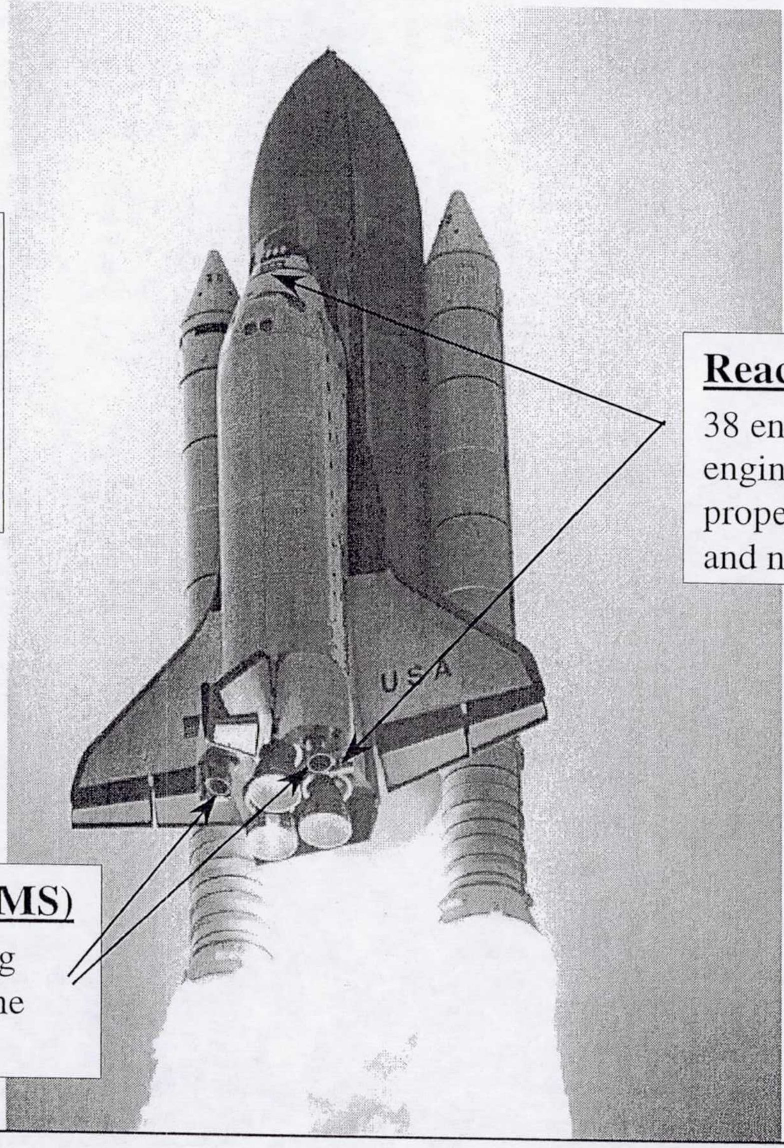
On-Orbit Propulsion
OMS/RCS

Energy Systems Division
Engineering Directorate
NASA/Johnson Space Center

April 26, 2001

On-Orbit Propulsion Systems



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

Orbital Maneuvering System (OMS)

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

SPACE SHUTTLE ASCENT

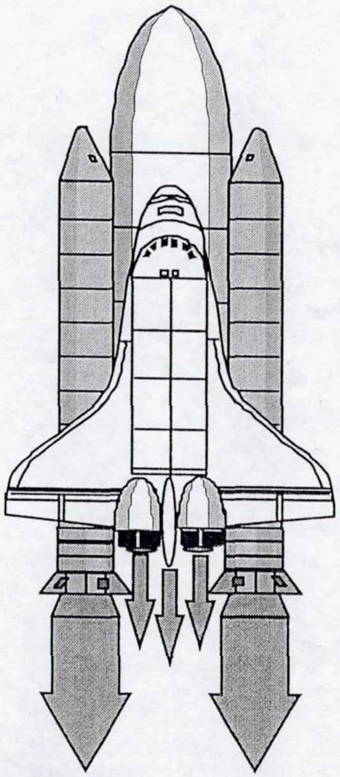
LIFT-OFF/ASCENT

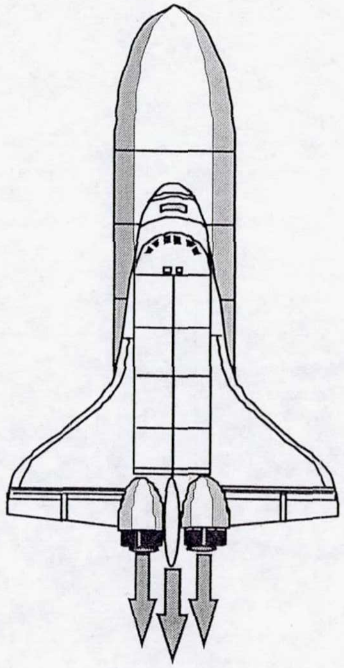
Solid Rocket Boosters (SRB's) and Main Engines (SSME's)

