ENGINE MANAGEMENT DURING NTRE START UP

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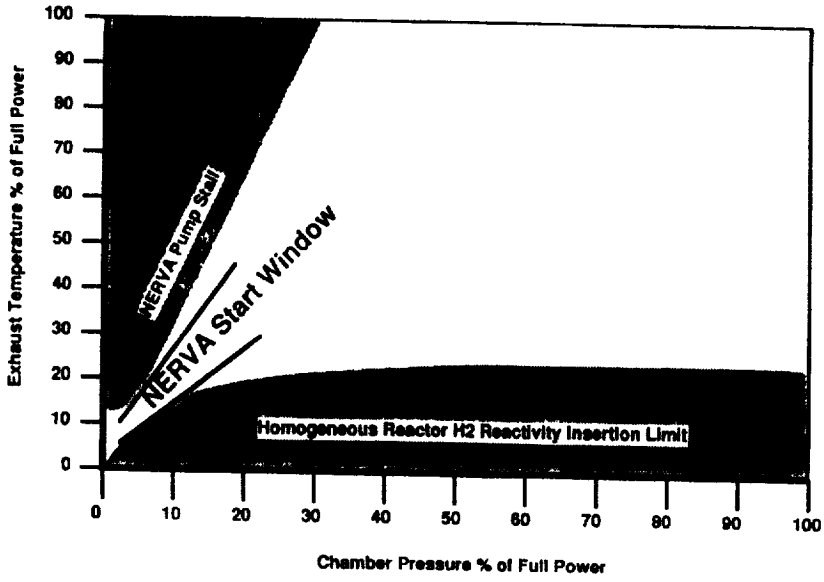
TOTAL ENGINE SYSTEM MANAGEMENT CRITICAL TO SUCCESSFUL NTRE START UP

- Reactor Power Control
  - Hydrogen Reactivity Insertion
  - Moderator Effectiveness (Reactor Spectrum)
- Reactor Cooling
  - Moderator Cooling Loop
  - Fuel Assembly Thermal Shock
- Propellant Feed System Dynamics
  - Pump Characteristics
  - Feed System Pressurization
- Engine Performance
  - Propellant Expended at Low I_{sp}

NERVA Type Engines Have A Narrow Start Window



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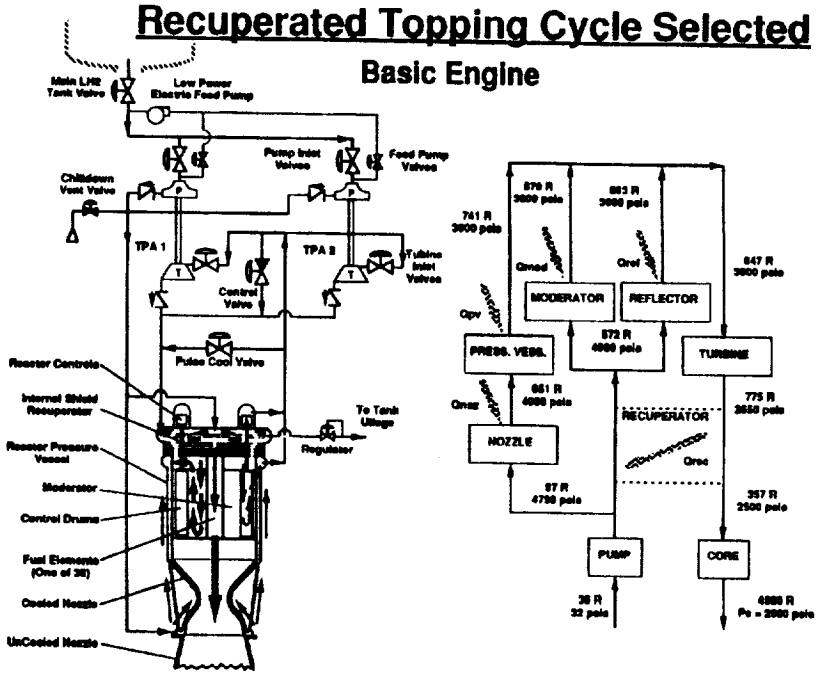
Recuperated Topping Cycle Selected

Basic Engine



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REACTOR POWER CONTROL SUPERIOR WITH HETEROGENEOUS MODERATOR

- More Efficient Fuel Design
- More Efficient Moderator Design
- Less Sensitive to Hydrogen reactivity Insertion
- Reactor Time Constants Longer With more Thermalized Neutrons

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HETEROGENEOUS REACTOR COOLING MORE EFFECTIVE

- Moderator Cooled by Separate Loop
  - Fuel Assemblies Can Be Cooled up to Low Power Levels with Moderator Cooling Loop
- Fuel Assembly Inlet Temperature Controlled by Moderator Loop
  - Propellant Preheated in Moderator Loop
  - Recuperator Prevents Large Swings in Propellant Flow or Inlet Temperature (Avoids Thermal Shock)

