Designing Liquid Rocket Engine Injectors for Performance, Stability, and Cost

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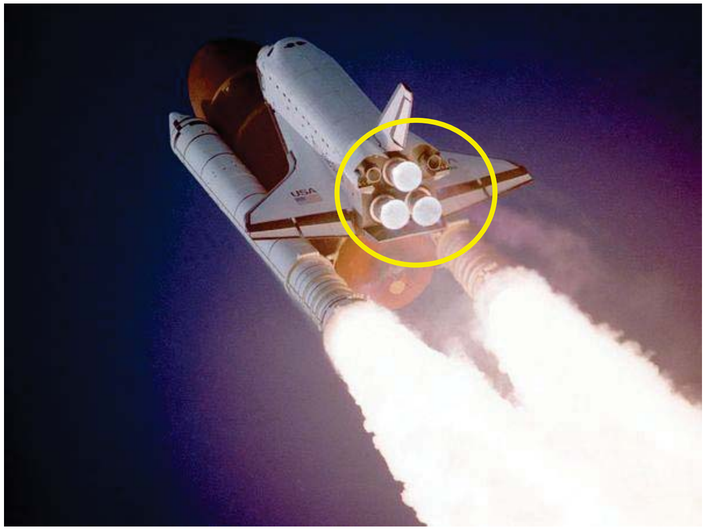
The Power of Rocket Engines



The 3 Space Shuttle Main Engines (SSMEs) are Liquid Rocket Engines and had a combined thrust of over 1.2 Million Pounds at Lift-off. With the Solid Rocket Boosters, total thrust was nearly 7 Million Pounds at Lift-off

The 5 F-1 Liquid Rocket Engines on the Saturn V Moon Rocket had a combined thrust of over 7.5 Million Pounds at Lift-off

The Space Launch System will have a Combined Thrust of over 9.2 Million Pounds at Lift-off

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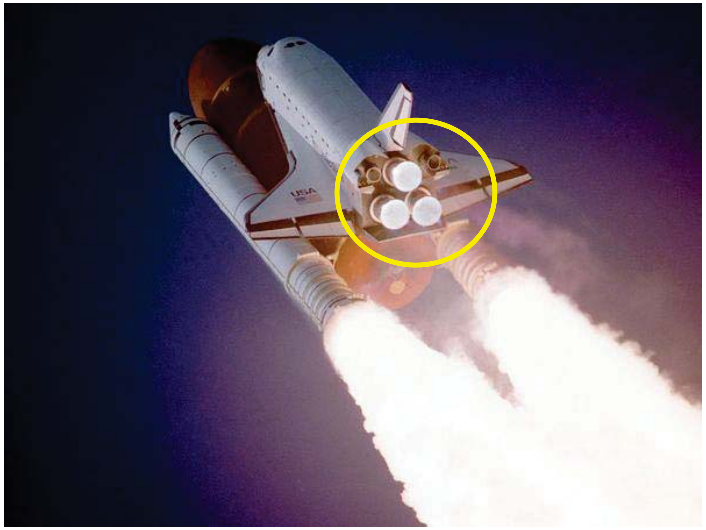

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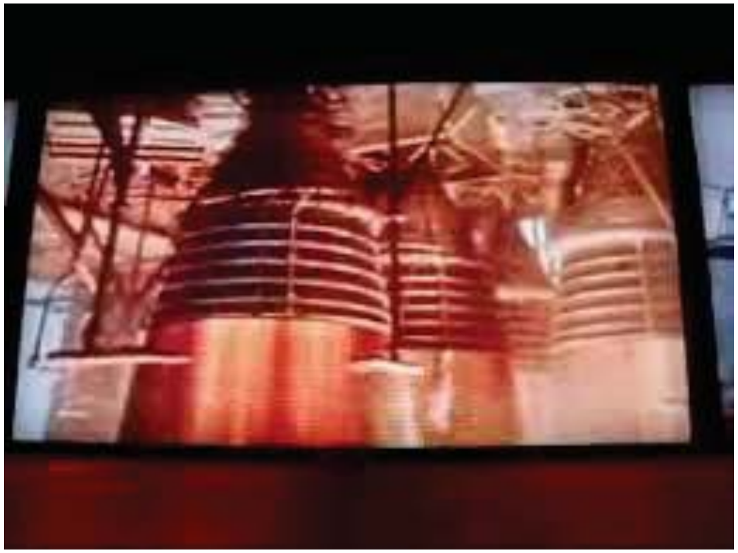

