EXPANDING THE ADN-BASED MONOPROPELLANT THRUSTER FAMILY

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In North America ECAPS is represented by:
Alliant Techsystems Inc. (ATK), Tactical Propulsion & Controls Division
and
Moog Inc., Space and Defense Group.

Outline

1. Introduction
2. HPGP Thrusters Development
3. HPGP Propulsion Systems
4. Conclusions and Future Work

Propulsion Based on ADN

- 1971 ADN was invented in the USSR and later used in the TOPOL ICBM
- 1989 SRI re-invents ADN (Patented 1991)
- 1994 FOI starts developing production methods for ADN intended for use in solid propellants
- 1997 - SSC defines the concept of High Performance Green Propellants (HPGP) and in cooperation with FOI invents a family of ADN-based liquid monopropellants
  - FOI´s method for production of ADN patented
- 1998 SSC receives the first ESA Contract for developing ADN Thrusters
- 1999 SSC test fires the first experimental 1 N HPGP Thruster
- 2006 LMP-103S, the first ADN-based storable monopropellant is qualified and approved for transport according to UN 1.4S
- 2007 The first HPGP Propulsion System is qualified and delivered to PRISMA
- 2008 ECAPS test fires 5 N and 22 N HPGP Thrusters
- 2009 ECAPS receives first commercial order of 1 N HPGP thrusters. ECAPS test fires first 50 N HPGP Thruster. PRISMA scheduled for launch

Why Liquid ADN-based Propellants?

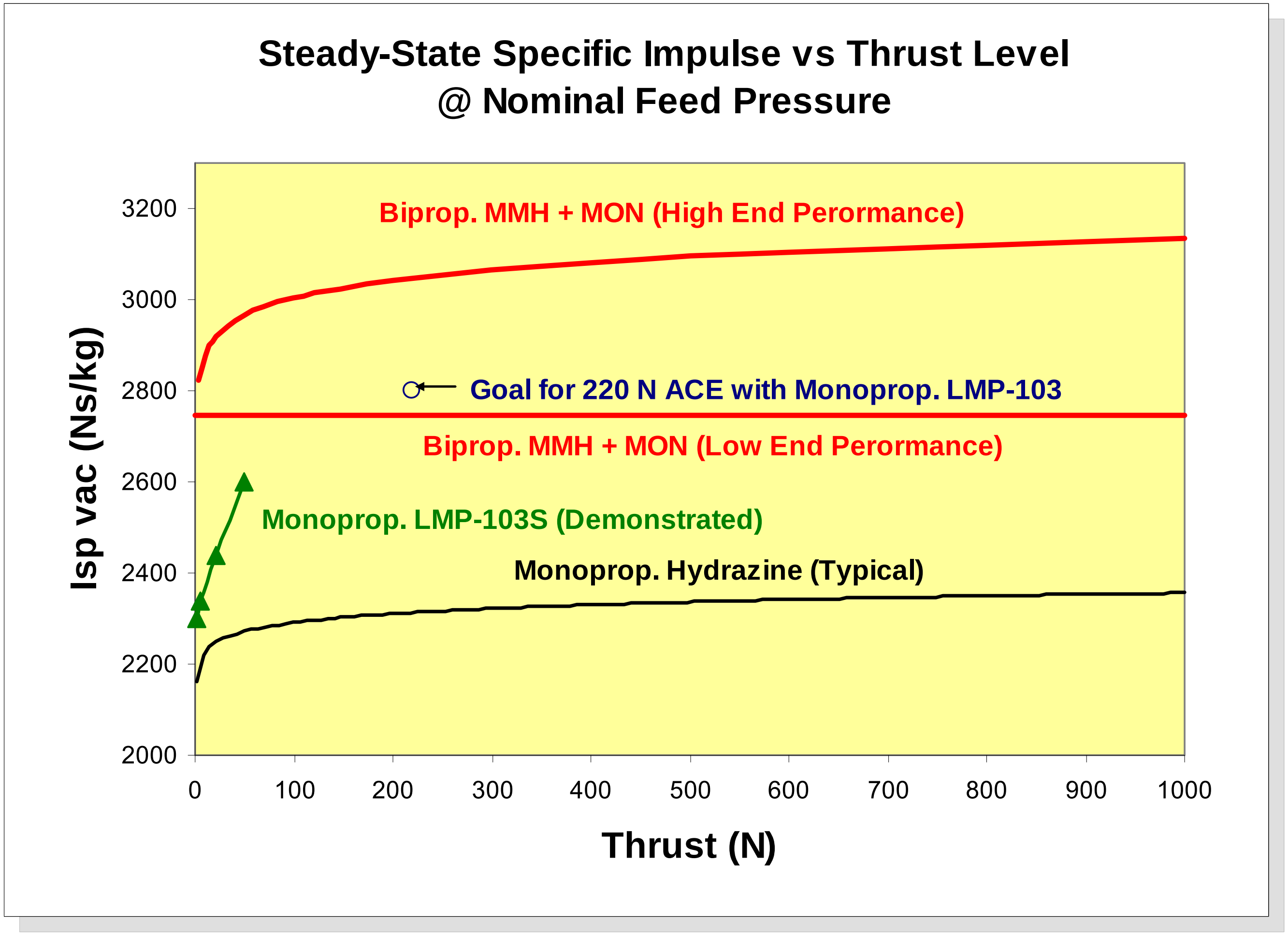
Compared to hydrazine, storable liquid ADN-based monopropellant blends offers:

- Improved performance (Isp and Density impulse)

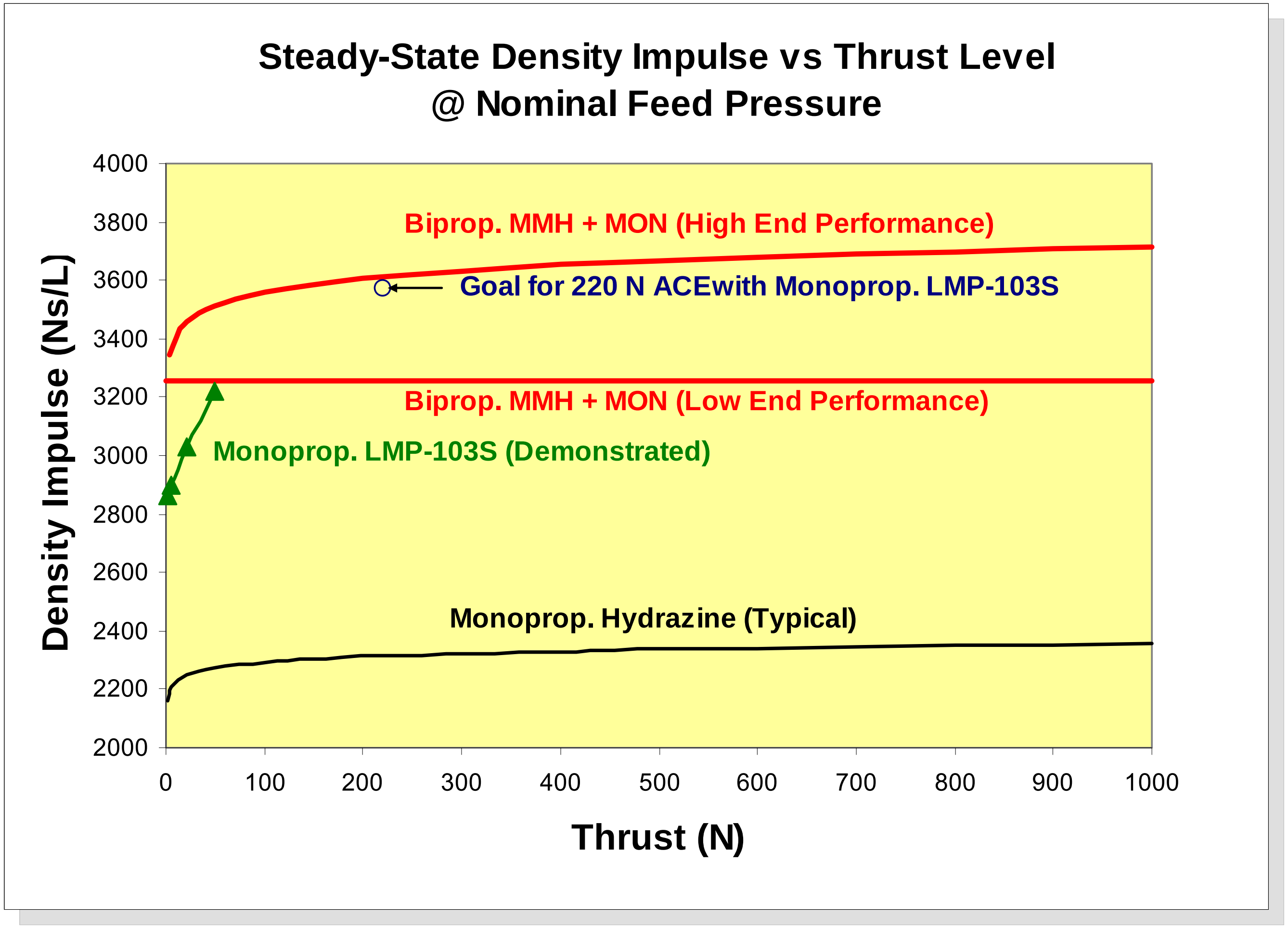
- Simplified handling and transport due to reduced hazards (i.e. low sensitivity, non-carcinogenic, low toxicity and environmentally benign. Spacecraft loading with LMP-103S does not require SCAPE operations and is judged as a ***"Non Dangerous Operation"*** by the Russian launch authorities, Yazny/Baikonour)

