ENERGY SYSTEMS DIVISION

PRESENTATION to YUZHNOYE SDO

Propulsion Technology Development Overview

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JSC ROLE IN PROPULSION

Past and Present to the Future

- Reaction Control System
- Descent & Ascent Propulsion

APOLLO

SPACE SHUTTLE

- Reaction Control & Orbit Maneuvering Systems
- Main Propulsion Systems

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

ISS

X-38

- Hydrazine De-Orbit Module
- Cold Gas GN_2 RCS

- Liquid Propulsion Lead
- Test & Verification

CONSTELLATION

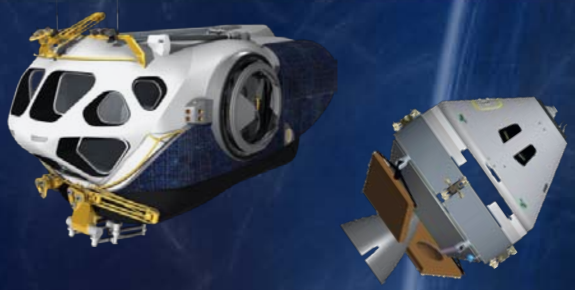
ORION / ALTAIR

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

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

EXPLORATION

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)

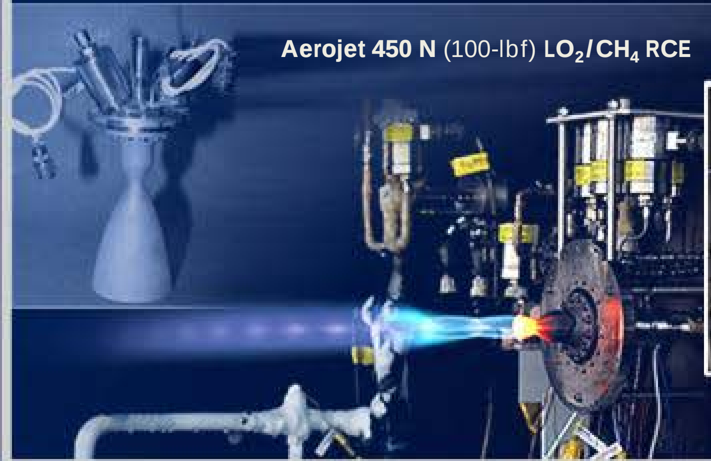
High Power Electric Propulsion Systems
For Missions to GEO, Outpost, & Planetary Destinations
- Enable <1 year transit times
- 100’s KW to MW class at 1,000 to 10,000 sec Isp
- High thrust capability (e.g. 25 N/MW at 5,000 sec Isp using Argon)
- VAriable Specific Impulse Magnetoplasma Rocket (VASIMR)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

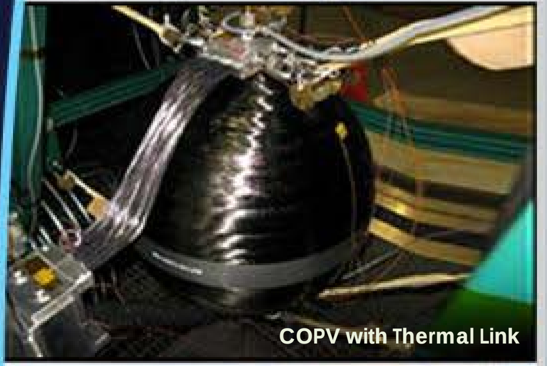
Northrup Grumman
450 N (100-lbf)
LO_2/CH_4 RCE

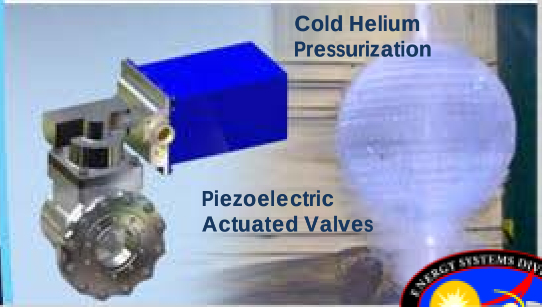
CRYOGENIC FLUID MANAGEMENT

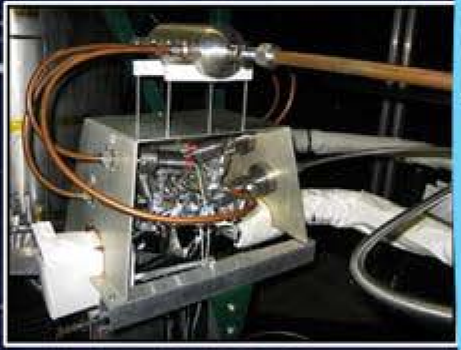
Technology Development to Support Space Storable Cryogenic Propulsion Systems

- **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



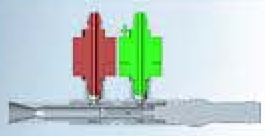

Thruster Pod Simulator


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

IN-HOUSE DEVELOPMENT

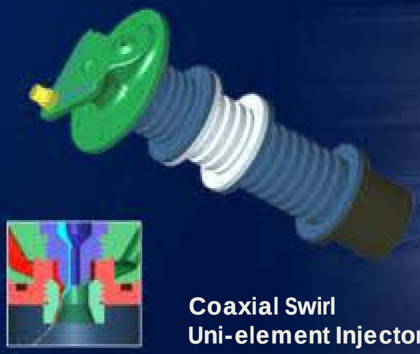
Sustained JSC IR&D Investment in Propulsion Technologies

- **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



Coaxial Swirl Uni-element Injector

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

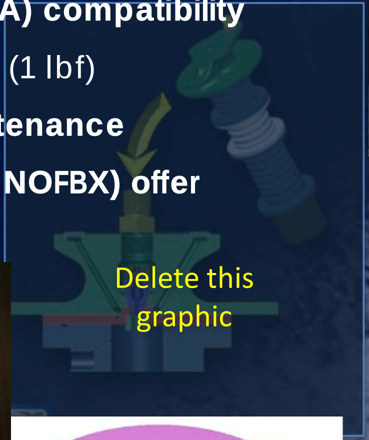
LOX/CH4 18 kN (4,200 lbf) **4:1 Throttling Main Engine**

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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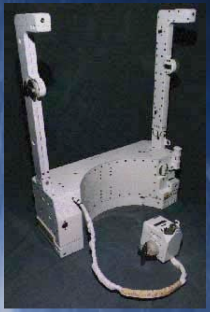
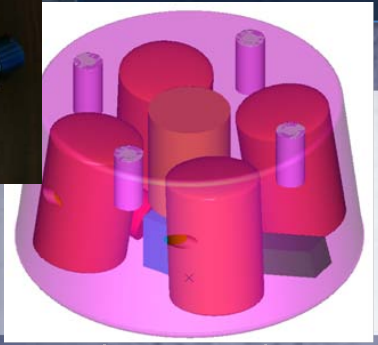
Mini-thruster, manifold, and regulator


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.**

Lower airlock, cargo, CG

30-cell Delphi 1-KW SOFC Stack