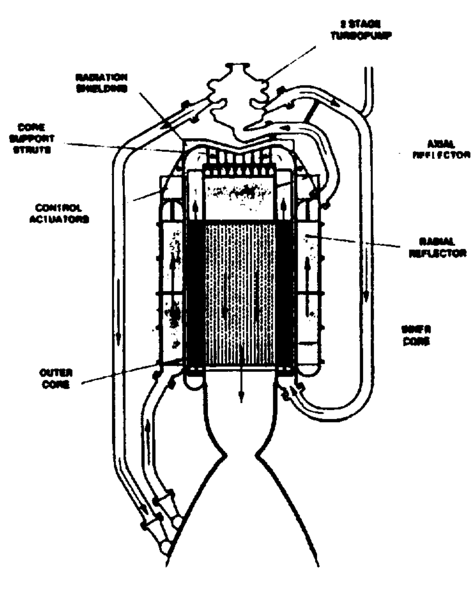
N93-26956

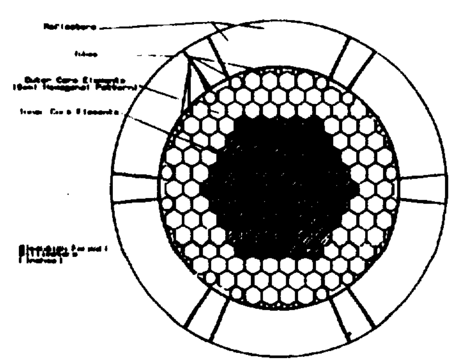
COMPUTATIONAL MODELING OF NUCLEAR THERMAL ROCKETS

Steven D. Peery
Pratt & Whitney
22 October 1992

XNR2000 NTR BASELINE DESIGN

Dual-Pass Cermet Fueled Reactor





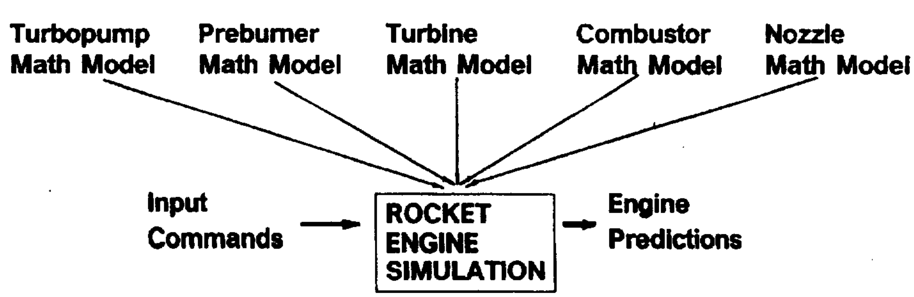
ROCKET ENGINE TRANSIENT SIMULATION (ROCETS) SYSTEM

Developed Under MSFC Contract NAS8-36994

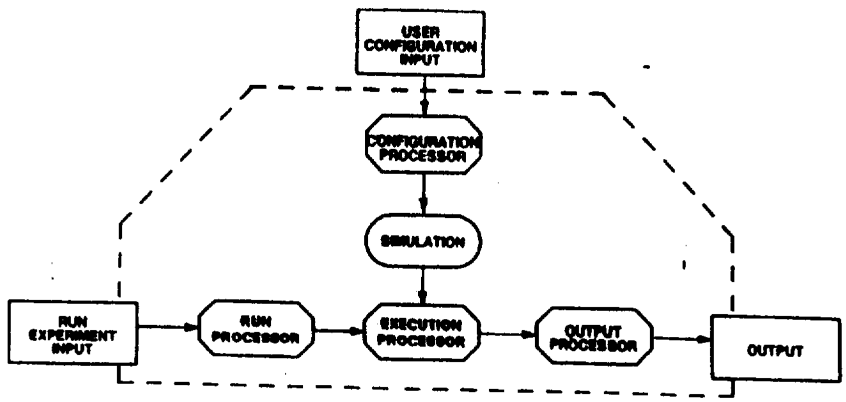
- System Developed To Model Steady-State and Transient Performance of a Wide Variety of Rocket Engine Cycles
- System Has Been Expanded for Nuclear Thermal Rocket (NTR) Concept Studies

