TRANSIENT ANALYSIS
BRAYTON ISOTOPE POWER SYSTEM
SUPPLEMENT I

75-311279
Supplement I

April 2, 1976

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

MASTER

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

DISTRIBUTION OF THIS DOCUMENT IS 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.

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, 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.

TRANSIENT ANALYSIS
BRAYTON ISOTOPE POWER SYSTEM
SUPPLEMENT I

75-311279
Supplement I

April 2, 1976

Prepared by: Engineering Staff/ BJB

Approved by: H.W. Lange for
J.E. McCormick, Program Manager
Mini-BRU Systems

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

REPORT NO. 75-311279 Supplement I

TOTAL PAGES 15

ATTACHMENTS: Appendix A (2 pages)
Appendix B (24 pages)

REV	BY	APPROVED	DATE	PAGES AND/OR PARAGRAPHS AFFECTED

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

The principal investigator for this effort was

B.J. Minshall

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

TRANSIENT ANALYSIS
BRAYTON ISOTOPE POWER SYSTEM

SUPPLEMENT I

1. INTRODUCTION

This report, prepared by the AiResearch Manufacturing Company of Arizona, A Division of The Garrett Corporation, presents the results of the thermal effects of ducting on the transient start up of the Brayton Isotope Power System and is a supplement to AiResearch Report No. 75-311279 ("Transient Analysis - Isotope Brayton Flight System") issued in May, 1975.

Report No. 75-311279 presented the results of a computer study in which the entire Flight System (FS) was dynamically modeled. The system model included the compressor map, turbine map, alternator performance, heat source, recuperator, cooler, duct volumes, and controls. The model thus allowed system parameters to be observed as a function of time. Typical output displayed the following as a function of time:

- o Temperature of all major stations around the loop, including heat exchangers
- o Pressure at all major stations around the loop
- o Turbine and compressor flow, high and low pressure recuperator flow, bypass flow, bearing flow, leakage, and any other applicable flows
- o Engine speed
- o Area of bypass valves (if overspeed protection is included for the system)

- o User load and parasitic load

These parameters are displayed in the form of computer printouts or Calcomp plots. The data obtained from the supplemental study is also presented by these plots (see Appendix B).

The program could be used to study:

- o Thermal transients during start up
- o Alternator performance during transients
- o System stability
- o Starter requirements
- o Shutdown transients

The NASA is particularly interested in using the program to predict system thermal start up transients. These transients produce thermal stresses in the heat source heat exchanger and the recuperator which are of concern, relative to component life. The program results previously reported in Report No. 75-311279 were questioned in that they did not contain the temperature drops of the ducts. The program was modified to include three ducts in the model and to update the component masses and rotating group inertia. The three ducts included were the HSA inlet duct, HSA exhaust duct, and turbine exhaust-recuperator inlet duct.

Appendix A presents the new values used in the program for:

- (a) Recuperator
- (b) HSA
- (c) Ducts
- (d) Rotating Inertia

In general the mass of all items increased and, therefore, the thermal inertia increased.

2. PROGRAM OPERATION

The basic program and its operation are as previously described in Report No. 75-311279. The duct addition requires three temperature integrations to be added to subroutine DEREV at appropriate locations.

The initial conditions for the program were computed by hand to provide the proper start inventory. That is, the start pressure is calculated at the corresponding starting duct temperature to yield an inventory of 1.5 lbs (3 HSA) and 0.97 lbs (2 HSA). These values were computed for the vertical Mini-BRU configuration (See comments, Section 4).

