



Source of Acquisition
NASA Johnson Space Center



On-Orbit Propulsion OMS/RCS

Energy Systems Division
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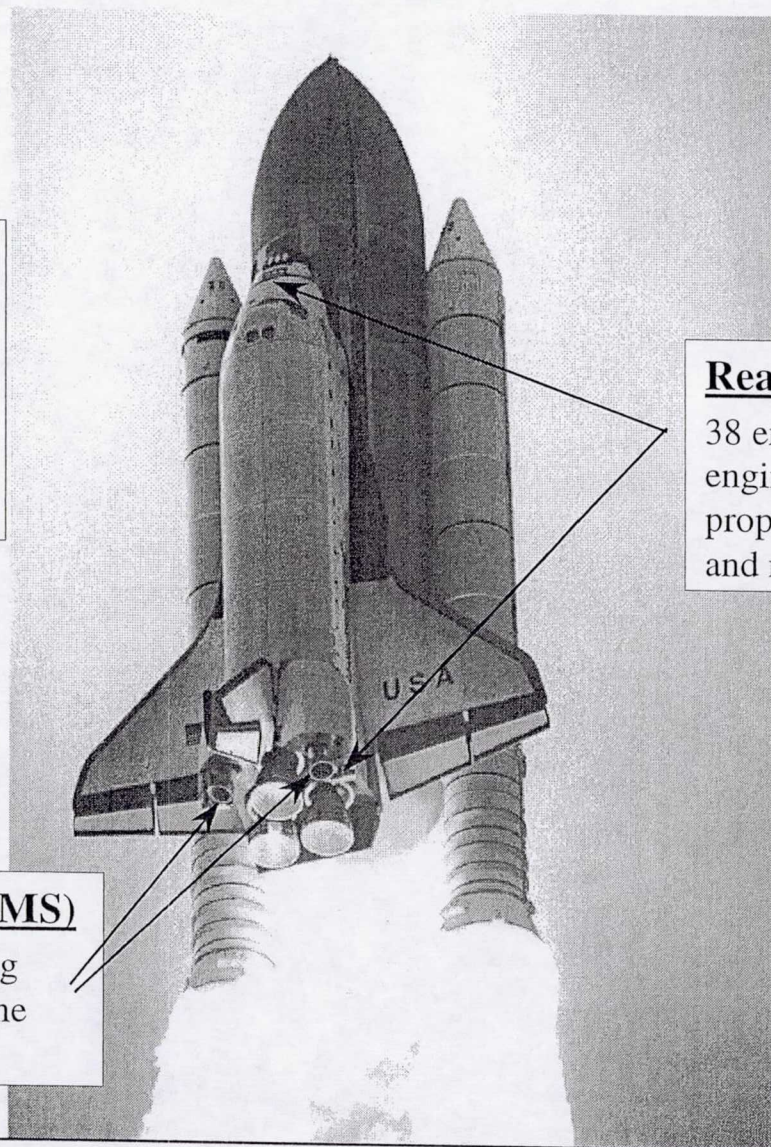




On-Orbit Propulsion Systems

Orbital Maneuvering System (OMS)

2 engines at 6000 lbf thrust each burning liquid propellants (monomethylhydrazine and nitrogen tetroxide) while on orbit



Reaction Control System (RCS)

38 engines at 870 lbf thrust each and 6 engines at 25 lbf each burning liquid propellants (monomethylhydrazine and nitrogen tetroxide) while on orbit





