ISE-100 Development

Reginald Alexander
Huu Trinh
Chuck Pierce
MSFC, Propulsion Department

CHEMICAL SPACE PROPULSION

Capability Goal: 100-lbf Class MON-25/MMH Bipropellant Engine

- **CAPABILITY NEED – "Improved Solar System Access"**
  - **Compact, Lightweight, Low-Cost Chemical Propulsion –** *"Reduced Spacecraft Burdens"*
  - **Access to Extreme Environments & Long Duration Storage –** *"Low-Freezing-Point and/or Freeze-by-Design"*
- **QUANTIFIABLE CAPABILITY METRICS**
  - **Goal:** *"100-lbf Class MON-25/MMH Bipropellant Engine"*
  - **Multi-Purpose Space Mission Utilization –** *"Economy-of-Scale Benefits"*
    - > Adaptability for Lander Descent/Ascent & Spacecraft MPS/RCS
  - **Enhanced Propulsion System SWaP – "***Increase S/C Payload Capacity & Improve Lander Packaging"*
    - > Reduce propulsion system volume ≥ 50%
    - > Reduce propulsion system mass ≥ 80%
    - > Reduce propellant freezing point < -40 °C
    - > Eliminate propellant conditioning S/C power draw
  - **Enhanced Affordability –** *"Shrink Propulsion System Cost Elements"*
    - > Integrated design, composite materials, & advanced manufacturing
    - > Reduced propulsion system costs ≥ 50%
- **TECHNOLOGY LANDSCAPE & APPROACH**

Stable of 100-lbf Class Flight Qualified Bipropellant Thrusters

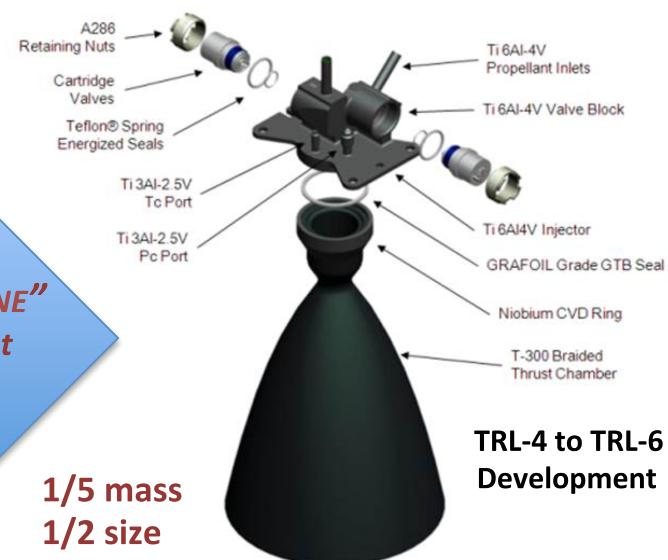
R-4D-11 (AR)
MON-3/MMH

HiPAT (AR)
MON-3/MMH

LEROS 2B (Moog)
MON-1/MMH

"ENHANCED IN-SPACE ENGINE"
MON-25/MMH Bipropellant Thruster Architecture

ISE-100
MON-25/MMH Bipropellant Thruster



1/5 mass
1/2 size
1/3 cost

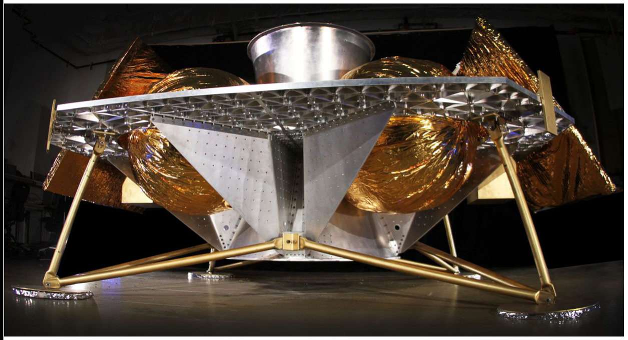
TRL-4 to TRL-6 Development

CHEMICAL SPACE PROPULSION

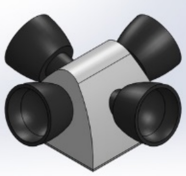
Capability Goal: 100-lbf Class MON-25/MMH Bipropellant Engine Technology Infusion & Mission Utilization Potential