ROCETS PERFORMANCE SIMULATIONS COMPOSED OF INTEGRATED COMPONENT MODELS

- Thermal-Fluid Component Models
- Component-by-Component
- Transient and Steady State



ROCETS SYSTEM ARCHITECTURE SIGNIFICANT FEATURES



ROCETS ENGINEERING NTR MODULES

Component Performance Models

Reactor (Core, Reflector, Shielding) —	• Neutronics · Diffusion · Transport · MCNP • Thermal Fluid CFD • Properties
Turbopump	
Turbine	
Plumbing & Valves	
Mixers	
Chamber & Nozzle Cooling	
Nozzle Performance	
Weight	

ROCETS SYSTEM EASILY ADAPTS FORTRAN ENGINEERING MODULES

CALL LIST
c INTERFACE DATA
c INPUTS/OUTPUTS & DEFINITIONS c ENGINEERING DESCRIPTION c TEST CASE & REF TO QTP RESULTS c SUB-MODULES NEEDED c HISTORY
FORTRAN CODE

UNIQUE TO ROCETS

- o Converts Fortran Parameter Names to ROCETS Nomenclature
- o Outside Code Becomes Operational In ROCETS by Adding This Interface
- o "Comment Cards" So Module Can Independently Operate (Decoupled From ROCETS If Required)

ROCETS NTR REACTOR MODULE

Fluid Thermodynamic Model

Reactor Module Input

- Propellant inlet conditions
- Propellant flow rate
- Desired exit temperature
- Calculated radial and axial power profiles
- Fuel element geometry

Reactor Module Output

- Required reactor power
- Propellant thermophysical properties throughout reactor
- Reactor temperatures

ROCETS NTR TURBOMACHINERY MODULE

Hardware Modeling and Clean-Sheet Design Capability

Turbopump Module

- Sets speed based on Nss
- Determines power and size for requested headrise
- Calculates efficiency and pump design parameters

Turbine Module

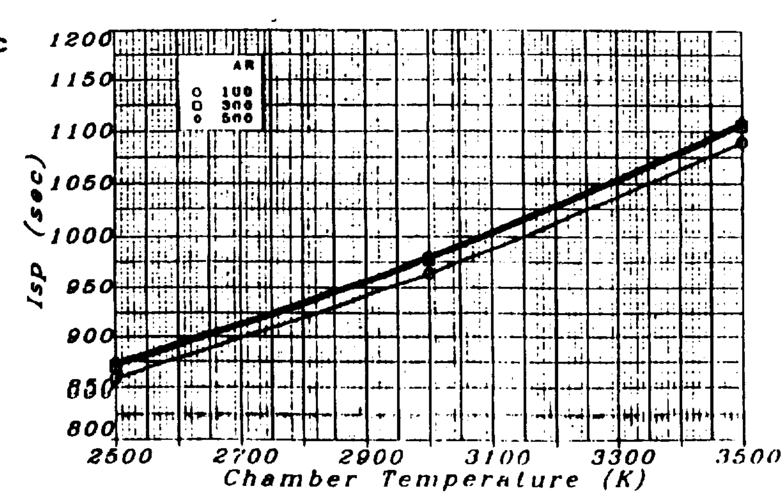
- Determines size and exit conditions for required power
- Limits wheel speed to stay within stress limits
- Calculates efficiency and turbine design parameters

ROCETS NTR NOZZLE PERFORMANCE MODULE

2-DK with Finite Rate Chemistry and Boundary Layer Analysis

Determines Delivered Nozzle Performace and Contours for Both High and Low Pressure Concepts