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Rocket Engines: Simple Principle
Newton's Third Law of Motion

<u>Newton's Third Law of Motion:</u> For Every Action there is an Equal and Opposite Re-Action

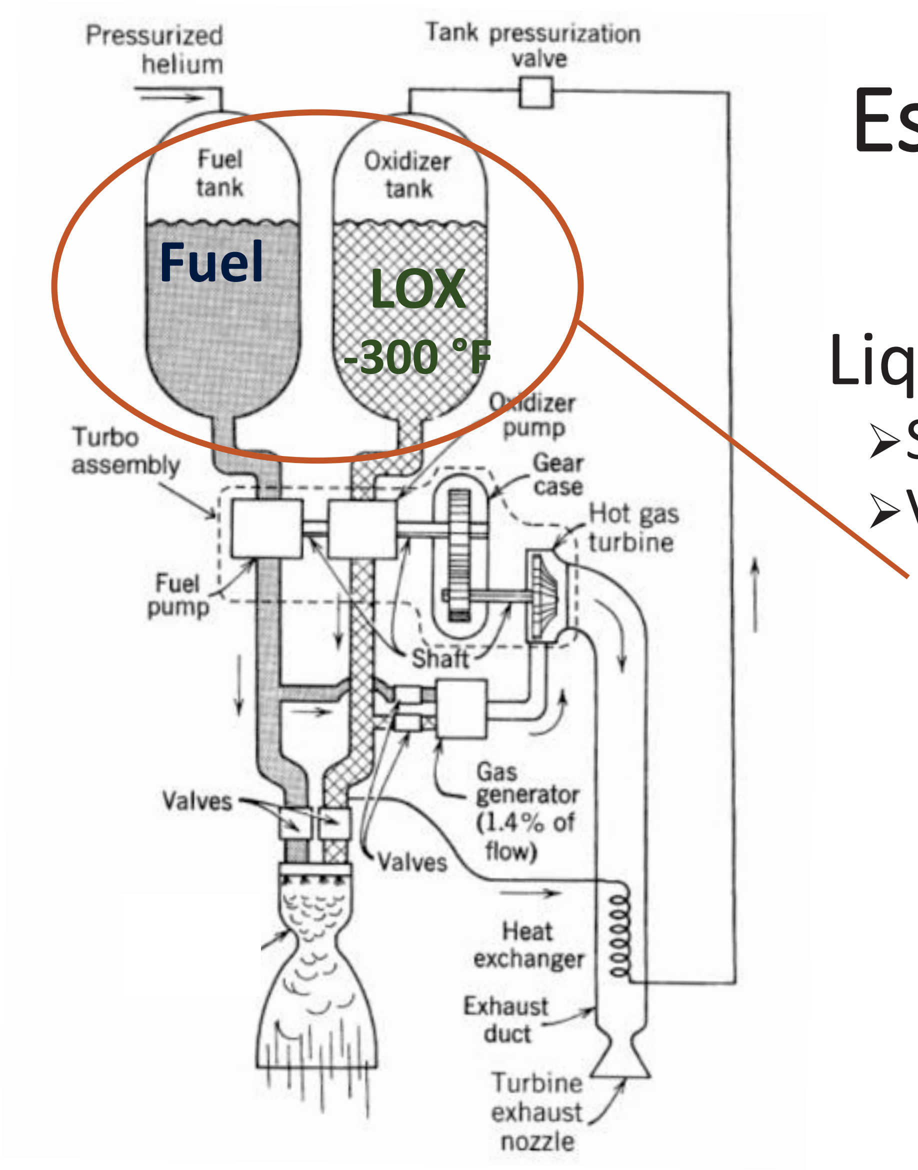
Aqua-Man Wannabe Propelled by Jet-Ski Water Exhaust