SPACE SHUTTLE ASCENT



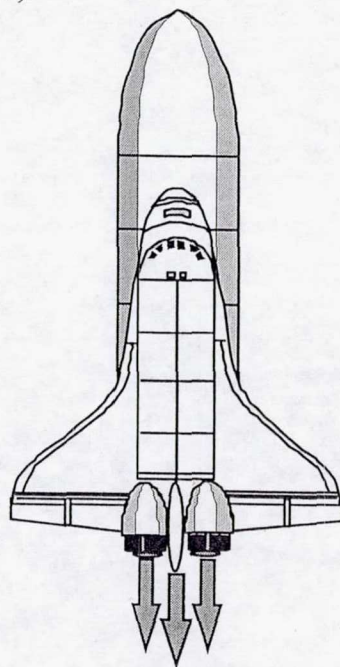
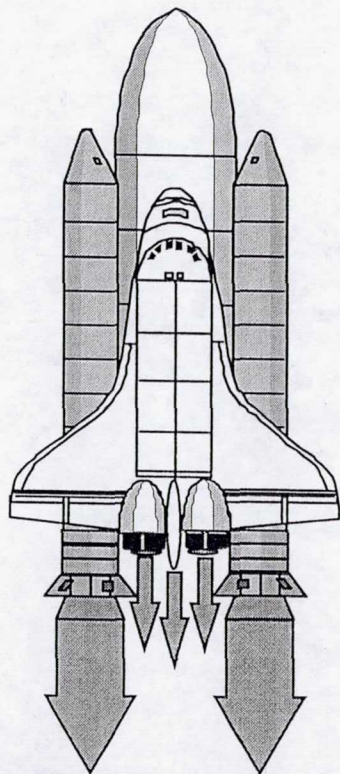
LIFT-OFF/ASCENT

Solid Rocket Boosters (SRB's)
and Main Engines (SSME's)

Mission Time = 2 min

Altitude = 150,000 ft

Velocity = 4200 ft/sec



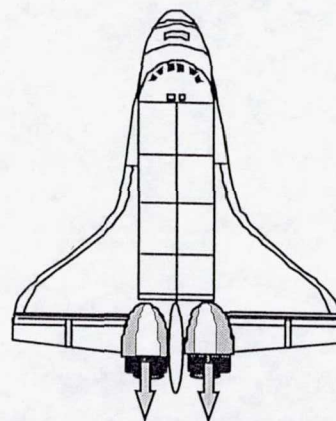
ASCENT

Main Engines (SSME's)