Mission Time = 2 min

Altitude = 150,000 ft

Velocity = 4200 ft/sec





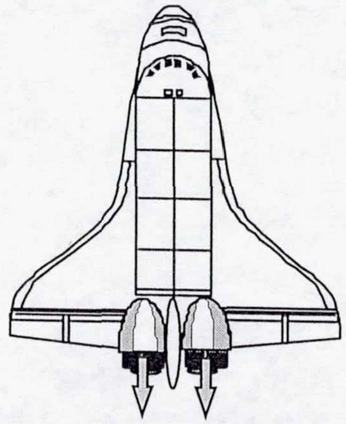
ASCENT

Main Engines (SSME's)

Mission Time = 8.5 min

Altitude = 365,000 ft

Velocity = 26,000 ft/sec



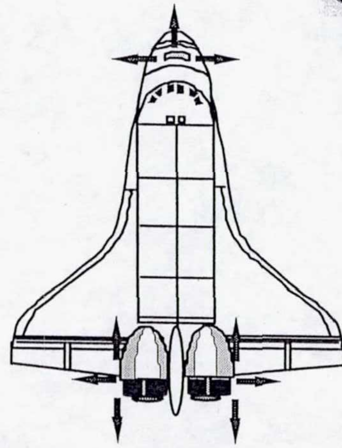
ORBITAL INSERTION

Orbital Maneuvering System (OMS) Engines

Mission Time = 40 min

Altitude = 100-200 nmi

Velocity = 17,500 mi/hr



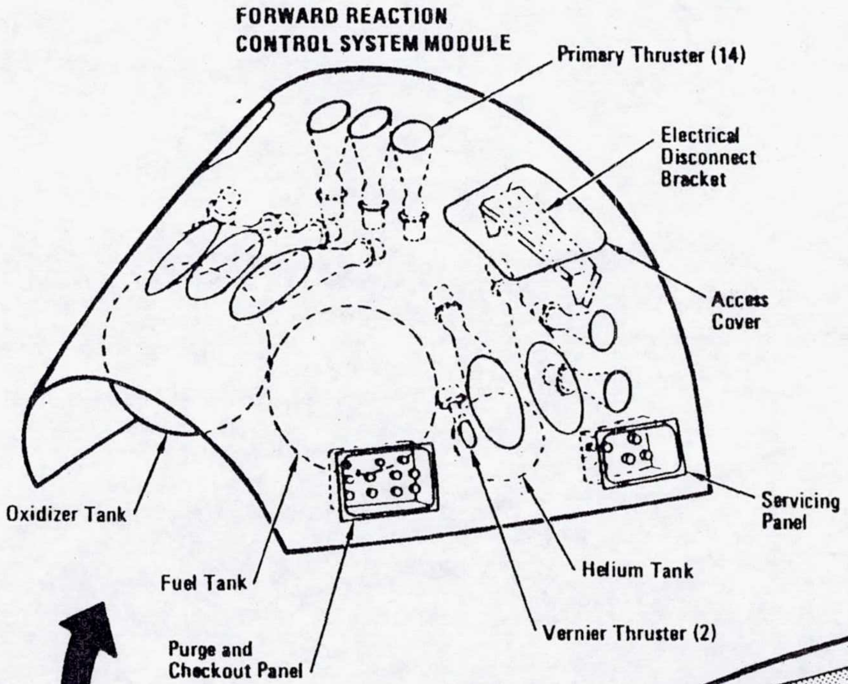
ON-ORBIT OPERATIONS

Reaction Control System (RCS) Engines

Mission Time = N/A

