ENERGY SYSTEMS DIVISION

PRESENTATION to YUZHNOYE SDO

Propulsion Technology Development Overview

April 5, 2011

John Applewhite
Chief, Propulsion Systems Branch

National Aeronautics and Space Administration

JSC ROLE IN PROPULSION

Past and Present to the Future

APOLLO

- Reaction Control System
- Descent & Ascent Propulsion

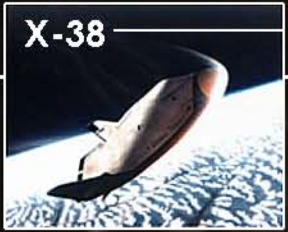
SPACE SHUTTLE

- Reaction Control & Orbit Maneuvering Systems
- Main Propulsion Systems

ISS

- O2/H2 & Hydrazine Control & Reboost
- US Propulsion Module
- Orbiter Reboost

X-38



- Hydrazine De-Orbit Module
- Cold Gas GN_2 RCS

CONSTELLATION

- Liquid Propulsion Lead
- Test & Verification

ORION / ALTAIR

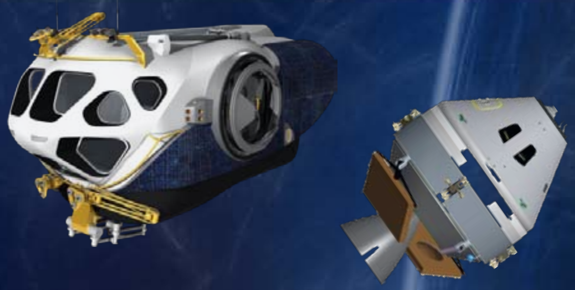
Hydrazine CM RCS, MMH/NTO SM Main & RCS, LO_2-Methane Design Concepts for CM & Lander

EXPLORATION

- High Performance Non-Toxic Propulsion
- ISRU Compatible Propellants
- Integrated Propulsion, Power, ECLSS
- Propellant Storage & Transfer

PROPULSION CHALLENGES
FOR FUTURE EXPLORATION MISSIONS

Advanced Space Storable Propellants
For In-Space Reusable Multi-Mission Service Vehicles
- Non-Toxic Propellants
- Better Performance than Earth Storable Hypergolic
- Highly Integrated Propulsion, Power, ECLSS
- Compatible with In-Situ Resource Utilization (ISRU)



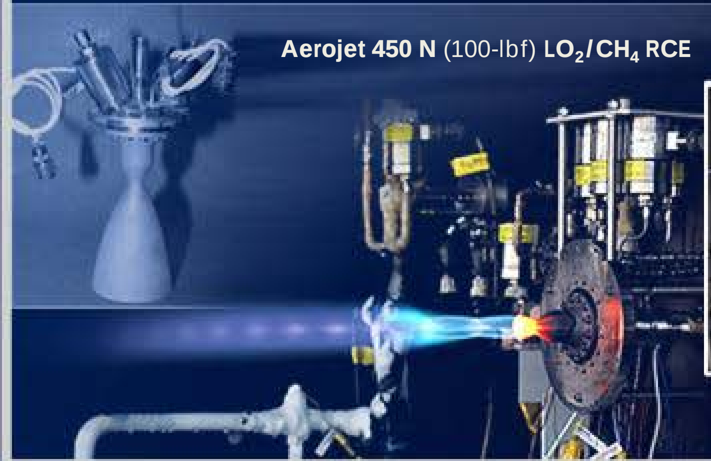
High Power Electric Propulsion Systems
For Missions to GEO, Outpost, & Planetary Destinations
- Enable <1 year transit times
- 100's KW to MW class at 1,000 to 10,000 sec Isp
- High thrust capability (e.g. 25 N/MW at 5,000 sec Isp using Argon)
- VAriable Specific Impulse Magnetoplasma Rocket (VASIMR) as example

Long-Term Cryogenic Storage & Transfer
LO_2, LH_2, and CH_4 for Spacecraft and Transfer Stages
- 1 to 5+ years on-orbit storage
- Transfer capability for Re-supply & Propellant Depot operations
- Zero-G liquid acquisition & mass gauging, automated fluid couplings, and low heat leak valve technologies