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OUR PROPELLANT FEED SYSTEM DYNAMICS ARE EFFICIENTLY CONTROLLED

- Engine Prestart Conditioning
  - Pumps Chilled In
  - Reactor Warmed
  - Feed System Pressurized
    (Reduces Inrush Dynamics)
- Aerojet Pumps are Designed with Greater Stall Margin
- Our Recuperated Cycle Greatly Aids The Start up
  - Ample Thermal Power Accelerates Bootstrap
  - Provides Thermal and Hydraulic damping
  - Isolates Fuel Assembly from Feed System
- Our Integrated Controller can Choose the Optimun path to Full Power, Balancing:
  - Isp Loss
  - Fuel Element Thermal Shock

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INTEGRATED NTRE START SEQUENCE

- Engine Prestart Conditioning
  - Pump Chill In
  - Moderator Loop Pressurization with TPA Chill H_2 (First Start Only)
  - Closed Loop Engine Warm Up (First Start Only)
  - Engine Now on Standby Mode for Starting
- Start
  - Spin Start TPAs with Warm Presurized H_2 From Moderator Loop
  - TPA Acceleration Dominated by Engine Thermal Mass (Power for Approx. 10 Starts In Recuperator Alone)

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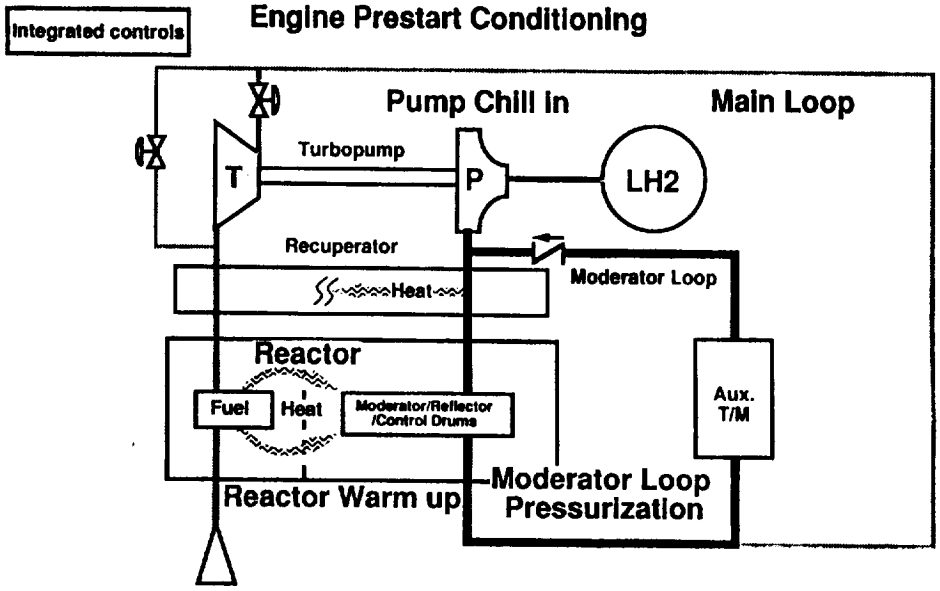
Moderator Cooling Loop Key to Efficient NTRE Starting



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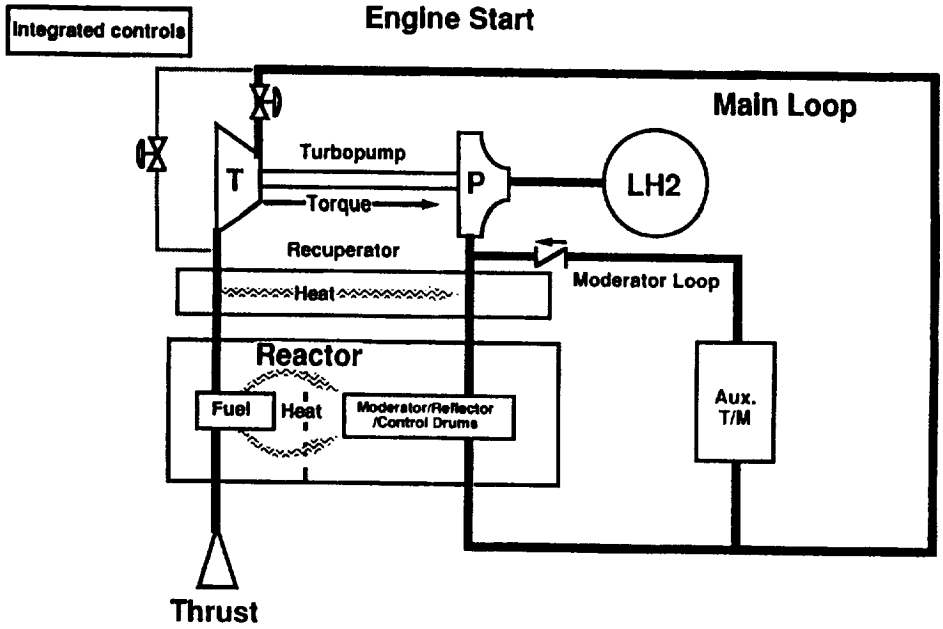

