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REON

ROCKET ENGINE OPERATIONS - NUCLEAR

REPORT NO. RN-S-0066

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

CONTROLS ANALYSIS PRESENTATION TO SNPO-C

NERVA PROGRAM

CONTRACT SNP-1

5 MARCH 1964

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A G E N D A

<u>Topic</u>	<u>Speaker</u>
I. INTRODUCTION - MATERIAL TO BE PRESENTED	E. L. Kornfeld
II. RESULTS OF E-1 ENGINE CONTROLS STUDIES	
A. Performance Map	
B. Standard Start-up & Shut-down Runs	
C. Effects of Variation in Start-up Conditions	
D. Control System Malfunctions	
E. Closed Loop Responses for Malfunction Control Methods	
III. ALTERNATE CONTROLS METHODS	J. J. Carroll
A. Various Control Points and Feasibility of Their Utilization	
B. Preliminary Results of Alternate Control Methods	E. L. Kornfeld
1. Fixed Orifice- T_c and Flux Control	
2. Variables Orifice P_c and Flux Control	
IV. CONCLUSIONS	

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49. Start-up transient, using fixed orifice and P_c
controlled flux loop
50. Start-up transient, using fixed orifice and P_c
controlled flux loop
51. Start-up transient, using P_c controlled flux loop
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52. Start-up transient, using P_c controlled flux loop
with TPCV position as a function of P_c
53. Start-up transient, using P_c controlled flux loop
with TPCV position as a function of P_c

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REFERENCE DOCUMENTS FOR STEADY STATE (T_c - P_c)
MPA OPERATIONAL LIMITS

1. Nozzle Wall Temperature Operational Limit 1960°R
 - Ref: AGC Technical Memo 734-63-001 by R. D. CoNine and D. A. Bergmann Steady State Hot Bleed Engine Program
2. (a) Limiting pressure drop across reactor core - 130 psi
(b) Limiting flow rate through reactor core - 75 psi
(c) 1000°R and 1200°R tie rod limit at steady state operational points -WANL TNR-128
3. MARK III pump straight inlet cavitation and stall limits, AGC-LRP performance plots series 9675:64

STEADY STATE OPERATING MAP (U)

STEADY STATE OPERATING MAP (U)

Nominal Power Range Startup Transient

Temp of nozzle

Nominal Shutdown Transient

Startup Transient with TPCV Rate of
 $1.3^{\circ}/\text{sec}$

Startup Transient with TPC Rate of
1.4°/sec

Startup Transient with TPCV Rate of
1.7°/sec

Startup Transient with TPCV Rate of
 $1.9^{\circ}/\text{sec}$

Startup Transient from 0.1% Subpower Level

Startup Transient from 2nd Subpower Level

Startup Transient with the Temperature Loop
Closed at 1000°R and the Pressure Loop
Closed at 50 PSIA

Startup Transient with the Temperature Loop
Closed at 1000°R and the Pressure Loop
Closed at 125 PSIA

Startup Transient with the Temperature Loop
Closed at 1000°R and the Pressure Loop
Closed at 175 PSIA

Startup Transient with the Pressure Loop
Closed at 100 PSIA and the Temperature
Loop Closed at 900°R

Startup Transient with the Pressure Loop
Closed at 100 PSIA and the Temperature
Loop Closed at 1500°R

Startup Transient with Temperature Demand
Rate of 90°R/sec

Startup Transient with Temperature Demand
Rate of 110°R/sec

Startup Transient with Temperature Demand
Rate of 150°R/sec

Sudden Closure of TPCV While Operating
at Design Point with no Reactor Scram;
20 mm/sec

Sudden Closure of TPCV While Operating at
Design Point with Reactor Scram; 100 mm/sec

Loss of the Temperature Demand Signal
While Operating at Design Point

Loss of the Measured Temperature Signal
While Operating at Design Point

Loss of the Pressure Demand Signal While
Operating at Design Point

Loss of the Measured Pressure Signal While
Operating at Design Point

Loss of the Flux Transducer while Operating
at Design Point

Propellant Bubble Through the Turbopump
 While Operating at Design Point.
 Propellant Density Change from 4.4 lb/ft³
 to 1.0 lb/ft³ for .090 sec

Pump Overspeed with Bubbles of Various
Densities Passing Through the Pump

CLOSED LOOP RESPONSE OF INTERLOOP COUPLED
ENGINE CONTROL SYSTEM FOR A 10% STEP CHANGE
IN TEMPERATURE DEMAND AT DESIGN POINT

CLOSED LOOP RESPONSE OF UNCOUPLED ENGINE
CONTROL SYSTEM FOR A 10% STEP CHANGE IN
TEMPERATURE DEMAND AT DESIGN POINT

Closed Loop Response of Uncoupled Engine
Control System for a 10% Step Change
in Pressure Demand at Design Point

Closed Loop Response of Interloop Coupled
Engine Control System for a 10% Step Change
in Pressure Demand at Design Point

NOTE:

1. RELAY K_1 INTRODUCES THE MALFUNCTION CIRCUIT INTO THE CONTROLS SCHEME.
2. MALFUNCTION CIRCUIT SHOWN IN OPERATION.

F_i CHAMBER PRESSURE DEMAND AS A FUNCTION OF CHAMBER TEMPERATURE

Malfunction Compensation for Loss of Pressure Transducer Signal

Closed Loop Response of Engine Control
System Without Pressure Transducer

NOTE:

1. RELAY K_2 INTRODUCES THE MALFUNCTION CIRCUIT INTO THE CONTROLS SCHEME.
2. MALFUNCTION CIRCUIT SHOWN IN OPERATION.

F_1 CHAMBER PRESSURE DEMAND AS A FUNCTION OF CHAMBER TEMPERATURE

Malfunction Compensation for Loss of Flux Transducer Signal

Closed Loop Response of Engine Control
System Without Flux Transducer

NOTE:

1. RELAYS K_1 AND K_2 INTRODUCE THE MALFUNCTION CIRCUIT INTO THE CONTROLS SCHEME.

2. MALFUNCTION CIRCUITS SHOWN IN OPERATION.

F_1 CHAMBER PRESSURE DEMAND AS A FUNCTION OF CHAMBER TEMPERATURE

Malfunction Compensation for Loss of Pressure and Flux Transducer Signals

Closed Loop Response of Engine Control System Without Pressure or Flux Transducer

Damping Ratio of Temperature Control Loop
As a Function of Thermocouple Time Constant

NECESSARY CONDITIONS TO CONTROL A NUCLEAR ROCKET

- I. SYSTEM IS BOUND BY TWO DEGREES OF FREEDOM, THEREFORE, CONTROLS MUST BE RELATED TO AT LEAST TWO SYSTEM FEEDBACK PARAMETERS OR OPEN LOOP CONDITIONS.
- II. THESE TWO PARAMETERS/OR CONDITIONS MUST NOT BE TOTALLY DEPENDENT ON THE OTHER OR LINKED TO EACH OTHER IN SERIES FORM.
- III. FEEDBACK CONTROL PARAMETERS MUST BE SELECTED ON THE BASIS OF RELATIVE DEVELOPMENT STATUS OF INSTRUMENTATION.
- IV. OPEN LOOP CONDITIONS, IF SELECTED, MUST BE PREDICTABLE WITHIN THE DEVELOPMENT SPECIFICATION REQUIREMENTS.

NERVA PROGRAM

STARTUP TRANSIENT USING SINGLE FIXED ORIFICE
CONTROL.
ORIFICE - 2.73 SQ. IN.

STARTUP TRANSIENT USING SINGLE FIXED ORIFICE CONTROL.

ORIFICE - 2.73 SQ. IN.

STARTUP TRANSIENT USING SINGLE FIXED ORIFICE
CONTROL.

ORIFICE - 2.73 SQ. IN.

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
ORIFICE #1 - 1.31 SQ. IN.
ORIFICE #2 - 1.42 SQ. IN.
ORIFICE #2 CUT IN AT 50 PSIA CHAMBER PRESSURE
WITH NO TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
 ORIFICE #1 - 1.31 SQ. IN.
 ORIFICE #2 - 1.42 SQ. IN.
 ORIFICE #2 CUT IN AT 50 PSIA CHAMBER PRESSURE
 WITH NO TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
 ORIFICE #1 - 1.31 SQ. IN.
 ORIFICE #2 - 1.42 SQ. IN.
 ORIFICE #2 CUT IN AT 50 PSIA CHAMBER PRESSURE
 WITH NO TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
 ORIFICE #1 - 0.875 SQ. IN.
 ORIFICE #2 - 1.86 SQ. IN.
 ORIFICE #2 CUT IN AT 40 PSIA CHAMBER PRESSURE
 WITH A 4 SEC. TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
 ORIFICE #1 - 0.875 SQ. IN.
 ORIFICE #2 - 1.86 SQ. IN.
 ORIFICE #2 CUT IN AT 40 PSIA CHAMBER PRESSURE
 WITH A 4 SEC. TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
 ORIFICE #1 - 0.875 SQ. IN.
 ORIFICE #2 - 1.86 SQ. IN.
 ORIFICE #2 CUT IN AT 40 PSIA CHAMBER PRESSURE
 WITH A 4 SEC. TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
AND P_c CONTROLLED FLUX LOOP.
ORIFICE #1 - 2.18 SQ. IN.
ORIFICE #2 - 0.546 SQ. IN
ORIFICE #2 CUT IN AT 40 PSIA CHAMBER PRESSURE
WITH NO TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
AND P_c CONTROLLED FLUX LOOP.

ORIFICE #1 - 2.18 SQ. IN.

ORIFICE #2 - 0.546 SQ. IN

ORIFICE #2 CUT IN AT 40 PSIA CHAMBER PRESSURE
WITH NO TIME CONSTANT

STARTUP TRANSIENT USING FIXED ORIFICE CONTROL
AND P_c CONTROLLED FLUX LOOP.

ORIFICE #1 - 2.18 SQ. IN.

ORIFICE #2 - 0.546 SQ. IN

ORIFICE #2 CUT IN AT 40 PSIA CHAMBER PRESSURE
WITH NO TIME CONSTANT

STARTUP TRANSIENT USING A P_c CONTROLLED FLUX LOOP.

TPCV POSITION A FUNCTION OF P_c

STARTUP TRANSIENT USING A P_c CONTROLLED FLUX LOOP.

TPCV POSITION A FUNCTION OF P_c

STARTUP TRANSIENT USING A P_c CONTROLLED FLUX LOOP.

TPCV POSITION A FUNCTION OF P_c