- LMP-103S is not sensitive to humidity or air

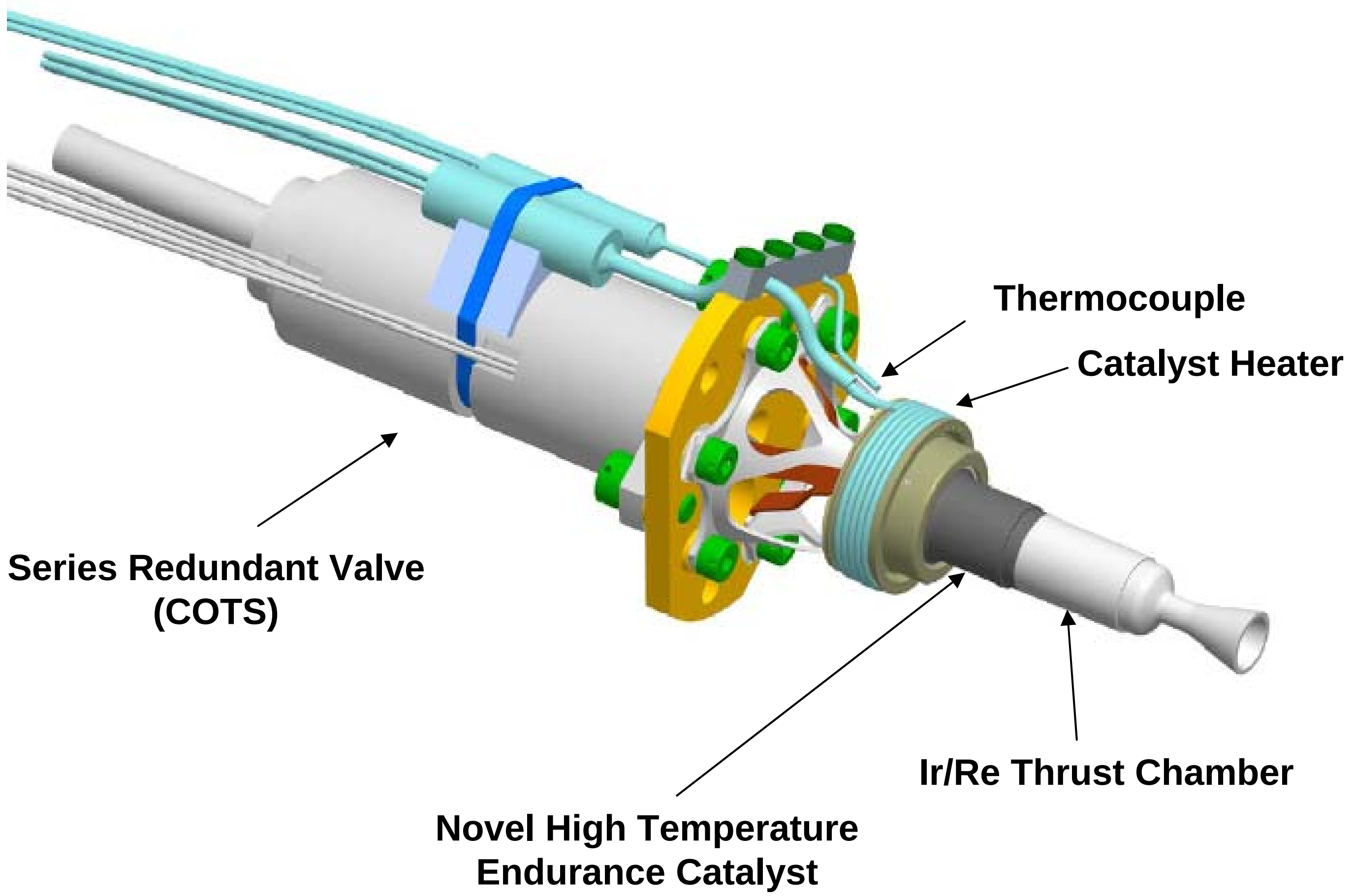
Storable Propellant Isp Performance Comparison & Predictions



Storable Propellant Density Impulse Performance Comparison & Predictions



1 N HPGP Thruster Design



Expanding the HPGP Thruster Family

1 N (0.2 lbf)
Ready for Flight Demonstration
TRL 7

5 N (1 lbf)
Under Development
TRL 4

22 N (5 lbf)
Under Development
TRL 4

50 N (10 lbf)
In Hot Firing
TRL 2→3

ACE-220 N (50 lbf)
Under Pre-functional Testing
TRL 2

Current HPGP Thruster Development at ECAPS

50 Thrusters Manufactured and Tested since 1998

Thrust Level	Propellant	Isp (Ns/kg)	Density Impulse (Ns/L)	Status
0.5 N	LMP-103S	2210* (~225 sec)	2730	TRL 5
1 N	LMP-103S	2310* (~235 sec)	2860	TRL 6
5 N	LMP-103S	2340* (~238 sec)	2900	TRL 4
22 N	LMP-103S	2445* (~249 sec)	3030	TRL 4
50 N	LMP-103S	2515** (~256 sec)	3120	TRL (3)
220 N	LMP-103	2800** (~285 sec)	3580	TRL 2

