NASA/TM—1999-209185

NASA Glenn Research Center's Hypersonic Propulsion Program

Donald T. Palac
Glenn Research Center, Cleveland, Ohio

Prepared for the
14th International Symposium on Airbreathing Engines
cosponsored by AIAA, AAF, ATI, CASI, DGLR, RAS, UKRAS
Florence, Italy, September 5–10, 1999

National Aeronautics and
Space Administration

Glenn Research Center

May 1999

Acknowledgments

The author wishes to thank Gary Klann, Hugh D. Perkins, Joseph Roche, Scott R. Thomas, Dr. Charles Trefny, James F. Walker, and Frank D. Berkopec, as well as the many members of the RBCC and TBCC teams at NASA GRC, for their contributions to NASA GRC's hypersonic propulsion projects, many of which appear in this paper.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076
Price Code: A03

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100
Price Code: A03

NASA GLENN RESEARCH CENTER'S HYPERSONIC PROPULSION PROGRAM

Donald T. Palac
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

NASA Glenn Research Center (GRC), as NASA's lead center for aeropropulsion, is responding to the challenge of reducing the cost of space transportation through the integration of air-breathing propulsion into launch vehicles. Air-breathing launch vehicle (ABLV) propulsion requires a marked departure from traditional propulsion applications, and stretches the technology of both rocket and air-breathing propulsion. In addition, the demands of the space launch mission require an unprecedented level of integration of propulsion and vehicle systems. GRC is responding with a program with rocket-based combined cycle (RBCC) propulsion technology as its main focus. RBCC offers the potential for simplicity, robustness, and performance that may enable low-cost single-stage-to-orbit (SSTO) transportation. Other technologies, notably turbine-based combined cycle (TBCC) propulsion, offer benefits such as increased robustness and greater mission flexibility, and are being advanced, at a slower pace, as part of GRC's program in hypersonics.

Introduction

In 1997, NASA enunciated its goals for Aeronautics and Space Transportation Technology. They are grouped into three "pillars"; the third pillar concerns access to space. Specifically, NASA's goal for earth-to-orbit transportation is to reduce the cost to low earth orbit by an order of magnitude within 10 years, then an additional order of magnitude by the year 2020[1]. NASA Glenn Research Center (GRC), under the sponsorship of the NASA Office of Aerospace Technology, is developing hypersonic air-breathing propulsion technology to enable this second order of magnitude reduction in cost to low earth orbit.[2] In the process of demonstrating this cost reduction potential, GRC also plans to develop a flight demonstration vehicle that responds to NASA's Revolutionary Technology Leaps pillar goal of providing experimental flight vehicles that will assist the aerospace community in reducing design and development time. GRC's response to these challenges builds on experience and facility capabilities exercised in an array of recent hypersonic propulsion research programs, including both rocket and turbine based combined cycle propulsion for atmospheric flight.

Rocket-Based Combined Cycle

Rocket-based combined cycle (RBCC) propulsion is a major emphasis of GRC's application of air-breathing propulsion to launch cost reduction. RBCC offers the potential to combine 40 years of all-rocket launch vehicle experience with the efficiency inherent in using atmospheric oxygen for a portion of the flight. The weight margin delivered by the high specific impulse air-breathing portion of the cycle is potentially much greater than the weight required to add the air-breathing propulsion system and associated vehicle accommodations. Determining the validity of this theoretical potential is the key focus of GRC's program. GRC has selected a performance target appropriate for the risk, cost, and schedule of a first-of-a-kind RBCC technology demonstration (fig 1.).

Single stage to orbit transportation is a challenge that will drive close attention to the allocation of mass in the launch system, even with the potential benefits of air-breathing propulsion. For this reason, GRC's RBCC propulsion technology program included three critical elements: 1) the development

*Acting Chief, Hypersonics Projects Office, AIAA Senior Member.

of a reference vehicle concept, 2)the development of component-and system-level propulsion technology, and 3) the planning for a self-powered flight demonstrator. These three components, illustrated in figure 2, are critical to the demonstration of the feasibility of RBCC technology for reduction in launch costs. The reference vehicle concept development ensures that the propulsion technology development encompasses all necessary challenges toward realization of launch cost reduction, and that propulsion technology difficulties are not re-allocated to other vehicle systems. A flight demonstration provides validation of the technology development and reference vehicle concept development, verifying launch cost reduction potential.