5 - 1500 psia Pc
2500 - 3500 K Tc
25 - 500 AR



XNR2000 ENGINE PERFORMANCE

Thrust = 25,000 lbf (Baseline)
T/W = 5.3
Isp = 900.0 sec

PROPELLANT FLOW ENGINE STATION CONDITIONS

Station Location	Pressure (psia)	Temperature (Deg K)	Flow (lbm/s)	Enthalpy (Btu/lbm)	Density (lbm/ft**3)
Engine Inlet	26.7	20.6	14.0	-108.0	4.38
Pump Inlet	25.7	20.6	14.0	-108.0	4.38
Pump Exit	2179.3	34.7	14.0	13.0	4.56
Nozzle Coolant Inlet	2157.6	34.8	8.4	13.0	4.55
Reflector Coolant Inlet	1932.6	103.1	28.1	440.9	1.77
Turbine Inlet	1901.6	226.9	11.8	1343.7	0.80
Turbine Exit	1218.2	207.2	11.8	1199.9	0.58
Outer Core Inlet	1108.9	210.4	27.8	1221.6	0.52
Inner Core Inlet	956.3	1659.4	27.8	8865.0	0.06
Chamber	765.9	2668.7	27.8	18188.3	0.03

REACTOR CHARACTERISTICS

Two-Pass Design		
Inner Core Diameter	11.5	in
Outer Core Diameter	18.1	in
Reflector Diameter	32.2	in
Pressure Drop	344.1	psia
Max. RX Fuel Temp.	2880.0	K
Outer Core Fuel Mt'l	Mo-UO2,90	
Inner Core Fuel Mt'l	W-UO2,61	
Power Density	9.41	MW/l
Total Power	510.4	MW

NOZZLE CHARACTERISTICS

Nozzle Area Ratio	200.	
Throat Area	18.8	in**2
Exit Dia.	5.8	ft
Nozzle C*	16443	ft/s
Nozzle Length	10.6	ft
Total S.A.	22524	in**2
Regen. Construction	Cu Tubes	
Rad. Construction	Cb Sheet	

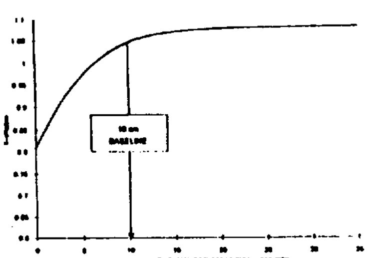
PUMP CHARACTERISTICS

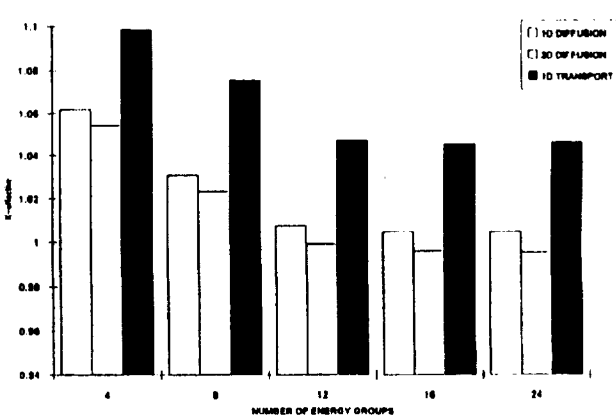
Overall Efficiency	73.2	%
Head Rise	69,018	ft
NPSH Avail.	302.9	ft
Speed	71,323	RPM
Power	2403.2	HP
Vol. Flow Rate	1379	gpm
Stg I Flow Coeff.	0.114	-
Stg II Flow Coeff.	0.113	-
Stg I Head Coeff.	0.521	-
Stg II Head Coeff.	0.521	-
Utip 1	1460.	ft/s
Utip 2	1460.	ft/s

TURBINE CHARACTERISTICS

Inlet Temperature	226.9	K
Inlet Pressure	1901.6	psia
Mass Flow	11.8	lbm/s
Overall Efficiency	85.4	%
Speed	71,233	RPM
Pressure Ratio	1.56	-
Inlet Flow Parameter	0.125	-
Overall Velocity Ratio	0.54	-
DH Actual	143.8	Btu/lb
AN**2(E-08)	193.	
Mean Dia.	4.66	in