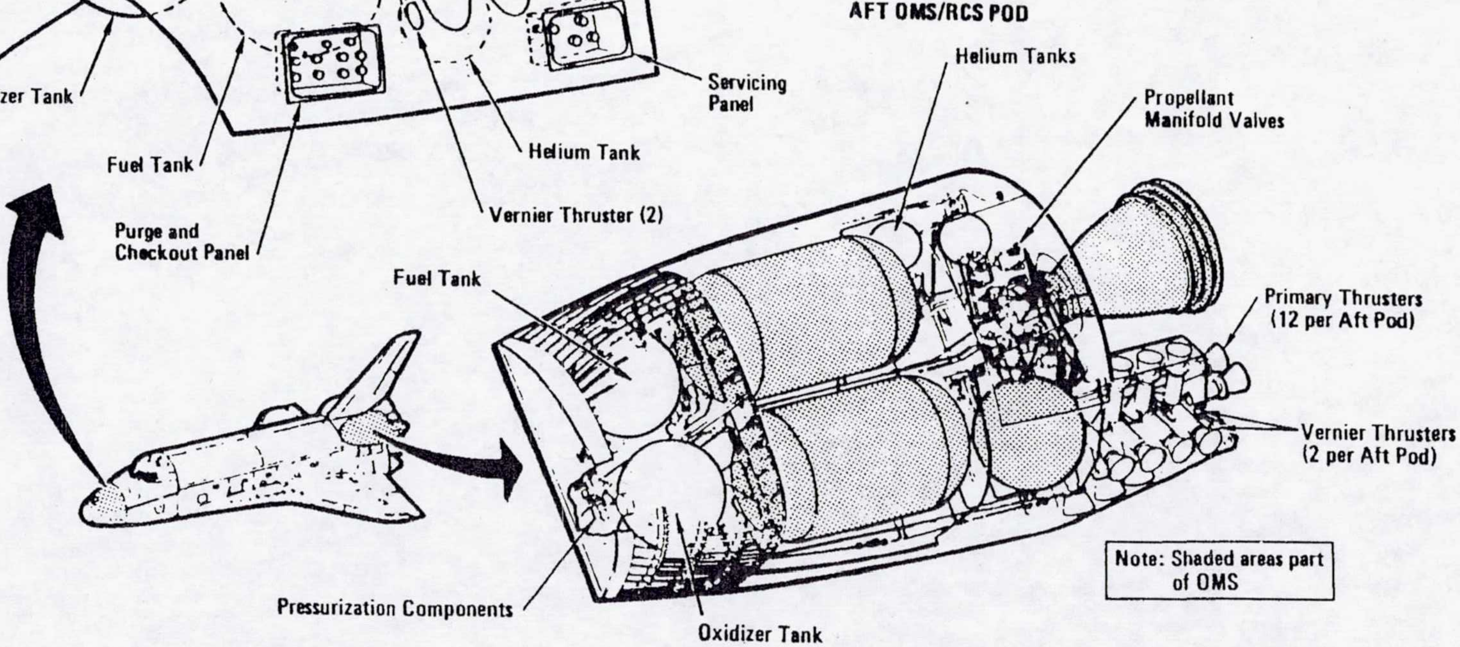
Altitude = 100-200 nmi

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



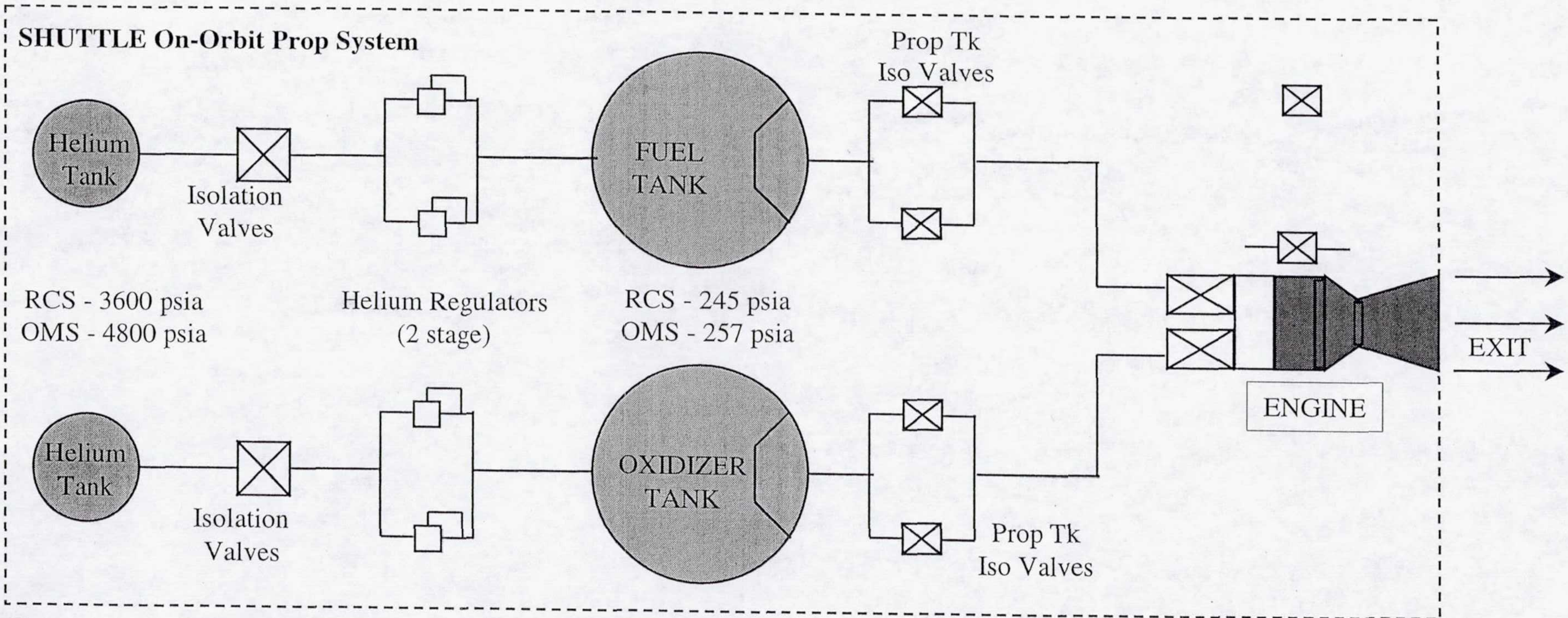
- **Orbital Maneuvering Subsystem Functions**
  - Provide thrust for:
    - Orbit Insertion
    - Orbit Circularization
    - Orbit Transfer
    - Rendevous
    - Deorbit
    - Launch Abort
  - Provide additional propellant for on-orbit RCS use
  - Crossfeed capability (system redundancy feature)

- **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)