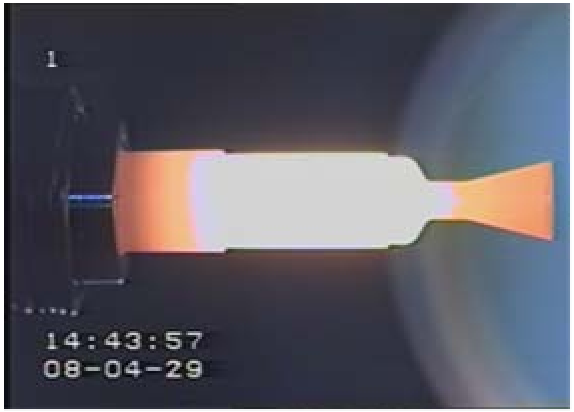
* Delivered steady-state vacuum specific impulse at MEOP and $\varepsilon = 150:1$

** Predicted steady-state vacuum specific impulse at MEOP and $\varepsilon = 150:1$

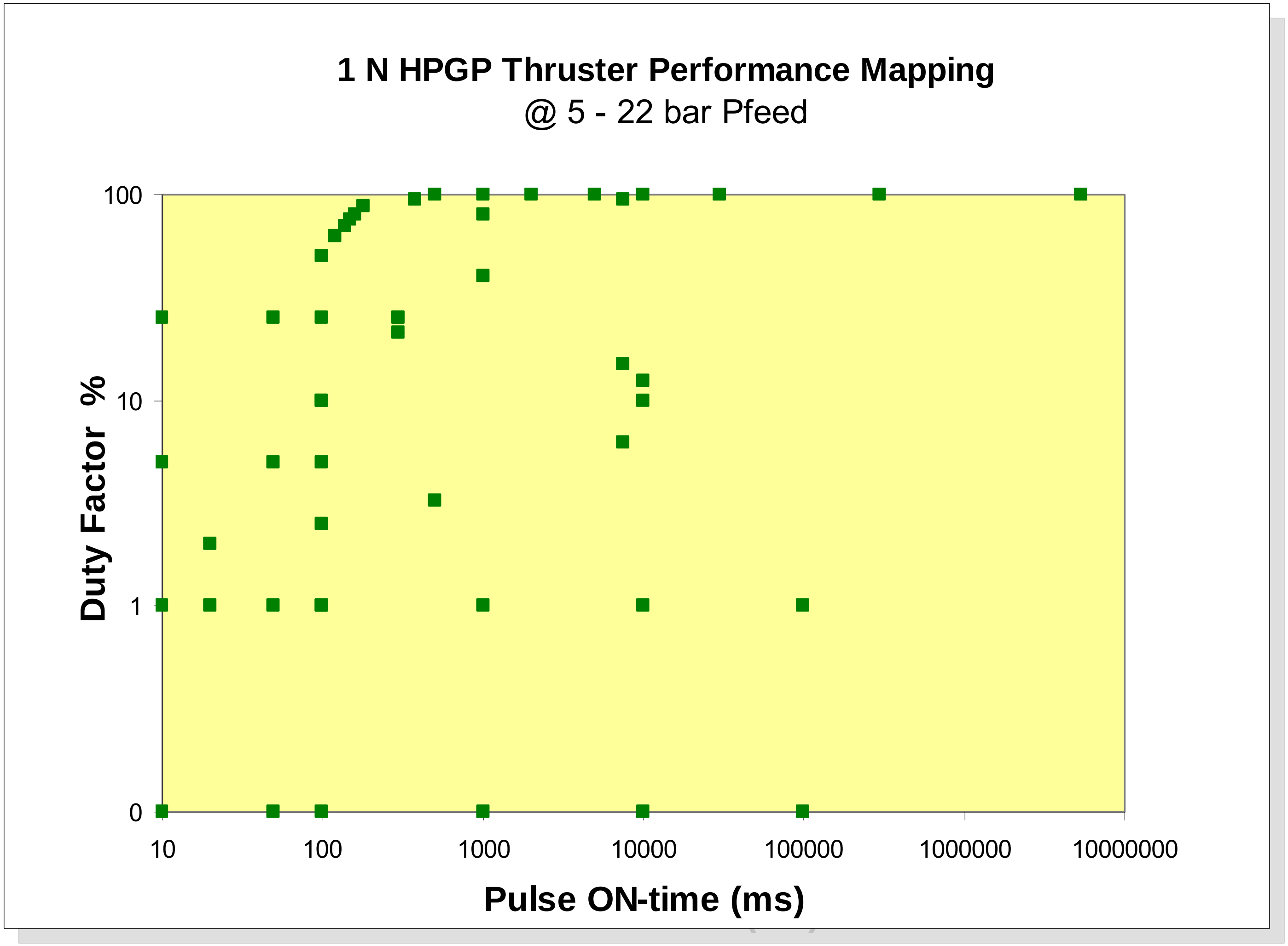
1N (0.2 lbf) HPGP Rocket Engine

1 N HPGP Rocket Engine Characteristics	
Propellant	**LMP-103S**
Inlet Pressure Range	**5.5 - 22 bar**
Thrust Range	**0.25 - 1 N**
Isp *vacuum*	**2010 – 2300 Ns/kg (205 - 235 sec)**
Density Impulse	**2850 Ns/L**
Minimum Impulse Bit	**0.01 – 0.05 Ns**
Overall Length	**176 mm**
Mass	**0.34 kg**
Demonstrated Life	
Total Impulse	**50 kNs**
Pulses	**60 500**
Propellant Throughput	**24 kg**
Accumulated Firing Time	**25 hours**
Longest Continues Firing	**1.5 hours**
Status	
Ready for flight on PRISMA 2009 (TRL 7)	