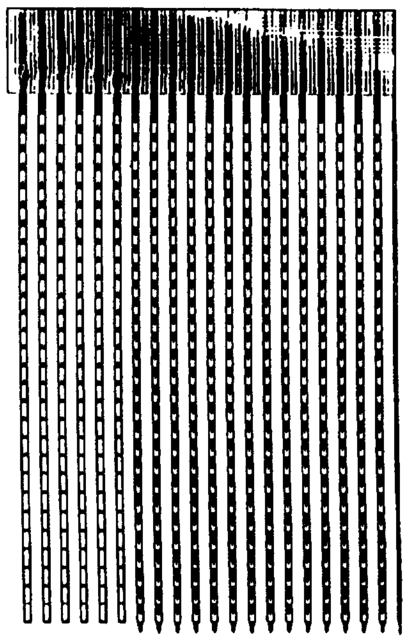
DETAILED REACTOR ANALYSIS CONDUCTED OUTSIDE OF SYSTEM PERFORMANCE EVALUATION

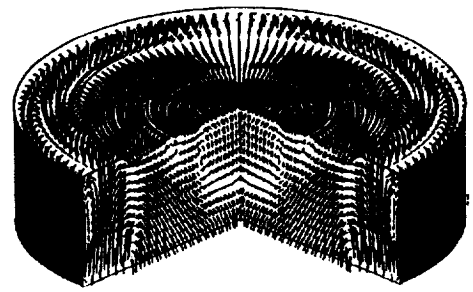




TFS PREDICTED FLOW DITRIBUTION

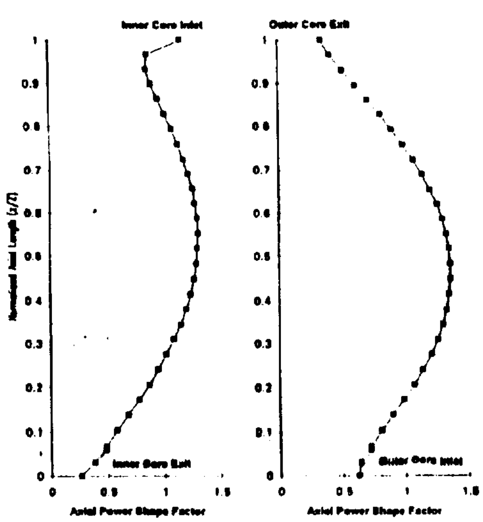
CFD Benchmarks Reactor Engineering Module

