*Record
Copy*

7/12/69

REON

SACRAMENTO PLANT

MASTER

REPORT NO. RN-S-0240
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE
AGC - WANL
COMMON MODEL FOR
ANALOG COMPUTER

NERVA PROGRAM

JULY 1965

CONTRACT SNP-1

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

REPORT NO. RN-S-0240
AGC - WANL
COMMON MODEL FOR
ANALOG COMPUTER

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM JULY 1965 CONTRACT SNP-1

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

AEROJET - GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

DISTRIBUTION

For

ABSTRACT

In accordance with agreements reached at the Systems Analysis Meeting held between WANL, AGC and SNPO personnel at WANL on 6 April 1965, an equation set has been developed which describes the NERVA systems. The equations are documented herein. Questions regarding additional information on these equations should be directed to Mr. R. D. Pfremmer, REON Dept. 7472.

W. D. Stinnett
Program Manager
REON

TABLE OF CONTENTS

	<u>Page</u>
Purpose	1
Summary	1
Equations	
Flow Loop (Feed System)	2
Flow Loop (Engine)	3
Flow Loop (Controls)	4
Temperature Loop	5
Flux Loop	8
References	9

PURPOSE

The equations in this document are to be used as a reference for Systems and Controls Analysis. The document will be updated in as timely a manner as is possible for the mutual usage of the equations by AGC and WANL. The basis for updating will be the latest information available for NRX/EST or X-E.

SUMMARY

The equations give a complete mathematical description of the nuclear engine system. A transient solution of the variables defined by the equations can be obtained with an analog computer. The complete equation set, mechanized for solution on an analog computer is referred to as the "Common Model".

The Systems Analysis Division developed this analog equation set in conjunction with the Systems Analysis Department of WANL as a result of a meeting at WANL between WANL, AGC and SNPO personnel on April 6, 1965. The equation set was to be sufficiently detailed to aid in systems analysis and development of the NERVA controls but simple enough to require no more than 200 amplifiers when mechanized on the analog computer.

The documentation of the model was to be handled in such a way that changes to the curves and equation set could be made without issuing a new report at the occasion of each change. The method which was suggested for this purpose was a document which would be prepared by the REON Documentation Services and distributed (both at the time of publication and at the occurrence of changes to pages) to interested parties at AGC, WANL, SNPO-C, and LASL.

The equation set which was tentatively agreed to by AGC and WANL through series of communications (Reference (1), (2), (3), (4), (5) and (6)), is the one contained herein.

The nomenclature which defines the variables in terms of the system location is included in Reference 7 and 8.

FLOW LOOP

(FEED SYSTEM)

$$P_4 = K_1 \int (W_P - W_{nc}) dt \quad (1)$$

$$W_P = K_2 \sqrt{P_3 - P_4} \quad (2)$$

$$P_3 = P_2 + K_3 N^2 + K_4 N W_P + K_5 W_P^2 \quad (3)$$

$$N = K_6 \int (M_t - M_P) dt \quad (4)$$

$$M_P = K_7 N^2 + K_8 N W_P + K_9 W_P^2 \quad (5)$$

$$M_t = K_{10} P_{15} \quad (6)$$

$$P_{15} = P_8 f_1(\theta_v) \quad (7)$$

$$\begin{aligned} K_1 &= 1.4 \times 10^4 \\ K_2 &= 11.8 \\ K_3 &= 1.2 \times 10^{-6} \\ K_4 &= 5.77 \times 10^{-4} \\ K_5 &= -9.85 \times 10^{-2} \\ K_6 &= 91 \\ K_7 &= -3.48 \times 10^{-7} \\ K_8 &= +1.065 \times 10^{-3} \\ K_9 &= -3.16 \times 10^{-2} \\ K_{10} &= 3.57 \end{aligned}$$

