ADDRESSING EMERGING MISSILE PROPULSION REQUIREMENTS WITH THE AIR-TURBO-ROCKET

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Presented at
Rafael

November 3, 2005

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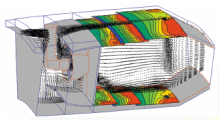
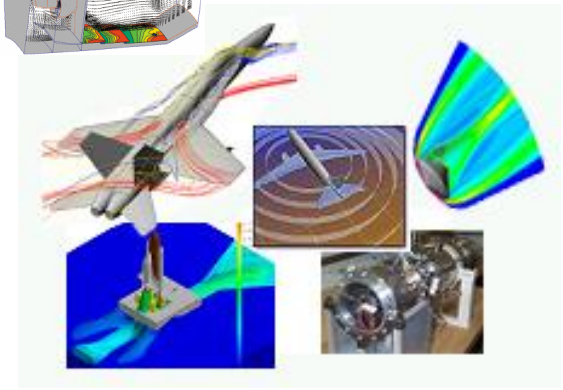
Business Focus Areas

Aerospace





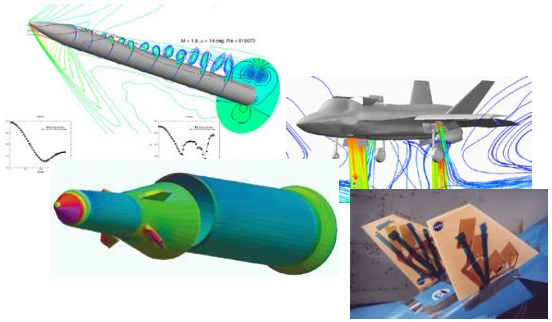
Aeromechanics - Combustion - Propulsion

Space Electronics - Plasma

Bio-Medical & Life Sciences

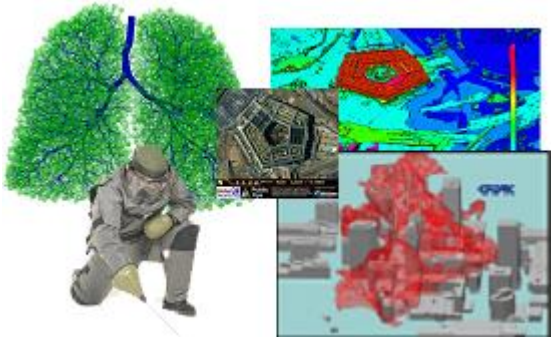
Drug delivery - Bio-Sensors - System Biology - Instruments

Defense



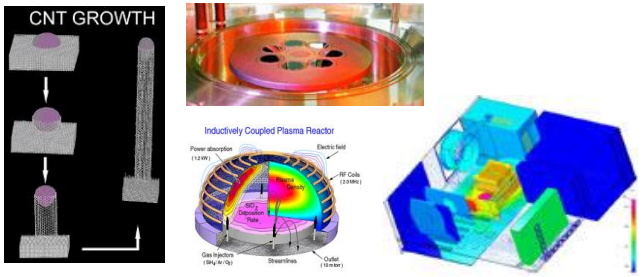
Missile Systems - Aircraft Systems - Space Systems - Radiation Effects – Human Safety

Homeland Security



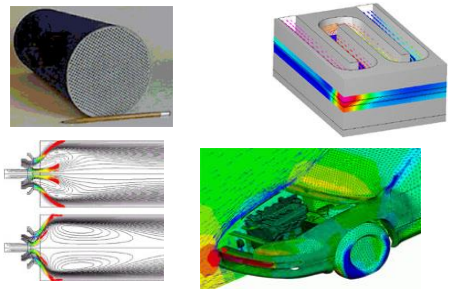
Threat Awareness - Risk Assessment - Sensor Technologies – Human Lethality

Materials and Processes



Semiconductors - IC Fabrication - Plasma - Compound Semiconductors - Nano-materials

Automotive, Chemical & Power



Fuel Cells - Laser Ignition - Climate Control – Industrial Equipment

References

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Air Turbo-Rocket Solid Propellant Development and Testing, M. Ostrander and M. Thomas, AIAA-1997-3258, AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Seattle WA, 1997

Customized Turbomachinery for Solid-Propellant Air Turbo Rockets, J.A. Bossard and M.E. Thomas, AIAA-1997-3257, AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Seattle, WA, 1997

The Influence of Turbomachinery Characteristics on Air Turbo Rocket Engine Operation, J.A. Bossard and M.E. Thomas, AIAA-2000-3308, AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Huntsville, AL, 2000

References

Addressing Emerging Tactical Missile Propulsion Challenges with the Solid Propellant Air-Turbo-Rocket, M.E. Thomas, J.A. Bossard, and M. Ostrander, AIAA-2000-3309, AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Huntsville, AL, 2000

Pintle Motor Challenges for Tactical Missiles, M.J. Ostrander, J.L. Bergmans, M.E. Thomas, and Burroughs, AIAA-2000-3310, AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Huntsville, AL, 2000

Vehicle Performance Optimization Utilizing the Air Turbo-Ramjet Propulsion System; Methodology and Development and Applications, K. Christensen, Dissertation-University of Missouri-Rolla, 1997

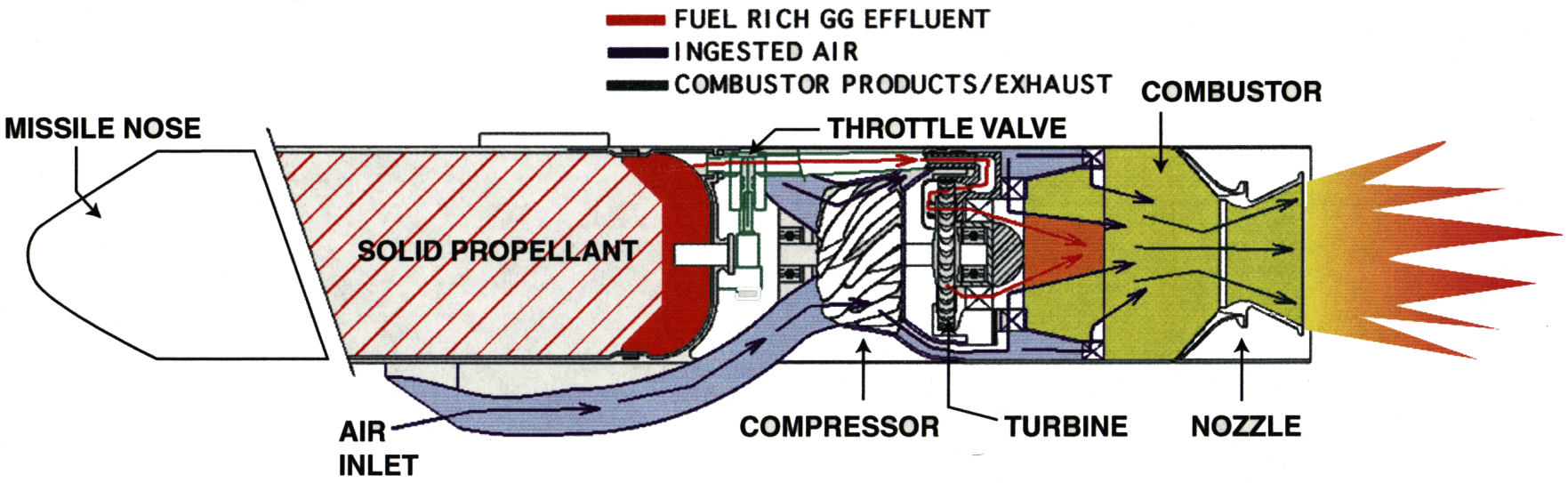
Experimental Evaluation of an Air Turbo Ramjet, J.S. Lilley, S.E. Hecht, B.G. Kirkham, C.A. Eadon, AIAA-1994-3386, AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Indianapolis, IN, 1994

The Air Turbo Rocket

What Is It?

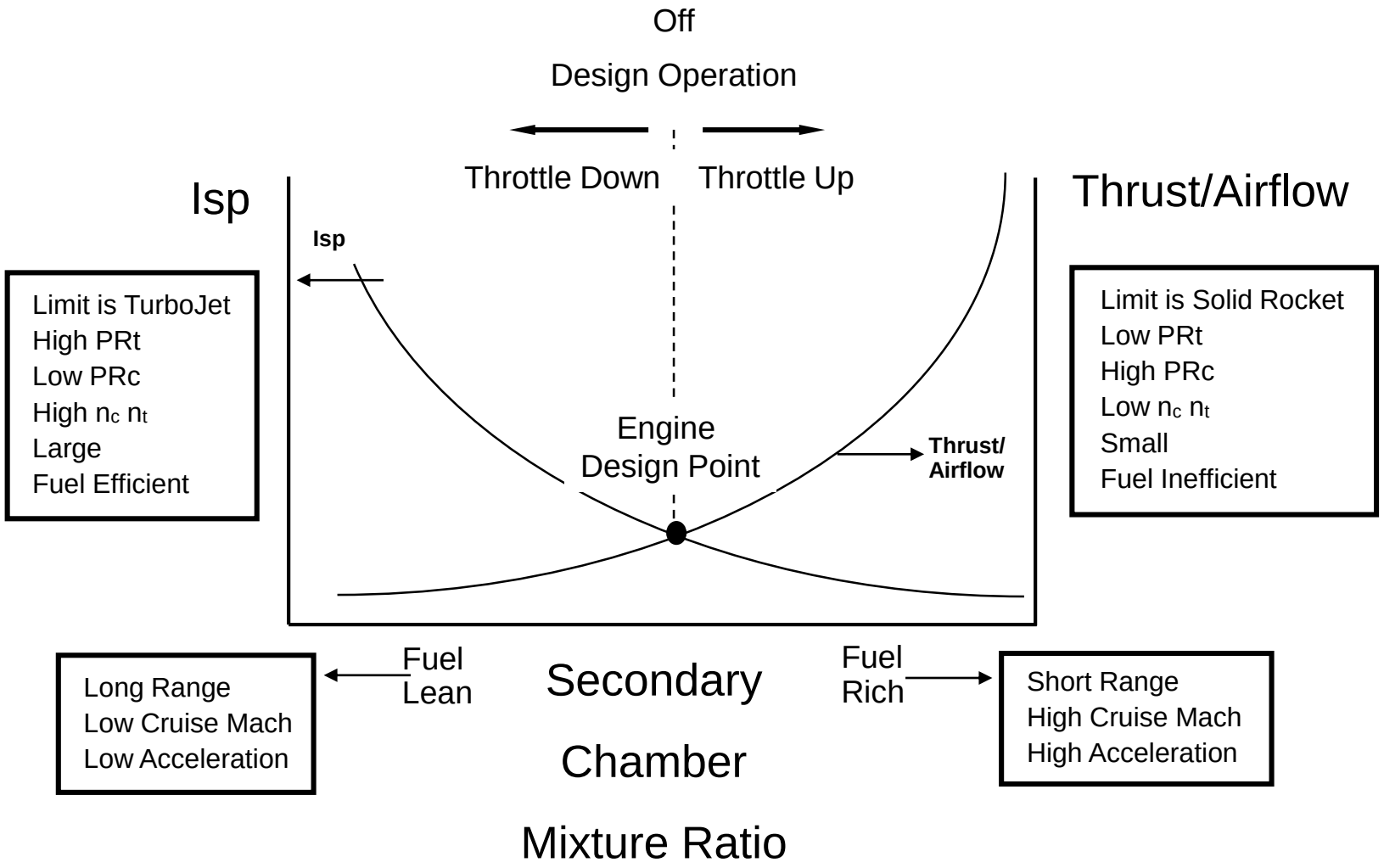
ATR - Air Turbo Rocket:

A Hybrid Propulsion System Blending the High Thrust of a Rocket with the Fuel Economy of a Turbojet



