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 Iₚ
NERVA Type Engines Have A Narrow Start Window

![Graph showing Exhaust Temperature % of Full Power vs. Chamber Pressure % of Full Power]

NERVA Start Window

Homogeneous Reactor H2 Reactivity Insertion Limit

NERVA Type Engines

GenCorp
Energopool
Babcock & Wilcox

MJD 10/15/92

Re recuperated Topping Cycle Selected

Basic Engine

GenCorp
Energopool
Babcock & Wilcox

NTP: Systems Modeling
574
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

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)
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 Optimum path to Full Power, Balancing:
  - Isp Loss
  - Fuel Element Thermal Shock

INTEGRATED NTRE START SEQUENCE

- Engine Prestart Conditioning
  - Pump Chill In
  - Moderator Loop Pressurization with TPA Chill H₂ (First Start Only)
  - Closed Loop Engine Warm Up (First Start Only)
  - Engine Now on Standby Mode for Starting

- Start
  - Spin Start TPAs with Warm Pressurized H₂ From Moderator Loop
  - TPA Acceleration Dominated by Engine Thermal Mass (Power for Approx. 10 Starts in Recuperator Alone)
Moderator Cooling Loop Key to Efficient NTRE Starting

Engine Prestart Conditioning

Pump Chill In

Turbopump

Recuperator

Heat

Reactor

Fuel

Heat

Moderator/Reflector

/Coolance Drums

Reactor Warm up

Moderator Loop

Pressurization

Main Loop

LH2

Aux. T/M

Integrated controls

Engine Start

Turbopump

Torque

Recuperator

Heat

Reactor

Fuel

Heat

Moderator/Reflector

/Coolance Drums

Trans

Thrust

Main Loop

LH2

Aux. T/M

Integrated controls

Thrust
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

ACCURATE SIMULATION IS ACHIEVED THROUGH DYNAMIC COUPLING OF PHYSICAL PROCESSES

- TPA Power Balance
- TPA Inertia
- Flow Dynamics and Resistance
  - Method of Characteristics
  - Volume Filling
- Heat Transfer to Propellant and Components
- Fission Heat Generation / Decay Heat
  - Deposited in Fuel
  - Deposited in moderator
- Momentum, Energy, and Flow Conservation
- Feedback Control Loop
**Integrated NTRE Improves Mission Performance**

- 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 (s) available any time during Mission
  - No Deep Reactor Thermal
  - Refrigeration Option
- OMS & RCS Thrust Available @ High isp

**GENCORP**
**AEROJET**
**Energopool**
**Babcock & Wilcox**