Flight and Terminal Ballistic Performance Demonstration of a Gun-Launched Medium Caliber Ramjet Propelled Air Defense Projectile

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TNO | Knowledge for business

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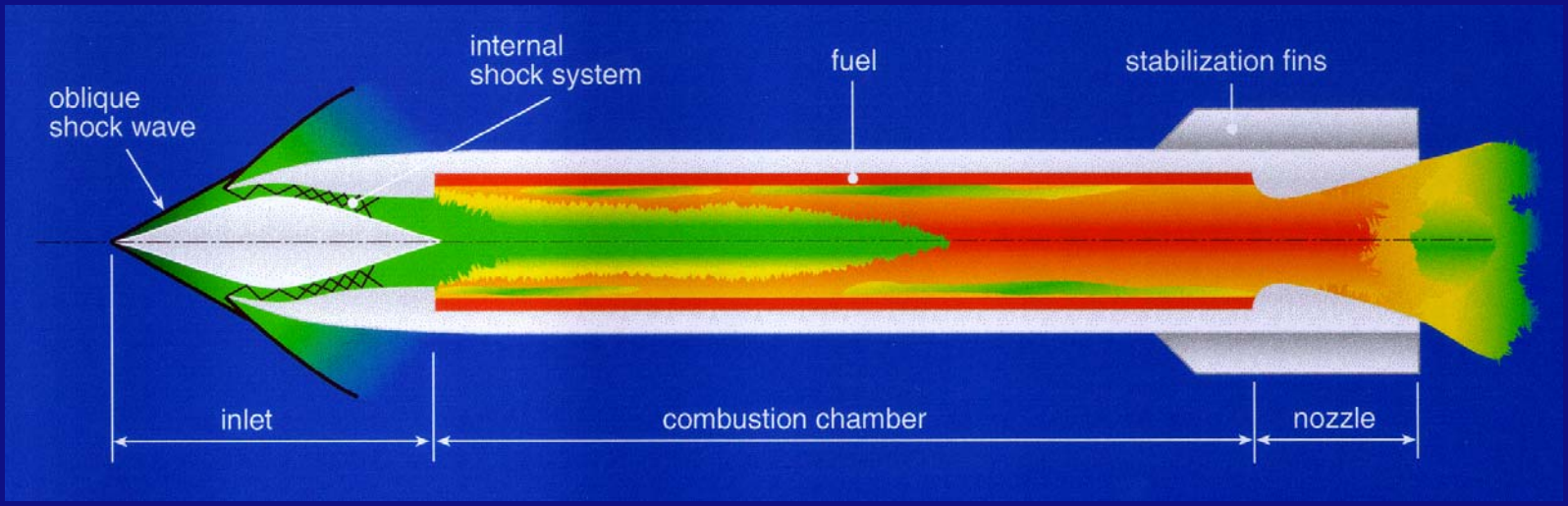
Solid Fuel RamJet (SFRJ) Projectile Concept

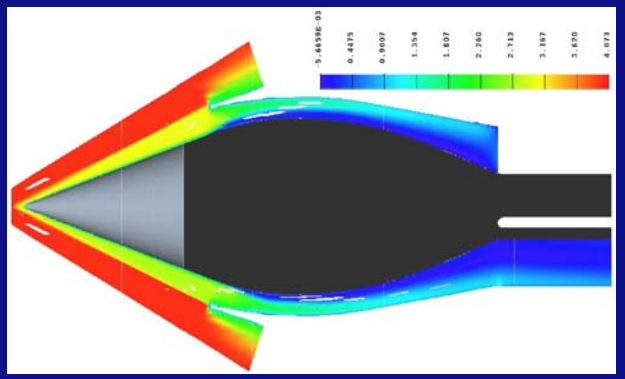


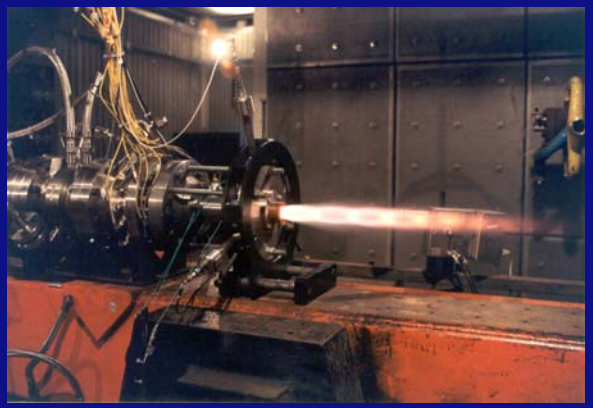
- No on-board oxidizer ⇒ superior propulsive performance
- Applications
  - Naval Fire Support, artillery (extended range & reduced time-to-target)
  - Direct-hit ammunition (reduced time-to-target & increased kinetic energy)
- Technology development at TNO since 1980