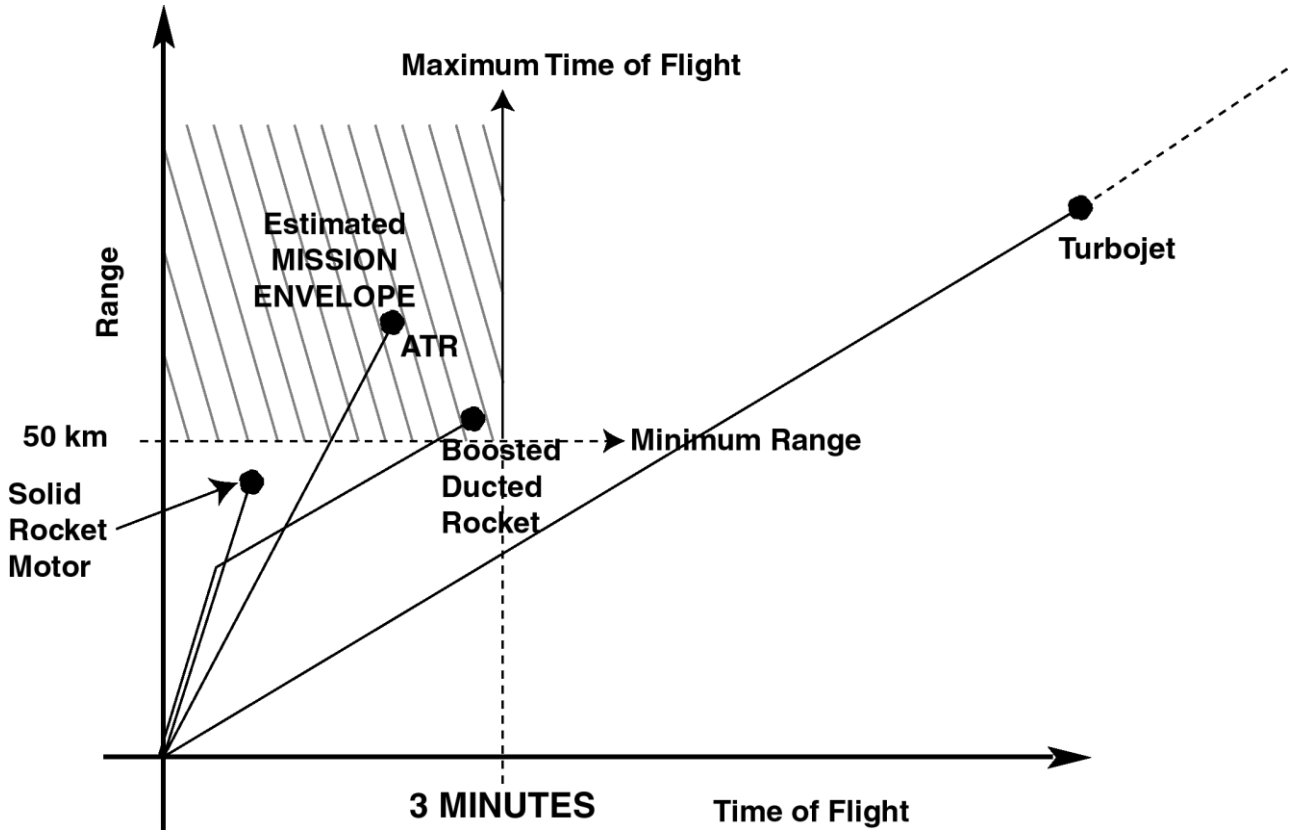
Air Turbo Rocket

Performance Tradeoff



Air Turbo Rocket

Special Attribute



Range vs. TOF

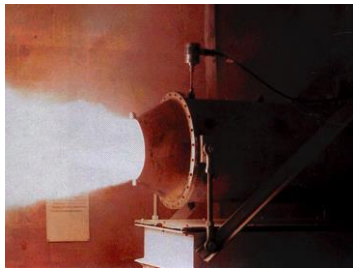
- **Makes Range and TOF Constraints with Margin**

Air Turbo Rocket

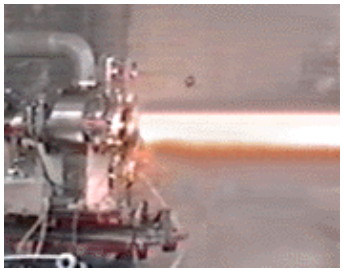
Technology Status

- **Prior ATR Demonstrations**
  - **Solid (2)**
  - **Liquid Bipropellant (1)**
  - **Monopropellant (1)**

Aerojet 1982 - 1989



AMCOM 1988 - 1991

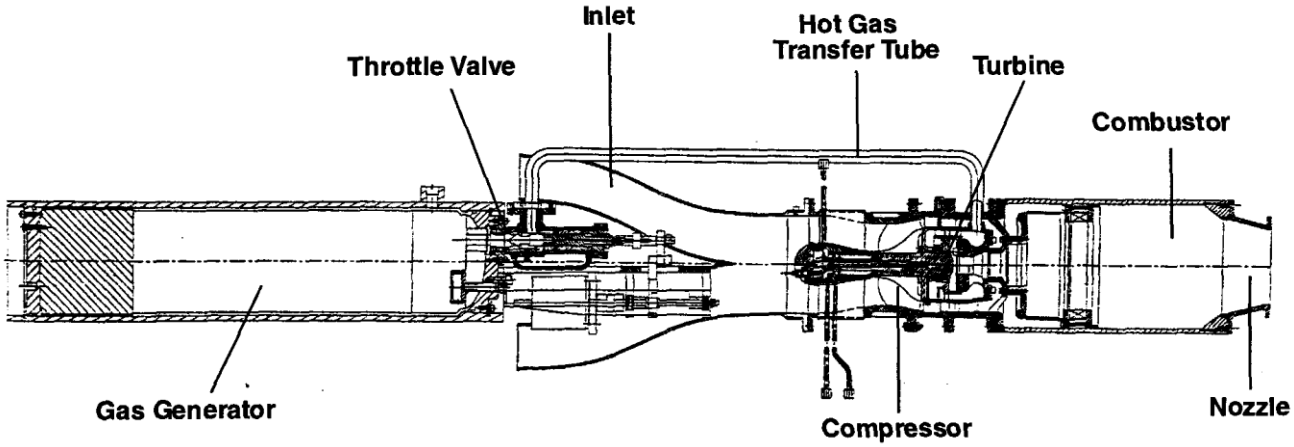


CFDRC 1995 - 2002

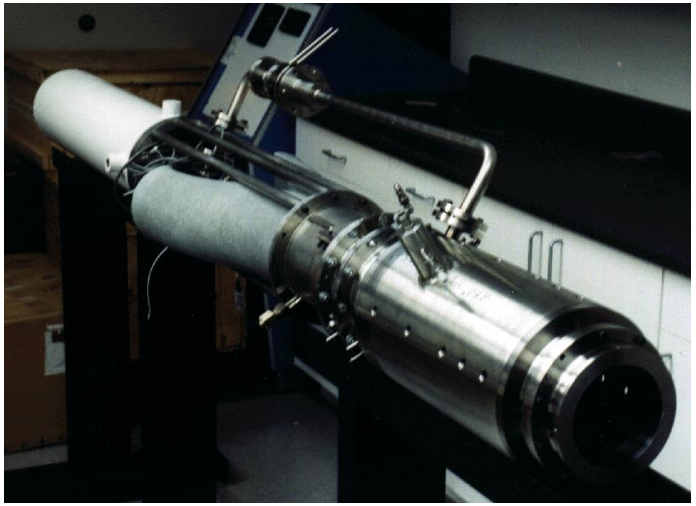
- **High-Performance Six-Inch Developed**
- **Critical Component Demonstrations Completed**
  - **Propellant** - **Turbomachinery** - **Throttling**
- **Studies on Smaller (3 inch Diameter) and Larger (>> 6 inch Diameter) ATRs Scaled from Current Demonstrator Completed**

Air Turbo Rocket

Engine Demonstrator



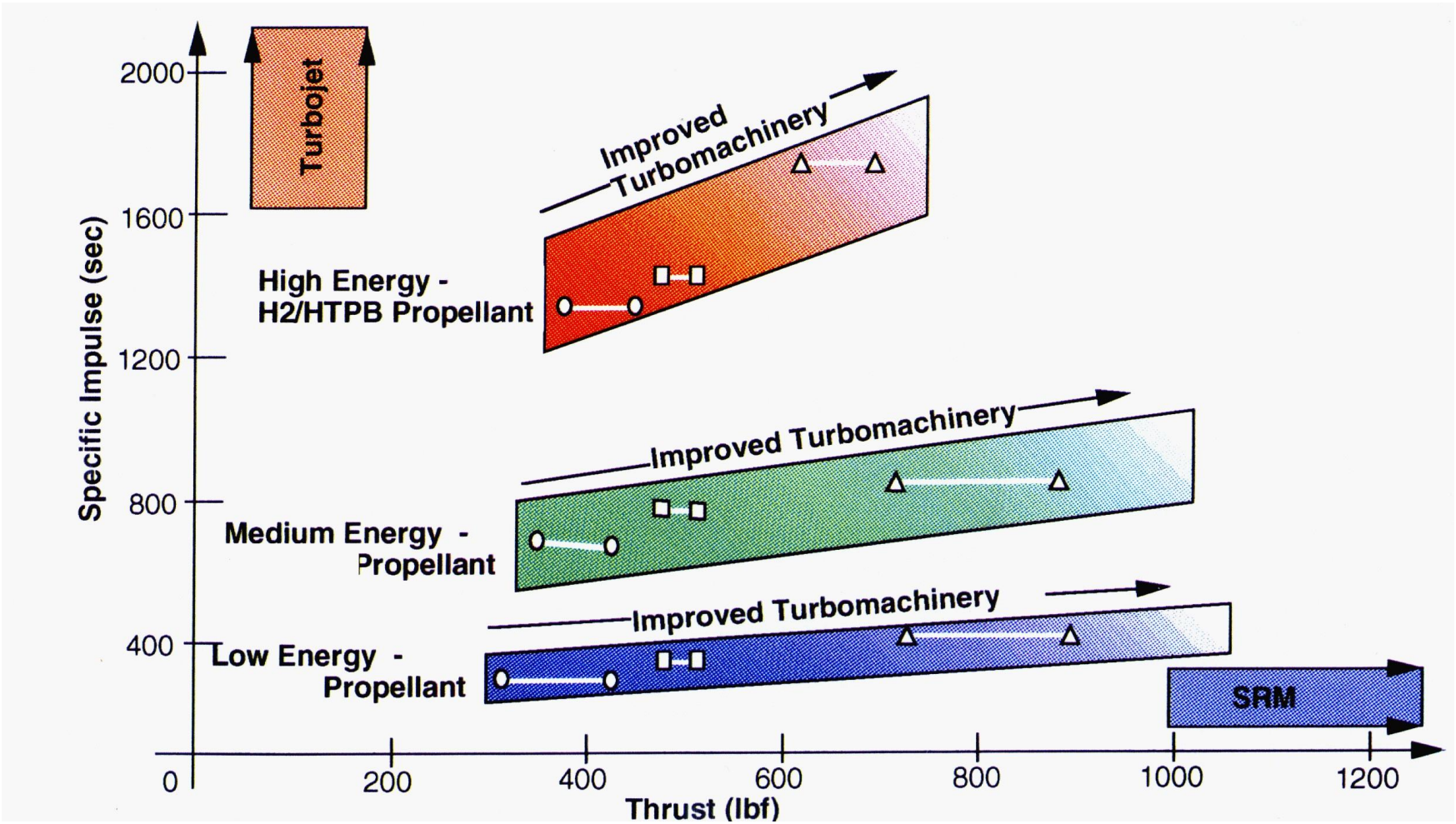
Hardware Schematic



Demonstrator Engine

Air Turbo Rocket

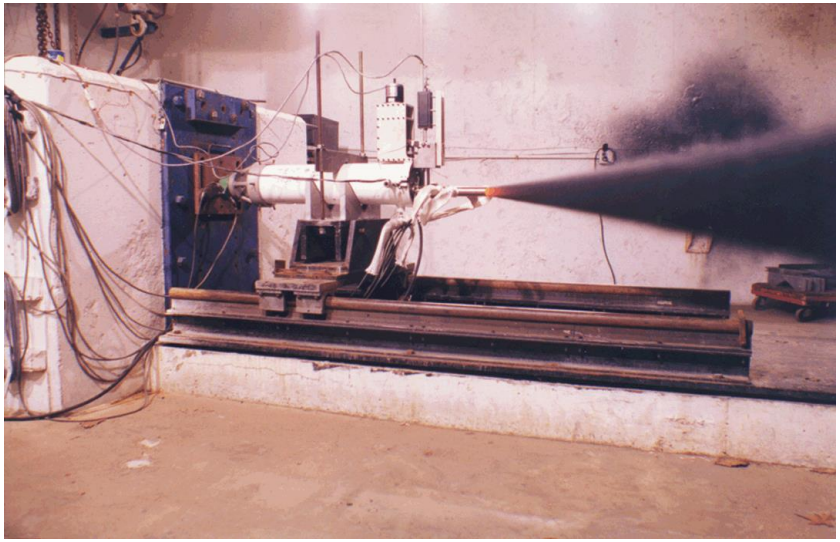
Gas Generator/Turbomachinery Matching Critical