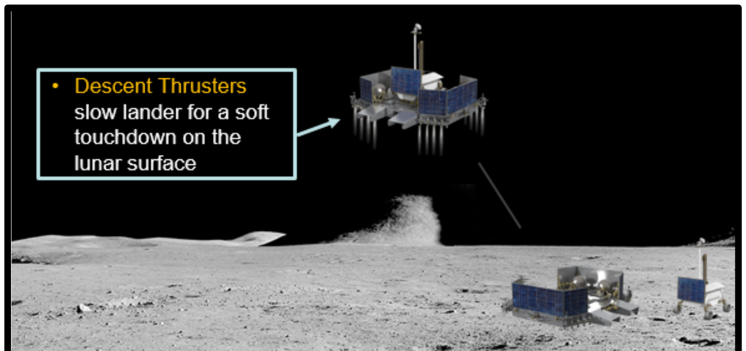
HEOMD ⟷ SMD

CATALYST – Astrobotic Lunar Lander



Exploration Class RCS

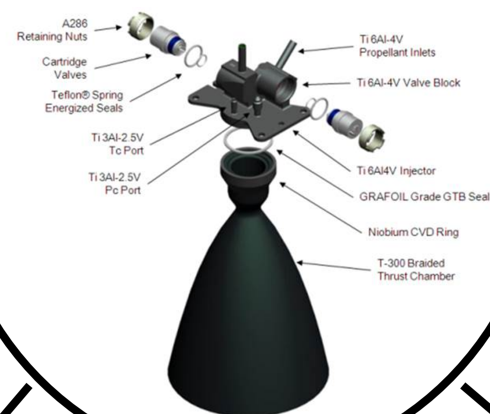




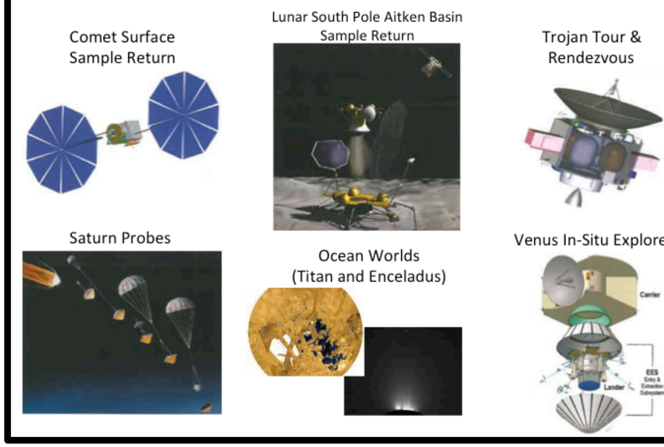
Resource Prospector

ISE-100

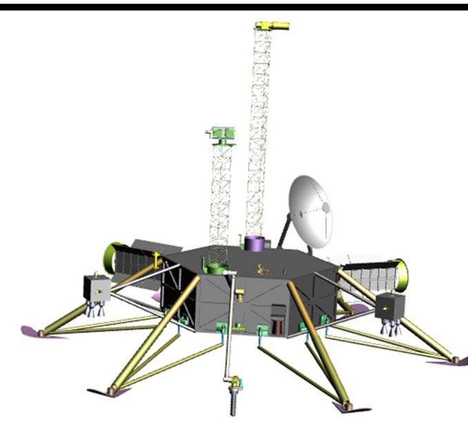
MON-25/MMH Biprop Thruster



New Frontiers AO



Mars Sample Return



Europa Lander

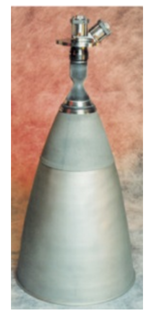
ISE TECHNOLOGY BENEFITS

Comparison of ISE with Competing Engine Technologies

- **ISE-100 Benefits – *"The Technology Rationale"***
  - *Low Propellant Temperature Operability*
    > Reduced propellant heating power & robust operation
  - *Compact & Lightweight*
    > Reduced engine envelope with eased system packaging & enhanced payload capacity
  - *Low Cost*
    > Leverages MDA investments in miniaturized engine technology
  - *Extensible Total Impulse*
    > Tipping Point Redesign & Δ-Qualification