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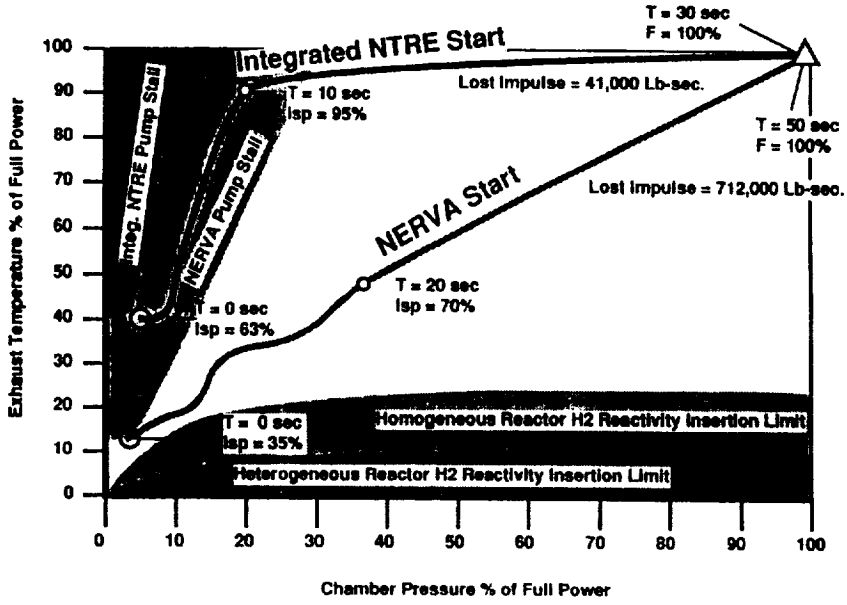
Our Integrated Engine Starts More Reliably

And With Less Impulse Loss than Nerva Type Engines



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We Are in the Process of Upgrading NETAP

Constructing New Modules for:

- Recuperator
- Moderator
- PBR and CIS Fuel Elements
- Twin 4-Stage TPAs
- Auxiliary Turbo Circulation System

ANALYTICAL SIMULATION IS CRUCIAL TO PROVIDING A LOW RISK ENGINE DEVELOPMENT

- Determine Start Sequence and Operating Limits
  - Valve Phasing
  - Reflector Positioning
  - Thermal Requirements
- Verify Adequate Component Operating Margins Throughout Transient Operation
  - Avoid Pump Stall or Cavitation
  - Reactor Overheating
  - Nozzle Flow Choking
  - Satisfactory Power Balance for Bootstrap
- Establish Control Feedback Requirements

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ACCURATE SIMULATION IS ACHIEVED THROUGH DYNAMIC COUPLING OF PHYSICAL PROCESSES

- TPA Power Balance
- TPA Inertia
- Flow Dynamics and Resistance
  - Method of Charactoristics
  - Volume Filling
- Heat Transfer to Propellant and Components
- Fission Heat Generation / Decay Heat
  - Deposted in Fuel
  - Deposted in moderator
- Momentum, Energy, and Flow Conservation
- Feedback Control Loop

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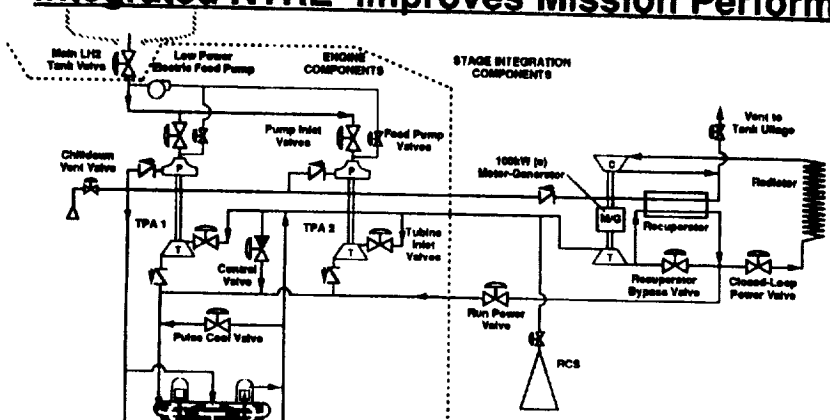
Integrated NTRE Improves Mission Performance



Mission Benefits of Integrated NTRE

- Robust , Low Loss Start
- High Performance,Light Weight Engine
- Safe,Efficient Shut Down
  - Five Core Cooling Systems
  - Closed Cycle Decay Heat Removal Saves 100,000+Lbm IMLEO
- Dual Mode Option
  - 100kW (e) available any time during Mission
  - No Deep Reactor Thermal
  - Refrigeration Option
- OMS & RCS Thrust Available @ High I_{sp}

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