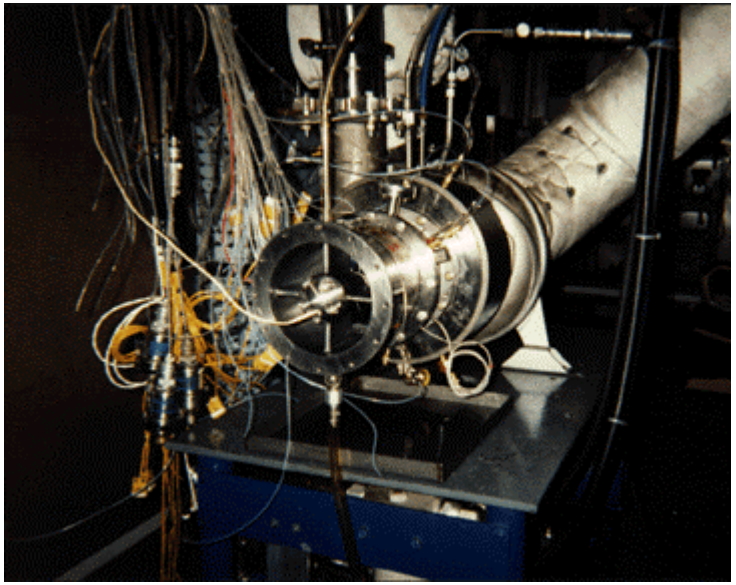
Air Turbo Rocket

Component Testing

Solid Propellant Gas Generator



Turbomachinery

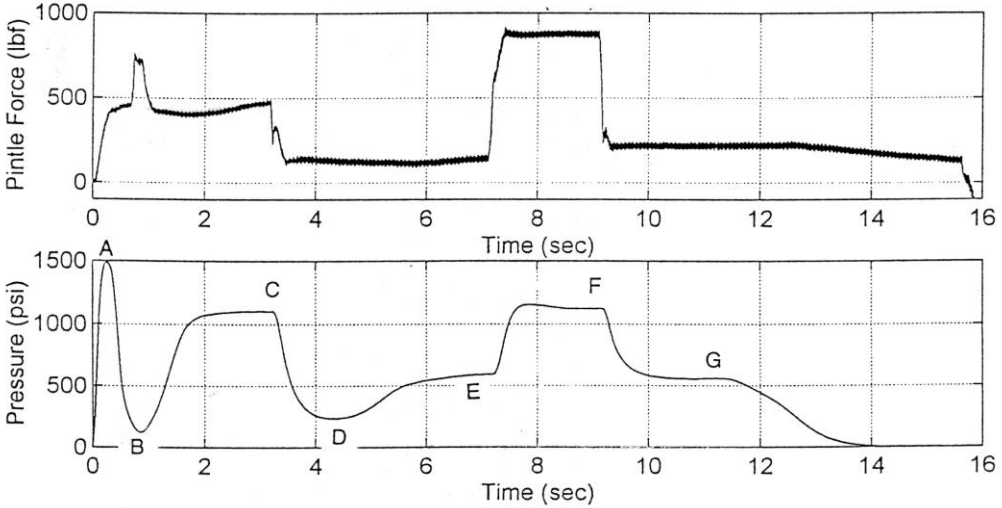


Air Turbo Rocket

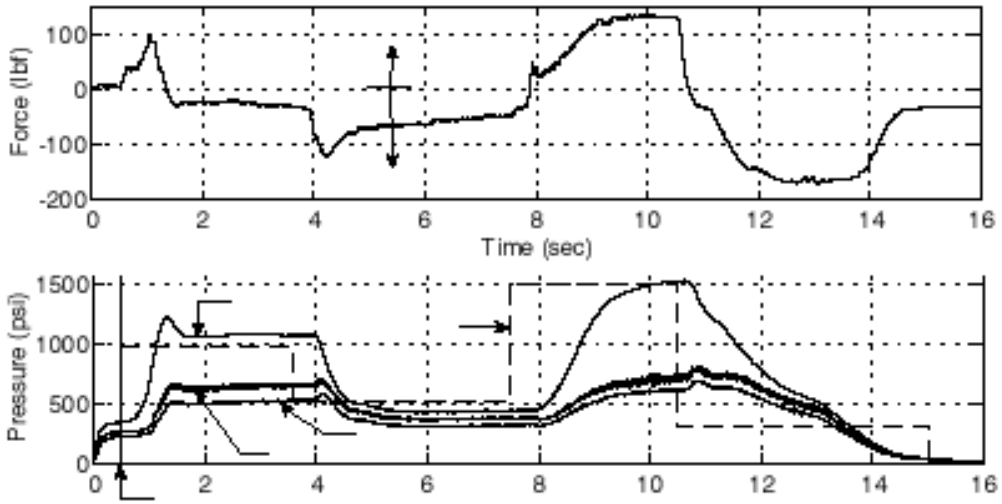
Throttle Valve

Prototype Throttle Valve

No Pressure Balance



Pressure Balance



Turbomachinery

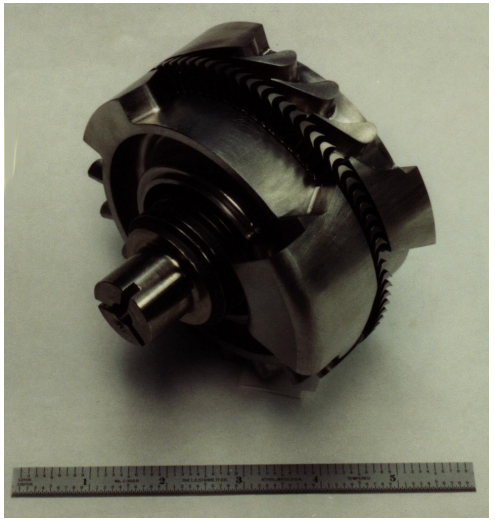
Air Turbo Rocket

Compressor

Turbine

Diffuser

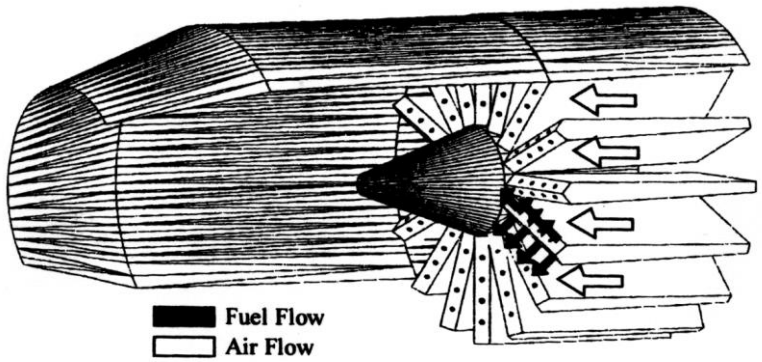
Re-Entry Manifold



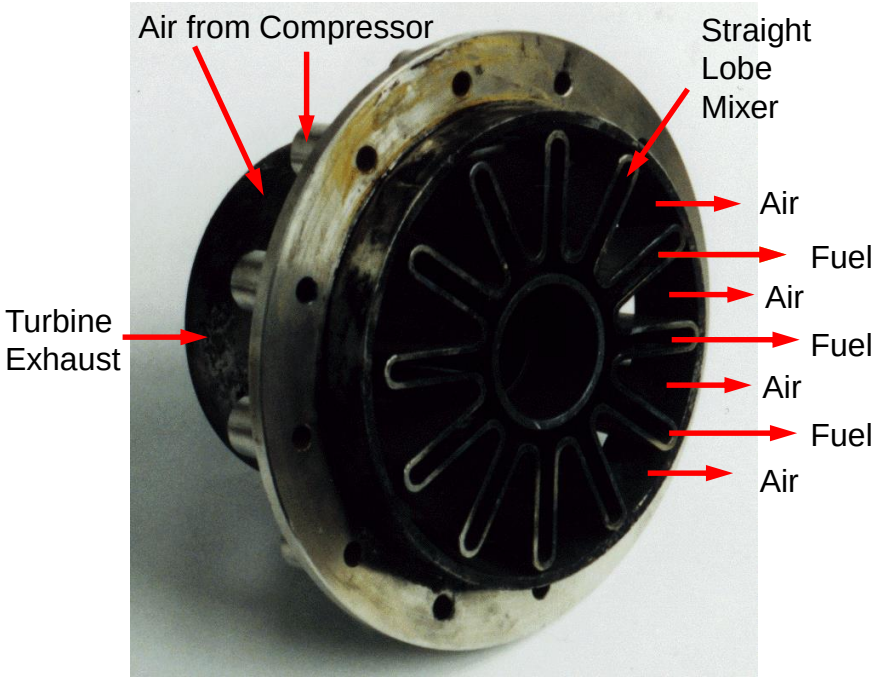
Combustion

Air Turbo Rocket

Aerojet



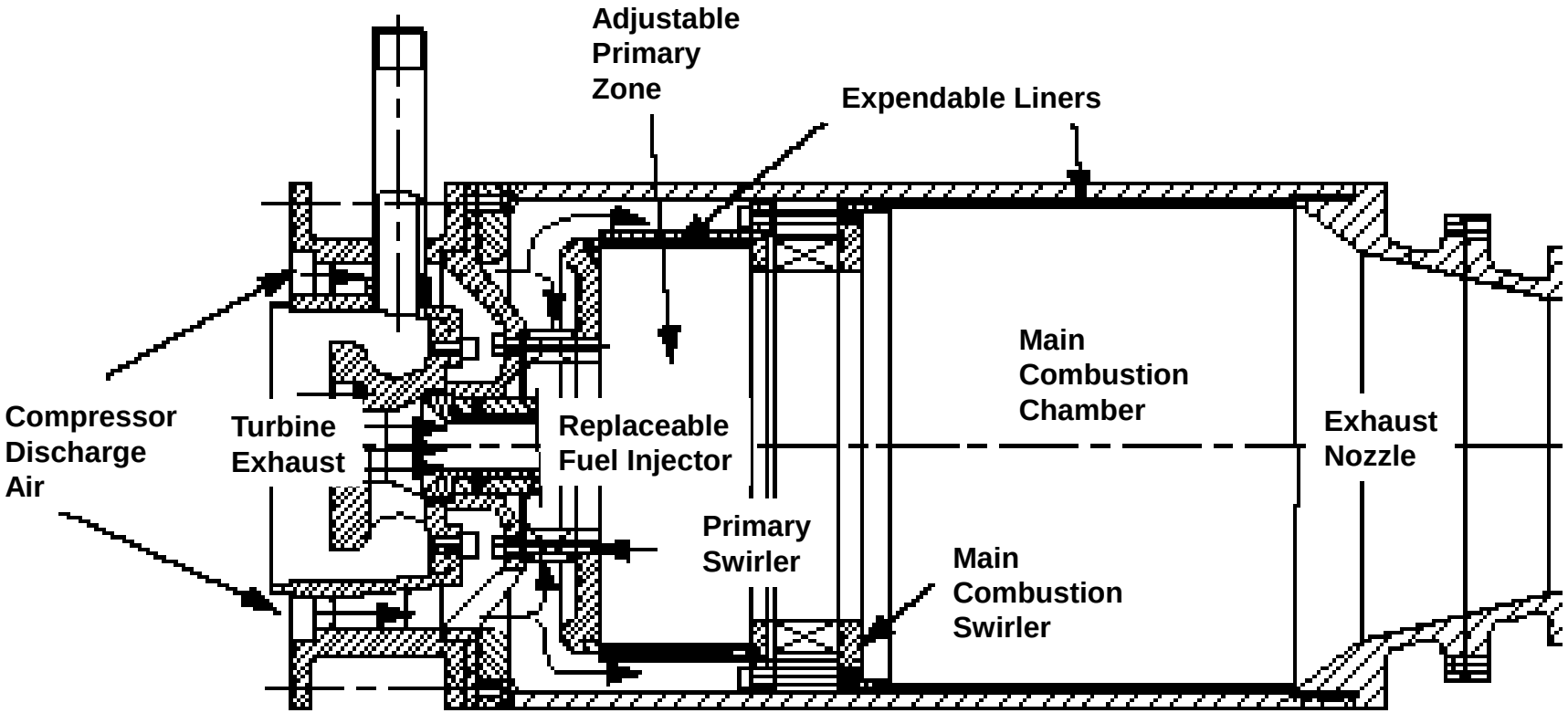
AMCOM



Air Turbo Rocket

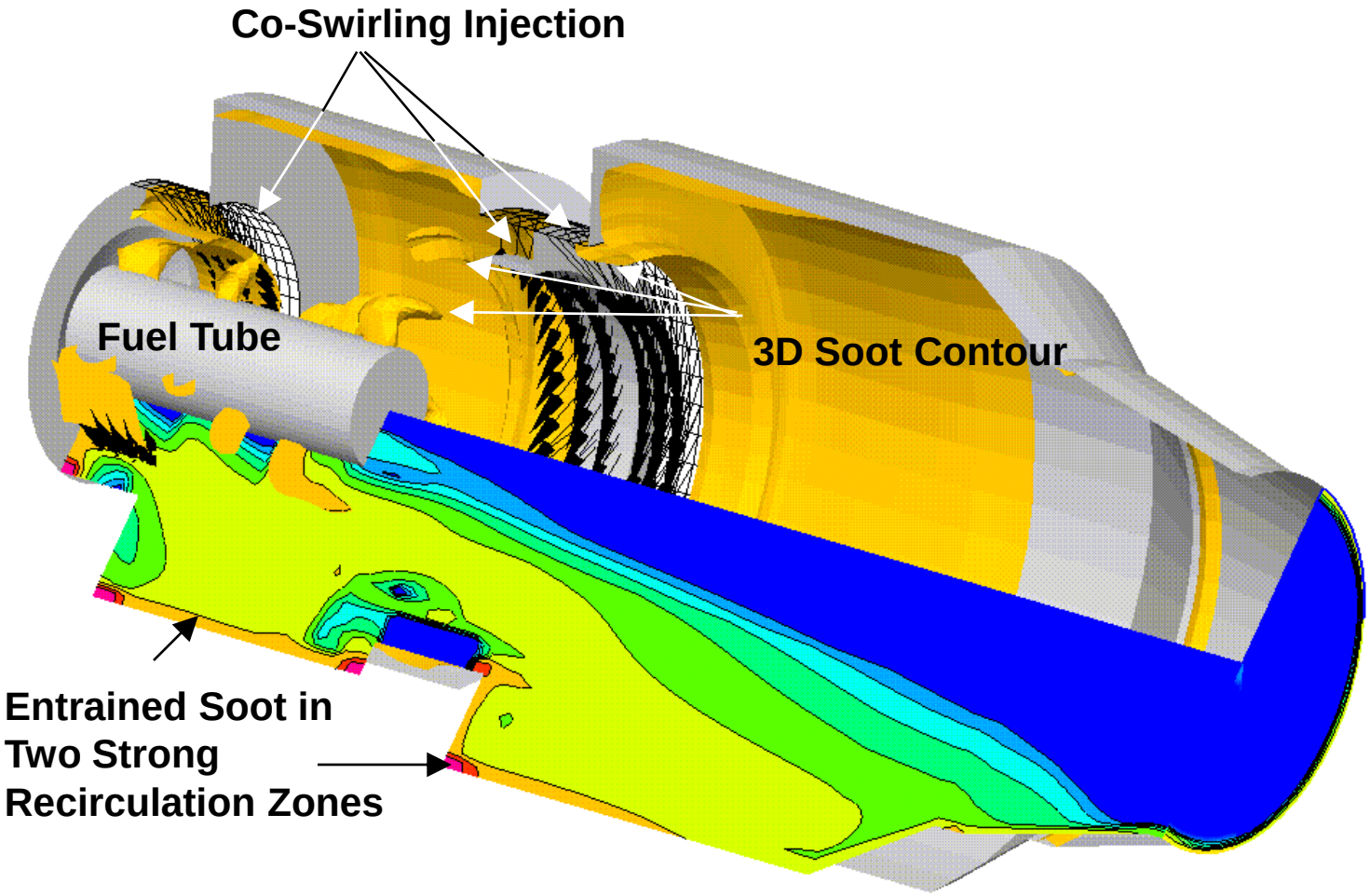
Swirl Stabilized Combustion

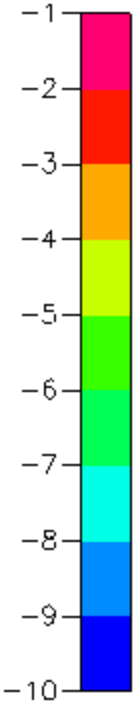
Mixing, Particulate Resident Time and Lean Stability Key Focuses