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

3. NOMENCLATURE

The nomenclature is as presented in the previous report (No. 75-311279) and included on Figure 1 herein, with the following additions:

T5B - HSA inlet temperature, i.e., T5 after effects of HSA inlet duct

T6B - Turbine inlet temperature, i.e., T6 after effects of turbine inlet duct

T9B - Recuperator inlet temperature, i.e., T9 after effects of turbine discharge duct

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

PROGRAM BRTDYN NOMENCLATURE

FIGURE 1

4. INITIAL THERMAL CONDITIONS

The steady state duct temperatures, as they are anticipated to exist at start up, were predicted to be:

T1 = 390°R
T5 = 627°R
T10 = 627°R
T9 = T9B Duct = 683°R
T5 = T5B Duct = 614°R
T6 = T6B Duct = 614°R

These values were determined via a computer program for the system in space with the HSA filled with the Auxiliary Cooling System (ACS) cover gas. The program computes the radiation heat transfer (conduction and convection in space are assumed negligible). The heat transfer is based on the view factor between the ducts and the BIPS components. Four assumptions were made and they were:

- (1) The emissivity of the outer wall of the HSA is 0.20
- (2) Each HSA radiates 2400 watts
- (3) The heat sink temperature is 390°R
- (4) The emissivity of the radiator is 0.80

The steady state temperature of the HSA outside housing is 1397°R (determined by General Electric).

These initial conditions were used for all start cases including 3 HSAs and cases starting at reduced HSA temperature. It is recognized that the duct starting temperature is, in reality, influenced by several factors. However, these influences are in general believed small and the order of magnitude calculation can be performed from these data.

The temperatures determined above were used to calculate the initial loop pressure to arrive at the proper loop inventory.

5. RESULTS AND CONCLUSIONS

The purpose of this study was to obtain a simulation of the most rapid start up thermal transient which would be encountered in the BIPS operation. As an aid in reducing the severity of the transient, it was agreed with the NASA that the case to examine would be determined by the following logic:

- (a) Determine the lowest temperature at which a start could be accomplished using a 2 HSA configuration
- (b) Define the transients for a 3 HSA start which was initiated when the heat source achieved the start temperature determined for the 2 HSA configuration of (a)

This approach limits the transient analysis of the recuperator and the HSA to a single case. (The 2 HSA start requires a higher initial temperature due to lower thermal capacity with only two HSA's). The transient defined is "worst case" for either two or three HSA operation.

In order to obtain the above data, several computer cases were run. Table 1 presents a summary of the computer runs made for this report. Note that the computer run numbers that represent a 3 HSA configuration are numbered in the 100 series and those that represent a 2 HSA configuration are of the 200 series.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

TABLE 1

SUMMARY OF COMPUTER RUNS

THREE (3) HSA

<u>Run No.</u>	<u>HSA Temperature</u>
111	1460°R
112	1660°R
113	1860°R

TWO (2) HSA

211	1460°R
212	1660°R
213	1860°R
214	2060°R

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

The HSA temperature range to be used during start up was determined from steady state data. Figures 2 and 3 are plots of net engine power delivered to the alternator as a function of T6 for the 2 HSA and 3 HSA configuration under the following conditions:

- (a) Compressor inlet temperature is 390°R
- (b) Recuperator at matched steady state operating point
- (c) Entire system at steady state, i.e., radiator cold, ducts at steady state temperature, heater at steady state thermal equilibrium
- (d) Engine speed 52,000 rpm

Since the above conditions change rapidly during the transient of the start up, the conditions do not match a start up at any point but serve as an indication of the transients of interest. Two major boundaries may be established by these plots:

- o First, the engine will not self-sustain at turbine temperatures below 1060°R .
- o Second, the 3 HSA case is in danger of producing more power than the alternator can absorb if a start is made above 1860°R . [The reason for this excess power is the cold (T1) compressor inlet. As the loop warms up the T1 temperature will rise faster than the (T6) turbine inlet temperature. With initial T6 temperature of 1860°R or less, an excess power condition will not be encountered].

Thus, several computer runs within this band were made.