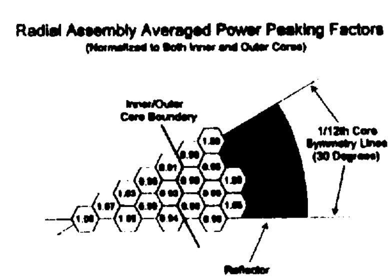


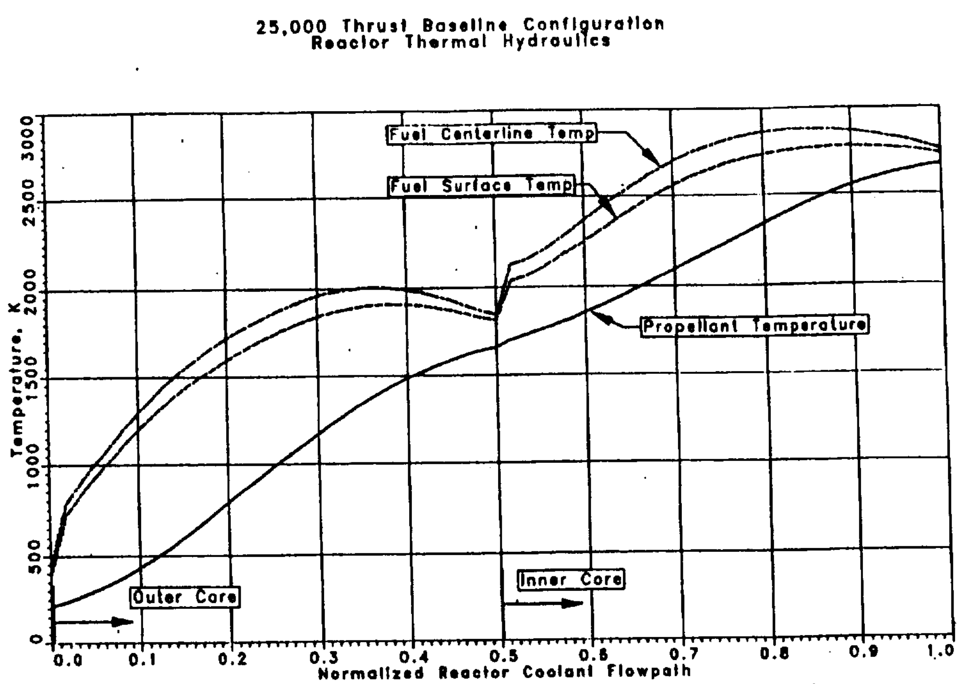


PREDICTED REACTOR POWER PROFILES

Input for Reactor Engineering Module

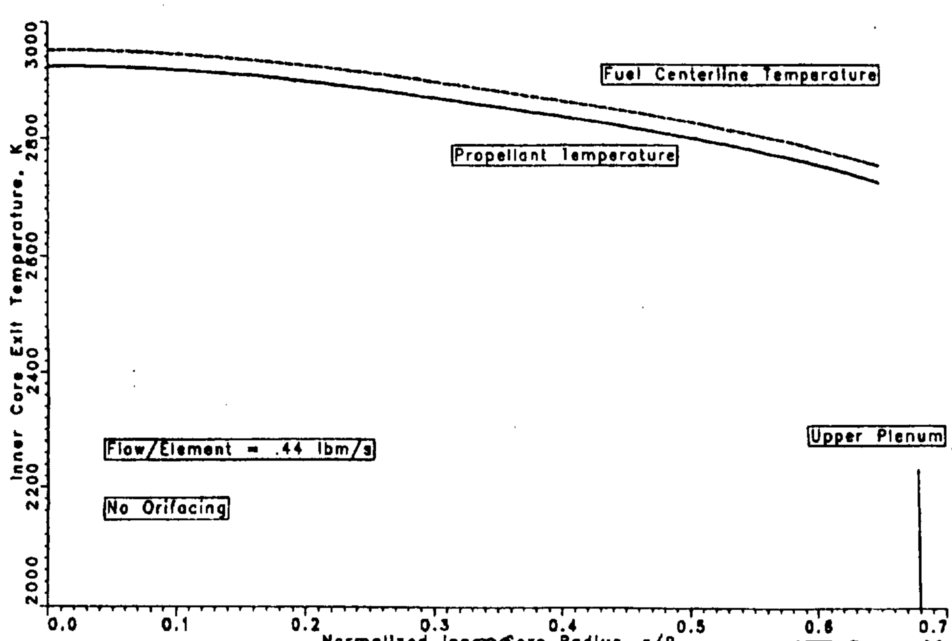