Air Turbo Rocket

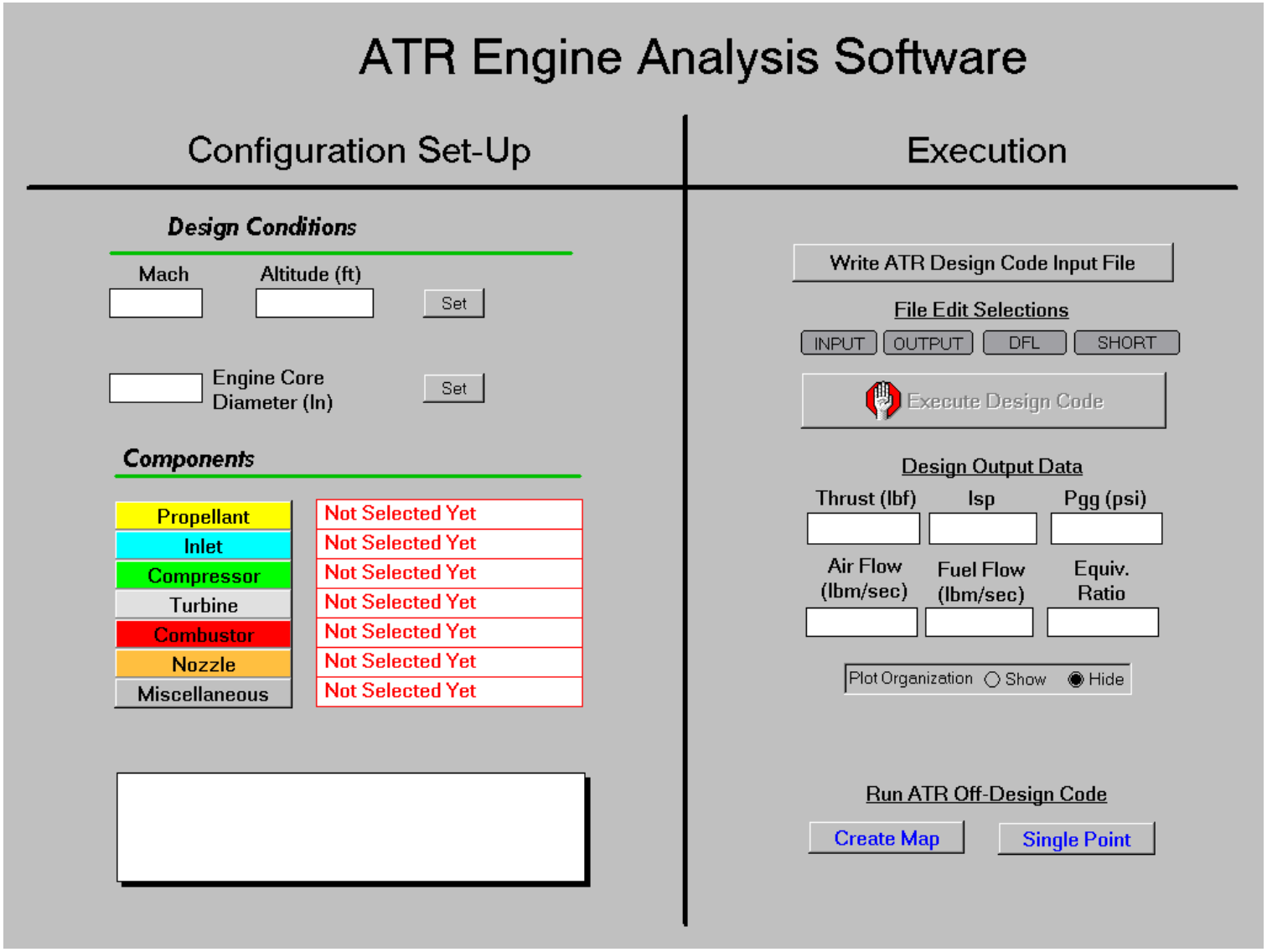
Combustor Simulation



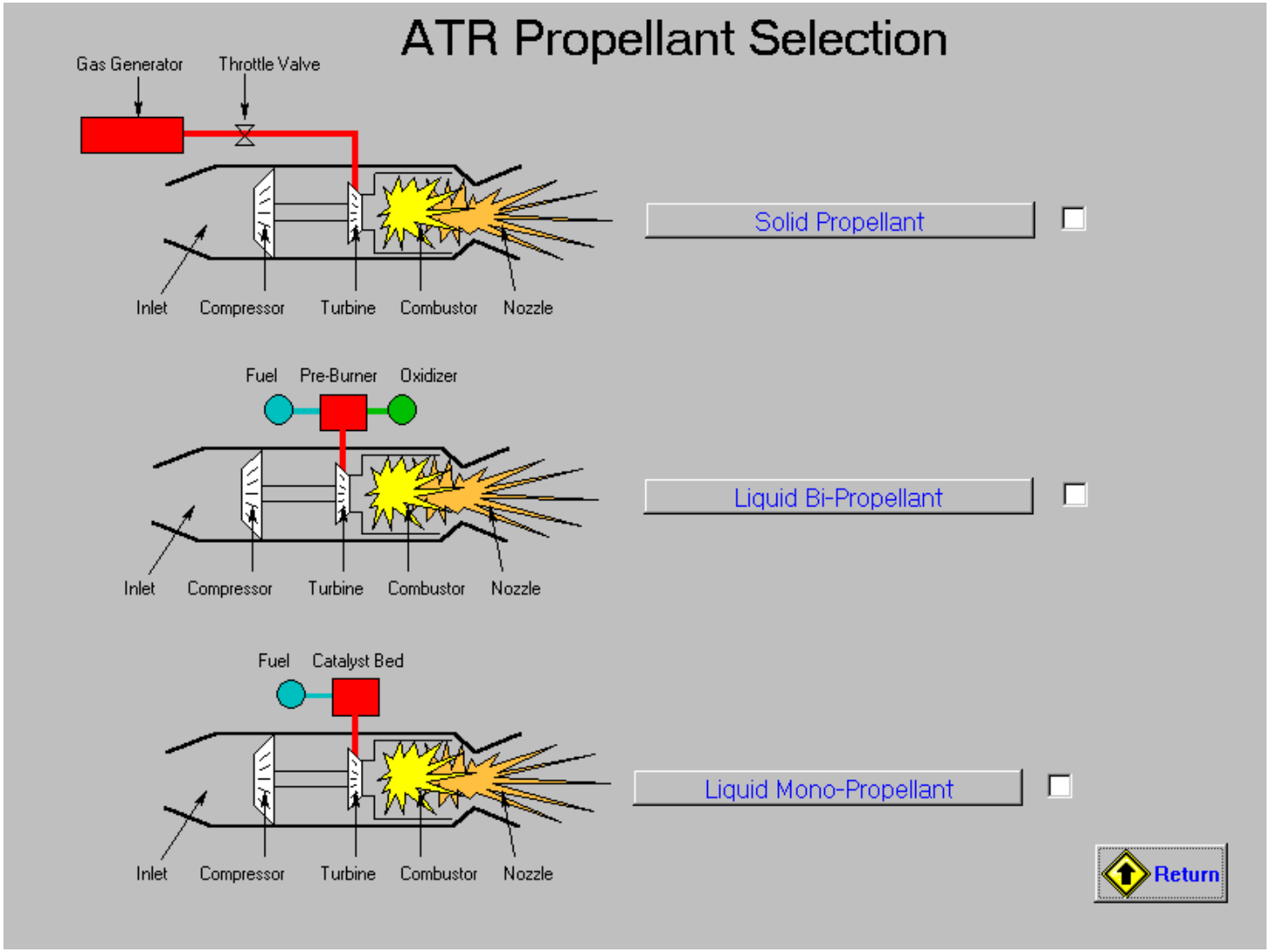


α - Particle Concentration by Volume

Air Turbo Rocket

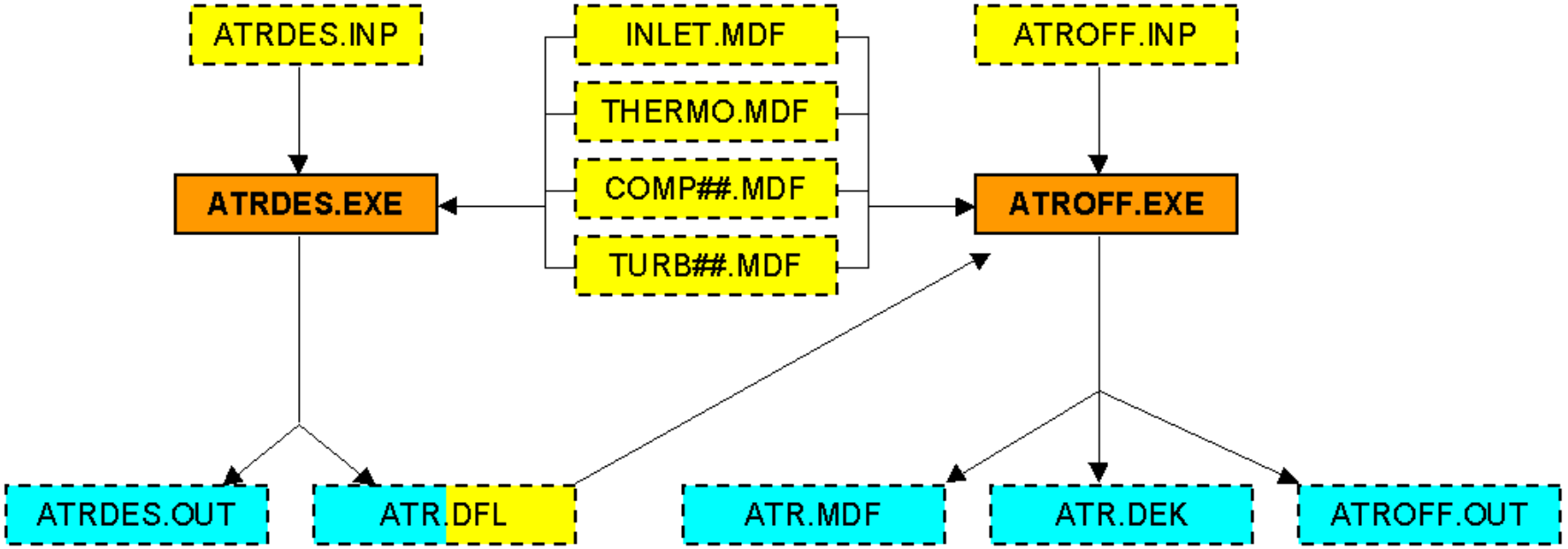


Air Turbo Rocket



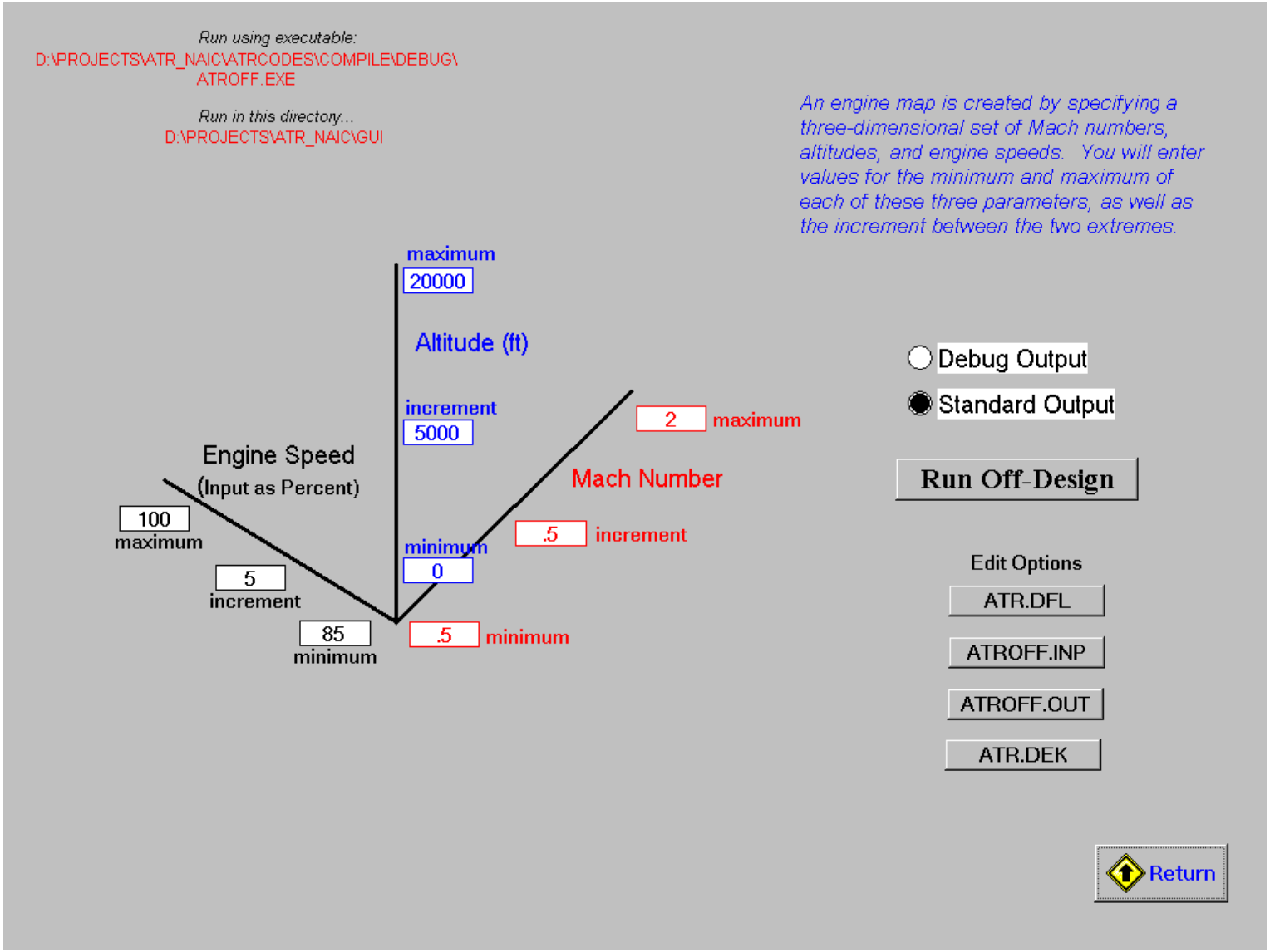