Mission Time = 8.5 min

Altitude = 365,000 ft

Velocity = 26,000 ft/sec



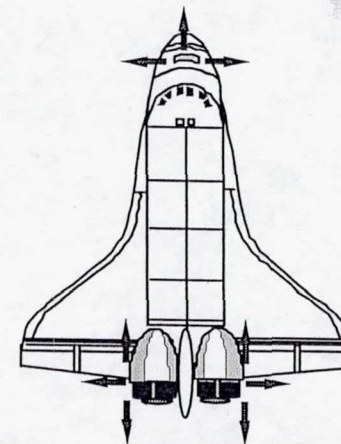
ORBITAL INSERTION

Orbital Maneuvering System
(OMS) Engines

Mission Time = 40 min

Altitude = 100-200 nmi

Velocity = 17,500 mi/hr



ON-ORBIT OPERATIONS

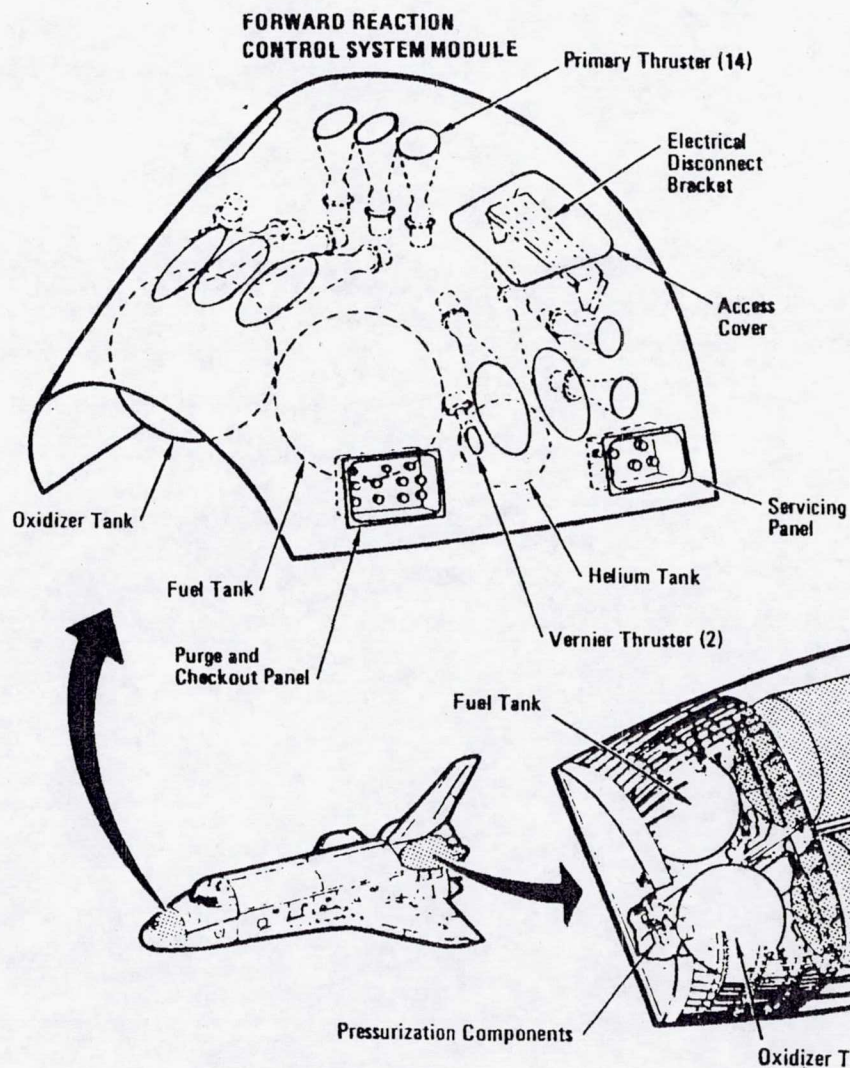
Reaction Control System
(RCS) Engines

Mission Time = N/A

Altitude = 100-200 nmi

Velocity = 17,500 mi/hr





38 Primary Thrusters (14 Forward, 12 per Aft Pod)
Thrust Level = 3,870 Newtons (870 lb) Vacuum
6 Vernier Thrusters (2 Forward, 4 Aft)
Thrust Level = 106 Newtons (24 lb) Vacuum

Propellants: N_2O_4 and MMH
Forward and Aft RCS Oxidizer
Tanks: 674 kg (1,488 lb) each
Forward and Aft RCS Fuel Tanks: 421 kg (930 lb) each





- **Orbital Maneuvering Subsystem Functions**
 - Provide thrust for:
 - Orbit Insertion
 - Orbit Circularization
 - Orbit Transfer
 - Rendezvous
 - Deorbit
 - Launch Abort
 - Provide additional propellant for on-orbit RCS use
 - Crossfeed capability (system redundancy feature)





- **Orbital Maneuvering System Description**

- Located in two independent pods on the aft end of the Orbiter
 - Each pod contains one OMS engine, one fuel tank, one oxidizer tank, one helium storage tank, associated pressurant/propellant feed system valves and tubing
 - OME Performance:
 - » Thrust – 6,000 lbf
 - » Specific Impulse (Isp) – 315 secs
 - » Nominal Chamber Pressure – 130 psia
 - Propellants, monomethyl hydrazine (MMH) and nitrogen tetroxide (N_2O_4) are **hypergolic - react on contact**
 - Each engine can be fed from either pod (i.e., either engine can burn propellants from left, right, or both pods)
 - Each pod contains interfaces to EPD&C (power to valves), GN&C (engine controls), D&C (crew insight), instrumentation, thermal control system circuitry, and C/W.





- **Reaction Control System Function**
 - Provide thrust for velocity changes along the axis of the Orbiter
 - Separation from the External Tank (FRCS)
 - Minor orbit adjustments during rendezvous (fwd & aft)
 - Reboost for ISS, HST
 - Back-up to OMS for Deorbit
 - Provide vehicle attitude control – on orbit and entry
 - Maneuver to attitude for rendezvous, payload deployment/capture, special mission requirements
 - Vehicle control during entry prior to aerosurface control (yaw jets used down to 45Kft)