Re-Action

Action

Space Shuttle Propelled by High-Velocity Combustion Gas

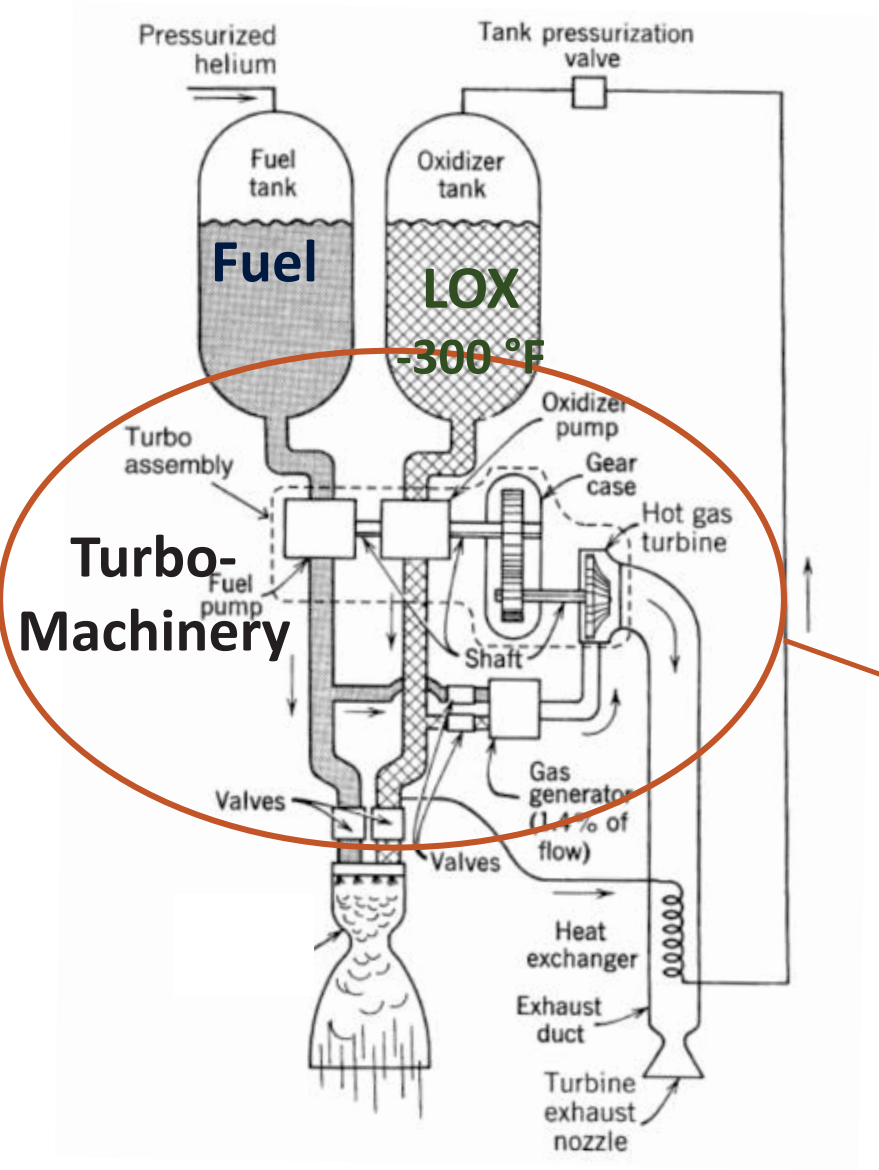
Escaping Earth’s Gravity and Space Travel



Liquid Rocket Engine Design

- ➢Simple Principle (Newton’s Laws of Motion)
- ➢Very Complex Design is Required
  - Large Tanks filled with Liquid Oxygen (LOX), and Liquid Fuels
  - Extremely Complex Turbo-Machinery and Plumbing
    - ○ Turbines and Pumps that spin > 30,000 RPM
  - **<u>Thrust Chamber Assembly</u>**
    - ○ **Where oxidizer and fuel mix and combust**
    - ○ **Extreme Temperature and Pressures, High Velocity and Complex Flow**