Air Turbo Rocket

File Structure



Air Turbo Rocket

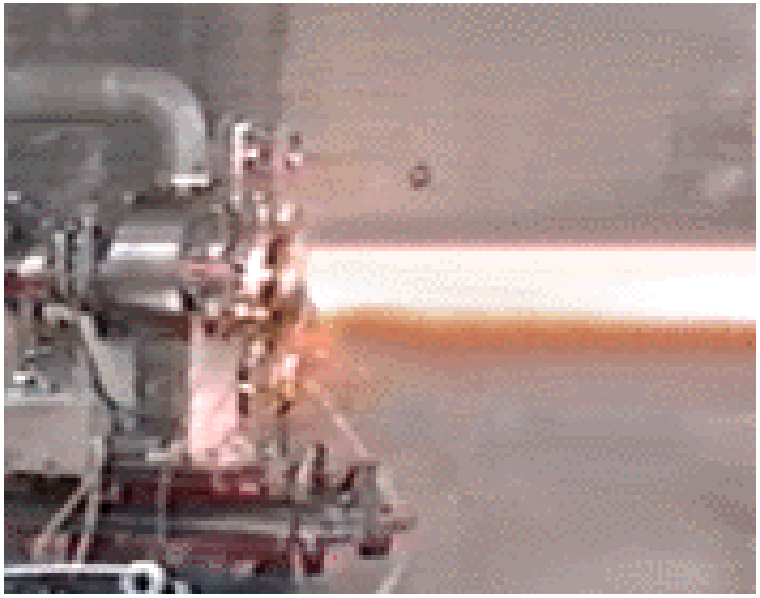
Off-Design Execution



Air Turbo Rocket

Engine Analysis Software Validation

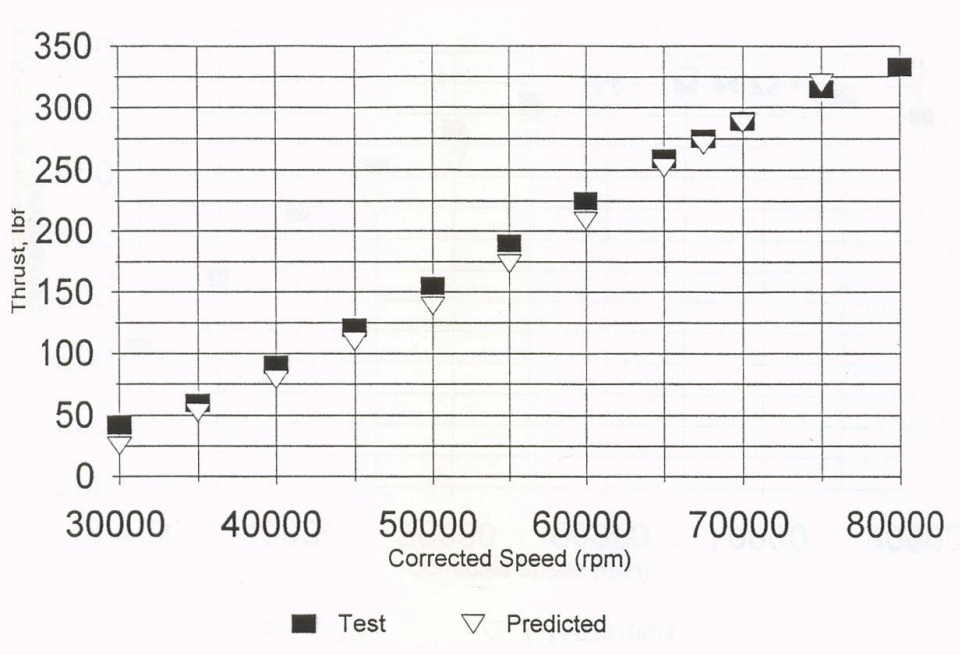
Utilize AMCOM Solid and Monopropellant Test Data