(ENGINE)

$$\rho_5 = \int K_{11} (W_{nc} - W_r) \quad (8)$$

$$W_{nc} = \sqrt{K_{12} \rho_5 (P_4 - P_5)} \quad (9)$$

$$P_5 = K_{13} \rho_5 T_5 \quad (10)$$

$$\rho_6 = K_{14} \int (W_{nc} - W_c - W_{db}) dt \quad (11)$$

$$W_r = \sqrt{K_{15} \rho_6 (P_5 - P_6)} \quad (12)$$

$$P_6 = K_{16} \rho_6 T_6 \quad (13)$$

$$\rho_8 = K_{17} \int (W_c - W_n - W_t + W_{db}) dt \quad (14)$$

$$W_n = \frac{K_{18} P_8}{\sqrt{T_8}} \quad (15)$$

$$P_8 = K_{19} \rho_8 T_8 \quad (16)$$

$$W_c = \sqrt{K_{20} \rho_8 (P_6 - P_8)} \quad (17)$$

$$W_t = \frac{K_{21} P_{15}}{\sqrt{K_{22} T_8 + K_{23} T_6}} \quad (18)$$

$$W_{db} = K_{24} \sqrt{\rho_6 (P_6 - P_8)} \quad (19)$$

$$K_{11} = .202$$

$$K_{12} = 34.4$$

$$K_{13} = 5.15$$

$$K_{14} = .056$$

$$K_{15} = 195$$

$$K_{16} = 5.48$$

$$K_{17} = .0575$$

$$K_{18} = 8.15$$

$$K_{19} = 5.33$$

$$K_{20} = 1660$$

$$K_{21} = .595$$

$$K_{22} = .249$$

$$K_{23} = .77$$

$$K_{24} = .693$$

(CONTROLS)

$$\theta_{vD} = K_{25} \int (P_{8D} - P_8) dt + K_{26} (P_{8D} - P_8) \quad (20)$$

$$P_{8D} = f_2(T_{8M}) \quad (21)$$

$$\theta_v = \frac{\theta_{vD}}{K_{56}s^2 + K_{57}s + 1} \quad (21a)$$

$$K_{25} = .1$$

$$K_{56} = 1.75 \times 10^{-4}$$

$$K_{26} = .07$$

$$K_{57} = 1.3 \times 10^{-2}$$

TEMPERATURE LOOP

$$\dot{H}_n = \int \left[K_{27} W_n \cdot^8 (T_8 - \vartheta_n) - K_{28} W_{nc} \cdot^8 (\vartheta_n - T_5) \right] dt \quad (22)$$

$$\vartheta_n = f_3(H_n) \quad (23)$$

$$T_5 = \vartheta_n - K_{29} W_{nc} \cdot^2 (T_5 - T_2) \quad (24)$$

$$\dot{H}_r = \int \left[K_{30} \dot{n} - K_{31} W_r \cdot^8 (\vartheta_r - T_6) \right] dt \quad (25)$$

$$\vartheta_r = f_4(H_r) \quad (26)$$

$$T_6 = \vartheta_r - K_{32} W_r \cdot^2 (T_6 - T_5) \quad (27)$$

$$\dot{H}_{c.1} = \int \left[K_{33} \dot{n} - K_{34} W_c \cdot^8 (\vartheta_{c.1} - T_{c.1}) \right] dt \quad (28)$$

$$\vartheta_{c.1} = f_5(H_{c.1}) \quad (29)$$

$$T_{c.1} = \vartheta_{c.1} - K_{35} W_c \cdot^2 (T_{c.1} - T_6) \quad (30)$$

$$\dot{H}_{c.2} = \int \left[K_{36} \dot{n} - K_{37} W_c \cdot^8 (\vartheta_{c.2} - T_{c.2}) \right] dt \quad (31)$$

$$\vartheta_{c.2} = f_6(H_{c.2}) \quad (32)$$

$$T_{c.2} = \vartheta_{c.2} - K_{38} W_c \cdot^2 (T_{c.2} - T_{c.1}) \quad (33)$$