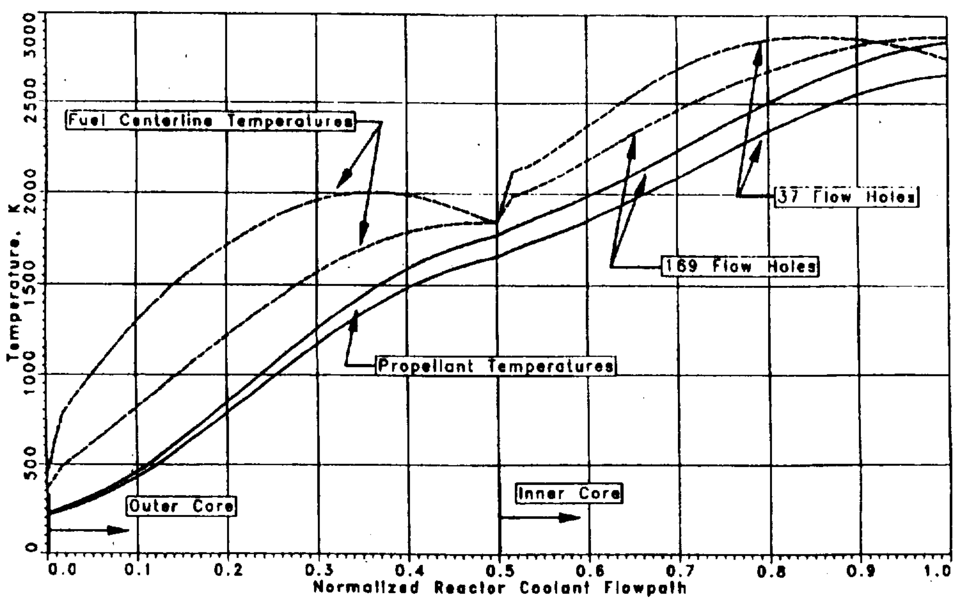


XNR2000 INNER CORE EXIT TEMPERATURE DITRIBUTION

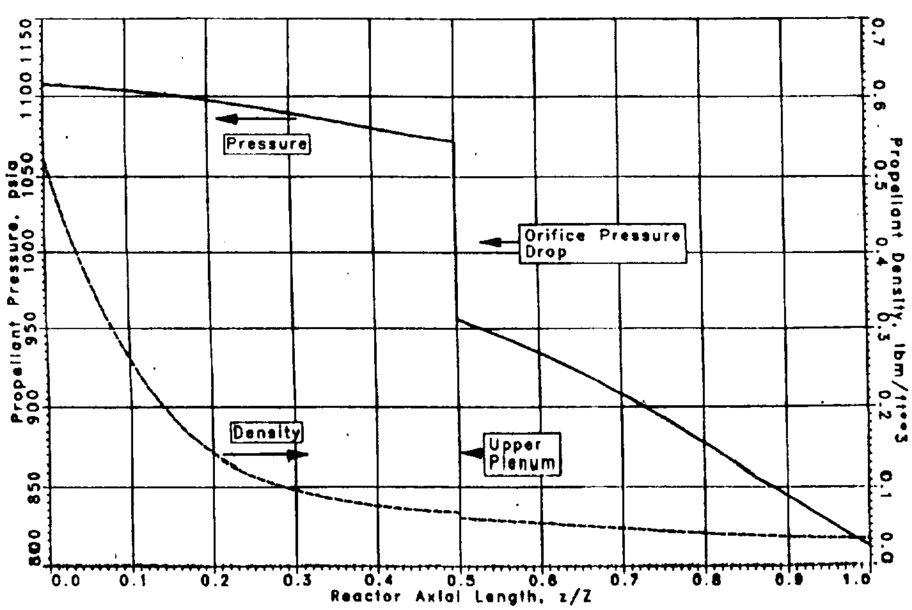
Accounting for Radial Power Distribution