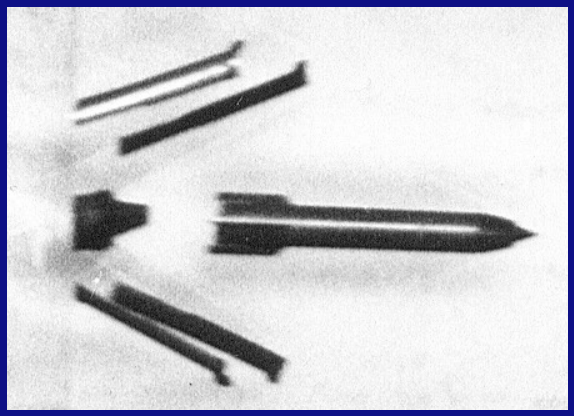
Ramjet Projectile Technology Development
Cooperative TNO/FOI research program (1995-2000)

Demonstration SFRJ propulsion for generic projectile through

- design
- manufacturing
- development
- flight testing







Thrust equal to drag capability demonstrated in flight tests

Ramjet Projectile Technology Demonstration Program
Program definition

Joint effort by TNO and RWMS

Goal
- Demonstrate SFRJ technology for a specific application

Application
- Medium calibre spin-stabilised air defence projectile
- Fired from a standard gun

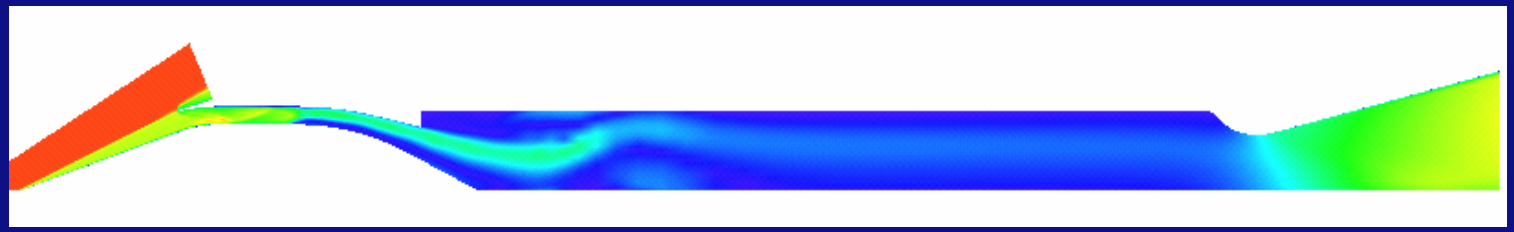
Approach
- Design
- Manufacturing
- Flight testing of a technology demonstrator
- Firings to obtain indication of terminal ballistic performance

Ramjet Projectile Technology Demonstration Program
Projectile design requirements & strategy

- Requirements
  - Total projectile length ≤ 179 mm
  - Projectile launch mass ≤ 0.375 kg
  - Acceleration load ~70000 g
  - Spin rate at launch ~80000 rpm
  - Propelled flight range ~3 km (~constant flight velocity)
- Design strategy
  - Geometric projectile design based on aero-thermodynamics
  - Mechanical design using geometric design as input
  - Perform experiments to verify different aspects of projectile design
  - Iterate projectile design until requirements are satisfied
- Challenges
  - Extreme interaction between aerodynamic & mechanical design
  - Aero-heating of intake and gas dynamic heating of nozzle

Ramjet Projectile Technology Demonstration Program
Aero-thermodynamic projectile design

