Hypersonic propulsion work supported by the United States National Aeronautics and Space Administration had a primary focus on Space Transportation during the period from 1995 to 2005. The framework for these advances was established by policy and pursued with substantial funding. Many noteworthy advances were made, highlighted by the pinnacle flights of the X-43. This paper reviews and summarizes the programs and accomplishments of this era. The accomplishments are compared to the goals and objectives to lend an overarching perspective to what was achieved.

At least dating back to the early days of the Space Shuttle program, NASA has had the objective of reducing the cost of access to space and concurrently improving safety and reliability. National Space Transportation Policy in 1994 coupled with a base of prior programs such as the National Aerospace Plane and the need to look beyond the Space Shuttle program set the stage for NASA to pursue Space Transportation Advances. Programs defined to pursue the advances represented a broad approach addressing classical rocket propulsion as well as airbreathing propulsion in various combinations and forms. The resulting portfolio of activities included systems analysis and design studies, discipline research and technology, component technology development, propulsion system ground test demonstration and flight demonstration.

The types of propulsion systems that were pursued by these programs included classical rocket engines, “aerospike” rocket engines, high performance rocket engines, scram jets, rocket based combined cycles, and turbine based combined cycles. Vehicle architectures included single and two stage vehicles. Either single types of propulsion systems or combinations of the basic propulsion types were applied to both single and two stage vehicle design concepts. Some of the propulsion system design concepts were built and tested at full scale, large scale and small scale. Many flight demonstrators were conceptually defined, fewer designed and some built and one flown to demonstrate several technical advancements including propulsion. The X-43 flights were a culmination of these efforts for airbreathing propulsion.

During the course of that period, there was a balance of funding and emphasis toward rocket propulsion but still very substantial airbreathing propulsion effort. The broad objectives of these programs were to both advance and test the state of the art so as to provide a basis for options to be pursued for broad space transportation needs, most importantly focused on crew carrying capability. NASA cooperated with the Department of Defense in planning and implementation of these programs to make efficient use of objectives and capabilities where appropriate. Much of the work was conducted in industry and academia as well as Government laboratories. Many test articles and data-bases now exist as a result of this work. At the conclusion of the period, the body of work made it clear that continued research and technology development was warranted, because although not ready for a NASA system development decision, results continued to support the promise of air-breathing propulsion for access to space.
Overview of Progress
From 1995 to 2005
ISABE 2007
Beijing, China

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Introduction

- NASA Hypersonic Investments 1995-2005 focused on Access to Space

- Objectives
  - Dramatic cost reductions
  - Manifold increases in reliability and safety

- Implementation
  - 2nd Generation
  - 3rd Generation (including hypersonics)
NASA’s New Integrated Space Transportation Plan (ISTP)

Space Shuttle Life
Extension Upgrades

Orbital Space Plane (OSP)
- ISS Crew Rescue by 2010
- ISS Crew Transfer by 2012

Next Generation Launch Technology (NGLT)
- Enabling Future National Launch Capabilities
Large 3rd Generation RLV Design Space

- Over 30 concepts (primarily using airbreathing propulsion)
- Selected by aerospace community (NASA, DOD, Industry)
- Probabilistic systems analysis for key technologies
Air Breathing Hypersonics
Access to Space Roadmap

Today

2005

2010

2015

2020

2025

Scramjet Flight Demos

Propulsion Ground Testbeds

Combined Cycle Flight Demo(s)

Airframe Testbeds

Supporting Component Research and Technology

X-43A
Ma 7
X-43C
Ma 5 to 7
X-43D
Ma 15

HC/H₂ Scramjet Turbine & Rocket Based Combined Cycle

Ma 0.7-7 Turbine &/or Rocket Based X-43B

Large Scale Reusable Flight Demo

Full Scale Development

IOC
NASA HYPERSONIC FLIGHT DEMONSTRATION PROJECTS

Hyper-X and ASTP Flight Demonstrators

**X-43A**
- Uncooled DMSJ
- Expendable
- H2 fuel
- 10 sec. powered
- M=7, 10
- First flight failure 6/01

**X-43C**
- Cooled DMSJ
- Expendable
- H/C fuel
- 5 min. powered
- M 5 to 7

**X-43B**
- Cooled RBCC
- Reusable
- H/C fuel
- 10+ min. powered
- M 0.7 to 7

**X-43D**
- Cooled TBCC
- RTA Turbojet
- Reusable
- H/C fuel
- 10+ min. powered
- M 0.7 to 7

Uncooled DMSJ
- Expendable
- H2 fuel
- 10 sec. powered
- M=7, 10

Cooled DMSJ
- Expendable
- H/C fuel
- 5 min. powered
- M 5 to 7

Cooled DMSJ
- Expendable
- LH2 fuel
- 10+ sec. powered
- M 15

Incremental development leading to 2025 IOC
Demonstrator Application

To Airbreathing Corridor

- To Orbit
- X-43C Flight Test
- TBCC Ground Testbed
- RBCC Ground Testbed & X-43B
- Large Scale Demonstrator
- X-43A
- X-43C
- High Speed Turbine
- RBCC
- X-43D
- Turbofan
- Ram/Scramjet
- Rocket

Altitude (1,000 ft)

Propulsion Mode:
- Turbofan
- Ram/Scramjet
- Rocket

Mach
Enabling “Firsts” in Space Launch Technology

Booster Engine Prototype
- Highly reliable hydrocarbon fueled rocket booster engine
- High reliability, long life hydrogen rocket engines

Auxiliary Propulsion
- Non-toxic propellants for orbital propulsion

Vehicle Research and Technology
- Airframes capable of containing cryogenic propellants and reentering the Earth’s atmosphere
- Durable high temperature thermal protection systems
- An intelligent, autonomous “all electric” launch system

Propulsion Research & Technology
- Long life, lightweight high temperature materials, seals and components

X-43A and C
- 1st controlled flight of a vehicle powered by a scramjet from Mach 5 - 7 and 10

Revolutionary Turbine Accelerator
- Lightweight, long life jet engines capable of flight at Mach 4
Accomplishments

- Analytical Methods
- Systems Analysis and concept exploration
- Supporting Technologies
  - High Temperature materials and structures
  - Aerosciences
- Components
- Aerodynamic Database
Measuring Our Progress

X-43A
- Redesign completed
- 2nd Flight - Mach 7
- 3rd Flight - Mach 10

X-43C
- Concept Design and System Requirements Complete
- Award of Demonstrator and Launch Vehicle Contracts

Turbine Based Combined Cycle
- 2002
  - Awarded Mach 4 demonstrator engine contract to GE Aircraft Engines
- 2003
  - Complete Project Readiness Review and Definition of System Requirements
- 2004
  - Complete design of Mach 2.5 fan

Rocket Based Combined Cycle
- Awarded Contract to Aerojet, Pratt and Whitney, Rocketdyne Consortium. System Requirements Complete
- Complete concept design
- Complete the preliminary design of the ground test engine
Some Examples
NASA’s B–52B launch aircraft cruises to a test range over the Pacific Ocean carrying the third X–43A vehicle attached to a Pegasus rocket on November 16, 2004.
Summary- NASA Hypersonics 1995-2005

- Focus on ambitious safety and cost objectives for access to space
- Substantial progress on variety of fronts
- Preferential direction identified / Achievability not known

- Pinnacle reached with flights of X-43
- At end of period NASA investments reduced
  - Exploration focus
  - Remaining technical challenges