$$\dot{H}_{c.3} = \int \left[K_{39} \dot{n} - K_{40} W_c \cdot^8 (\vartheta_{c.3} - T_{c.3}) \right] dt \quad (34)$$

$$\vartheta_{c.3} = f_7(H_{c.3}) \quad (35)$$

$$T_{c.3} = \vartheta_{c.3} - K_{41} W_c \cdot^2 (T_{c.3} - T_{c.2}) \quad (36)$$

$$T_8 = K_{42} T_{c.3} \quad (37)$$

$$T_{8c} = T_{8d} - \frac{T_8}{1 + K_{43} s / \sqrt{W_c}} \quad (38)$$

TEMPERATURE LOOP

$K_{27} = .262$

$K_{28} = .59$

$K_{29} = 6.78$

$K_{30} = 276$

$K_{31} = 13.6$

$K_{32} = .279$

$K_{33} = 3477$

$K_{34} = 17.6$

$K_{35} = .199$

$K_{36} = 4581$

$K_{37} = 23.5$

$K_{38} = .157$

$K_{39} = 2081$

$K_{40} = 29.9$

$K_{41} = .1435$

$K_{42} = .955$

$K_{43} = 2.5$

TEMPERATURE LOOP

FLUX LOOP

$$n_m = \int \frac{\Delta k n_o}{\left[1 + \sum_{i=1}^6 \frac{Bi}{s + \gamma_i} \right]} dt \quad (39)$$

$$\Delta k = K_{44} \sin^2 \left(\frac{\theta_d}{2} \right) + K_{45} (K_{46} \rho_6 + K_{47} \rho_8) + K_{58} (K_{46} \rho_6 + K_{47} \rho_8) \phi_{c.2} \quad (40)$$

$$\theta_d = \frac{\theta_{dd} + K_{48} \phi_{c.2} + K_{49}}{K_{50} s^2 + K_{51} s + 1} \quad (41)$$

$$\theta_{dd} = K_{52} (\log n_d - \log n_m) + K_{53} \int [\log n_d - \log n_m] dt \quad (42)$$

$$\log n_d = K_{54} T_{8e} + \int K_{55} T_{8e} dt \quad (43)$$

$$K_{44} = .0702$$

$$K_{45} = .1578$$

$$K_{46} = .156$$

$$K_{47} = .844$$

$$K_{48} = -5.23 \times 10^{-6}$$

$$K_{49} = .03844$$

$$K_{50} = .0016$$

$$K_{51} = .04$$

$$K_{52} = 10$$

$$K_{53} = 100$$

$$K_{54} = 6 \times 10^{-5}$$

$$K_{55} = 1.2 \times 10^{-4}$$

$$K_{58} = -2.6 \times 10^{-6}$$

REFERENCES

- (1) Letter, 7472:L-2040 to H. F. Faught from C. M. Rice, dtd 21 April 1965
- (2) Letter to J. L. Dooling from H. F. Faught, dtd 21 April 1965, subj: "Proposed Common Engine Model in Power Range"
- (3) Telecon, 7472:T-2044, to J. C. Buker from R. D. Pfremmer, dtd 30 April 1965, subj: "AGC-WANL 'Common Model' for Analog Computer Studies"
- (4) Telecon, 7472:T-2060, to J. C. Buker from R. D. Pfremmer dtd 15 June 1965, subj: "AGC-WANL 'Common Model' for Analog Computer Studies"
- (5) Letter to J. L. Dooling from H. F. Faught, dtd May 17, 1965 subj: "Transmittal and Numerical Preliminary Form of the Common Analog Computer Model of the NERVA System"
- (6) Letter, 7472:L2047 to H. F. Faught from C. M. Rice dtd 17 May 1965, AGC-WANL "Common Model"
- (7) RN-S-0091, Basic Analog Model for NERVA Engine, May 1964
- (8) RN-S-0202, "Basic Analog Model for X-E, NRX/EST and CFDTS Turbopump and TPCV" Feb 1965