Escaping Earth's Gravity and Space Travel



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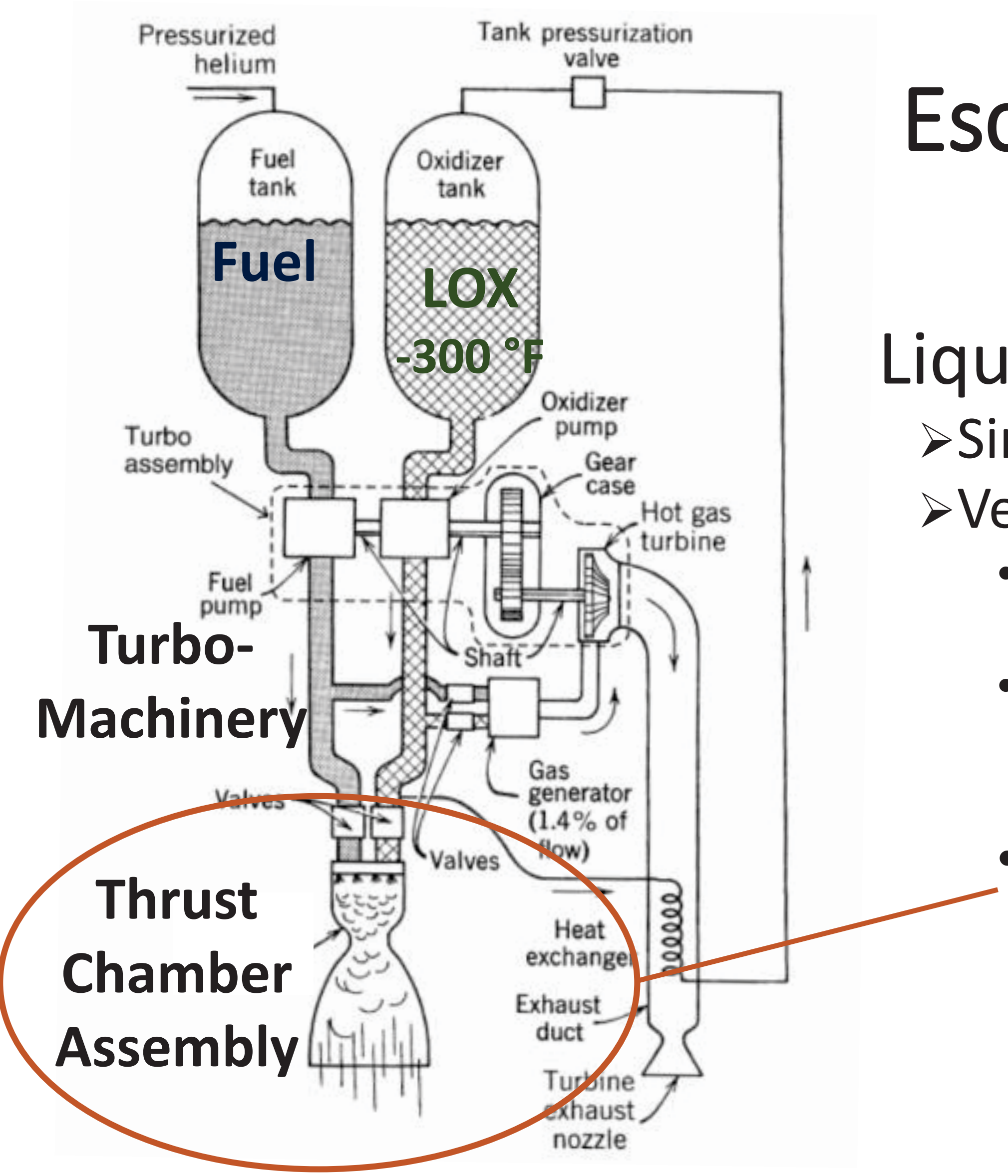