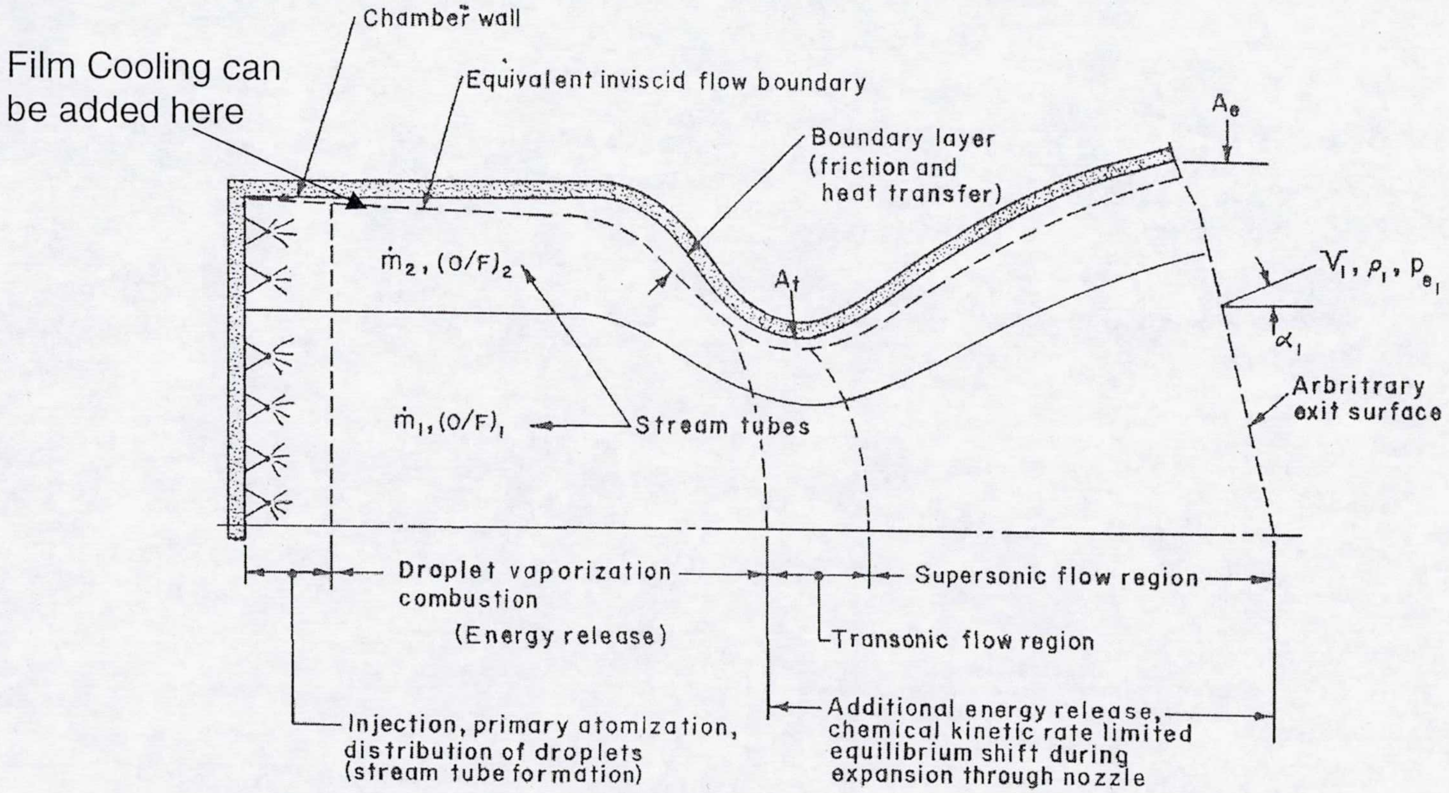
- **Reaction Control System Description**
  - Fwd RCS includes 14 primary (870 lbf) and 2 vernier (25 lbf) jets
  - Aft RCS (located in OMS pods) each contain 12 primary and 2 vernier jets
    - Aft RCS manifolds can be fed by RCS tanks in the opposite pod (crossfeed mode)