- **Reaction Control System Description**

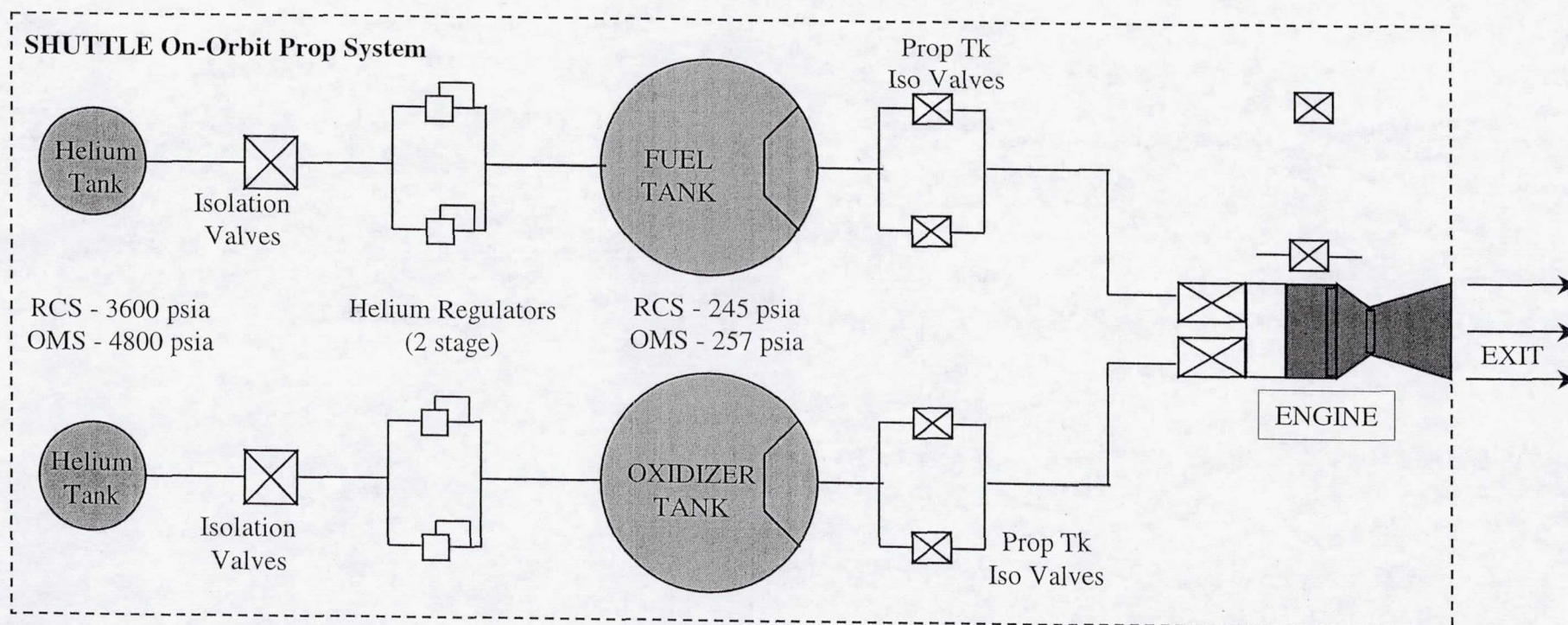
- Fwd RCS includes 14 primary (870 lbf) and 2 vernier (25 lbf) jets
- Aft RCS (located in OMS pods) each contain 12 primary and 2 vernier jets
 - Aft RCS manifolds can be fed by RCS tanks in the opposite pod (crossfeed mode)
 - or OMS propellant tanks from either pod (interconnect mode)
 - FRCS manifolds are stand-alone (we ALMOST had fwd interconnect)
- Each RCS contains a helium storage tank, one fuel tank, one oxidizer tank, associated feed/pressurization system valves and plumbing
 - Unlike OMS, the RCS fuel and oxidizer tanks are pressurized by independent helium systems





- **How Does the Shuttle OMS/RCS Work?**

- Regulated helium pushes liquid fuel (MMH) and oxidizer (N_2O_4) into rocket engine for spontaneous combustion
- Propellant Acquisition Devices (screens) use capillary forces to collect propellant and direct it to tank outlet