169 vs 37 Fuel Element Coolant Channels
Reactor Thermal Hydraulics



Reactor Thermal Hydraulics
Baseline Design



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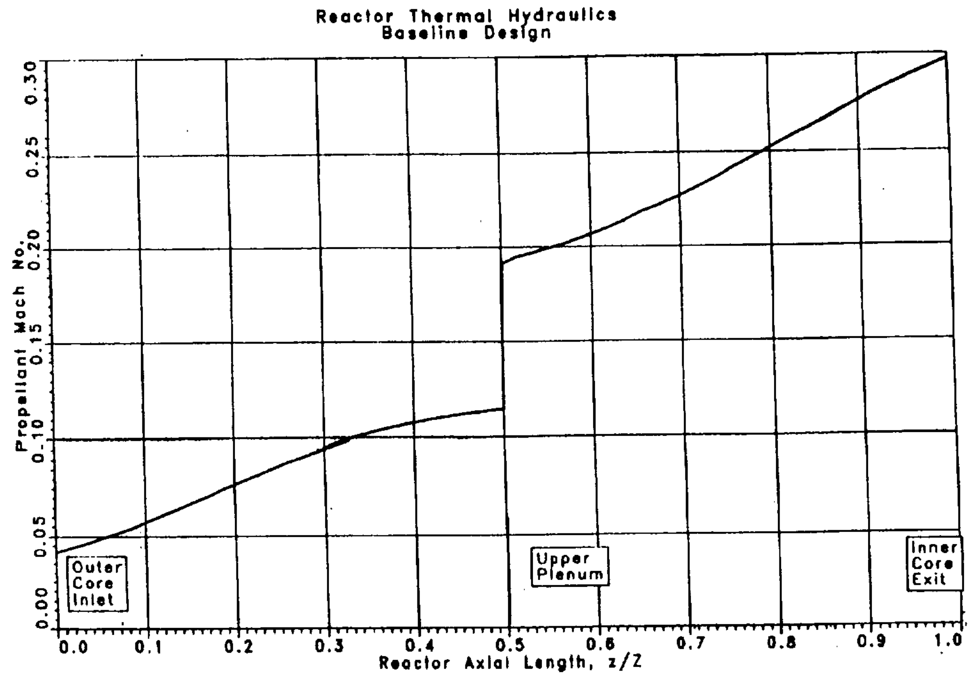

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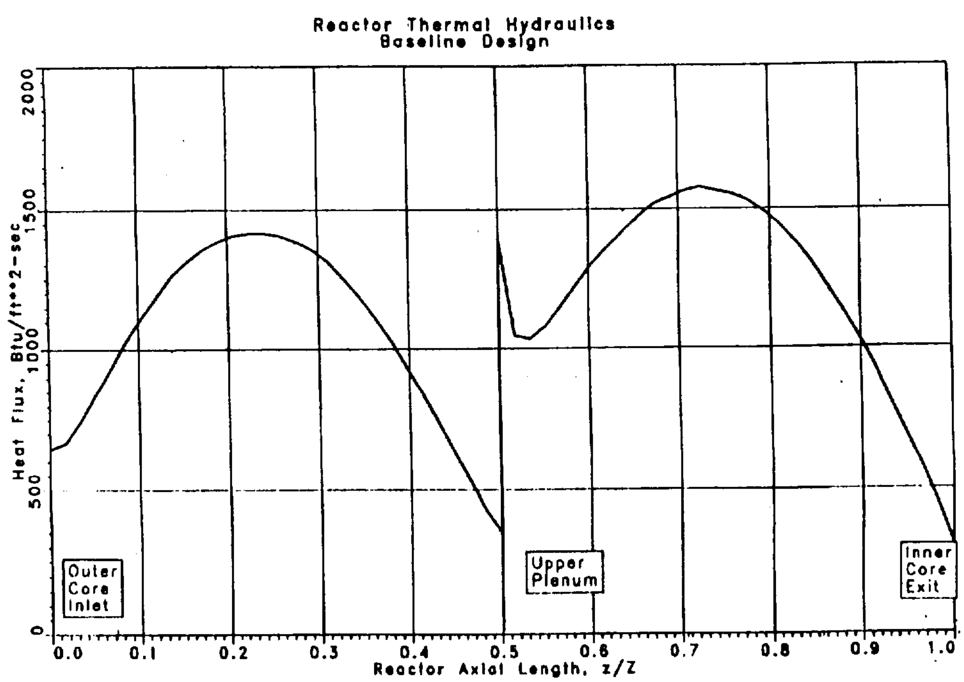