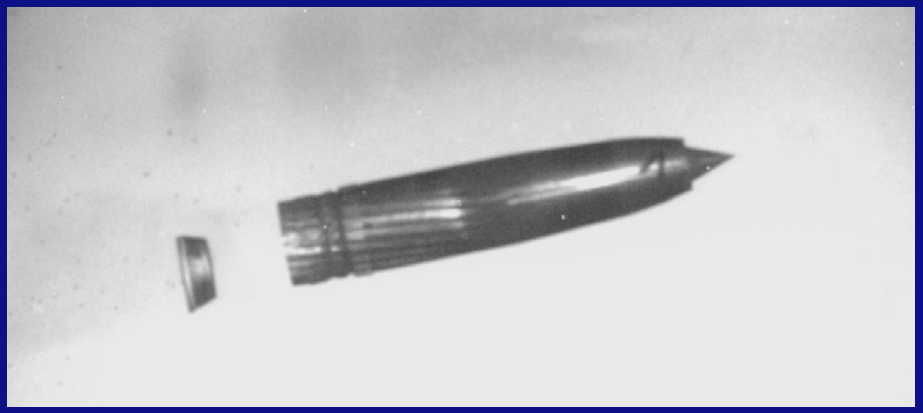
- Air intake design based on engineering design rules
- CFD calculations by CFS Engineering SA using NSMB code
  - Calculation of complete internal flow field of projectile

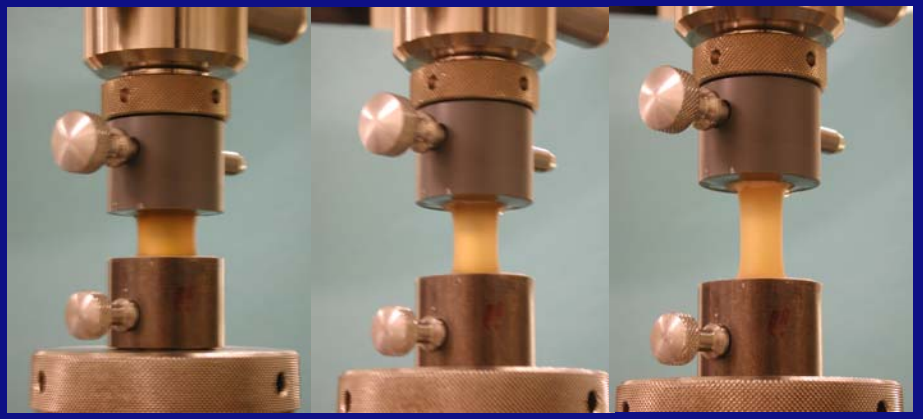


- Projectile flight performance prediction
  - RP^5 = Engineering code modelling subsystem performance and their interaction
  - Optimize projectile configuration

Ramjet Projectile Technology Demonstration Program
Mechanical projectile design

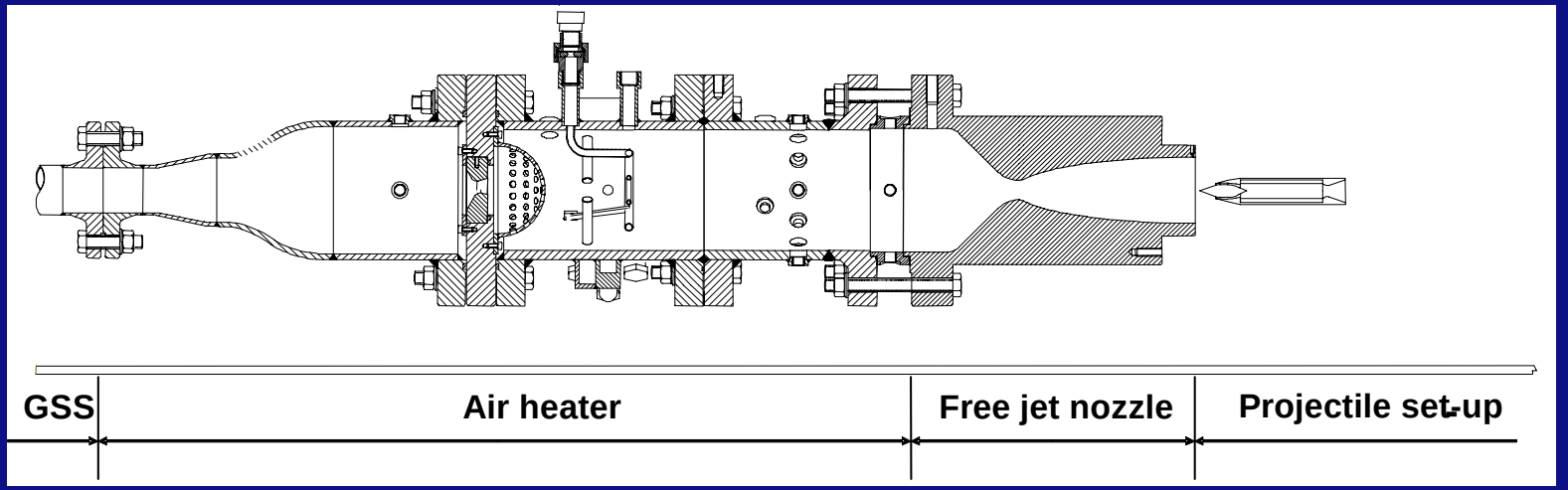
- Mechanical design based on engineering design rules
- Verification of structural integrity
  - Projectile structure by gun firings
  - Fuel by tensile tests and bonding tests
  - Fuel grain by gun firings