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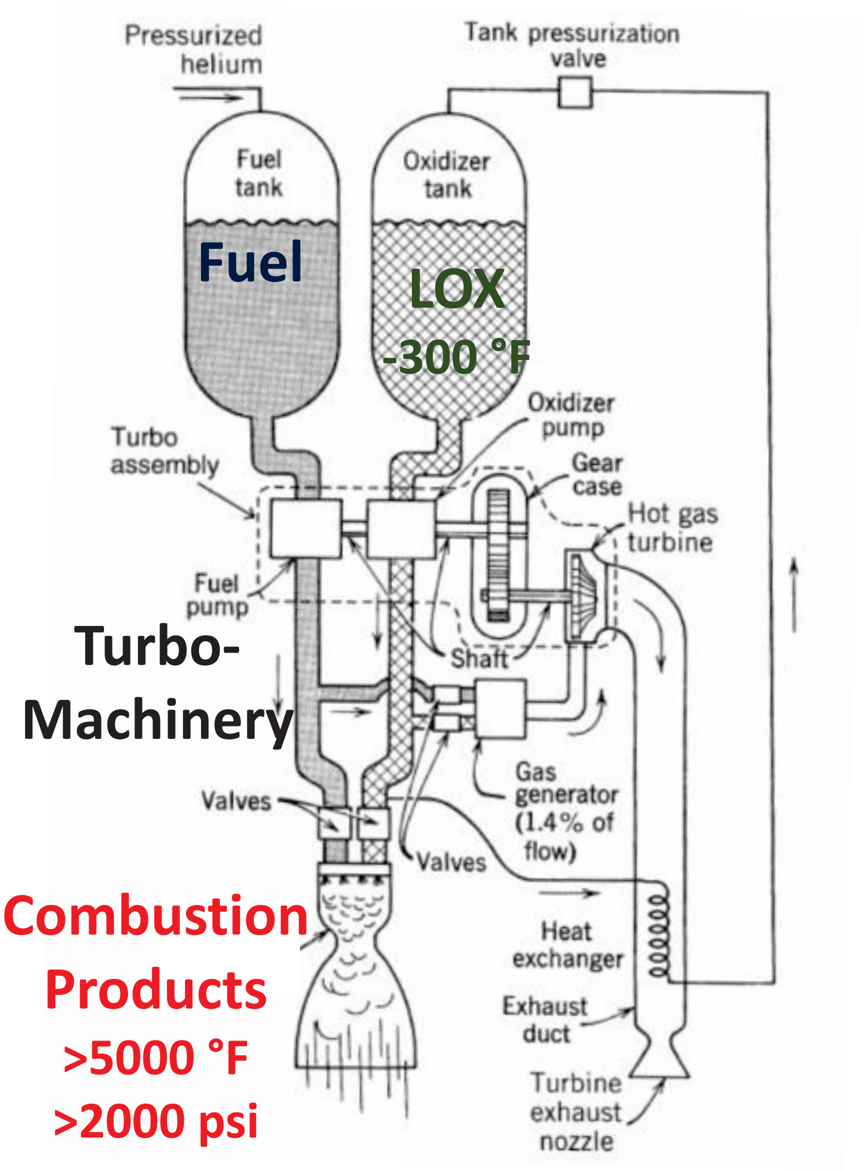

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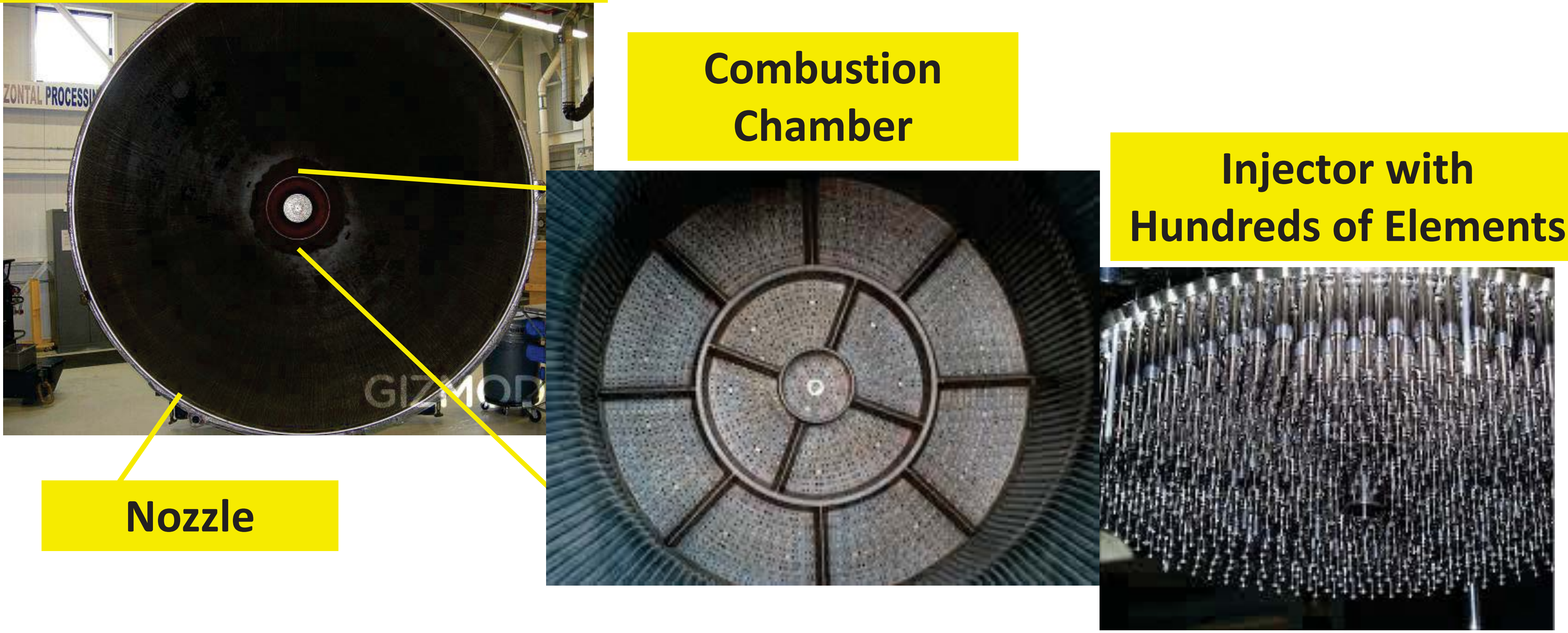
Thrust Chamber Assembly Components