Air Turbo Rocket

System Software Validation

Thrust



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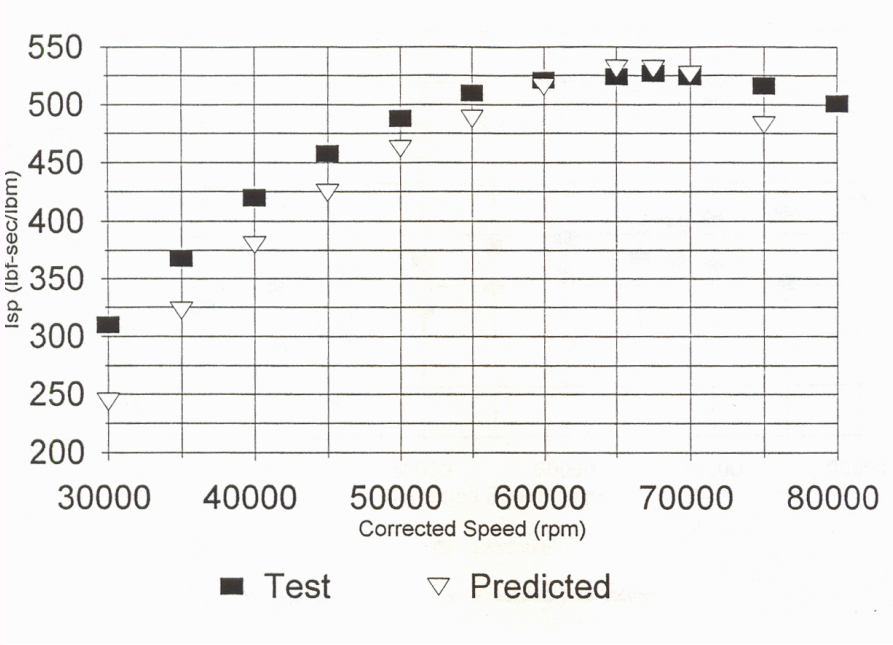
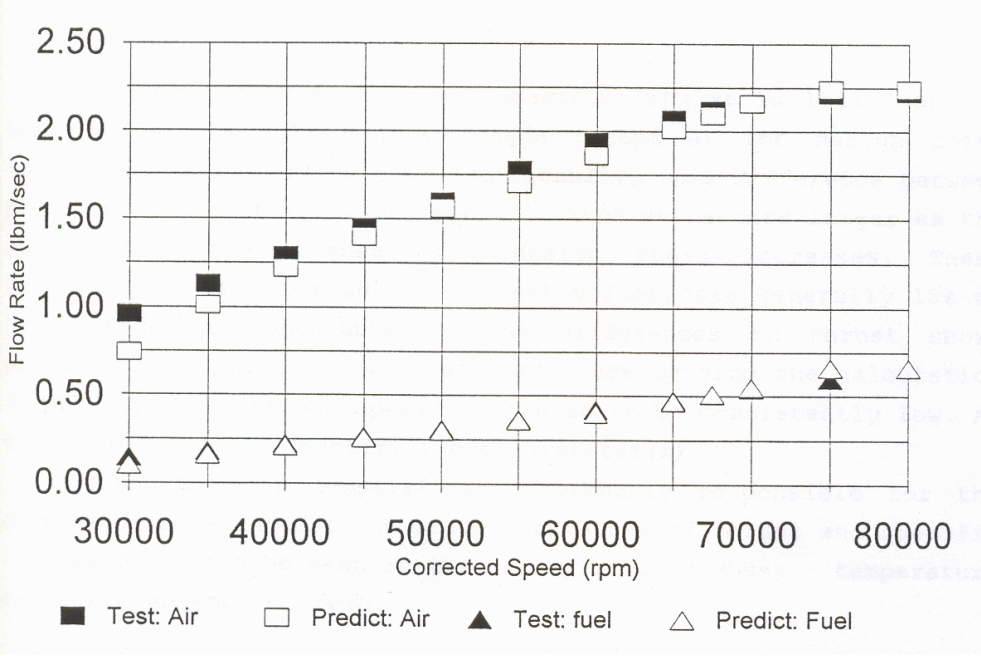


- **1991 AMCOM Test Data**

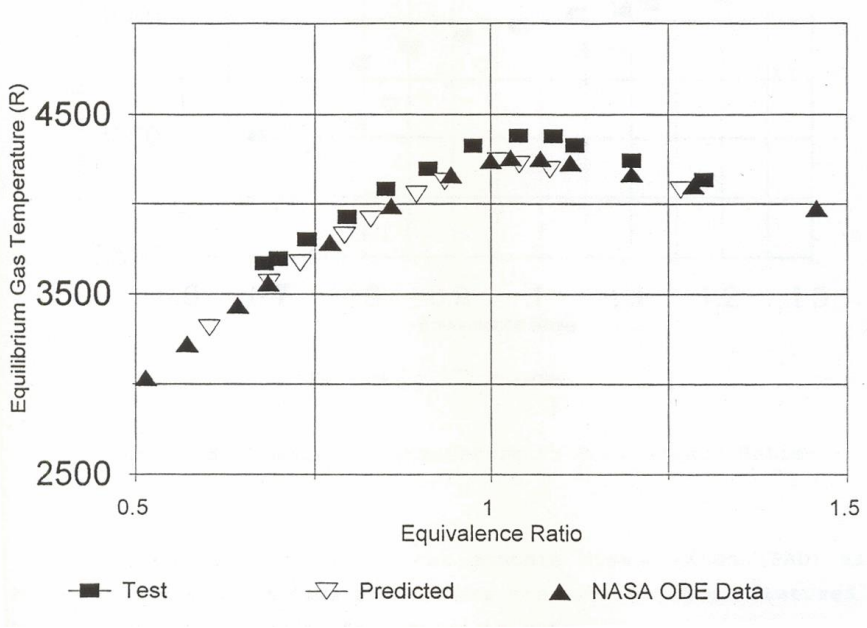
Air Turbo Rocket

System Software Validation

Flow Rate



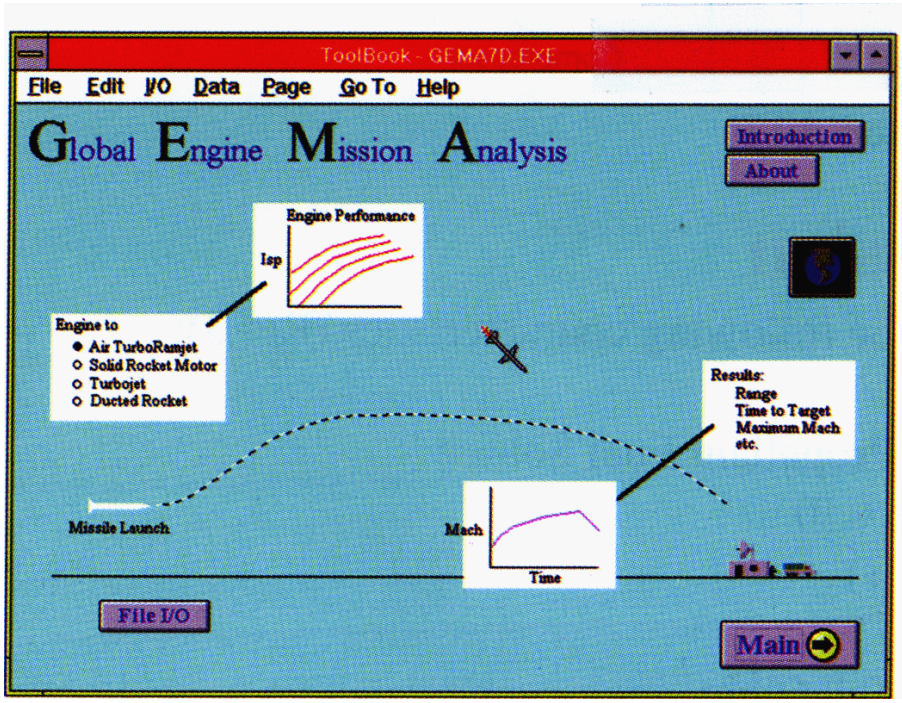
Equilibrium Gas Temp



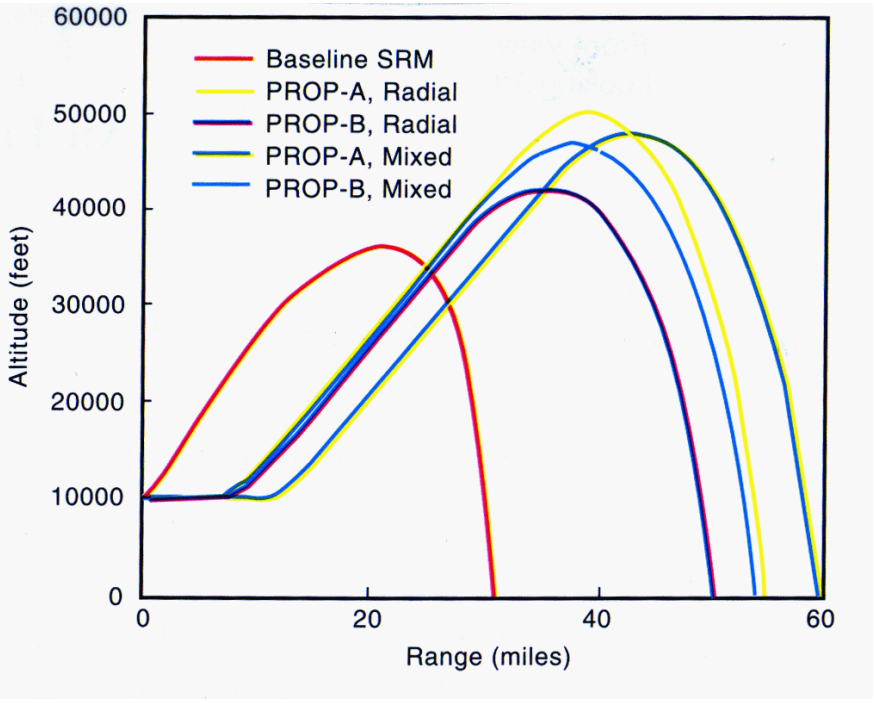
- **1991 AMCOM Test Data**

Air Turbo Rocket

Trajectory Analysis Software Output



GEMA Graphical User Interface



Sample Results Showing Propellant/ Compressor Influences on Vehicle Range

Air Turbo Rocket

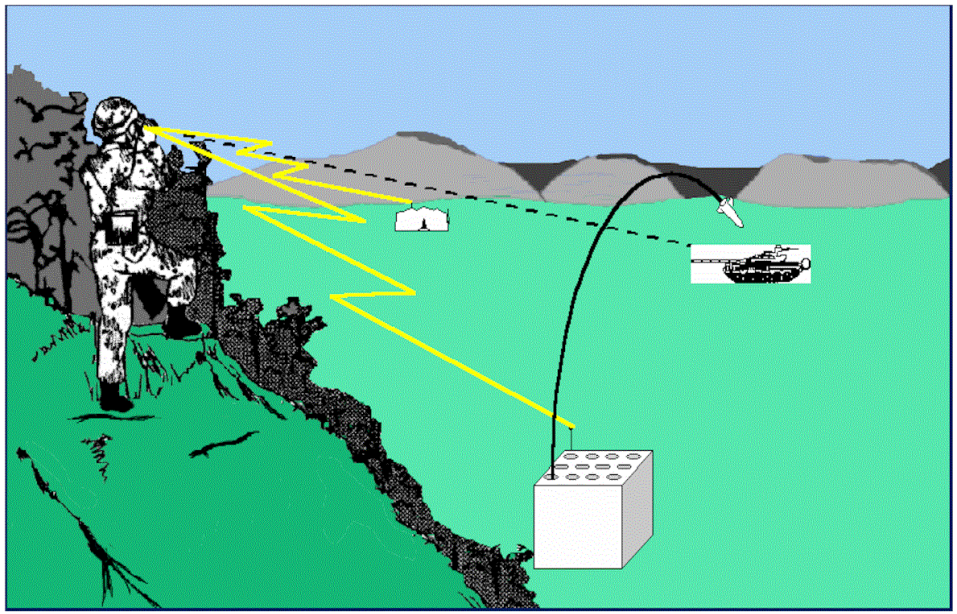
Vehicle/Trajectory Analysis

- Ground Launched Fire Support (GLFS)
- Air to Ground (ATG)
- Low-Cost Cruise Missile Defense (LCCMD)

Ground Launched Fire Support (GLFS)