The currently funded RBCC program consists of the propulsion systems analysis and a set of component rigs that will, by 2001, demonstrate inlet and nozzle performance, rocket element performance and operation, ramjet/scramjet performance and operation, and propulsion/vehicle integration technologies (fig. 3). During 1998 and 1999, the inlet, combustion (rocket and ramjet/scramjet), and vehicle interactions rigs have been tested or are in progress. The nozzle rig is planned for development and test in 2000[3]. These propulsion technology maturation rigs are conducted in parallel with a reference vehicle/propulsion system concept definition effort that provides a basis for propulsion system configuration and allows determination of overall mission performance. Planning is in place to continue the current program through flight-weight propulsion system development and test, and ultimately, development and flight of a partial-scale self-powered flight demonstrator by 2010. Because it attempts to establish baseline, measured-risk performance that "blazes the trail" to the high potential of the RBCC class of propulsion system options for space access, GRC named its RBCC program "Trailblazer" (fig. 4).[4]

The Trailblazer RBCC propulsion system is planned to operate as shown in figure 5. At liftoff, most or all of the thrust from the propulsion system comes from the rocket element. There is one rocket element in each of the three propulsion pods. A propulsion technology assessment of the benefits of the "ejector ramjet" mode of operation of a rocket in a duct is in progress. Use of the ejector ramjet effect requires a longer (heavier) propulsion system pod in order to mix entrained air with the fuel-rich rocket exhaust, or multiple thrust chambers to shorten required mixing length. If this extra weight pays for itself in propulsion system performance, an ejector ramjet mode will be included in the propulsion system concept. In either case, as the vehicle accelerates through Mach 1, fuel will be injected into the incoming air, and the propulsion system will operate as a combined rocket and ramjet until about Mach 2.5, when sufficient thrust is available from the ramjet to shut off the rocket. The propulsion system will operate as a ramjet, then as a supersonic combustion ramjet (scramjet), until the vehicle reaches the point for transition to all-rocket mode, at approximately Mach 10. The inlet center body, which is the only moving part of the propulsion flowpath, is translated aft during ramjet and scramjet modes as necessary to maintain the optimum contraction ratio. At transition to all-rocket mode, the center body is moved back to the point of closing off the inlet, allowing the air-breathing flowpath and vehicle base to act as an extension of the rocket nozzle[5].

A significant component of the Trailblazer project is the integration of supporting technologies. Primary among these supporting technologies are the materials, structures, and thermal management technologies. GRC is building a NASA/industry team to take advantage of the wealth of information in these areas that is the heritage of the National AeroSpace Plane (NASP) program, and other programs that have advanced the state of the art in hypersonic propulsion.

Turbine-Based Combined Cycle

GRC's hypersonic propulsion program also has included a smaller effort in turbine-based systems, applicable to both access to space and atmospheric cruise missions. The joint NASA/Airforce High Mach Turbine Engine (HiMaTE) program resulted in the development of components of GE's Variable Cycle Hyper Jet, and Pratt and Whitney's Air Core Enhanced Turbo-Ramjet. A lower-risk concept for a parallel flowpath turbine-based combined cycle (TBCC) propulsion system was developed at GRC, based on use of an existing turbojet engine. That engine was tested at GRC's Propulsion Systems Laboratory direct-connect facility at Mach 3 using water-spray cooling of the compressor[6,7].

The Japanese Institute of Space and Astronautical Sciences is investigating another TBCC concept know as the Air Turbo Ramjet with Expander (ATREX) propulsion system, which is a derivative of a Russian concept involving inlet pre-coolers and a tip-turbine operated by fuel circulated the inlet pre-cooler and combustor heat exchangers. The inlet for this system will be tested in the 1X1 foot Supersonic Wind Tunnel in 1999, and planning is in progress for a possible full scale test in the 10X10 Supersonic Wind Tunnel in 2001[8].

Other Hypersonic Propulsion Systems

In addition to RBCC and TBCC, other propulsion technologies offer the potential for a breakthrough in the performance or cost of hypersonic systems. Pulsed detonation engines, which take advantage of the efficiencies of detonation as opposed to deflagration in traditional aeropropulsion devices, are the subject of a recently initiated propulsion technology project at GRC. Among many challenges, the GRC pulsed detonation engine technology program will focus on the inlet and fuel/air mixing technologies, as well as engine controls for this unsteady propulsion device.