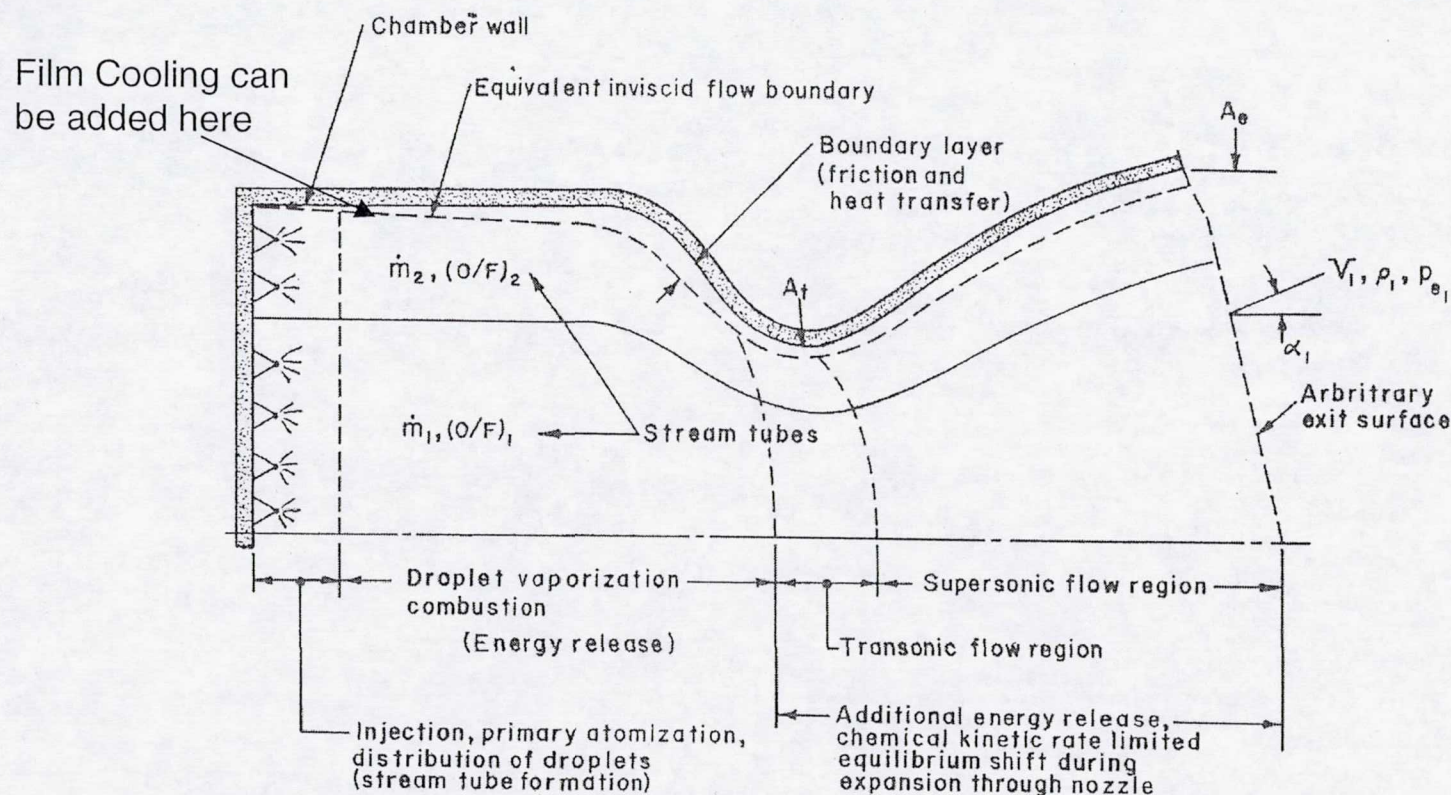


OMS/RCS Thruster Fundamentals





Thrust Chamber Performance



$$F_{vac} = \int_s \dot{m}_i V_i \cos \alpha_i + \int p_{e_i} dA_{e_i}$$

- $I_{sp} = F_{vac} / \dot{m}_{dot}$ (Overall Performance - Thrust per propellant consumption)
 $C^* = P_c A_t / \dot{m}_{dot}$ (Combustion Chamber Performance – characteristic velocity)
 $C_f = T / (P_c A_t)$ (Nozzle Performance – Thrust coefficient)