Ramjet Projectile Technology Demonstration Program
Free jet test facility

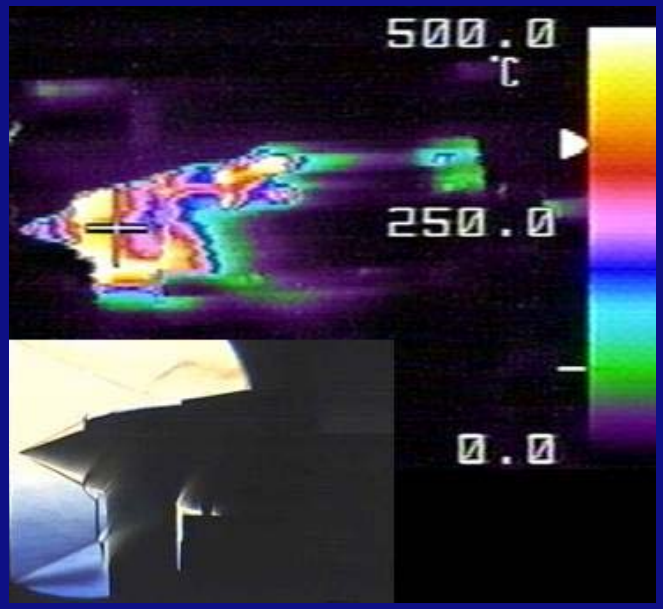
- Following ignition problems encountered in TNO/FOI flight tests
- To enable on-ground verification of intake performance and projectile functioning
- Free jet Mach numbers: 3.25 and 4.0
- Fixed projectile as well as spinning set-up available



Ramjet Projectile Technology Demonstration Program
Free jet aerodynamic heating tests

- Aluminium nose cone
- Schlieren video

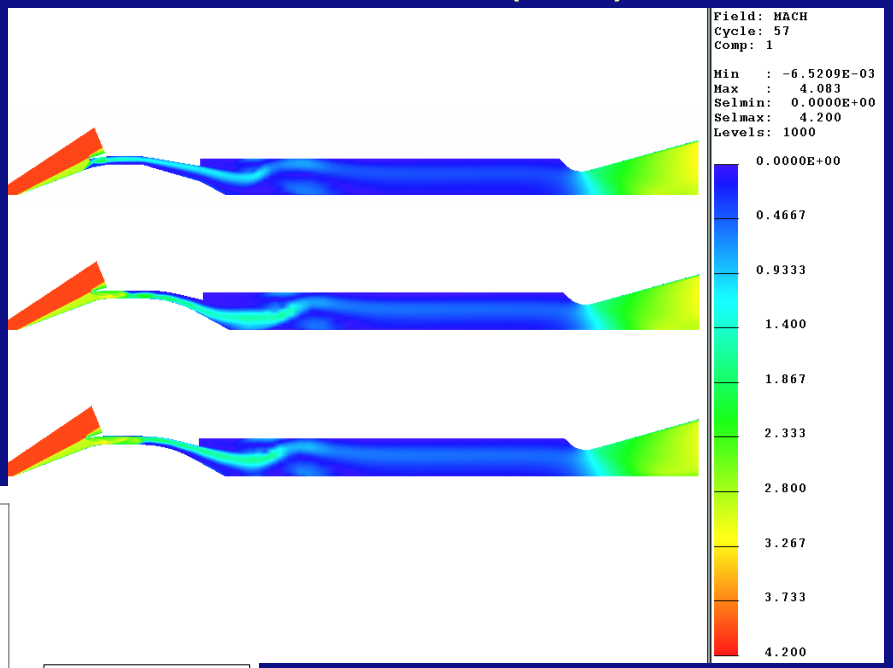
- Projectile intake
- Thermo-graphic image (top)
- Schlieren image (bottom)