More Payload
More Science

1/5 mass
1/2 size
1/3 cost



AR = Aerojet Rocketdyne

MODEL (Manufacturer)	ISE-100 (AR)	R-4D-11 (AR)	HiPAT (AR)	LEROS 2B (Moog)	AMBR (AR)
Fuel	MMH	MMH	MMH	MMH	Hydrazine
Oxidizer	**MON-25**	MON-3	MON-3	MON-1	MON-3
Operational Prop.Temperature	***-22 F - 100 F***	40 F - 120 F	40 F - 120 F	40 F - 120 F	45 F - 120 F
Thrust	100 lbf	110 lbf	100 lbf	100-lbf	140-lbf
Specific Impulse	300 sec (Target)	311 sec	323 sec	319 sec	333 sec
Area Ratio	70:1	150:1	375:1	360:1	400:1
Inlet Pressure Range	350 psia	247 psia	100 - 400 psia	13.4-18.0 bar	400 psia
Max. Impulse	600,000 lbf-sec (Target)	4,500,000 lbf-sec	4,635,000 lbf-sec	2,180,000 lbf-sec	1,255,800 lbf-sec
Minimum Impulse Bit	0.88 lbf-sec	3,5 lbf-sec	8 lbf-sec	-	-
Weight	***1.63 lbm***	8.3 lbm	12 lbm	10 lbm	12 lbm
Engine Length	**11 in**	19.3 in	26.1 in	30.6 in	26.1 in
Nozzle Exit Diameter	**5.5 in**	11 in	14.3 in	13.1 in	14.3 in
Status	Development	Qualfied	Qualified	Qualified	Development
Cost per unit	***$183k***	$600-800k	Higher than R-4D	$580k	At least $600-800k

Advanced Manufacturing Technology Engine Developments

Graham Nelson

Reginald Alexander

Propulsion Department, NASA Marshall Space Flight Center

May 2016

National Aeronautics and Space Administration

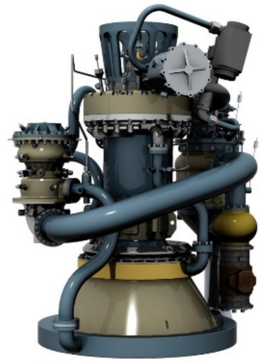
George C. Marshall
Space Flight Center

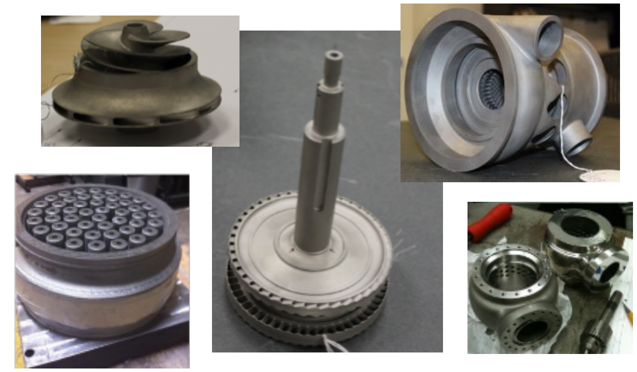
Propulsion Department, ER

Additive Manufacturing Demonstrator Engine (AMDE) Objectives Overview

Primary Objectives:

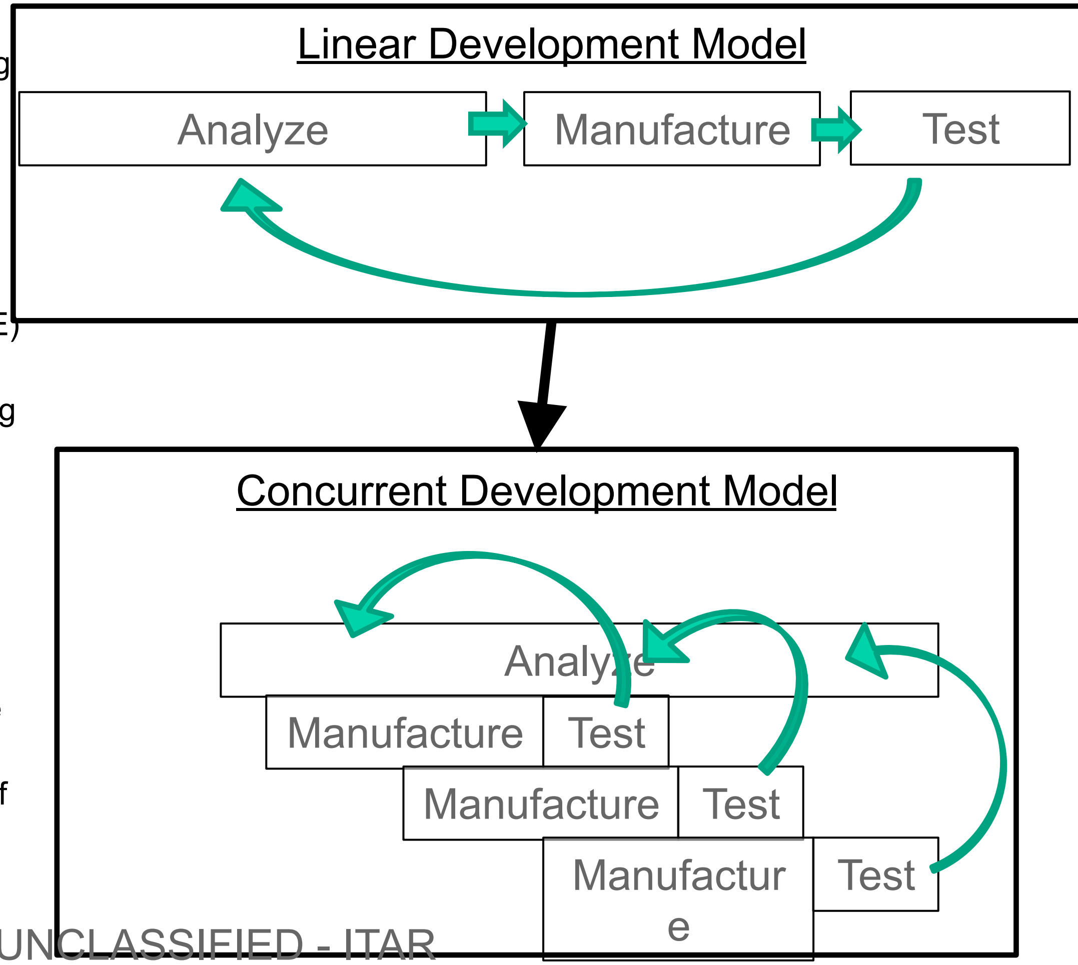
- Demonstrate an approach that reduces the cost and schedule required for new rocket engine development
  - **Prototype engine in 2.5 years**
  - Operate lean
    - (~ 25 people/year; $5M/year hardware and testing)
  - Shift to Concurrent Development
    - Use additive manufacturing (AM) to facilitate this approach
- Advance the TRL of AM parts through component/system testing
- Develop a cost-effective prototype
  - Upper-Stage or In-Space Class