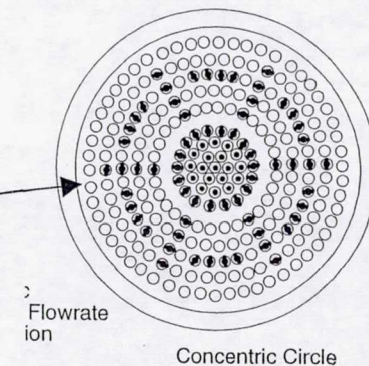
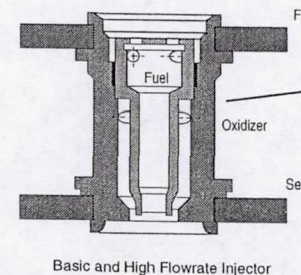
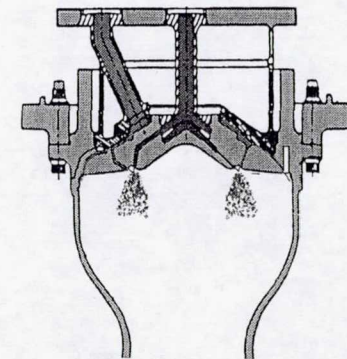
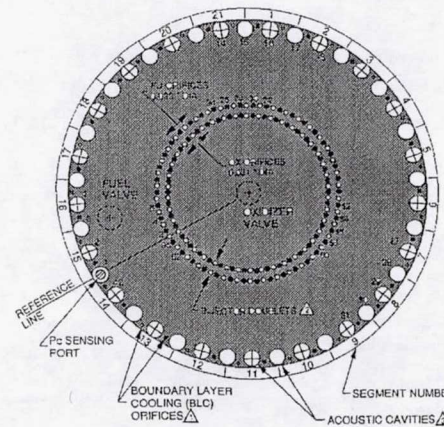
Typically Analyzed By using TEP and TDK (see division analysis tools)



Injectors



- Several different types
 - Pintle
 - Coaxial
 - Impinging
- Several manufacturing Techniques
 - Drilled
 - Etched Platelet
 - Machined (Coaxial and Pintle)



From NASA SP194



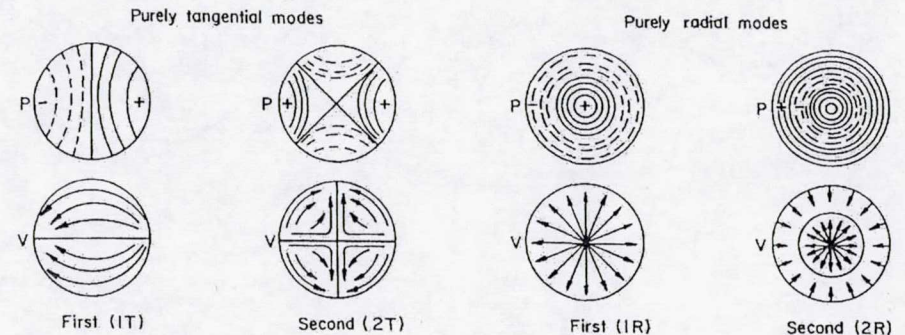


Combustion Instability



- **Definition**
 - An undesirable dynamic interaction between the combustion process and other parts of the system or engine
- **Low frequency (Chugging)**
 - Coupling between engine and feedsystem
 - Apollo R4D used on Cassini required modification of feedsystem
- **First Longitudinal Chamber Mode**
- **High Frequency**
 - Coupling between chamber acoustics and the combustion process
 - Fix is to use acoustic damping devices to damp oscillations or inherently stable injector (pintle)
 - Shuttle primary RCS engine experienced instability
 - Triggered by gas injection in the fuel side during start-up, which caused a disturbance sufficient to create an instability
 - Instability was the 1T at 6000 Hz

Some High Frequency Modes





Chambers



- Regeneratively Cooled
 - Fuel or oxidizer is routed through chamber wall (nickel or stainless steel)
 - OMS Engine is fuel cooled
- Film Cooled
 - C103 (Niobium) with disilicide coating
 - RCS engine use this material and film cooling





Non Toxic OMS/RCS





Trade Study Comparison of Propellants



Performance	MMH/NTO Pressure-Fed	H2O2/H-C Pressure-Fed	LOX/Alcohol Pressure-Fed	LOX/Methane Pressure-Fed	LOX/Methane Pump-Fed	LOX/LH2 Pump-Fed
Total Mass (Isp)	SOA	-	+	+	+	+
Power Required (Heaters)	SOA	-	+	+	+	+
Volume, (Density Isp)	SOA	+	+	-	+	-
Reliability and Safety						
Number of Components	SOA	+	+	+	-	-
Explosive Residues	Need Imp	+	+	-	+	+
Plume Contamination		-	+	+	+	+
Non-Corrosive	Need Imp	-	+	+	+	+
Low Leakage	Need Imp	+	+	+	+	-
Fast Response	SOA	+	+	+	-	-
Toxicity	Need Imp	+	+	+	+	+
Flammability	Need Imp	+	+	+	+	-
Cost						
Inert (Dry) Mass	SOA	+	+	+	-	-
Propellant Cost	Need Imp	-	+	+	+	-
Number of Components	SOA	+	+	+	-	-
Operations						
Long Term Storability (Years)	SOA	-	-	-	-	-
Propellant Management	SOA	-	+	+	-	-
Ground Propellant Handling	Need Imp	-	+	+	+	+
Integration w/Power/ECLSS	Need Imp	-	+	+	+	+
Commonality with HEDS Roadmap	Need Imp	-	+	+	+	+
Total +		9	18	16	13	9