1 N HPGP Thruster (FM)

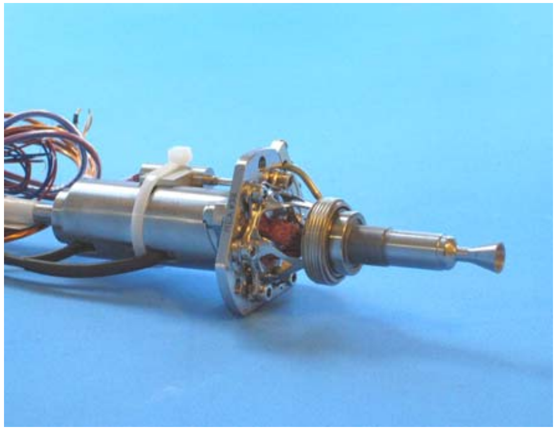


Thruster Performance Mapping



0.5 N (0.1 lbf) HPGP Rocket Engine SIT (Small Impulse BIT Thruster)

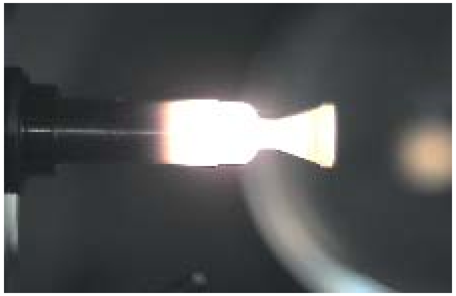
1 N HPGP Rocket Engine Characteristics	
Propellant	**LMP-103S**
Inlet Pressure Range	**7- 25 bar**
Thrust Range	**0.18 – 0.55 N**
Isp ***vacuum***	**1970 – 2200 Ns/kg (200 - 225 sec)**
Density Impulse	**2728 Ns/L**
Minimum Impulse Bit	**0.0025 – 0.0125 Ns**
Overall Length	**176 mm**
Mass	**0.34 kg**
Status	
TRL 5	



0.5 N HPGP Thruster

5 N (1 lbf) Rocket Engine

5 N X-1 HPGP Rocket Engine Quick-look Data	
Propellant	LMP-103S
Inlet Pressure Range	5.5 - 22 bar *abs.*
Thrust Range *vacuum*	1.5 - 6 N
Isp *vacuum*	2010 - 2300 Ns/kg (205 - 235 sec)
Density Impulse *vacuum*	2600 – 2800 Ns/L
Overall Length	178 mm
Mass	0.36 kg
Demonstrated Operation	
Pulses	677
Propellant Throughput	~ 1 kg
Accumulated Firing Time	~ 8 minutes
Longest Continues Firing	60 sec
Status	
Under Development TRL 4	



5 N HPGP X-1 Firing

22 N (5 lbf) HPGP Rocket Engine

22 N HPGP Rocket Engine Demonstrated Characteristics	
Propellant	LMP-103S
Inlet Pressure Range	5 - 25 bar
Thrust Range *vacuum*	5 - 22 N
Isp *vacuum*	2200 - 2400 Ns/kg (224 - 245 sec)
Density Impulse *vacuum*	2700 - 2975 Ns/L
Rise Time *to 90% thrust*	50 ms
Decay Time *to 10% thrust*	< 300 ms
Overall Length	216 mm
Mass	0.75 kg
Demonstrated Operation	
Pulses	> 200
Propellant Throughput	> 1.5 kg
Accumulated Firing Time	> 5 minutes
Longest Continues Firing	30 sec
Status	
Under Development TRL 4	

22 N HPGP
X-2 Firing

50 N (10 lbf) HPGP Rocket Engine

Advanced Concept Engine (ACE)

Goals for the ACE:

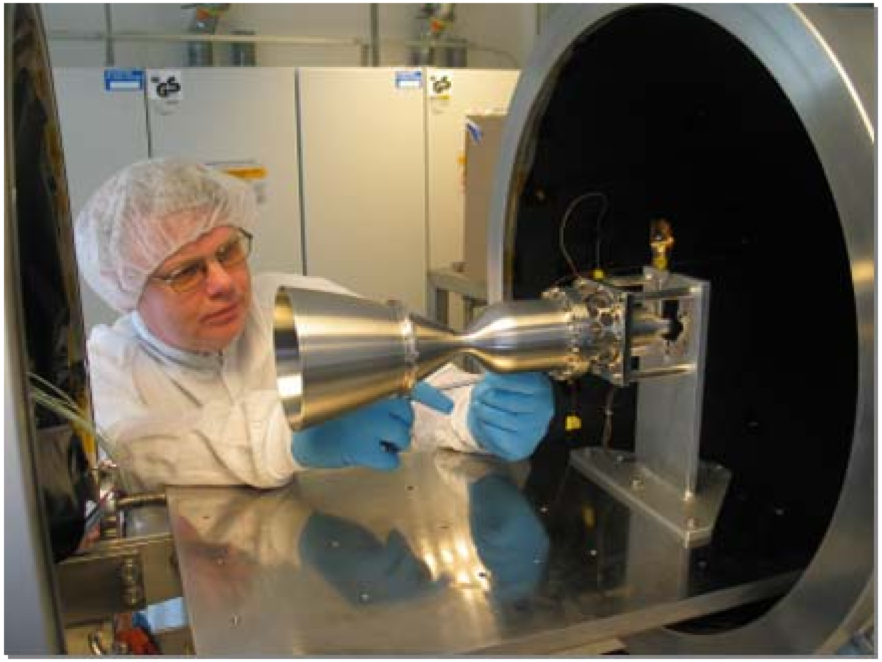
- *Thrust level ≥ 220 N (50 lbf)*
- *Isp ≥ 2800 Ns/kg (285 sec)*
- *Apogee Engine Capability*

Design Features:

- *Modular Design*
- *Multi-fuel Capability*
- *Dual Mode*
- *Throttable*

Challenges:

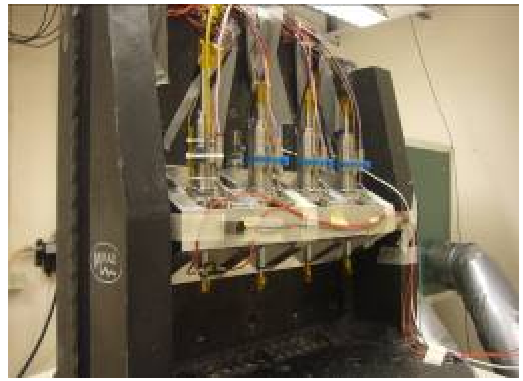
- *Propellant Formulations*
- *Reactor Design*
- *Thermal Management*



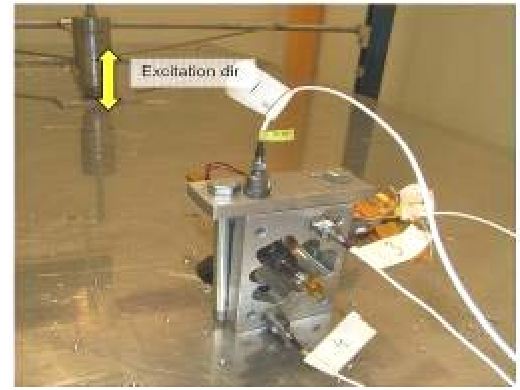
Preparing 220 N ACE for Thermal-Vacuum Test

HPGP Thruster
Manufacturing and Test

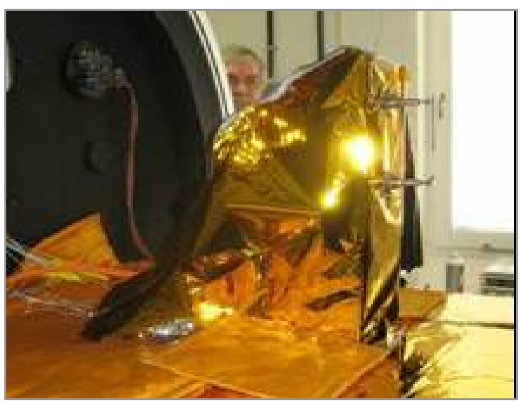
Thruster Assembly



Vibration Tests

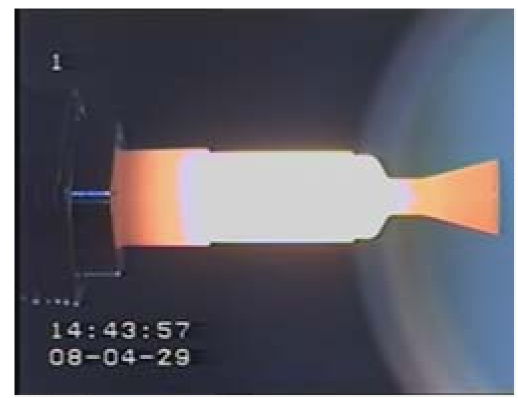


Shock Test



Thermal/Vacuum Tests

Firing Test Facility

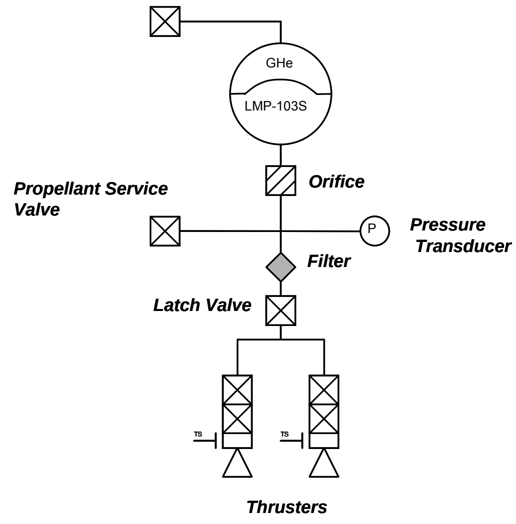


Hot Firing Test

HPGP RCS Design (PRISMA)