Hypersonic Propulsion Facilities

GRC's capability to conduct hypersonic propulsion research is enhanced by a suite of test facilities that allow a range of test conditions, scales, and facility complexity and cost. The Hypersonic Tunnel Facility, a Mach 5 to 7 capability non-vitiated blow-down facility at GRC's satellite Plum Brook Station, is premiere among them. It is expected to be used for testing of hypersonic propulsion systems during 1999. The 1X1 foot Supersonic Wind Tunnel, capable of operation from about Mach 2.5 to Mach 6, allows the testing of models at a relatively low cost, facilitating the research process through the potential for model modification and re-testing. Hypersonic propulsion systems are also required to operate through the subsonic and supersonic speed ranges. GRC's suite of propulsion facilities, including the 10X10 Supersonic Wind Tunnel, the 8X6/9X15 Wind Tunnel, the Propulsion Systems Laboratory (2 cells with altitude capability up to 25 km at greater than Mach 3), and the direct-connect Engine Components Research Laboratory, provide the potential for a wide range of hypersonic propulsion system testing in one geographic area[9,10,11,12,13].

Conclusion

NASA's Glenn Research Center stands ready to pioneer the frontier of hypersonic propulsion technology into the next millennium. As NASA continues to focus on space transportation as the most promising application of hypersonic propulsion for civilian use, GRC's projects in RBCC, TBCC, and newly emerging technologies, combined with its premiere propulsion facilities, offer the potential for a dramatic reduction in the cost of access to space.

References

[1] Aeronautics & Space Transportation Technology: Three Pillars for Success, Office of Aeronautics and Space Transportation Technology (now Office of AeroSpace Technology), March, 1997.

[2] Propulsion Systems Research and Technology Base Level I Program Plan, April, 1997.

[3] Smith, Timothy D., Steffen, Christopher J. Jr., Yungster, Shaye, Keller, Dennis J., Rocket-Based Combined Cycle Nozzle Analysis Using NPARC, AIAA-98-0954, Jan. 1998.

[4] Trefny, Charles J., An Air-Breathing Launch Vehicle Concept for Single-Stage-to-Orbit, AIAA-99-2730.

[5] Smith, Timothy D., Steffen, Christopher J. Jr., Yungster, Shaye, Keller, Dennis J., RBCC Rocket Mode Parametric Performance Analysis Using CFD, Propulsion Engineering Research Center Ninth Annual Symposium, Oct. 1997.

[6] Trefny, C.J., and Benson, T.J., An Integration of the Turbojet and Single-Throat Ramjet, 1995 Airbreathing Propulsion Subcommittee, sponsored by the Joint Army-Navy-NASA-Air Force Interagency Propulsion Committee.

[7] Walker, James F., Thomas, Scott. R., Sorge, Richard N., Demonstration of J85 Turbojet Operation at Mach 3 Using Pre-compressor Water Injection, 35th JANNAF Combustion Subcommittee / Propulsion Systems Hazards Subcommittee / and AirBreathing Propulsion Subcommittee Joint Meeting, December 1998.

[8] Tanatsugu, N., et al, Development Study on ATREX Engine, AIAA 96-4553.

[9] Soeder, Ronald H., NASA Lewis 8- By 6-Foot Supersonic Wind Tunnel User Manual, NASA Technical Memorandum 105771, February 1993.

[10] Soeder, Ronald H., NASA Lewis 9- By 15-Foot Low-Speed Wind Tunnel User Manual, NASA Technical Memorandum 106247, August 1993.

[11] Soeder, Ronald H., NASA Lewis Propulsion Systems Laboratory Customer Guide Manual, NASA Technical Memorandum 106569, August 1994.

[12] Colantonio, Renato O., et al, Advanced Combustor Rig at NASA Lewis Research Center's Engine Components Research Laboratory, NASA Technical Memorandum 4546, March 1994.

[13] Soeder, Ronald H., User Manual for NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel, NASA Technical Memorandum 105626, November 1995.

