IAF-00-S.5.04
NASA's Advanced Propulsion Technology Activities for Third Generation Fully Reusable Launch Vehicle Applications

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51st International Astronautical Congress
2-6 Oct 2000/Rio de Janeiro, Brazil

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Abstract

NASA's Office of Aero-Space Technology (OAST) established the following three major goals, referred to as "The Three Pillars for Success": Global Civil Aviation, Revolutionary Technology Leaps, and Access to Space. The Advanced Space Transportation Program Office (ASTP) at the NASA's Marshall Space Flight Center in Huntsville, Ala. focuses on future space transportation technologies supporting the "Access to Space" pillar. The propulsion projects within ASTP under the investment area of Spaceliner100 focus on the earth-to-orbit (ETO) third generation reusable launch vehicle technologies. The goals of Spaceliner100 are to reduce cost by a factor of 100 and improve safety by a factor of 10,000 over current conditions.

The ETO propulsion projects in ASTP are actively developing combination/combined-cycle propulsion technologies that utilized airbreathing propulsion during a major portion of the trajectory. System integration, components, materials and advanced rocket technologies are also being pursued. Over the last several years, one of the main thrusts has been to develop rocket-based combined cycle (RBCC) technologies. The focus has been on conducting ground tests of several engine designs to establish the RBCC flowpaths performance. Flowpath testing of three different RBCC engine designs is progressing. Currently, a more balanced program is being implemented. Additionally, vehicle system studies are being conducted to assess potential operational space access vehicles utilizing various advanced propulsion systems. The design, manufacturing, and ground testing of a scale flight-type engine are planned. The first flight demonstration of an airbreathing combined cycle propulsion system is envisioned around 2006.

The paper describes the advanced propulsion technologies that are being developed under the ETO activities in

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the ASTP program. Progress, findings, and future activities for the propulsion technologies are discussed.

Introduction

NASA's Office of Aero-Space Technology (OAST) established three major goals, see Figure 1, referred to as, "The Three Pillars for Success". The Advanced Space Transportation Program (ASTP) Office at the NASA's Marshall Space Flight Center in Huntsville, Ala. focuses on future space transportation technologies under the "Access to Space" pillar.

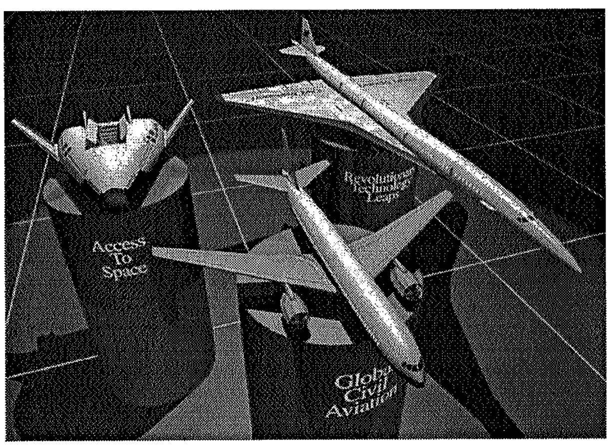


Figure 1. NASA's Office Of Aero-Space Technology Three Pillars For Success

The ASTP Program has as its primary objectives significant improvement in safety and reduction of payload transportation cost to low earth orbit (LEO) and in-space transfer. The Spaceliner100 investment area under ASTP focused toward the third generation reusable launch vehicle (RLV), the Space Shuttle is considered the first generation RLV, with goals to lower the transportation costs by a factor of 100 and improving safety by a factor of 10,000 over current conditions, see Figure 2.