Novel propellant and thruster technology

- Conventional Monopropellant Architecture
- Conventional COTS fluid components with extensive flight heritage
- Operation in Blow-down mode
- 2 x 1 N HPGP Thrusters
- Propellant load: 5.5 kg LMP-103S



HPGP RCS Hydraulic Schematic

Total Dry Mass: 4.5 kg
Propellant Mass: 5.5 kg
Total Wet Mass: 10 kg

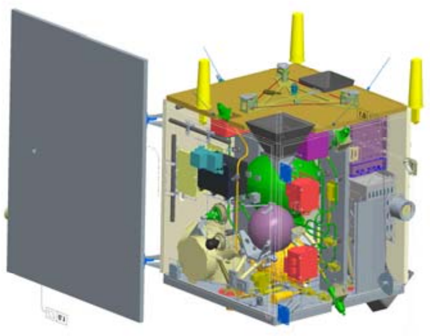
HPGP RCS Layout

PRISMA

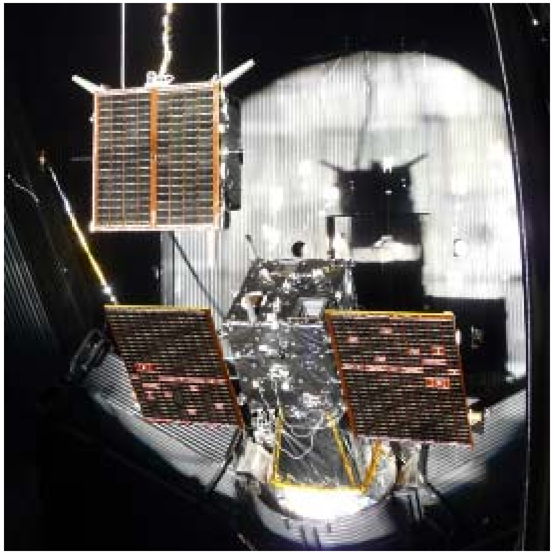
First Space Flight Demonstration of the HPGP Technology