    - or OMS propellant tanks 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 (N2O4) 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



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

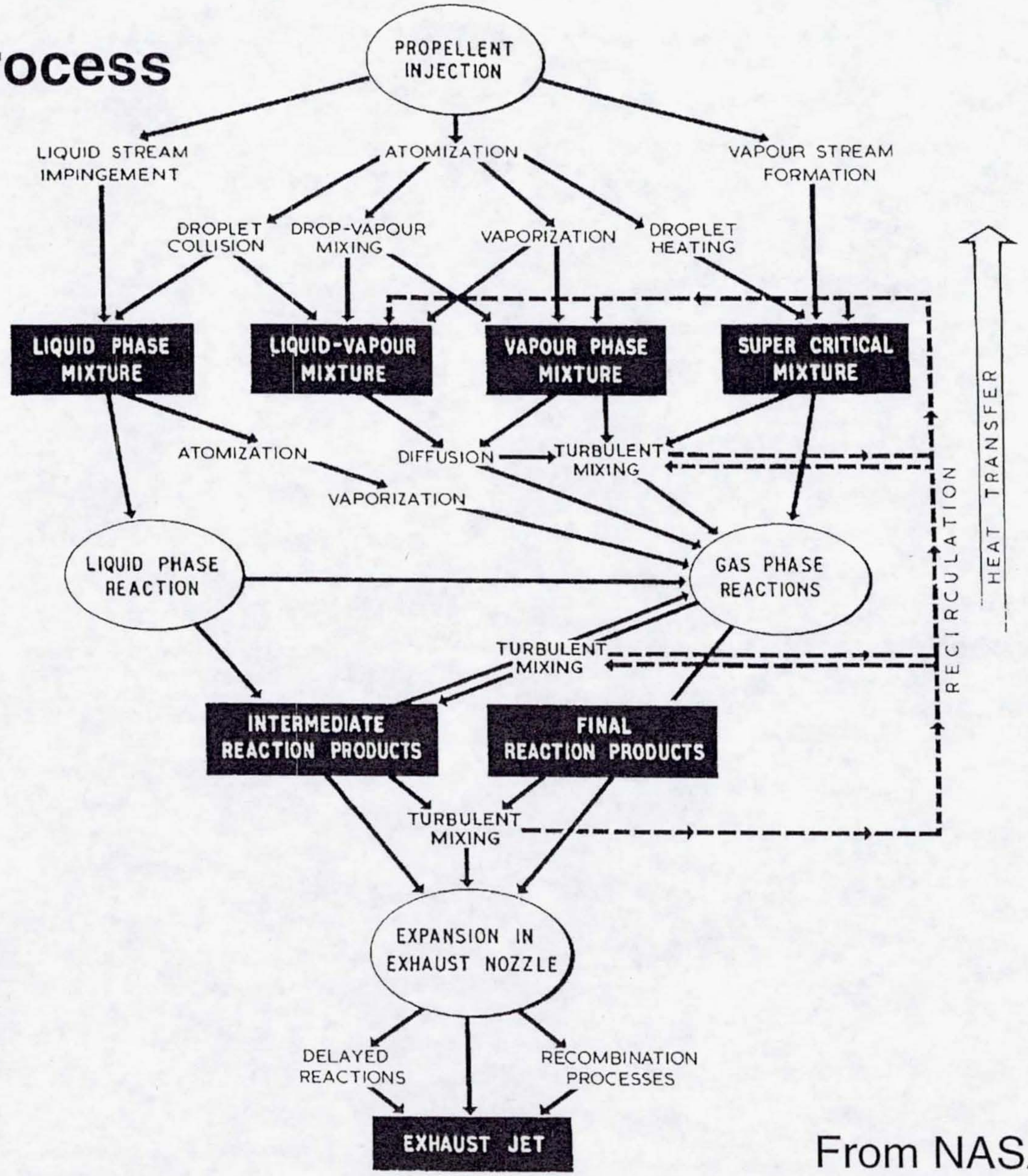
$Isp = F_{vac}/mdot$ (Overall Performance - Thrust per propellant consumption)