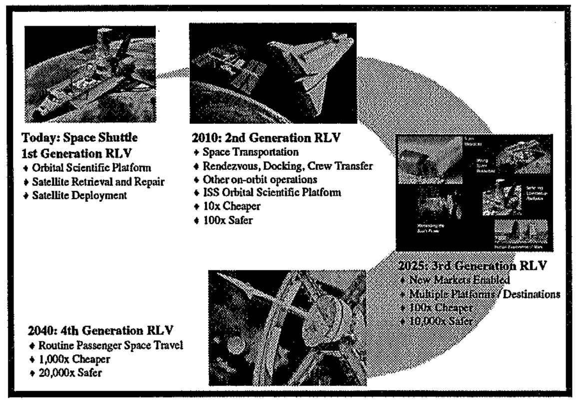


Figure 2. RLV Evolutionary Path

The plan is to substantially increase the design and performance margins of the third generation RLV by the incorporation of advanced propulsion systems, materials, structures, thermal protection systems, and avionics. The increase in margins will directly reduce the high operational costs associated with today's vehicles by allowing components to operate well below their design points. This would result in improve component operating life, reliability, and safety which in turn reduces both maintenance and refurbishment costs. Figure 3 depicts how in today's systems the operating and design range overlap resulting in conditions for potential failure. By minimizing the area of overlap, the operating risks are minimized, resulting in safer and more reliable systems. The separation of the design and operating range can be accomplished by increasing the systems operating margin or better defining both the design and operating environment, thus reducing the variability. To better define both the design and operating environments, a more rigorous testing program, along with improvements in analytical techniques, are needed.

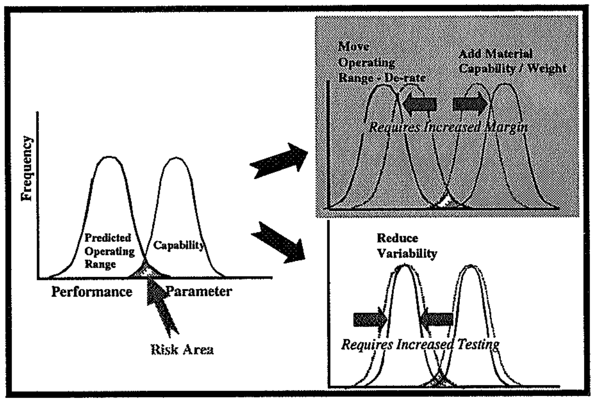


Figure 3. Improvement in Safety & Reliability

One of the main propulsion activities over the past few years has been on advancing the RBCC technologies. The introduction of airbreathing propulsion may also enable horizontal takeoff by reducing the takeoff weight to permit the utilization of existing infrastructure. This would be a major step toward the goal of airline-type operation. Recently, a more balanced program has been instituted to pursue alternate propulsion systems (e.g., turbine based combined cycles), advanced materials, component development and analytical tools. A significant effort of the propulsion activity is system development and ground testing leading to a flight demonstration of these technologies.

The technologies being pursued by the Spaceliner100 investment area in conjunction with increased flight rates from an expanding market will result in significant improvements in safety and reductions in operational costs of future vehicles.

Spaceliner100 Propulsion Project

The Spaceliner100 propulsion projects have set the following technical challenges:

- Mission average specific impulse > 500seconds
- Increased propulsion system thrust-to-weight
- Increased life cycle capability to 500 missions
- Decrease development and operational costs
- Improve flight safety
- Improve analytical tools

Due to limited resources available the last several years, the major emphasis has been on the development of the RBCC flowpaths. Recently the project has been refocused to provide a more balanced approach for developing propulsion technologies that meet the goals of the third generation RLV. The project was restructured into six main areas, see Figure 4. A strong set of foundational technologies and crosscutting component technologies that improve system performance margin and impacts all propulsion systems were put in place. The vehicle system analysis establishes the system benefits of individual technologies for various propulsion system/vehicle concepts. These products would feed the focused concepts that would further develop these technologies to specific design requirements. After developing the focus concepts, the technologies would be integrated into a ground demonstrator to test the technologies in a system environment. If the technologies require a flight demonstration, funding outside of the ASTP program would be required to develop the demonstrator vehicle.

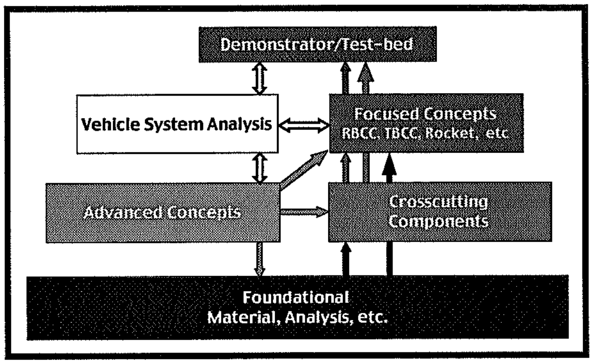


Figure 4. Project Structure

The budget distribution for the propulsion projects is shown in Figure 5. The majority of the available resources will be invested in demonstrator/testbed. Foundation, crosscutting, and focused technologies will be funded at approximately 20% of the available resources. A small amount of the budget, approximately 2%, is set aside for investment in new and innovative ideas for propulsion. The vehicle system analysis is funded by ASTP but not by the propulsion projects.