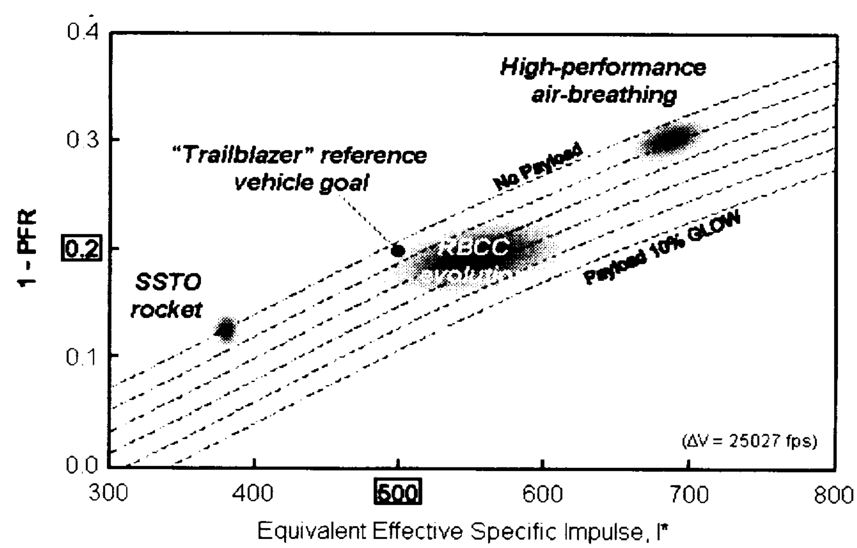

Figure 1—Trailblazer Performance Goals and Potential Evolution of RBCC-Powered SSTO Launch Vehicles.

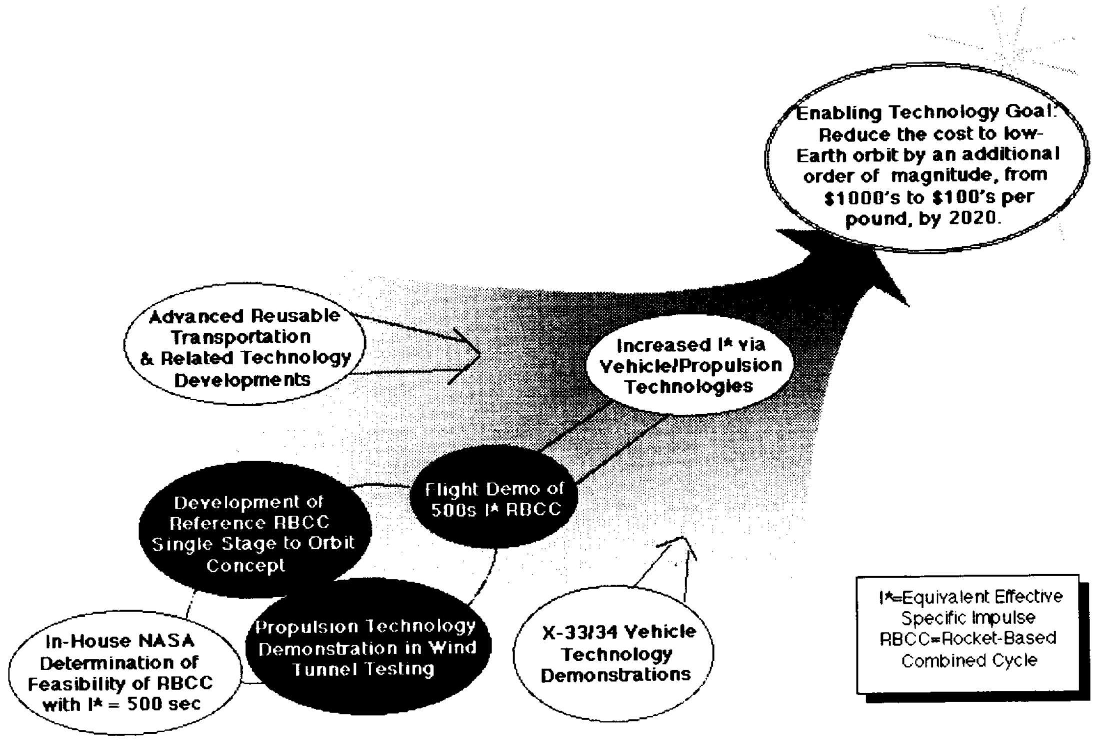

Figure 2—Approach to Third Pillar Goal.