ENGINE POWER TO ALTERNATOR
AS A FUNCTION OF T_6

FIGURE 2

ENGINE POWER TO ALTERNATOR
AS A FUNCTION OF T_6

FIGURE 3

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

A summary of the duct temperature profile as a function of time for both the three HSA and two HSA cases is presented in Tables 2 and 3. The tables present the inlet and discharge temperatures for the three ducts modeled and for three time periods (1 second, 5 seconds, and 30 seconds). These values can also be observed on the plots in Appendix B. It can be seen from the data that the effects of the ducts on temperature is large during the first 5 seconds while the flow is low. The temperature drop reduces as the speed and thus flow increase. A small flat can be seen on the temperature curves during the first (approximate) 0.4 seconds. This is caused by the minimum flow which is set into the program of 1.0×10^{-4} pounds per second instead of a flow of zero. (This minimum flow is used to avoid division by zero as there are equations in the program which contain flow in the denominator.) At this low flow, the energy carried to the HSA and recuperator should be negligible. If the flow started from zero, the initial temperature out of the ducts would be at duct temperature. In using the results of this computer simulation for thermal stress analysis, the initial duct temperature should be used as the starting point.

After the initial engine acceleration, the temperature drop encountered by the ducts agrees reasonably well with the hand calculated temperature drop. The duct temperature drops can be seen to approach zero on the time plots as time lengthens.

From the plots, it can be seen that Run Number 211 (2 HSA, 1460°R) represents the lowest temperature at which an engine start can be performed. At 130 seconds after start, the alternator output power (parasitic load PPL) is approximately 0.115 kw. This is believed too marginal to use for the design criteria. It is recommended that 1660°R (Run No. 212) be the minimum start temperature. This run at 170 seconds has decreased in power to 0.35 kw and is considered the minimum margin acceptable. The 3 HSA run which corresponds to this start up temperature is Run No. 112. It is then recommended that Run No. 112 be used as the anticipated start cycle.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

TABLE 2
SUMMARY OF DUCT TEMPERATURES

			T5	T5B	T6	T6B	T9	T9B
<u>3 HSA</u>								
111	1460°R	1 Sec	628	625	1463	1319	1294	957
		5 Sec	662	655	1462	1369	1271	1037
		30 Sec	903	870	1414	1360	1181	1046
112	1660°R	1 Sec	628	625	1663	1484	1459	1025
		5 Sec	671	663	1659	1545	1420	1130
		30 Sec	977	935	1586	1522	1316	1146
113	1860°R	1 Sec	628	625	1863	1646	1620	1091
		5 Sec	681	671	1857	1722	1563	1220
		30 Sec	1050	999	1760	1685	1454	1248

Note: All temperatures are in °R

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

TABLE 3

SUMMARY OF DUCT TEMPERATURE

			T5	T5B	T6	T6B	T9	T9B
<u>2 HSA</u>								
211	1460°R	1 Sec	627	624	1463	1311	1286	935
		5 Sec	650	644	1462	1359	1271	1018
		30 Sec	830	802	1407	1342	1154	1005
212	1660°R	1 Sec	628	624	1663	1474	1448	1006
		5 Sec	656	649	1659	1532	1427	1107
		30 Sec	888	852	1571	1494	1281	1094
213	1860°R	1 Sec	628	624	1863	1632	1606	1059
		5 Sec	662	654	1857	1706	1580	1196
		30 Sec	943	900	1740	1650	1413	1185
214	2060°R	1 Sec	628	624	2062	1788	1762	1113
		5 Sec	667	659	2054	1880	1732	1283
		30 Sec	998	948	1912	1808	1547	1277

Note: All temperatures are in °R

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

In review of the above start up transient, it is recalled that the initial condition is $T_1 = 390^\circ\text{R}$ (subcooling is assumed while stored in the Shuttle) and the radiator sink temperature at start initiation is 450°R . Some question arises regarding the ability of the engine to start at high compressor inlet temperature (T_1). For this reason, a run was made using $T_1 = 610^\circ\text{R}$ initial condition (and retaining radiator sink at 450°R and $T_6 = 1660^\circ\text{R}$). The engine speed is accelerated by the starter (alternator) but does not self-sustain at the 26,000 rpm. The result is that the engine hangs at 26,000 rpm for approximately 30 seconds while the compressor inlet temperature decreases. Other simulated start ups at $T_6 = 2060^\circ\text{R}$ resulted in a 15 second time to reach speed from initiation of start. It is concluded that the 610°R T_1 condition represents an extreme, although possible, start condition with longer motoring.