ADVANCED PROPULSION

Significant Agency Investment In LO_2/CH_4 Propulsion Technology Development

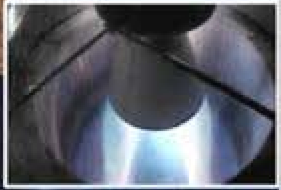
- **Compact Igniter Systems**
- **Altitude Ignition Testing**
- **Reaction Control Engine** (450N; 100-lbf)
- **Ascent Ascent Main Engine** (15 – 25 kN; 3,500-5,500 lbf)
- **Integrated Propulsion System Test Bed**



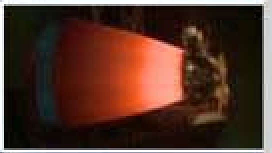
Aerojet 450 N (100-lbf) **LO_2/CH_4 RCE**

Altitude Ignition Testing

Aerojet 25 kN (5,500-lbf) **LO_2/CH_4 Ascent Main Engine**



PWR 15 kN 3,500 lbf)
RS-18 LO_2/CH_4

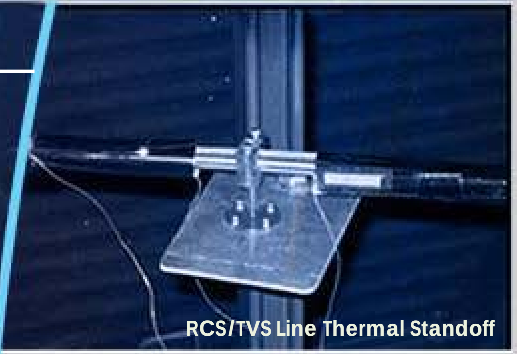


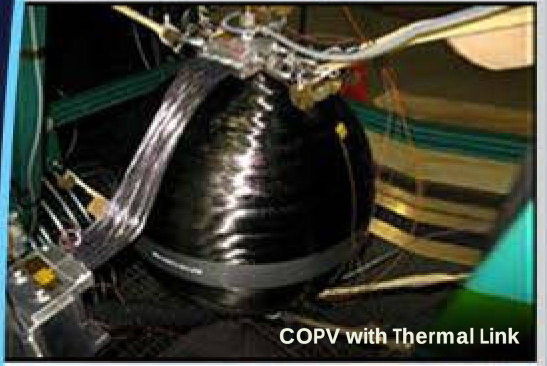
Northrup Grumman 450 N (100-lbf) **LO_2/CH_4 RCE**

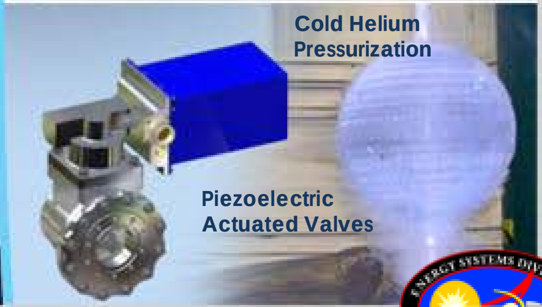
CRYOGENIC FLUID MANAGEMENT

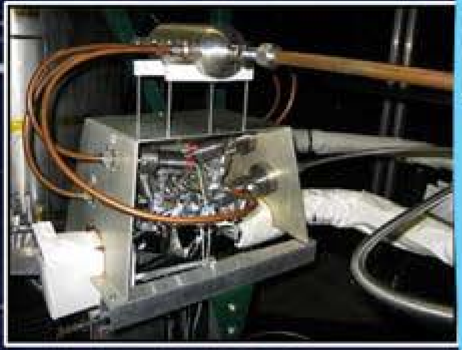
Technology Development to Support Space Storable Cryogenic Propulsion Systems

- **Cold Helium Storage** (90 K; -300 F)
- **Low Heat Leak Piezoelectric Valve Actuation**
- **Tank Applied Multi-Layer Insulation (MLI)**
- **Thermodynamic Vent System for RCS Feedline Conditioning**
- **Cryogenic Feedsystem Analysis Tool Development**
- **Integrated System Testing at High Vacuum** (10^{-5} torr)