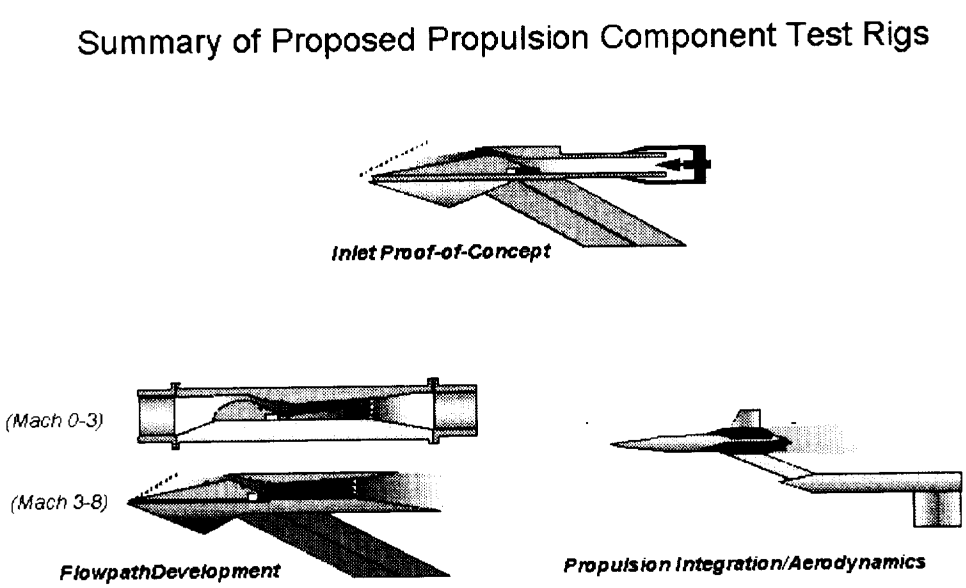

Figure 3—Summary of Proposed Propulsion Component Test Rigs.

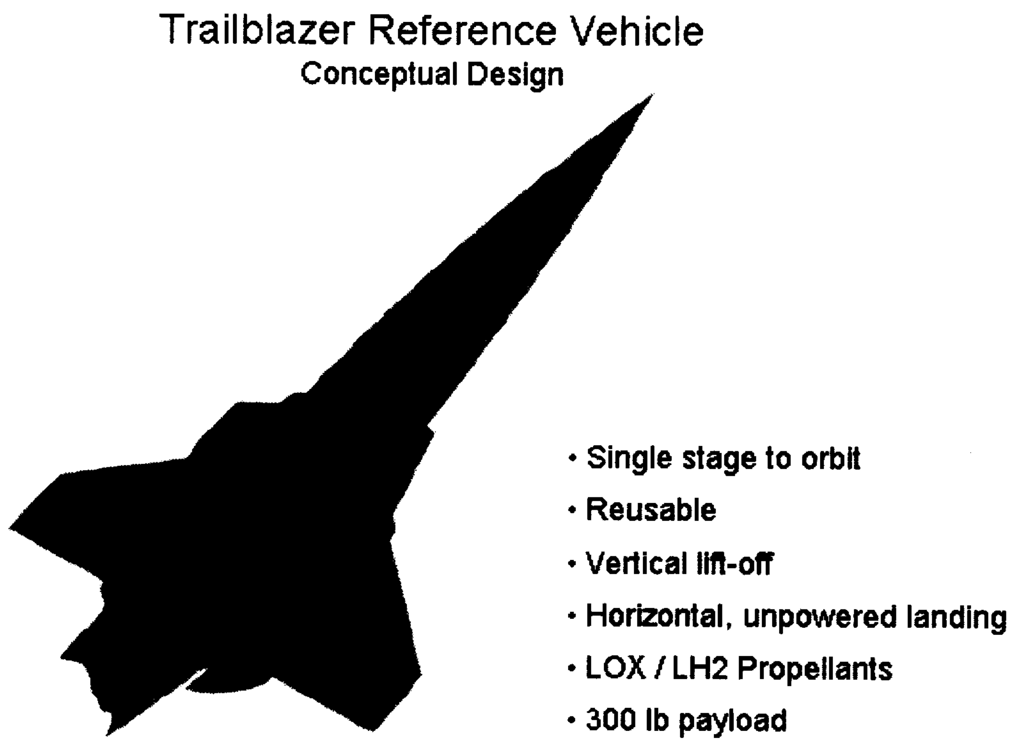

Figure 4—Trailblazer Reference Vehicle (Conceptual Design).