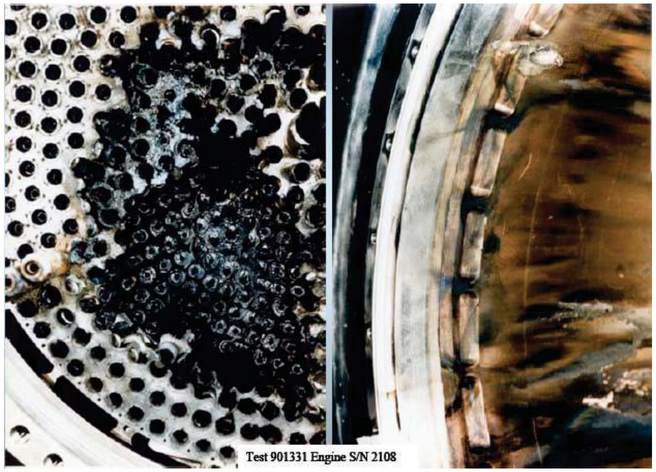
Thrust Chamber Assembly

Combustion Chamber

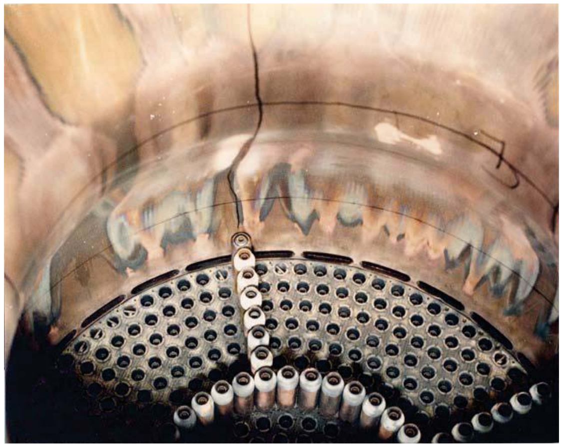
Injector with Hundreds of Elements

Nozzle

Combustion Anomalies in Thrust Chamber Leads to Damage or Complete Destruction



Main Injector Failure

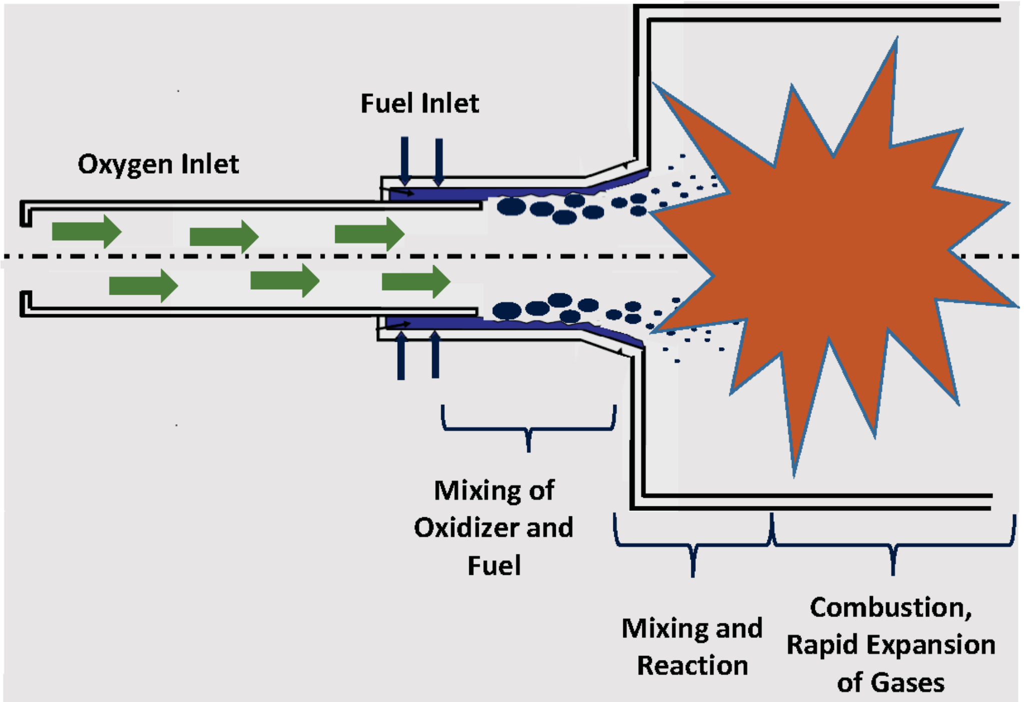


Surface Degradation and Cracking of Chamber Walls

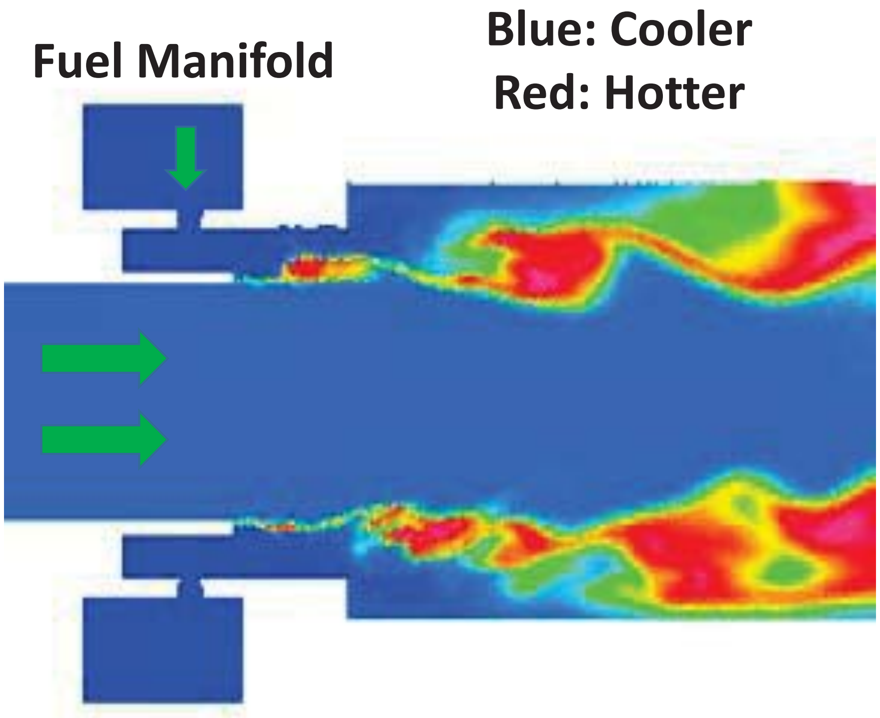
- **Combustion Instability**
  - ➢Characterized by Pressure peaks and temperature spikes
    - Often Un-predictable
  - ➢Driven by Injector Design and Flow Conditions
  - ➢It is very costly to have an anomaly on the Test Stand and then re-design
  - ➢Therefore, NASA is very driven to use and continually improve predictive tools that can aid in the design process prior to expensive testing

NASA invests in simulation tools that can help Avoid the Time-Consuming and Costly “Test-Fail-Fix” Cycle

