials; thermal protection systems (TPS); and avionics/operations. Funding for structures and materials has been given to such areas as advanced composite matrix development, advanced TPS/cryogenic insulation, composite cryotanks joining technologies, cryotank cylinder shear forming, and advanced aluminum lithium alloy C458. In the case of the Al-Li work, initial results have indicated a 5-percent improvement in density, a 10-percent improvement in modulus, improved isotropy and enhanced ductility in the transverse direction. This alloy, C458, is also in the public domain. A "round robin" assessment is currently being performed. MSFC evaluation of C458 have found that the alloy is weldable with fusion or friction stir welding processes and weld strengths and elongation are comparable to Al-Li 2195 alloy. To date, C458 plate has exhibited excellent combinations of strength, fracture toughness, welding behavior, and corrosion resistance.

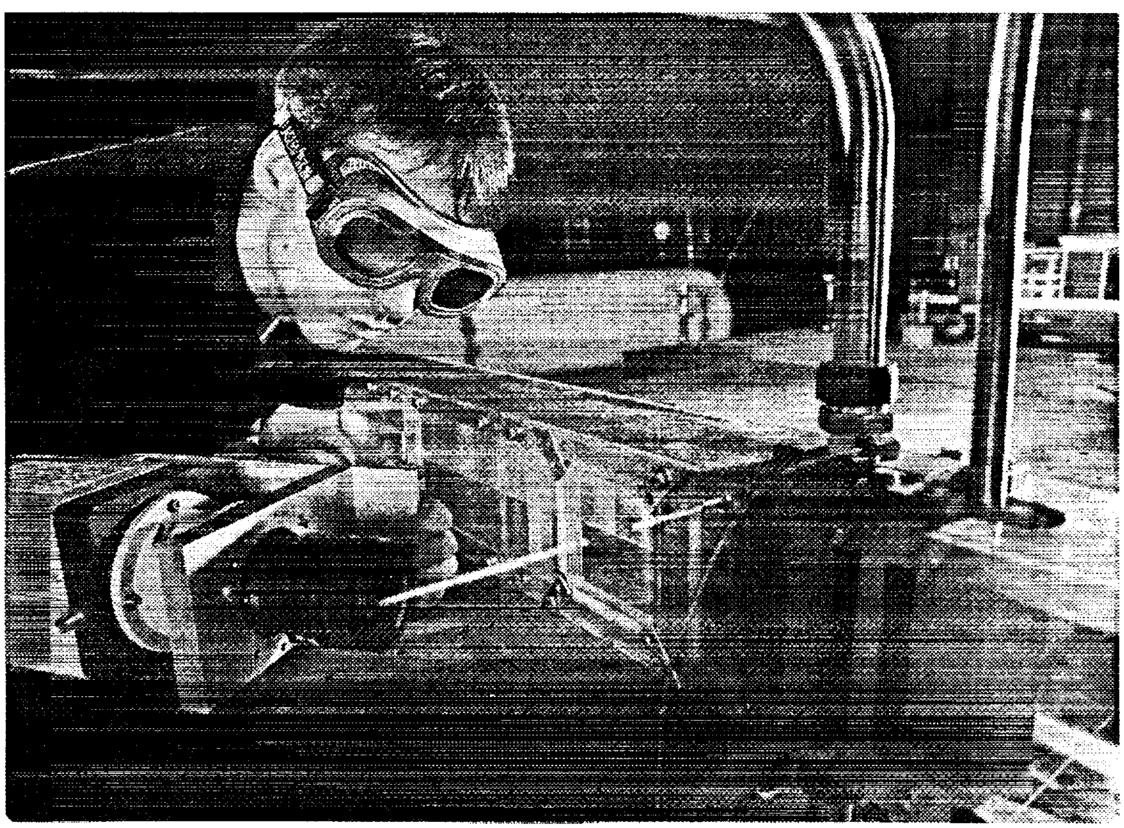

Fig. 5. UAH mixing experiments.

In the area of operations/avionics funding has been given to automated rendezvous and docking efforts and to super capacitor development. Marshall Space Flight Center currently has under advanced development a system for Automatic Rendezvous and Capture. This system consists of hardware and software required for autonomous rendezvous and docking with the *International Space Station* or other space platforms. The current system uses a video-based rendezvous sensor for terminal docking operations. This sensor concept is a key enabling technology required for rendezvous and docking. Funding in fiscal year 1998 will be to investigate the use of an active target and/or optical target with a 2nd generation Video Guidance Sensor. Systems demonstration will at first be done in the MSFC flight robotics lab with planning also begun for a technology flight experiment of the target and guidance sensor. Funding for super-capacitor development is directed towards development of chemical double layer capacitors as an advanced power source. The goal of this effort is to reduce power source weight by up to 50-percent over existing systems.

In the year 2000, an assessment will be made to decide whether the RLV should progress to the development stage or if technology development should continue. In support of this activity, NRA 8-21 was issued last February soliciting proposals for RLV-focused technologies. Last month, awards were made both to NASA centers and industry. In the area of airframe systems, awards were made in composite tanks, hot structures, advanced metallic TPS, high-temperature blanket TPS, and fuel cells. For propulsion-focused technologies, awards were made in lightweight thrust cells, Carbon matrix composite nozzles, high-performance lightweight turbomachinery, and composite lines and ducts. All these technology efforts will be completed by 2000 to support the RLV decision.

Next Steps

Testing continues or will be initiated shortly on the three engine contractors' freejet and direct connect engines at GASL, Inc. Due to schedule slips and facility delays, it is currently believed that the test program will be completed by the end of this calendar year. A combination of ART funding and contractor IRAD efforts will yield test results from sea-level static operation, to AAR operations, to ramjet operations, to scramjet operations, and finally to all-rocket ascent operations. PSU testing should also be completed by the end of the calendar year.

Also, this fall the ART project will host another workshop focusing on the RBCC vehicle technologies. The date for this workshop has not been established. Cycle 2 of NRA 8-21 will begin after receipt of proposals on October 15, 1998. Cycle 2 is focused on core activities, where core activities are defined as those which will provide for advancements in fundamental technologies which may enable or enhance a broad range of future reusable space transportation systems. Additional information on NRA 8-21 may be found on the internet at http://nais.msfc.nasa.gov/home.html.

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