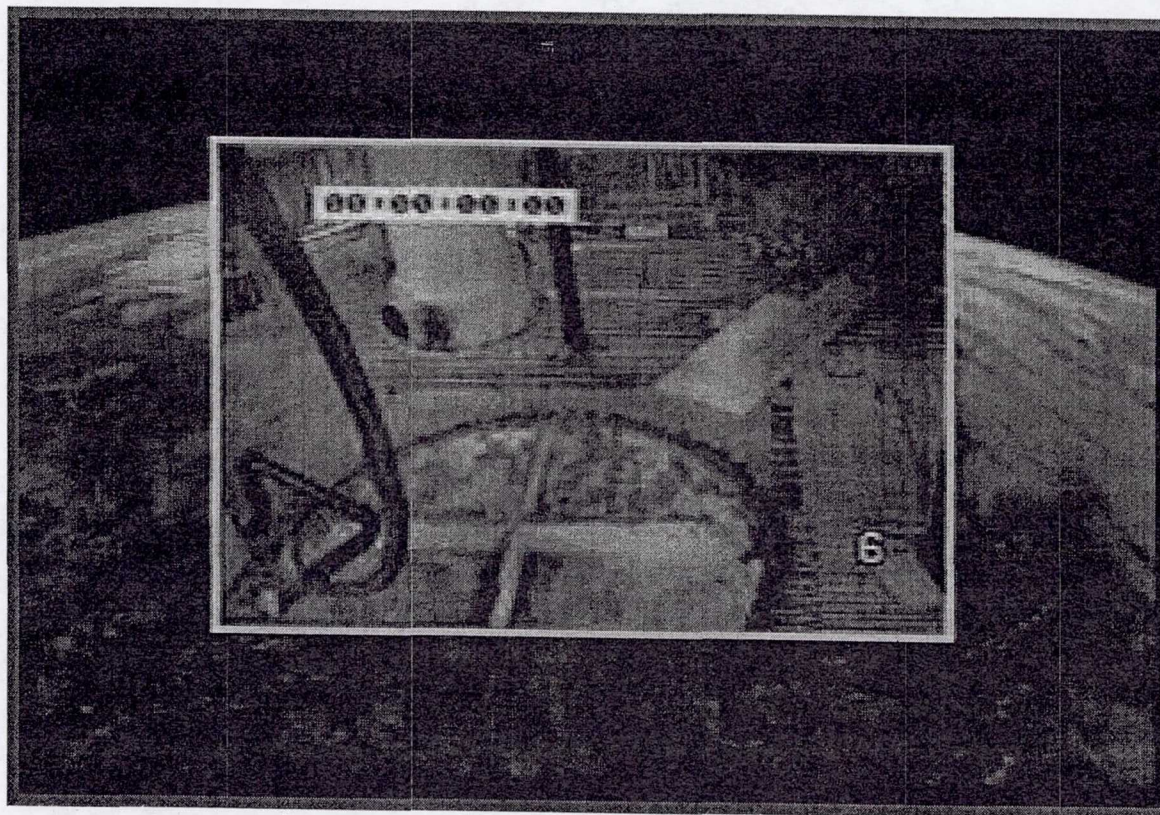
+ = Better than NTO/MMH (or equal to if also good)

- = Worse than to NTO/MMH

SOA = State of the Art



Lox/Ethanol Engine Firings





References

- AIAA Volume 147 "Modern Engineering for Liquid Propellant Rocket Engines"
- NASA SP-194 "Liquid Propellant Rocket Combustion Instability"
- AIAA Volume 169 "Liquid Rocket Engine Combustion Instability"