Modeling of One Injector Element with a CFD* Tool



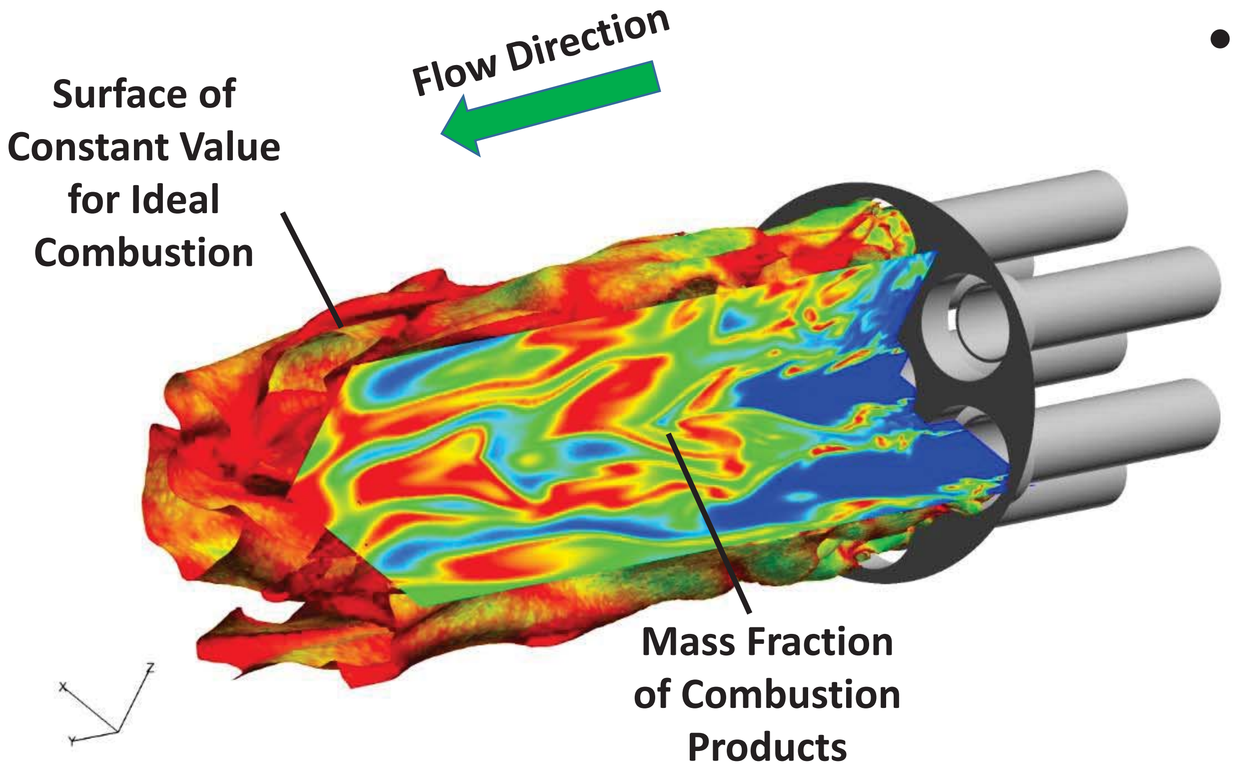
Simplified Schematic of Physics Occurring in the Thrust Chamber in and Near the Injector



Typical Temperature Results

* - CFD stands for Computational Fluid Dynamics

Modeling of Seven (7) Elements to Support an Advanced Booster Rocket Engine Design – Using CFD*



- - CFD stands for Computational Fluid Dynamics
- The CFD tool used is called Loci/STREAM

Modeling with a CFD Tool

- ➢The CFD results were used by Rocket Engine designers to fine-tune the initial design for performance and stability
- ➢The CFD provided design data and assessment of stability
  - This data is normally obtained by testing
  - CFD simulations provided more data, more quickly, at a lower cost
- ➢Simulation results include time-varying temperature and pressure predictions, and combustion metrics

Why High-End Computing Matters

- **Access to Pleiades Super-Computers was a Game-Changer in the Design of this Advanced Booster Engine**
  - The CFD simulations required large meshes ranging from 100-350 million cells
    - Physical laws represented by complex mathematical equations are enforced in every cell
  - Time-Steps on the order of 1 micro-second (1.0 X 10^{-6} seconds) were used
  - Simulations were normally executed in under 2 weeks using 2000-4000 processers
  - This quick turn-around enabled the CFD tool to be used in a design cycle with multiple iterations occurring in a relatively short time period
  - As NASA seeks to reduce the cost of access to space, CFD tools and the super-computing resources required for CFD will continue to be developed for higher fidelity and accuracy and will become an increasingly crucial part of the engine design cycle

*** - CFD stands for Computational Fluid Dynamics**