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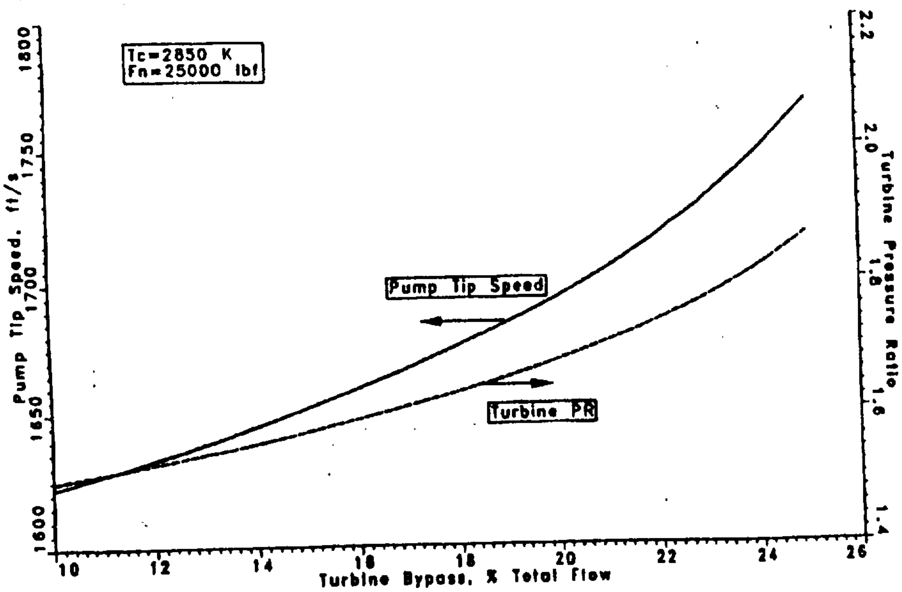
TURBINE BYPASS IMPACT ON SYSTEM

Cycle Impact on Component Design



ROCETS NTR ENGINE SIMULATION SUMMARY

- NTR Engine Simulation Computational Models In-Place
- NTR Simulation is Flexible
- Permits Great Level of Detail
- Permits Incorporation of Test Data
- Open Architecture Allows Continual Model Enhancements
- Permits Parametric NTR System Optimization

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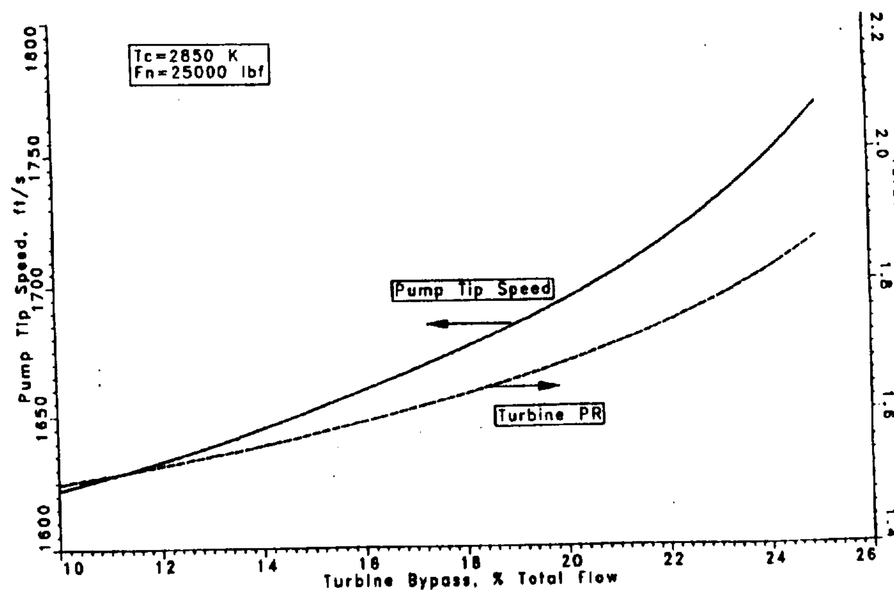

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