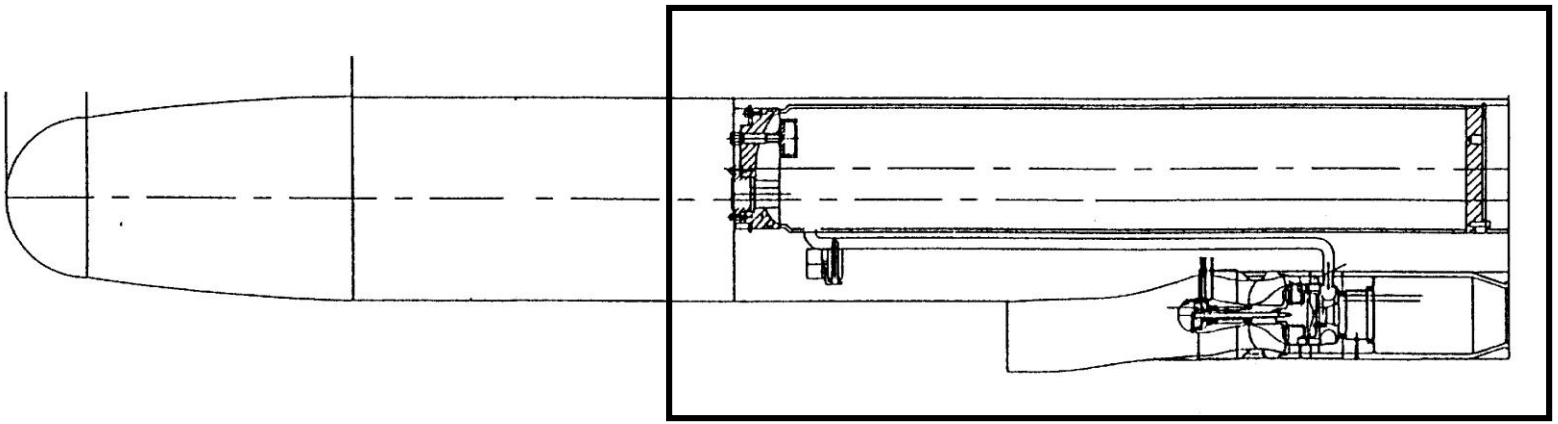
Missile System Features:

- Containerized Packaging
- Vertical Launch
- Multi-Mission Capability
- Rapid Response



Baseline Configuration

Same Propulsion Volume as a Pintle Motor Baseline



Established Propulsion Volume

Results:

- **2-3 Times the Range of a Baseline Pintle Motor Depending Upon Propellant**
- **30% Increased Cost Over a Conventional SRM**
- **Maximum Mission Flexibility**

GLFS ATR

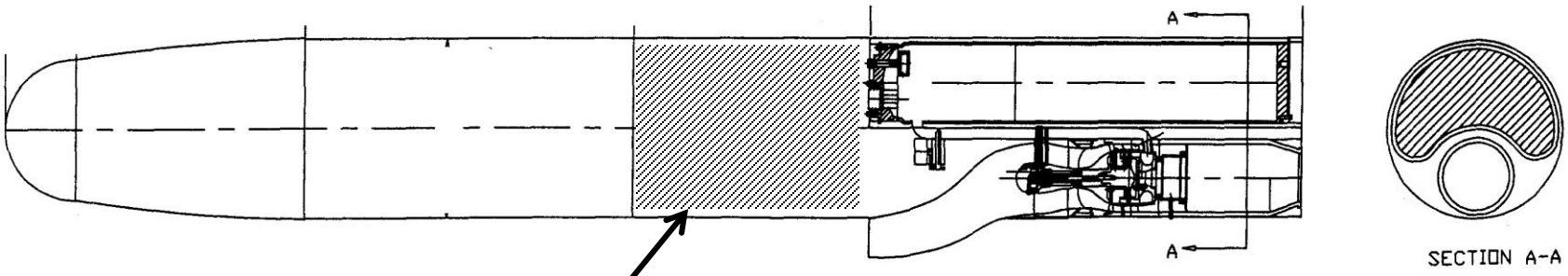
Fly-Out Results – 2 Profiles

	ATR	PM
Horizontal Cruise	40 km	13.2 km
Boost/Glide	237 km	50 km

GLFS ATR

An Alternate Configuration

ATR Propulsion Volume Sized to Deliver Pintle Motor Range

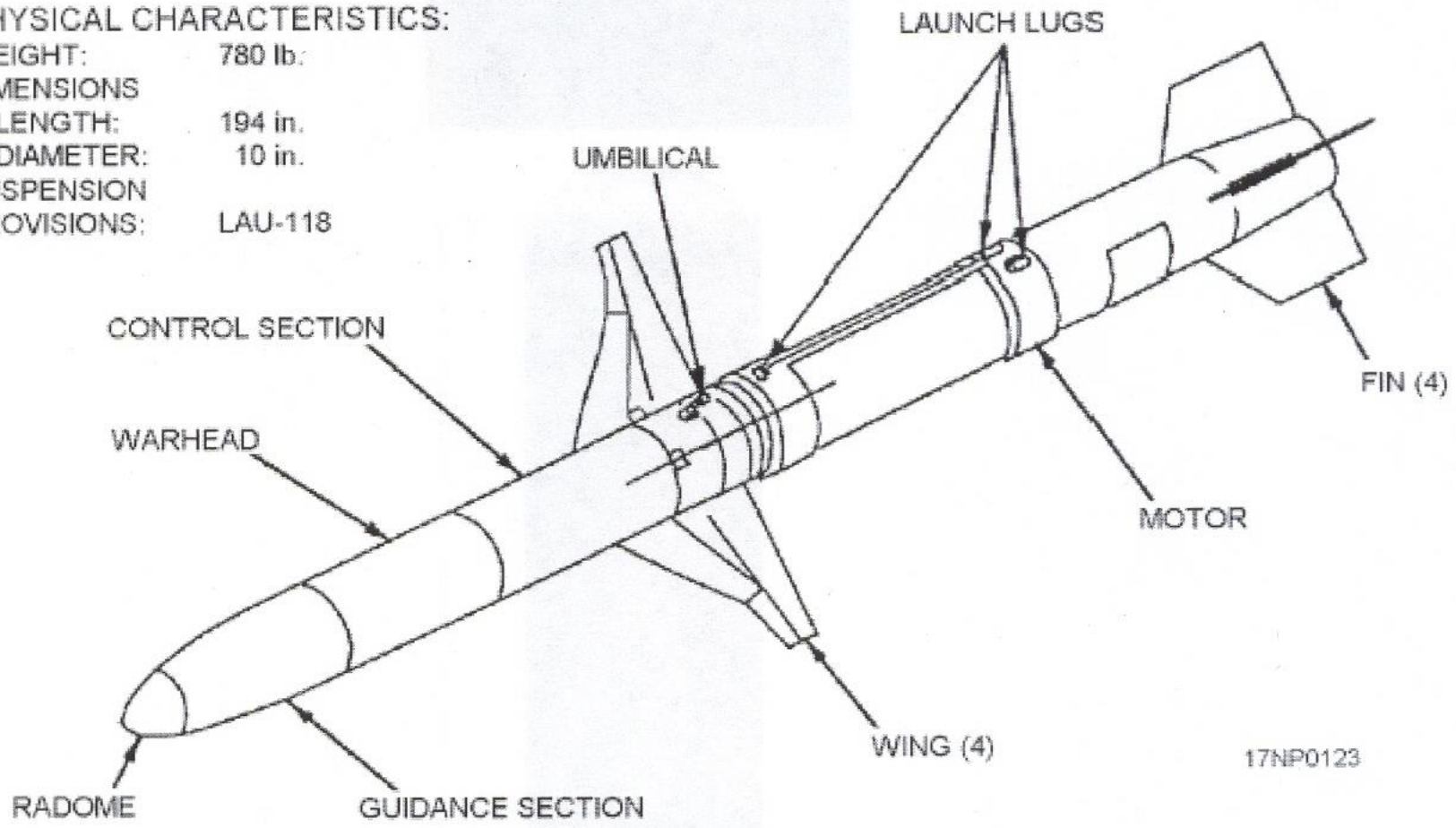


- **Increased Available Payload Volume - 36%**
- **Increased Available Payload Weight - 19 Pounds**
- **Comparable Mission Flexibility to Pintle Motors and Gels**

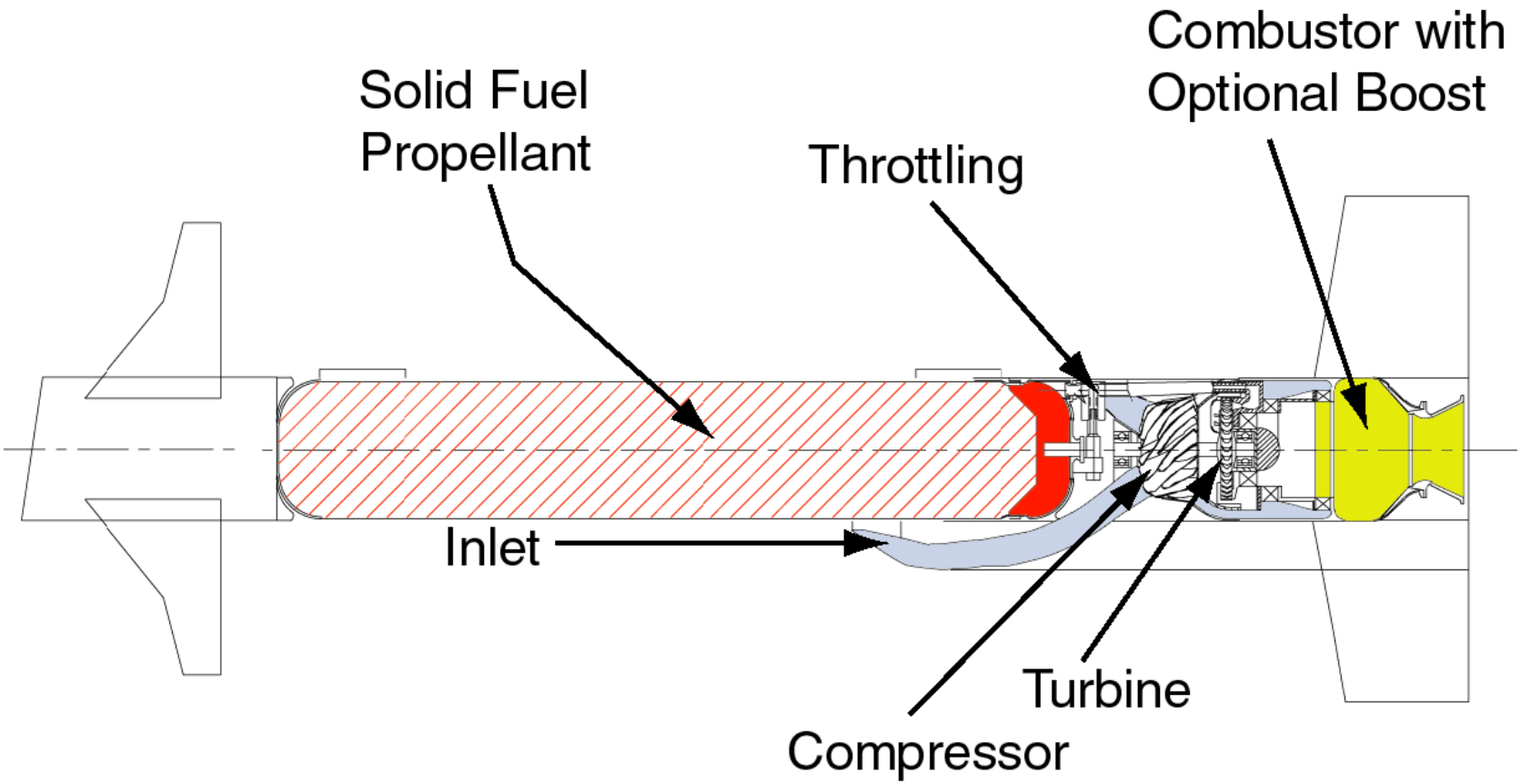
Air-To-Ground (ATG)

PHYSICAL CHARACTERISTICS:

WEIGHT:	780 lb.
DIMENSIONS	
LENGTH:	194 in.
DIAMETER:	10 in.
SUSPENSION PROVISIONS:	LAU-118

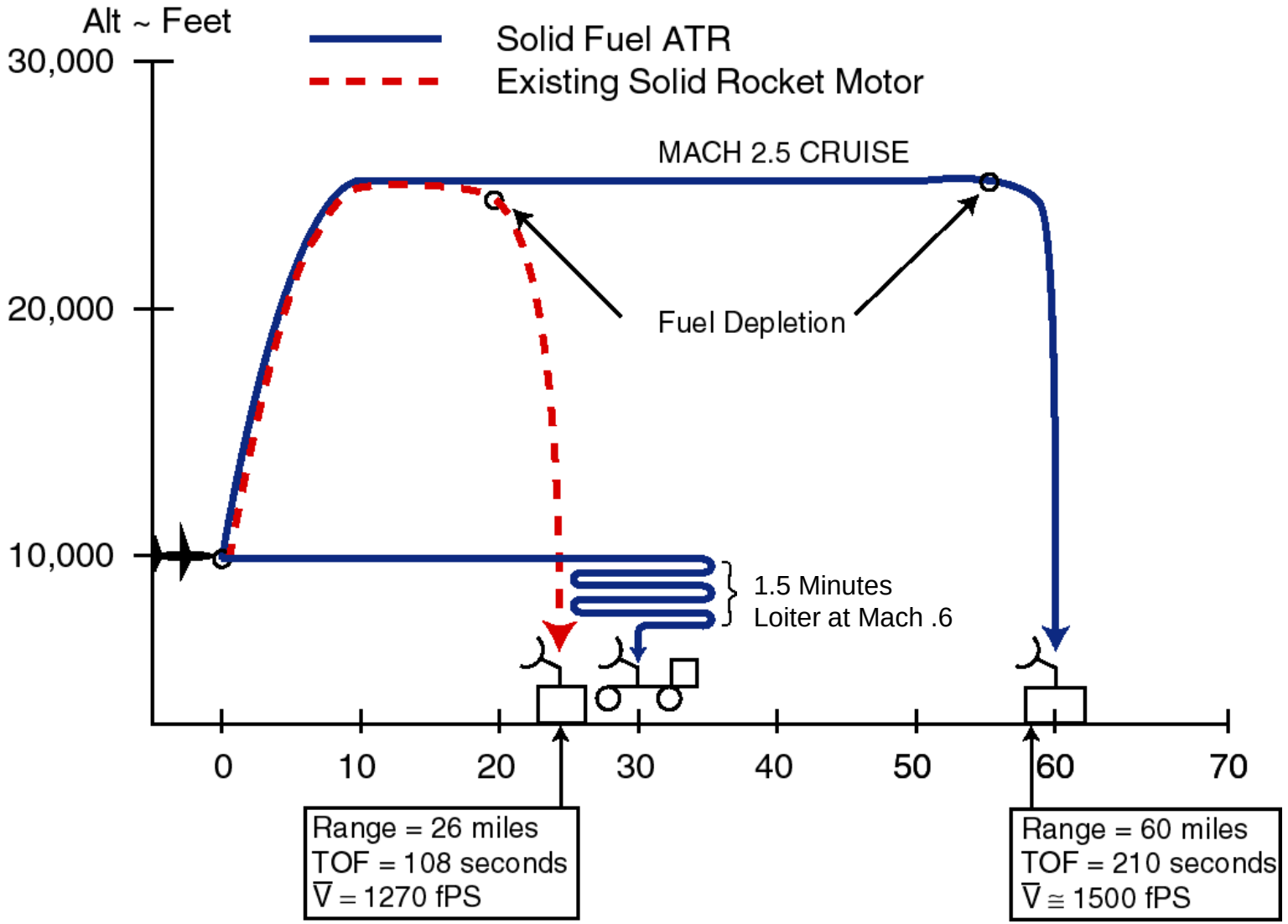


Missile Integration



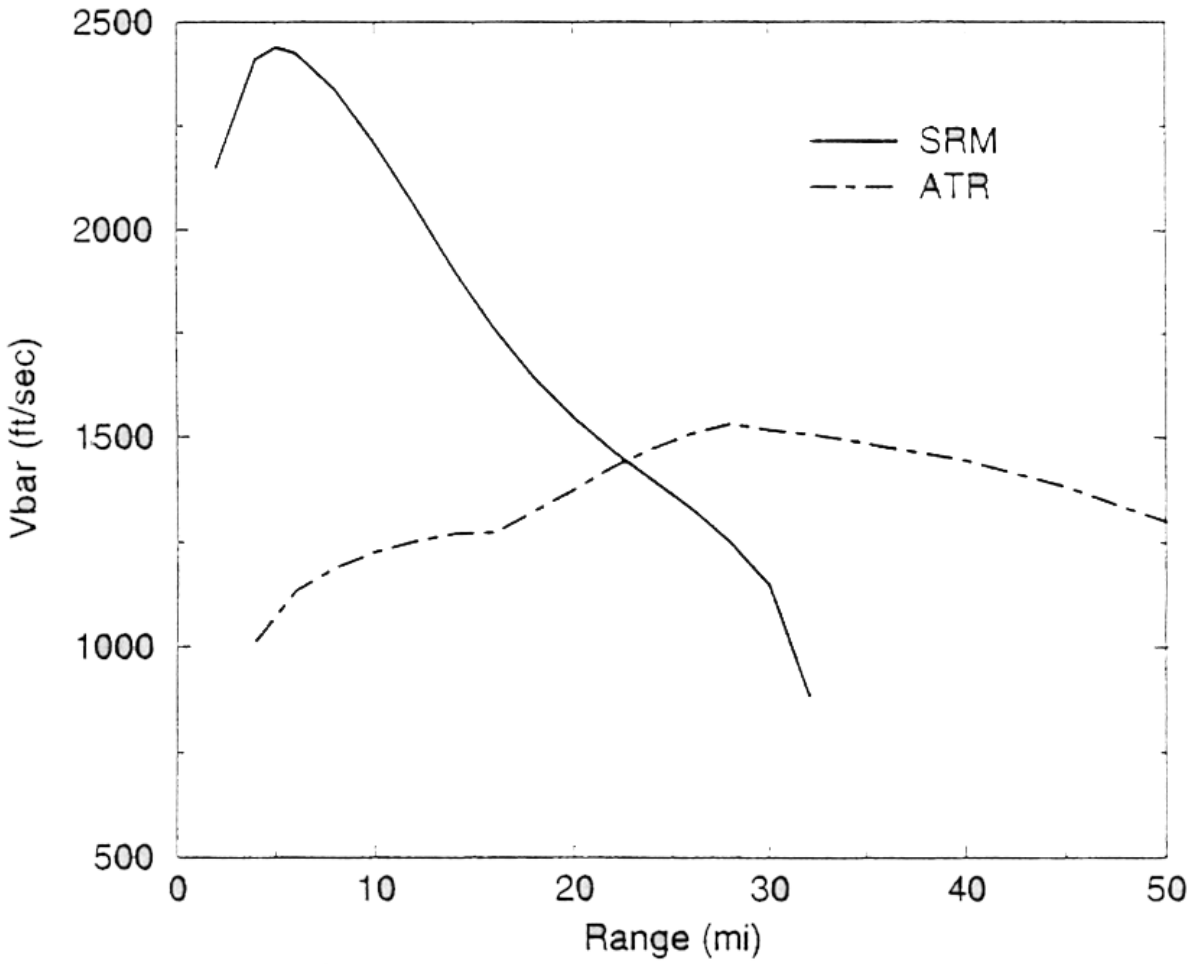
Air Launched Missile Integration

Fly-Out Results – 3 Profiles



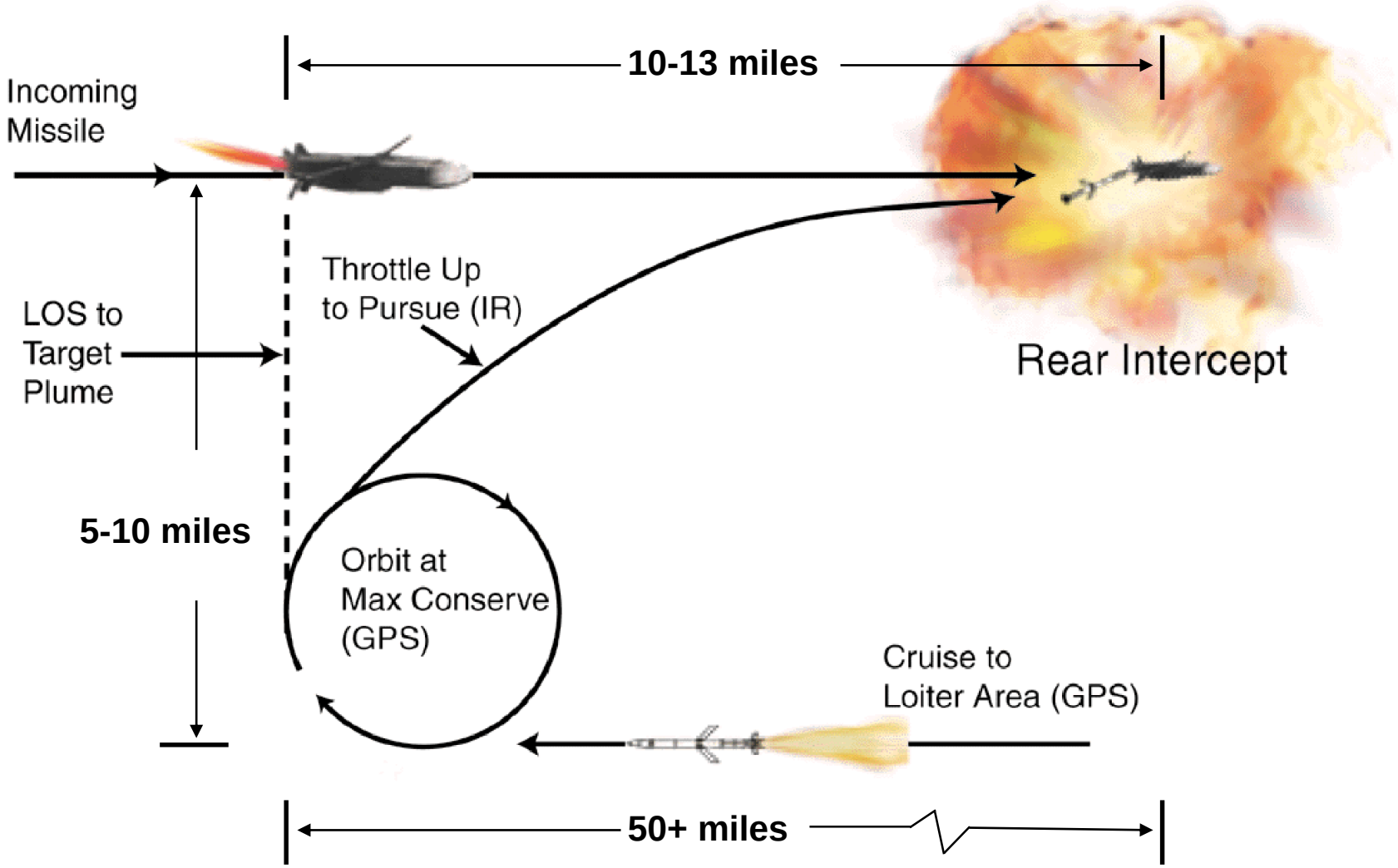
ATG ATR

Velocity/Range Tradeoff



Cruise Missile Defense

Fly-Out Result



Air Turbo Rocket

Technology Summary

- **Excellent Specific Impulse (2-4 times greater than rocket)**
- **Superior Static Air Breathing Specific Thrust (150-200 lbf-s/lbm)**
- **Independent Turbine Drive with Deep Throttling Provides Maximum Mission Flexibility**
- **Castable Monorotor Turbomachinery, IM Propellants, Tubular Combustor and Simple Feedback Control Minimizes Cost**
- **Turboelectric Power for <u>All</u> Missile Seeker, Fin Battery, etc.**

Air Turbo Rocket

Technology Summary

There are at least three mission types for which ATR propulsion may be optimum

- **Short and Moderate Range Ground Launched Fire Support**
- **Extended Range and Target Acquisition Air-to-Ground Missions**
- **Cruise Missile Defense**

Conclusions

- **The Air Turbo Rocket has Matured to the Point that it should Receive Serious Consideration in Future Missile System Development Initiatives**
- **The ATR Offers the Maximum Mission Flexibility (i.e., increased payload capacity, reduced missile weight, increased range, loiter capability >> pintle motor)**
- **The ATR's Low Cost Turbomachinery Allows it to be Cost Competitive with All Other Throttleable Missile Propulsion Systems**
- **The Scalability of the ATR will Allow Maximum Growth Potential (i.e., family of munitions, ….)**