Testbed History Development Overview

- Began with Additive Manufacturing Demonstrator Engine (AMDE) development (Oct, 2012 – Sep, 2015)
  - Original goal to build a 35 klbf O2/H2 prototype engine using a heavy amount of additive manufacturing (3-D printing)
- AMDE shifted to Breadboard Engine (BBE) development approach to accommodate shifting financial environments
  - Can add components as they are available
  - Flexibility to accommodate many layout, cycle, and propellant combinations
- BBE currently being evolved to focus around pump-fed methane engine development
  - Centered around risk-reduction activities for development of a 100 kN (22.5 klbf) O2/CH4 engine

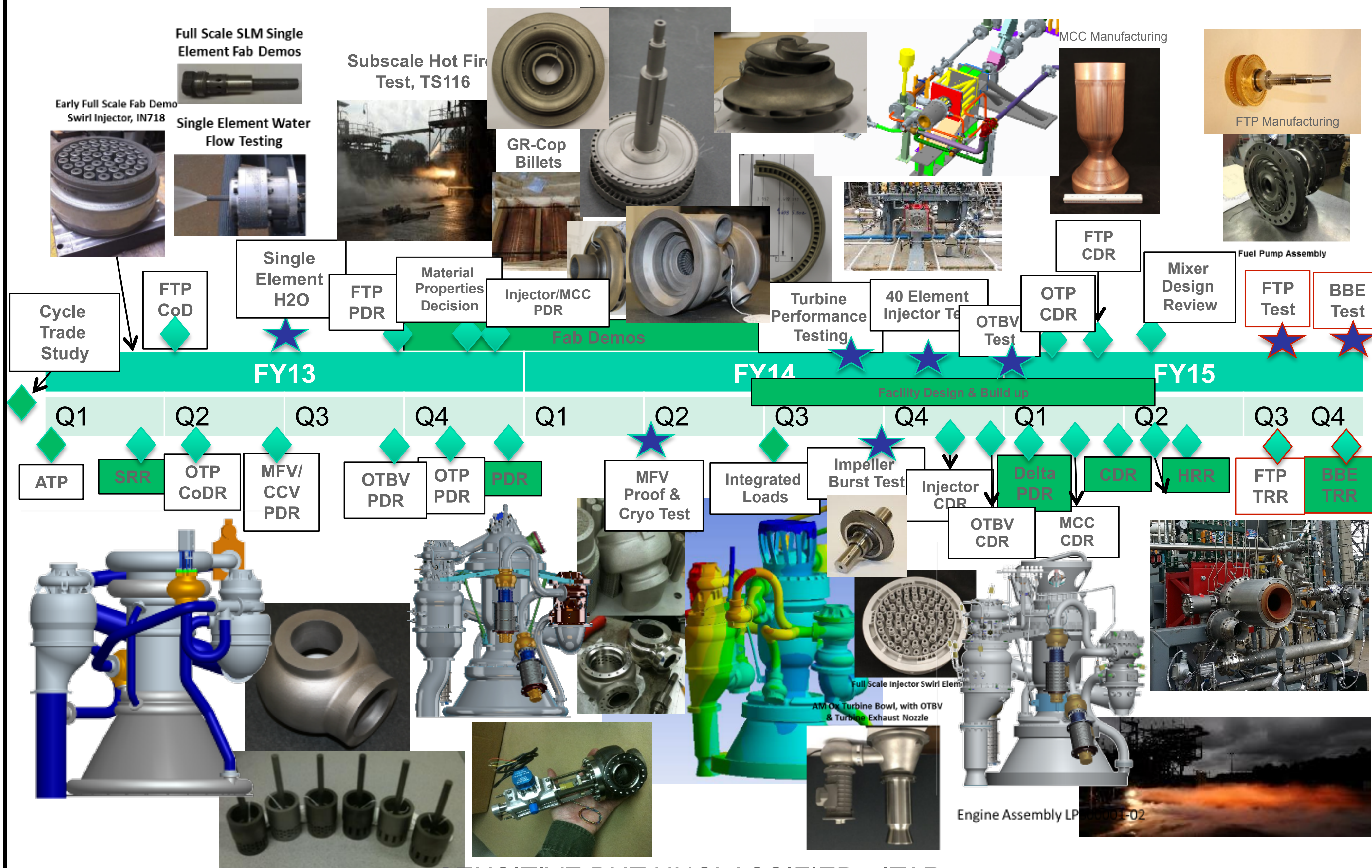


National Aeronautics and Space Administration

George C. Marshall
Space Flight Center

Propulsion Department, ER

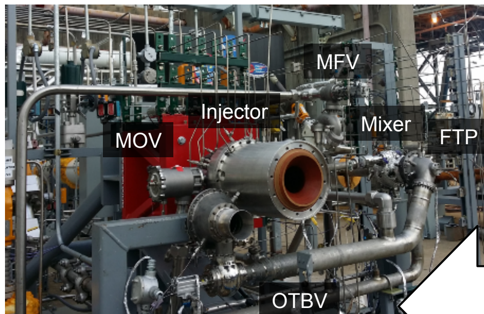
AMDE Development Overview



LH_2 and LCH_4 Testing

Hydrogen Breadboard Engine Testing

- Breadboard Engine (BBE) System flexibility allows for incremental improvements
  - Adding components as they are available
  - Evolving to new propellants (e.g. CH4)
  - Switching between different system configurations quickly
  - Potential for testing outside customer drop-ins
- Breadboard with an Ablative MCC (BBEA) tested in hydrogen Oct-Nov, 2015
  - 6 hot fire tests completed