RCS/TVS Line Thermal Standoff


COPV with Thermal Link



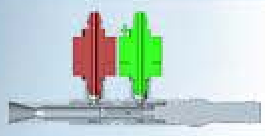

Thruster Pod Simulator


Integrated Cryogenic Feedsystem in 4.57m (15 ft) Thermal Vacuum Chamber

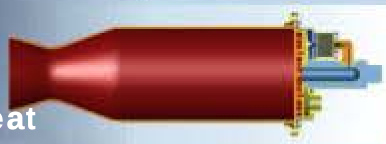
IN-HOUSE DEVELOPMENT

Sustained JSC IR&D Investment in Propulsion Technologies

- **Low Cost Reaction Control Engine** (22–66 N; 5–15 lbf)
- **4:1 Throttling LO_2-CH_4 Main Engines** (11–18 kN; 2,500–4,200 lbf)
- **Co-Axial Swirl Uni-element Injector** (270 N; 60 lbf)
- **Dual Bell Nozzle Development**
- **Piezoelectric Regulator / Isolation Valve**
- **VASIMR Electric Propulsion Integration, High Temperature Heat Rejection, and Propellant Delivery System Design**

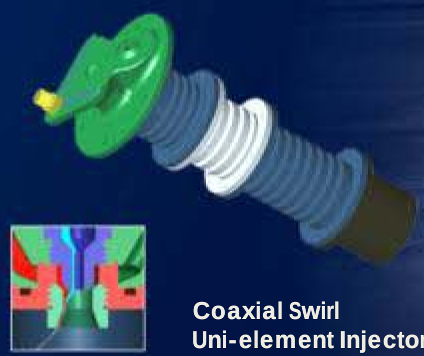


22 N (5 lbf) **"Pencil" Thruster**



Ascent Main Engine w/ Dual-Bell Nozzle

LOX/CH4 18 kN (4,200 lbf)
4:1 Throttling Main Engine



Coaxial Swirl Uni-element Injector

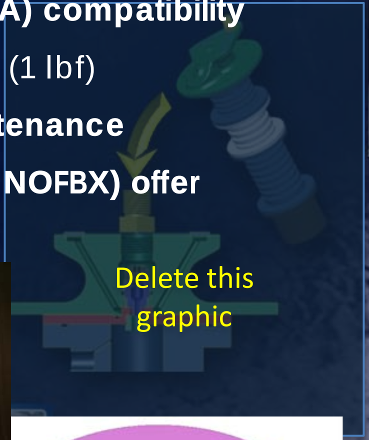
200 kW VX-200 VASIMR Courtesy Ad Astra Houston, TX

MINIATURE PROPULSION

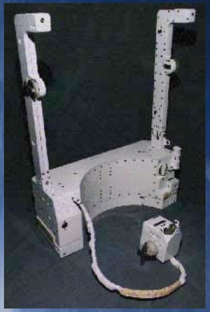
Low Thrust Solutions for Free Flyer Robotic and EVA Propulsion

- Cold Gas (GN_2, Xenon) and Warm Gas (Tridyne) solutions
- Non-Toxic for Extra / Intravehicular (EVA/IVA) compatibility
- Thrust range from < 0.05 N (0.01 lbf) to > 5 N (1 lbf)
- Designed for re-usability and on-orbit maintenance
- High Performance Green Propellants (ADN, NOFBX) offer potential upgrade options

SPRINT Free Flyer
STS-87

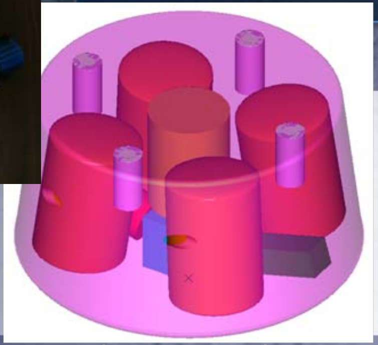


Mini-thruster, manifold, and regulator



SAFER EVA Backpack

Mini-AERCam Prototype



ISS Sample Return Capsule

IN-HOUSE DEVELOPMENT

MORPHEUS TERRESTRIAL FREE FLYER TEST BED

Free Flyer Test Bed

- Modular design enables enhancements and system upgrades.
- Ability to fly analog trajectories such as Lunar descent.
- LO_2/CH_4 propulsion for low-cost testing with rapid recycle time.