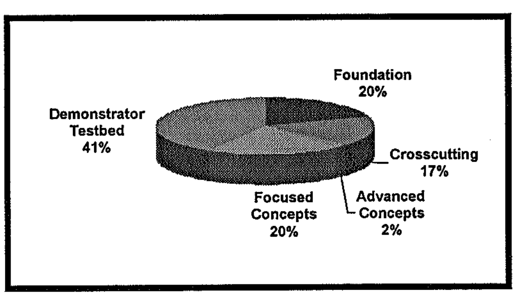


Figure 5. Budget Distribution

Foundational Technologies

The foundational technologies are considered the base technology activity. This area deals primarily with material development and characterization and tools development. A lot of the material development focuses on high temperature/high strength applications to improving the thrust to weight ratio and allowable operating margins of propulsion systems. The tool development applies to fluid, structural, and system analyses. The main areas of focus for the foundational technologies are shown in Figure 6.

- **Light Weight/ Long-Life Materials**
  - **Ceramic/CMC for Turbomachinery**
  - **Ceramic for Combustion Devices**
  - **Polymer Matrix Composite for Components**
  - **Cooled Composites for Nozzles & Structures**
- **Tools**
  - **Structures**
  - **Flow**
  - **System Analysis**
- **Advanced Propellants**
  - **Densified Propellants**
  - **High Energy Hydrocarbons**
  - **Advanced Monopropellants for Reaction Control Systems**

Figure 6. Foundational Technologies

Crosscutting Component Technologies

The crosscutting component technologies' primary focus is to develop components applicable to multiple propulsion concepts. The foundational technologies that have been developed will be incorporated into component designs. These components will feed both the focus and demonstrator technologies. The main technologies being pursued in this area are shown in Figure 7.

- Turbomachinery
  - CMC Blisk
  - Bearings
  - MMC Housings
  - Ceramic/CMC Materials
- Combustion Devices
  - Ignition Devices
  - Lightweight Injectors/Thruster
  - CMC Chambers
- Nozzles & Cooled Structure
- Valves
- Instrumentation
- Seals

Figure 7. Crosscutting Component Technologies

Advanced Concepts

The advanced concept's area focuses on identifying revolutionary or innovative propulsion concepts that reduce the cost and increase both reliability and safety of ETO space transportation systems. These will be solicited from non-traditional sources such as Universities, small businesses and national laboratories. The concepts will be evaluated by the vehicle system analysis to assess their impacts on the 3rd generation RLV goals and to identify promising technologies for further maturation. Either foundation or crosscutting technology areas will then fund the selected technologies.

Vehicle System Analysis

The vehicle system analysis, although not funded by the propulsion projects, is an integral activity for establishing the critical technologies required to meet the goals set for the third generation RLV. This activity will assess the contribution of the individual technologies toward the goals. Several vehicle configurations, Figure 8, and propulsion concepts, Figure 9, are being studied to establish which architecture would best meet the cost and safety goals. The most likely airbreathing propulsion applications are indicated in Figure 8. Single stage to orbit (SSTO) and two-stage to orbit (TSTO) vehicles that would utilize either vertical takeoff (VTO) or horizontal takeoffs (HTO) are being studied. All configurations land horizontally. Hydrocarbon, hydrogen, and dual fuel are part of the trade space.