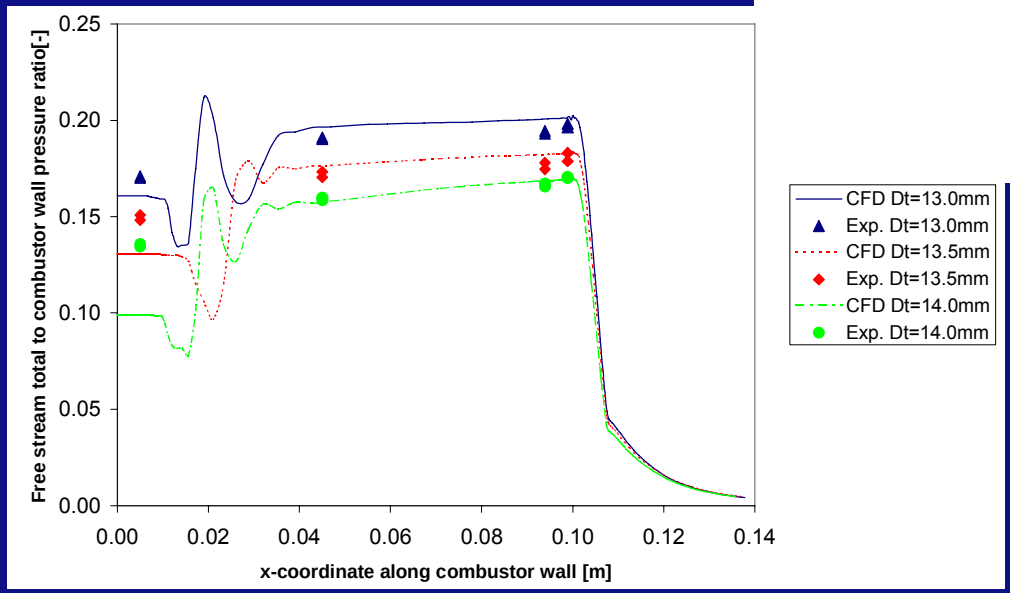


Material other than Aluminium is required for Mach 4 SL flight

Ramjet Projectile Technology Demonstration Program
Free jet intake performance verification tests (1/2)

- Fixed nozzle throat areas
- Pressure measured at 4 locations along combustor wall
- CFD predictions performed by CFS Engineering SA