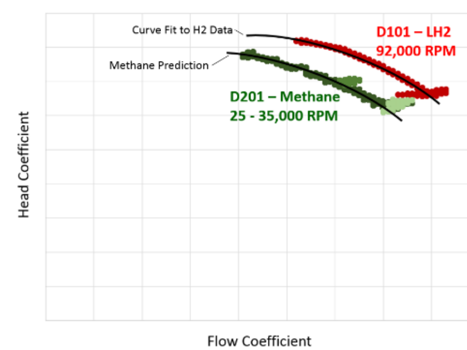
SENSITIVE BUT UNCLASSIFIED - ITAR

LH_2 Testing Summary

- 15 tests run initially, for a total of 136 seconds
- Longest single duration was 30 sec
- Generated 1,900 HP at 91,000 rpm
- Produces 40 HP / lbm
  - Potential for further weight reductions

Methane Fuel Pump Testing

- AMDE Fuel Turbopump unit 1 (FTP D101) chill tested in early FY16
- FTP unit 2 (FTP D102) tested in methane in March, 2016
  - Same design as D101
- D101 hydrogen test data used as anchor to methane performance predictions
- 6 tests run; speeds from 25 to 35 kRPM; up to 30 sec
- Methane performance predictions verified
  - Pump is suitable for use with methane engine



SENSITIVE BUT UNCLASSIFIED - ITAR

- Need for a 100-150 kN (22,500-35,000 lbf) O_2/CH_4 rocket engine
  - Both NASA and industry applications
- Elected to use the AMDE BBE testbed to perform risk-reduction activities on a pump-fed methane engine over the next couple years
- Primary objectives of the pump-fed methane engine risk reduction activities:
  1) Evaluate the reliability of pump-fed methane engine system operations
  2) Root out system issues unique to methane
  3) Gather performance data on the maximum amount of engine components possible to determine their suitability to future development

Pressure-Fed Methane Near-Term Plan