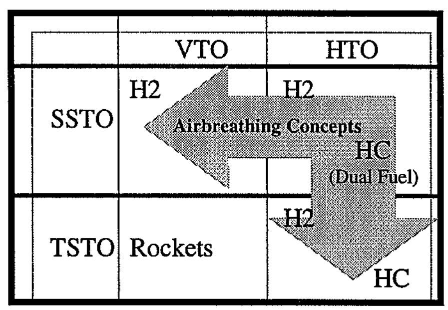
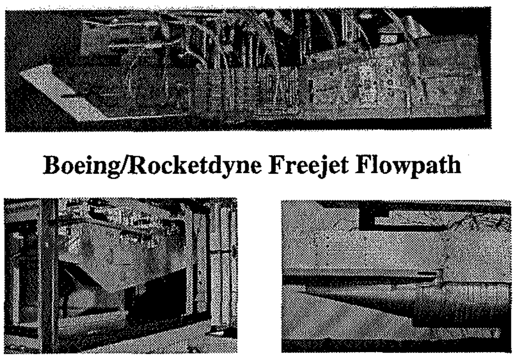


Figure 8. Vehicle Concepts

- Aibreathing Propulsion
  - Rocket-Based Combined Cycle (RBCC)
  - Turbine-Based Combination Cycle (TBCC)
  - Pulse Detonation Engine (PDE) Combined Cycle
- Rocket Propulsion
  - High Thrust-to-Weight/Long-life Advanced Rocket Engines
  - Pulse Detonation Rocket Engine (PDRE)

Figure 9. Propulsion Concepts

The focused concepts area evaluates specific advanced propulsion designs and performs detailed experimental evaluation, conceptual engine designs, and integrated flowpath performance assessment. This area focused primarily on the RBCC flowpath development in the last several years. Three flowpaths, Figure 10, have been tested in both direct and freejet tests facilities. Summaries of the test results were presented at AIAA conferences in 1999[1,2]. Future activities will include additional RBCC flowpath testing, turbine-based combined cycle testing, and pulse detonation wave rocket engine testing.



Boeing/Rocketdyne Freejet Flowpath

GenCorp/Aerojet Freejet Flowpath

NASA/GRC Freejet Flowpath

Figure 10. RBCC Test Articles

Demonstrator/Test-bed Technologies

The ground demonstrator/test-bed goals are to advance the propulsion technologies to a technology readiness level equivalent to system demonstration in a relative environment. This means that in some cases, the technologies will have to be flight demonstrated. The function is to demonstrate performance and operability to establish maintainability, reliability, safety, life and cost. The first demonstrator will be an RBCC engine system ground demonstrator. The engine system will include all the ancillary hardware (e.g., turbopumps, valves, manifolds, ignition systems, controller, etc.) that would be required for a flight demonstration engine system. The design and scale of the ground demonstration engine and the flight demonstration engine are intended to be the same. The airbreathing subsonic ground test facility will be located at Stennis Space Center (SSC). Ground testing of the first RBCC demonstrator engine is currently scheduled for 2004. Supersonic testing will take place in existing national facilities. Plans are to develop other demonstrators as the technology matures to the point of requiring system demonstration.

An advanced hydrogen rocket system testbed will also be available at SSC in 2003, to test third generation RLV rocket technologies. This testbed will be used for second generation RLV technology testing till 2003, and then transition to third generation activities.

Summary

The ASTP Propulsion Project has put in place a plan to mature the propulsion technologies required to meet the Spacliner100 goals to lower the transportation costs by a factor of 100 and improving safety by a factor of 10,000 over current conditions. The potential vehicle concepts being considered include both TSTO and SSTO. The initial operational capability for a third generation RLV is around

2025. Therefore, the technologies will have to be demonstrated in a relative system environment by approximately 2015. For some of the technologies, flight demonstrations will be required. The current plan is to first demonstrate through ground testing an RBCC propulsion system. The RBCC system ground demonstrator should be in tests by 2004. Flight testing of an RBCC engine is projected around the 2006 timeframe. A second ground demonstrator of an alternate propulsion system, e.g., TBCC, is being planned to begin around 2005. The actual number of demonstrators that will be developed and flown will be based on future analytical studies and test results of the technologies. The current plans are to have a leader, follower approach to the development of ground and flight demonstrators.

In parallel with the airbreathing activity, advanced rocket testing will be conducted in the hydrogen testbed facility located at SSC. This testing is scheduled to begin around 2003.

References

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2. Hueter, Uwe & Turner, Jim, "Rocket-based Combined Cycle Activities In The Advanced Space Transportation Program Office", AIAA 99-2352, Presented at the 35th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Los Angeles, CA, June 1999.