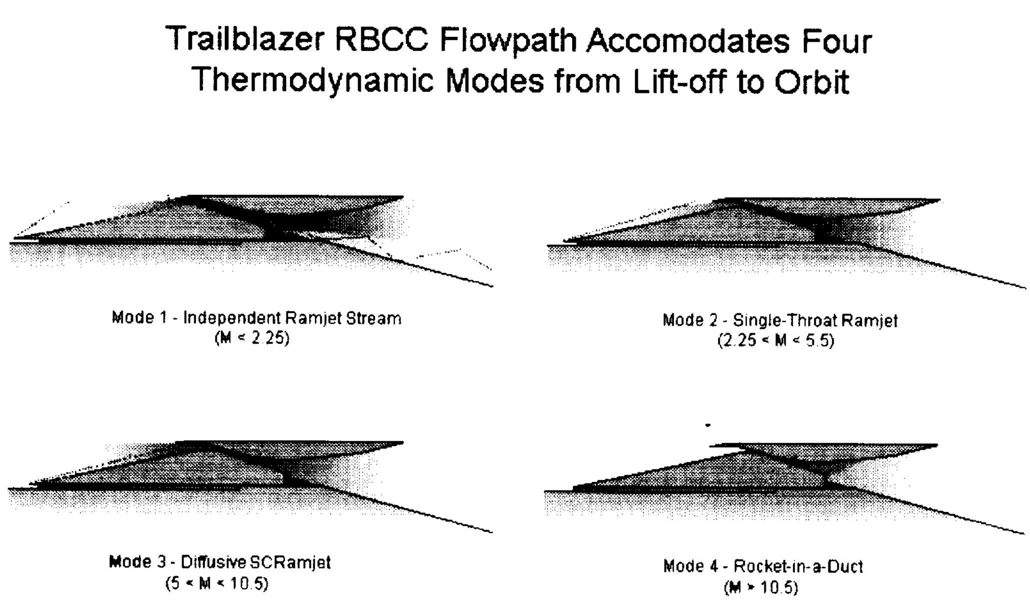

Figure 5—Trailblazer RBCC Flowpath Accommodates Four Thermodynamic Modes From Lift-off to Orbit.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1999	Technical Memorandum

4. TITLE AND SUBTITLE

NASA Glenn Research Center's Hypersonic Propulsion Program

5. FUNDING NUMBERS

WU-523-61-13-00

6. AUTHOR(S)

Donald T. Palac

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E-11696

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—1999-209185

11. SUPPLEMENTARY NOTES

Prepared for the 14th International Symposium on Airbreathing Engines cosponsored by AIAA, AAF, ATI, CASI, DGLR, RAS, UKRAS, Florence, Italy, September 5–10, 1999. Responsible person, Donald T. Palac, organization code 0142, (216) 977-7094.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 07 Distribution: Nonstandard

This publication is available from the NASA Center for AeroSpace Information, (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

NASA Glenn Research Center (GRC), as NASA's lead center for aeropropulsion, is responding to the challenge of reducing the cost of space transportation through the integration of air-breathing propulsion into launch vehicles. Air-breathing launch vehicle (ABLV) propulsion requires a marked departure from traditional propulsion applications, and stretches the technology of both rocket and air-breathing propulsion. In addition, the demands of the space launch mission require an unprecedented level of integration of propulsion and vehicle systems. GRC is responding with a program with rocket-based combined cycle (RBCC) propulsion technology as its main focus. RBCC offers the potential for simplicity, robustness, and performance that may enable low-cost single-stage-to-orbit (SSTO) transportation. Other technologies, notably turbine-based combined cycle (TBCC) propulsion, offer benefits such as increased robustness and greater mission flexibility, and are being advanced, at a slower pace, as part of GRC's program in hypersonics.

14. SUBJECT TERMS

Hypersonic propulsion

15. NUMBER OF PAGES

12

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	