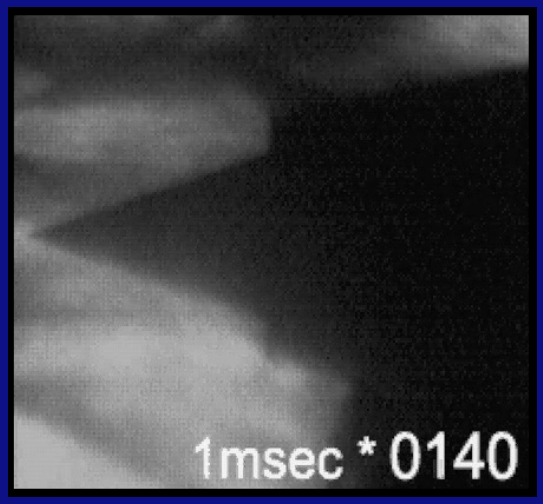


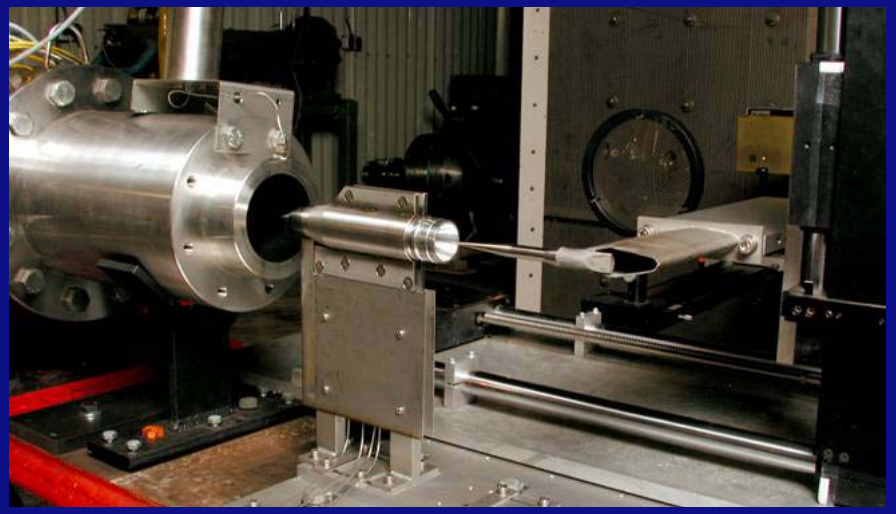
Good agreement with CFD predictions

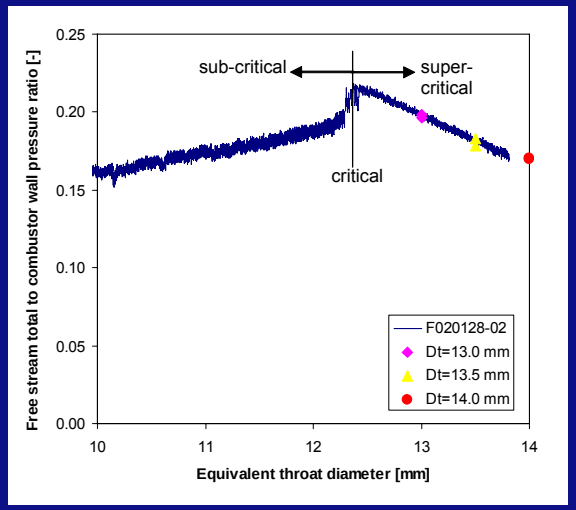
Ramjet Projectile Technology Demonstration Program
Free jet intake performance verification tests (2/2)