$C^* = P_c A_t/mdot$ (Combustion Chamber Performance – characteristic velocity)

$Cf = T/(P_c A_t)$ (Nozzle Performance – Thrust coefficient)

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

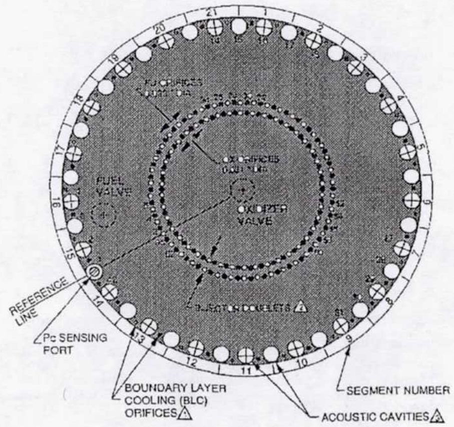
Combustion Process Description

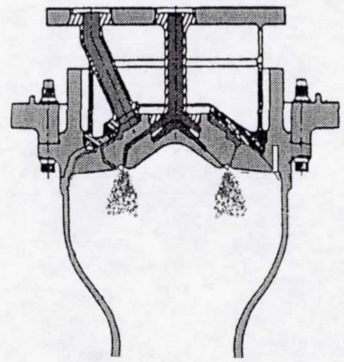


From NASA SP194

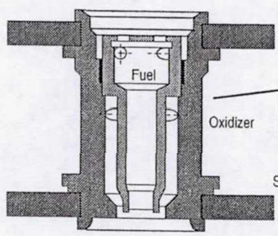
Injectors

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



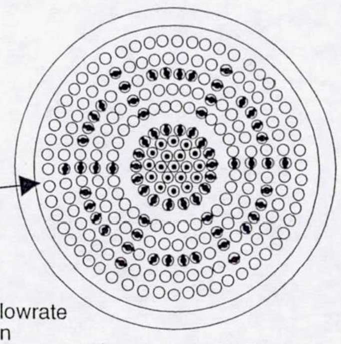


From NASA SP194



Basic and High Flowrate Injector

Flowrate
ion