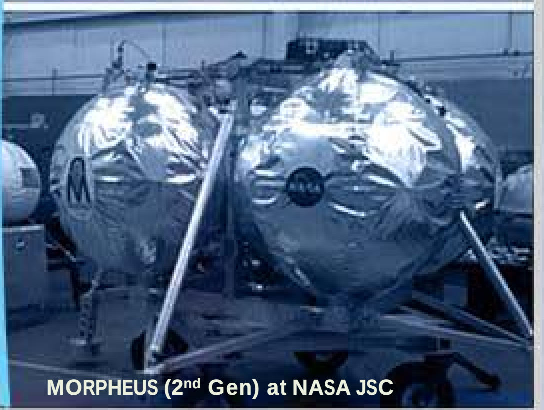
Versatile Platform for Fully Integrated Vehicle-Level Demonstrations

- Non-toxic propulsion system technologies.
- Integrated propulsion/avionics/GN&C architectures including Autonomous Landing Hazard Avoidance Technology (ALHAT).
- Ground operations, flight operations, range safety.

Vehicle Architecture is Evolvable

- Integrated Propulsion, Power, and ECLSS (emulator) across common ISRU-compatible fluids.
- Higher energy trajectories to assess aerodynamic controllability for Mars entry and Pad abort vehicles

1st Generation Vertical Test Bed



MORPHEUS (2nd Gen) at NASA JSC

BACK-UP

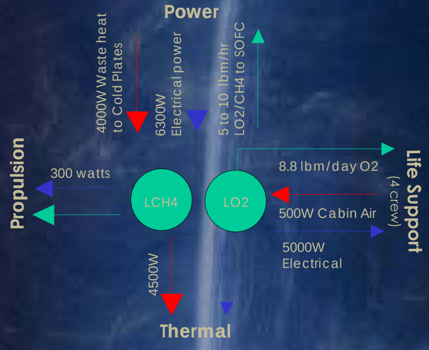
LO_2-CH_4 ADVANTAGES FOR SPACECRAFT PROPULSION

- **LOX/CH4 provides distinct advantages for spacecraft applications requiring:**
  - High performance
  - Long duration in-space storage
  - High density, low volume packaging
  - Non-toxic and low cost propellants
  - Fluid common with other systems (ECLSS/breathing O2, Fuel Cell reactants)
  - Compatibility with Mars and Lunar In-Situ Resource Utilization (ISRU)

Propellant	I_{sp} (94% ODE, 150:1)	Bulk Density S.G.	Energy Density BD x Isp	Space Storable (w/o Active Cooling)	ISRU Compatibility	Toxicity (TLV ppm)	Prop Cost ($/kg)
Hydrazine	240	1.004	241	Yes (heaters)	No	Yes (0.01)	$$$$
NTO/MMH	323	1.200	388	Yes (heaters)	No	Yes (3/0.2)	$$$$
LO_2/LCH_4	**364**	**0.804**	**293**	**Yes** (6m-1yr)	**Yes**	**Non-Toxic**	**$**
LO_2/LH_2	455	0.360	164	No	Yes	Non-Toxic	$$

LO_2-CH_4 ADVANTAGES
FOR SPACECRAFT PROPULSION

- **Performs and packages well for most in-space vehicle applications**
  - Service and Crew Module auxiliary and main propulsion.
  - Lunar or Martian surface ascent and descent stages.
  - Propellant depots/tankers and servicing vehicles.
  - Upper stage/spacecraft on-orbit RCS.
- **LO2 supports high degree of integration between Propulsion, Power, and ECLSS.**
  - Solid Oxide Fuel Cell enables both common reactant storage and a lightweight cooling system
- **Better packaging than LH_2 and simplifies main and auxiliary propulsion system integration.**
- **Significantly lower test cost compared to hypergolic propellants.**
- **ISRU compatibility makes LO2/CH4 enabling for sustained Mars or Lunar exploration.**




30-cell Delphi 1-KW SOFC Stack