- Variable nozzle throat area
- Good agreement with fixed nozzle results

Intake performance verification in one experiment

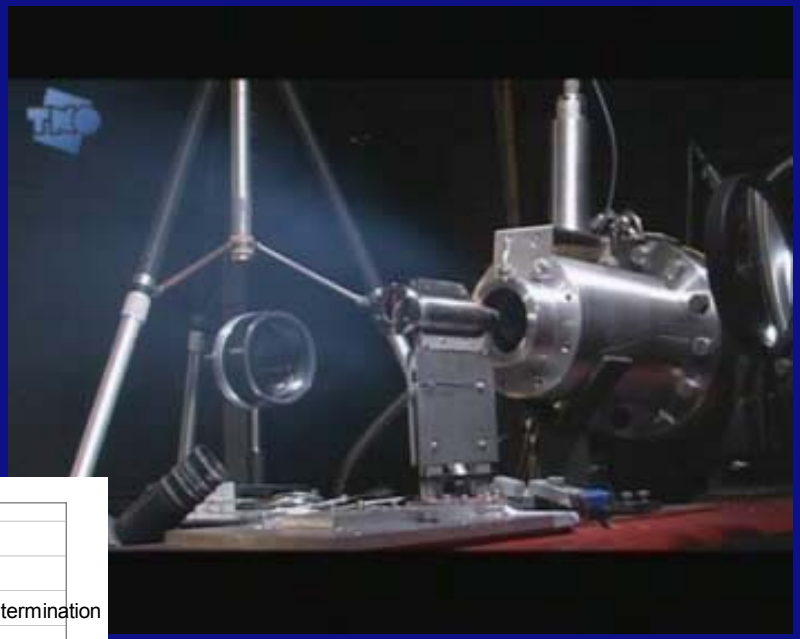


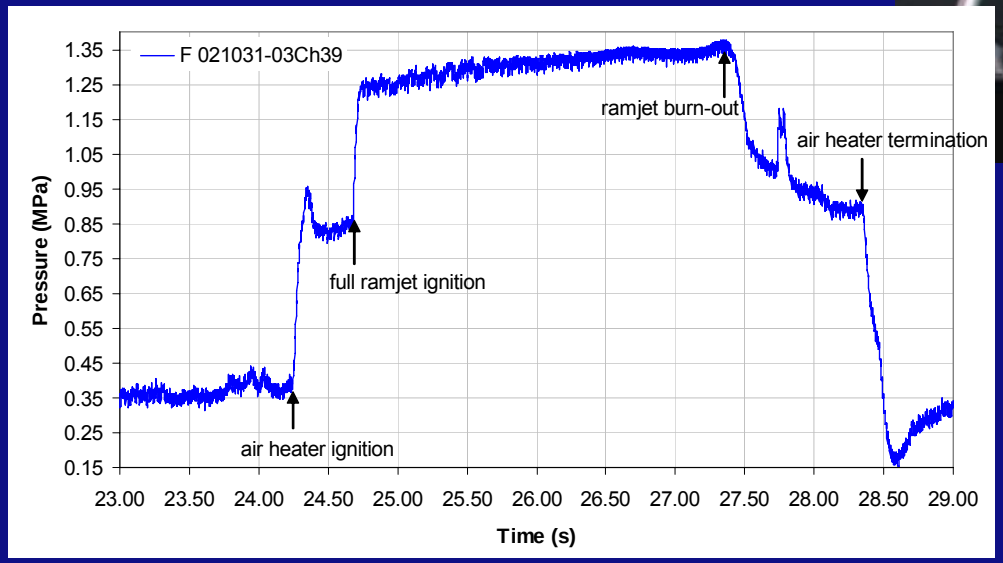




Ramjet Projectile Technology Demonstration Program
Free jet projectile performance verification tests

- Pressure measured at 1 location
- Fast auto-ignition
- Stable and efficient combustion until fuel burn-out



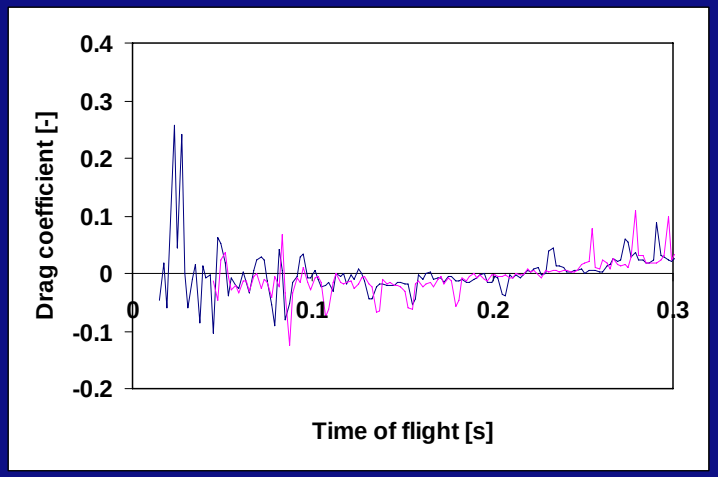


Proper functioning complete projectile demonstrated

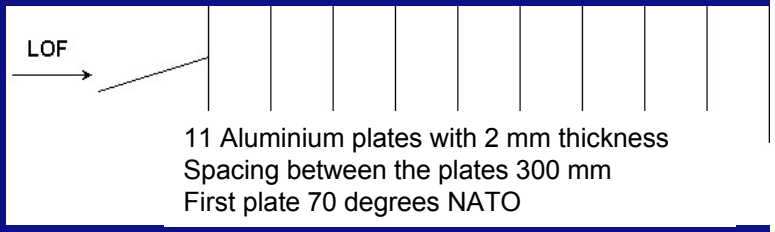
Ramjet Projectile Technology Demonstration Program
Flight demonstration tests

- Fast ignition
- Constant flight velocity
- Good reproducibility of flight performance

T = D @ 1400 m/s = world record !



Ramjet Projectile Technology Demonstration Program
Terminal ballistic firings (1/2)



- Firings on range targets representing the structure of a fighter aircraft

All plates perforated

- Damage on target plates

Ramjet Projectile Technology Demonstration Program
Terminal ballistic firings (2/2)

Spacing between the plates 700 mm
First plate 10 mm RHA, 60 degrees NATO
Second plate 2mm Steel, 30 degrees NATO
Plates 3-6: Aluminium plates with 2 mm thickness

- Firings on range targets representing the structure of an armored helicopter

- Damage on target plates

All plates perforated

Ramjet Projectile Technology Demonstration Program
Conclusions

- Projectile design satisfies mass & length requirements
- Structural integrity verified successfully in gun firings
- On-ground free jet tests verified
  - Aerodynamic heating
  - Intake performance
  - Projectile functioning
- Flight demonstration tests demonstrated
  - Very short ignition delay
  - Clear capability to maintain initial flight speed of 1400 m/s
- Firings on range targets demonstrated
  - Excellent terminal ballistic performance

SFRJ projectile technology = ready for application