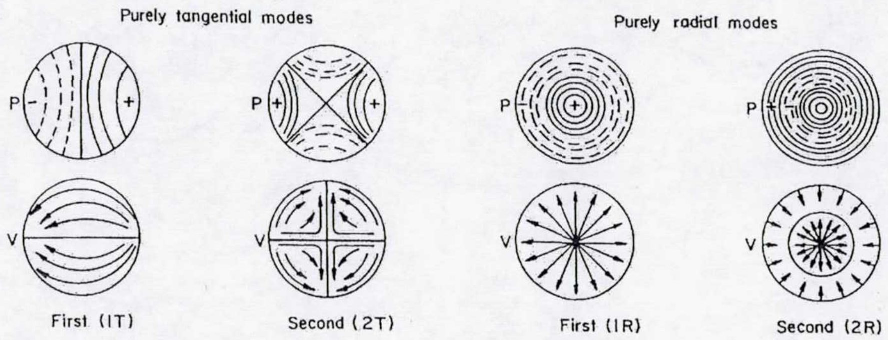


Concentric Circle

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 injestion 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

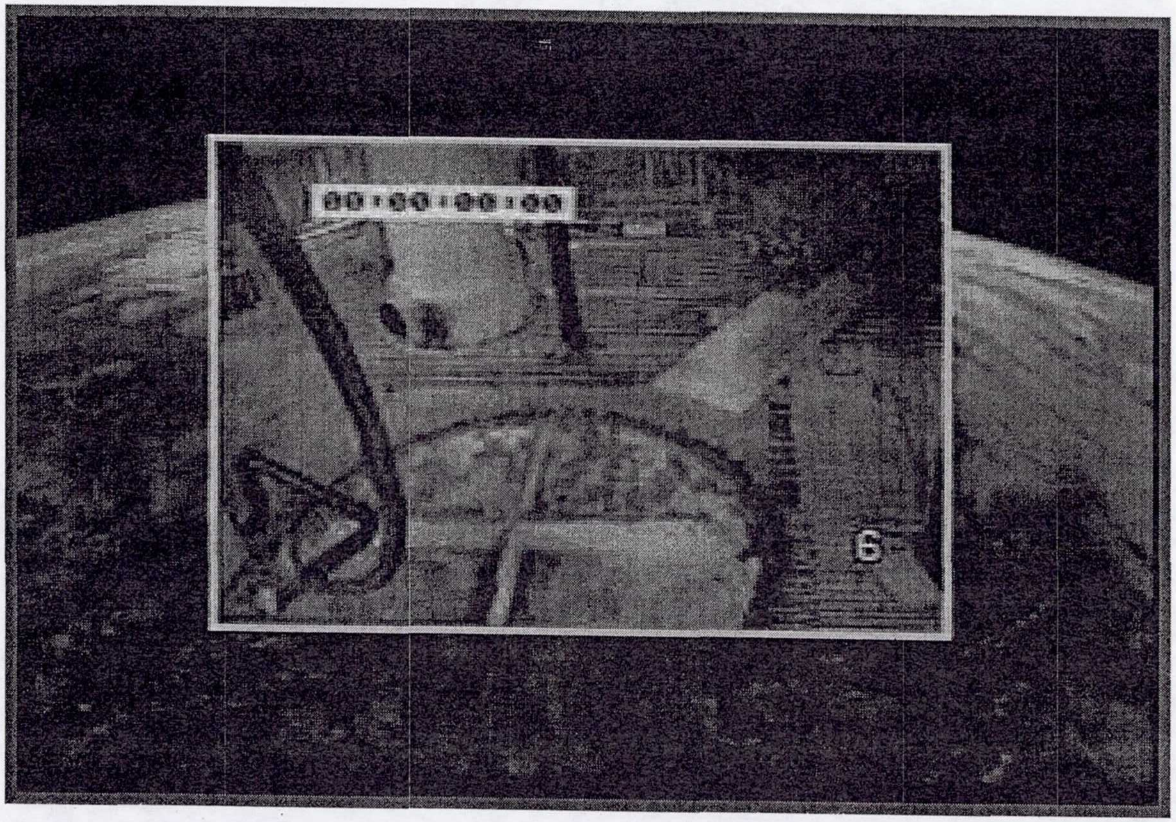
Performance	MMH/NTO Pressure-Fed	H2O2/H-C Pressure-Fed	LOX/Alcohol Pressure-Fed	LOX/Methane Pressure-Fed	LOX/Methane Pump-Fed	LOX/LH2 Pump-Fed
Total Mass (Isp)	**SOA**	-	+	+	+	+
Power Required (Heaters)	**SOA**	-	+	+	+	+
Volume, (Density Isp)	**SOA**	+	+	-	+	-
Reliability and Safety						
Number of Components	**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