It should be noted that modification of the start cycle can be accomplished. It is anticipated, and so assumed in the computer description, that the unit is allowed to accelerate directly to rated speed. It is possible to set the engine control at part speed for a relatively long period of time if a Space Shuttle launch is to be used (if there is continuous power available in the quantity required). It is also possible to ramp the start to further limit the initial transient if the transient defined by Run No. 112 is unacceptable for either the HSA or the recuperator.

In conclusion, Run No. 112 is the run to be used as a best estimate of the anticipated thermal start up transients.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

APPENDIX A

SUMMARY OF DUCT CHARACTERISTICS AND SYSTEM MODEL CHANGES

APPENDIX A

SUMMARY OF DUCT CHARACTERISTICS

HSA Inlet Duct

O.D. = 1.6 inches
Wall Thickness = 0.060
Material = Hastelloy X
Per Duct Length = 9.0
No. of Ducts = 2
No. of Bellows = 1

Total Weight of Section = 2.148 lbs

Turbine Inlet Duct

O.D. = 1.60 inches
Wall Thickness = 0.060
Material = C103
Per Duct Length = 6.5
No. of Ducts = 2
No. of Bellows = 1

Total Weight of Section = 1.93 lbs

Turbine Discharge Duct

O.D. = 2.50 inches
Wall Thickness = 0.035
Material = Hastelloy X
Per Duct Length = 47.6
No. of Ducts = 1
No. of Bellows = 4

Total Weight of Section = 5.189 lbs

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

SYSTEM MODEL CHANGES

Recuperator

Core Mass now 115.42 lbs, was 63.0 lbs

Specific heat of metal now a function
of average temperature.

HSA

Mass of HSHX = 19.6 lbs (per HSA)

Specific heat is a function of temperature.

ηhA is a function of flow rate

Inertia

Now 0.00021 ft-lbs^2 , was 0.000124

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

APPENDIX B

DYNAMIC SIMULATION

COMPUTER PLOTS

75-311279
Supplement I
Appendix B

RUN 112
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE--TG-1660 DEG R

RUN 112
BIPS COLD START - ALL COMPONENTS AT COLD START TEMPERATURE--T6=1660 DEG R

RUN 112

BIPS COLD START -- ALL COMPONENTS AT COLD START TEMPERATURE -- T6-1660 DEG R

4/ RUN 112
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE - T6-1660/DEC R

5 RUN 113
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE - - 16-1860 DEG R

RUN 113
BIPS COLD START - ALL COMPONENTS AT COLD START TEMPERATURE--T6:1860 DEG R

3 RUN 113
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE - T6-1860 DEG R

RUN 21:
BIPS COLD START -- ALL COMPONENTS AT COLD START TEMPERATURE--T6=1460 DEG R

RUN 211
BIPS COLD START -- ALL COMPONENTS AT COLD START TEMPERATURE -- T6=1460 DEG R

RUN 211
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE - T6=1460 DEG R

RUN 212
RIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE--T6=1660 DEG R

RUN 212
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE--T6-1660 DEG R

RUN 212
BIPS COLD START -- ALL COMPONENTS AT COLD START TEMPERATURE-- T6=1660 DEG R

RUN 212
BIPS COLD START -- ALL COMPONENTS AT COLD START TEMPERATURE--T6=1660 DEG R

7 RUN 213
BIPS COLD START - ALL COMPONENTS AT COLD START TEMPERATURE--T6:1860 DEG R

RUN 213

BIPS COLD START - ALL COMPONENTS AT COLD START TEMPERATURE - -16-1860 DEG R

RUN 214
BIPS COLD START - ALL COMPONENTS AT COLD START TEMPERATURE -TG-2C60 DEG R

RUN 214
BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE--T6-2060 DEG R

RUN 214

BIPS COLD START - - ALL COMPONENTS AT COLD START TEMPERATURE - T6=2060 DEG R