Mission: Autonomous Rendezvous and Formation Flying

SSC, CNES & DLR



Main S/C



PRISMA Satellites

Dnepr Launcher
Scheduled Launch 2009

Propulsion Subsystem
Fabrication, Assembly & Test

Tube bending

Orbital TIG Welding

Precision Cleaning

Radiography of weld joints

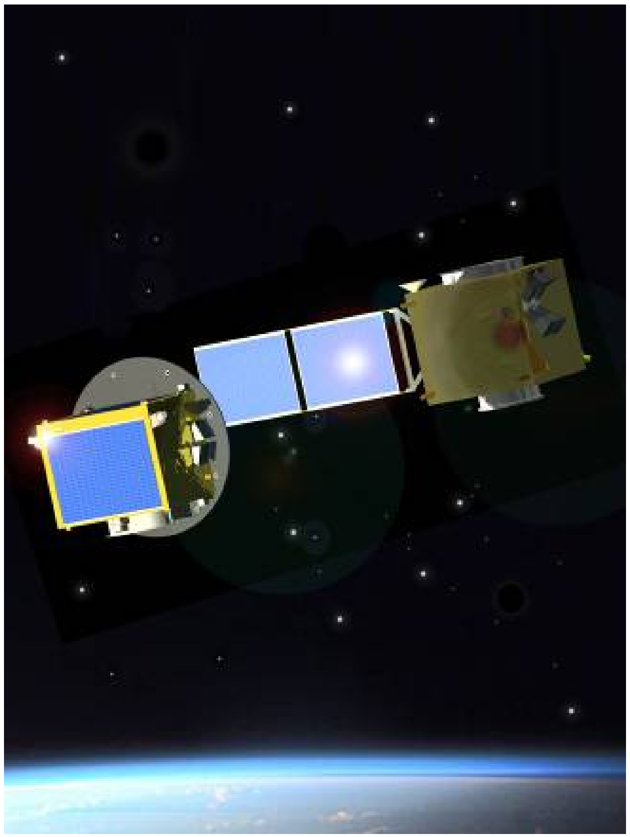
Pressure and Leak Check

HPGP Flight System

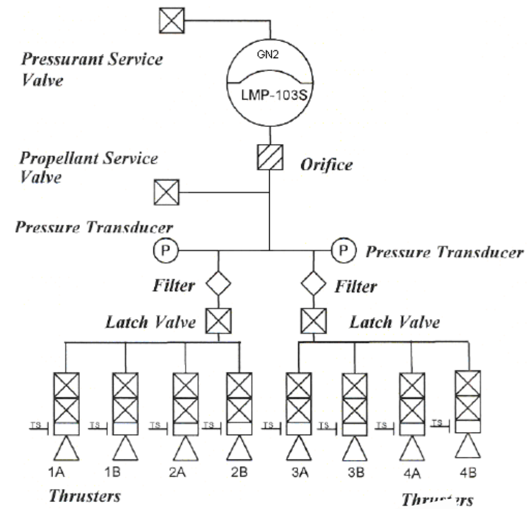
PROBA 3

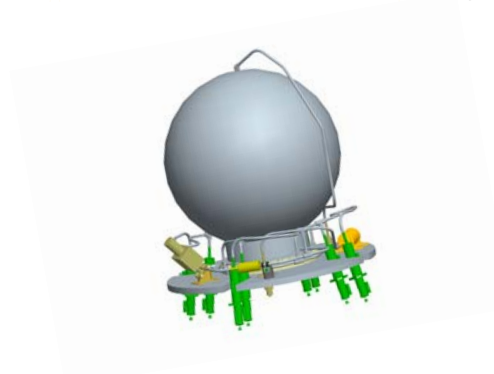
Mission: ESA Formation Flying

Baseline Propulsion: 8 x 1 N HPGP Thrusters



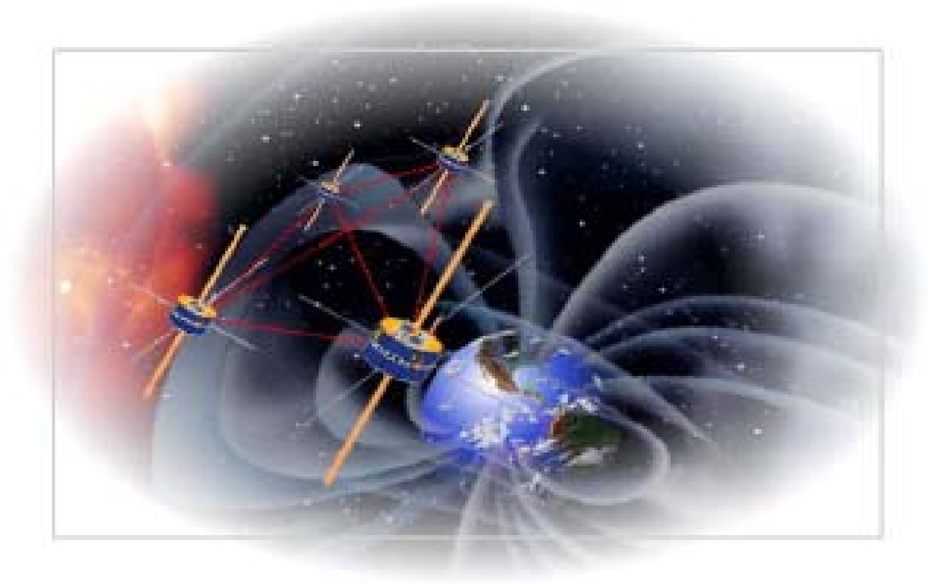
Planned Launch 2012



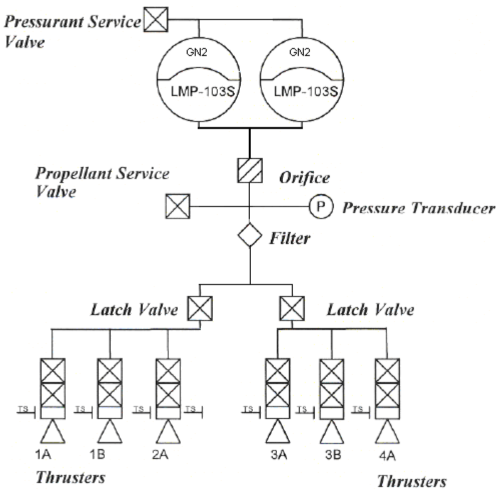


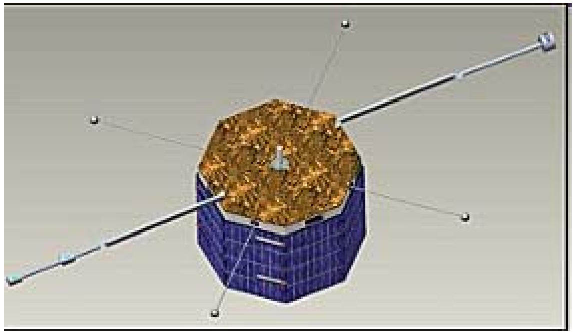
CROSS SCALE

Mission: ESA Cosmic Vision - 6 Satellite Constellation
Baseline Propulsion: 6 x 1 N HPGP Thrusters



Planned Launch 2017





Conclusions and Future Work

- 1 N HPGP thrusters has been tested to qualification levels (performance, environmental and life). The first ADN-based propulsion system has been delivered for flight demonstration on PRISMA and is scheduled for launch in late 2009.
- ADN-based propulsion systems are baseline for several new European and US missions and proposals have been submitted.
- Work on up-scaling to higher thrust levels and improvement of performance is ongoing. Successful hot firings has been performed of 5 N, 22 N and 50 N HPGP development thrusters
- The first hot firings of the first 220 N HPGP thruster is planned for August/September 2009 using LMP-103S as propellant.

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  - Subcontractors

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