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TECHNICAL PROPOSAL

DESIGN AND FABRICATION OF A SUPERALLOY
BIPS WORKHORSE LOOP AND
TECHNICAL ASSESSMENT OF AN OPTIMIZED
SUPERALLOY FLIGHT SYSTEM

76-311790

March 5, 1976

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

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Prepared by: Engineering Staff

Approved by: J.E. McCormick

J.E. McCormick
BIPS Program Manager

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1. INTRODUCTION

This document, prepared by the AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, for the USERDA NRA, proposes an add-on program to the existing Brayton Isotope Power System (BIPS) Contract E(04-3)-1123. The proposed program includes the design and fabrication of a superalloy BIPS "workhorse" loop and the technical assessment of an optimized superalloy flight system (FS).

Figure 1 presents the proposed program schedule and the inter-relationship of tasks.

It is incumbent upon the BIPS program management to identify and respond quickly to problems which could adversely affect program cost and/or scheduling. Success of the BIPS program depends, to a great extent, on anticipation of potential problem areas and the formulation and implementation of contingency plans should those problems arise.

One area of concern is the early initiation of the testing phase. AIRPHX feels it would be advantageous to initiate a step-by-step check-out of GDS components and subsystems at the earliest possible date. In order to begin testing early, the use of a workhorse loop is required. The proposed workhorse loop would use a workhorse loop heater assembly, which is a fixture comprised of an electric heater, simulated turbine plenum and associated interconnecting plumbing.

PROGRAM SCHEDULE

A second area of concern, to be addressed as early as possible during the GDS preliminary design (ending June 30, 1976), involves material compatibility and material selection. The use of superalloys should be investigated as an alternative to the refractory metals presently targeted as critical GDS components. AIRPHX routinely builds production gas turbines daily using superalloys and there is a tremendous experience base to draw upon.

The use of superalloys rather than refractory metals would result in system trade-offs. The assessment of these trade-offs through study and through testing of actual superalloy hardware in an all superalloy "workhorse" loop is required to develop confidence in the viability of a superalloy flight system. The workhorse loop is expected to demonstrate the competitive performance and five year reliability potential of a superalloy GDS; a superalloy flight system would provide, as a minimum, a high confidence option for the BIPS program.

As shown in Figure 1, this proposed program interrelates with an Alternate HSA Design Study program to be proposed soon. The two programs are related in two primary areas: First, the alternate HSA design study will culminate in a HSA configuration that likely will incorporate improvements over the existing design. Therefore, the selected alternate HSA design may well determine the superalloy FS HSA configuration. Second, it is conceivable that AIRPHX would prefer to test the GDS with the alternate HSA if available in time.

It is the intention of AIRPHX to expedite this proposed program in order to generate as much information as possible for the BIPS preliminary design review in June - July 1976.

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2. PROGRAM OBJECTIVES

The objectives of the proposed program are:

- (a) Determine the performance of an all superalloy FS
- (b) Define the superalloy turbine plenum and ducting for five year life
- (c) Design and fabricate a "workhorse" loop heater assembly
- (d) Assemble the workhorse loop

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3. TECHNICAL DISCUSSION

3.1 Workhorse Loop Design and Fabrication

The BIPS reference flight system design includes a hot end constructed entirely of columbium. The hot end consists of two Heat Source Assemblies (HSAs), a turbine plenum and the required ducting. In order to closely simulate the FS, the Ground Demonstration System (GDS) will also use these Cb components. The GDS will be subjected to rigorous performance testing during the test program.

The proposed workhorse loop is configured differently from the GDS and FS in that a special fixture (workhorse loop heater assembly) would simulate the two HSAs, the turbine plenum, and the ducting.

There are two primary reasons for including a workhorse loop in the program:

- (1) Earliest possible checkout testing of GDS components and subsystems, and
- (2) Facilitates testing to $2100 W_e$.

While the system will be tested over a range of power levels, the two HSA design will limit its output to $1300 W_e$. The use of an electric heater to simulate the HSA would permit power levels to reach the design requirement of $2100 W_e$.

3.2 Optimized Superalloy FS Assessment

The value of an all superalloy FS is that it provides an option to the present conceptual FS which is constructed of refractory metals. AIRPHX has assessed the trade-offs of a superalloy FS vs a refractory FS in a qualitative manner. The trade-offs resulting from a superalloy FS include:

- (a) Reduced life (lower material high temperature strength) at the same turbine inlet temperature
- (b) Higher system weight (heavier structural cross sections)
- (c) Lower cycle efficiency (due to lower turbine inlet temperature)
- (d) A new set of materials development problems (determination of long term superalloy creep properties and the effects of contamination, hard vacuum and pure working fluid)
- (e) A new set of fabrication development problems (brazing creep strength, diffusion bonding, weld crack prevention)

Despite the trade-offs incurred, the all superalloy FS could be developed at low risk and would result in a design which may be competitive and would provide high reliability for five years.

3.2.1 Cycle Reoptimization

Initially, the thermodynamic cycle will be redefined in order to achieve the highest possible efficiency using the existing recuperator and Mini-BRU components. Cycle analyses will be performed by varying the turbine inlet temperature (T_6), compressor inlet temperature (T_1)

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and radiator pressure drop ($\Delta P/P$). The results of this effort will be summarized as a series of carpet plots showing the effect of T_1 and $\Delta P/P$ (at constant T_6) on cycle efficiency, turbine inlet pressure, and radiator area and weight. T_6 , in turn, will be varied to 1300°F in 50°F increments. Figure 2 shows the form in which the data will be presented to facilitate the material stress evaluation.

An important trade-off involves increasing the radiator size in order to lower T_1 . Lowering T_1 is necessary to maintain a high cycle efficiency which would otherwise be reduced by lowering of T_6 as required to obtain desired component life.

The new cycle would be defined so as not to change the Mini-BRU rotating speed or other critical design parameters.

3.2.2 Turbine Plenum Redesign

The redefined cycle state points enable the redesign of the plenum structure, presently designed using refractory columbium alloy C-103. The required preliminary analysis steps include selection of the material properties, followed by an iteration between the thermal analysis and stress analysis.

The iterative loop is:

- (a) Optimize plenum configuration for fabrication in superalloy, i.e., provide adequate flexibility in load paths assuring tolerance to thermal loading due to higher modulus of elasticity of the superalloys.
- (b) Conduct a series of turbine plenum elastic stress analyses in order to choose candidate superalloys for various operating temperatures.

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TURBINE INLET TEMPERATURE = CONSTANT

CYCLE STUDY DATA FORMAT

FIGURE 2

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- (c) Having optimized a candidate superalloy for a selected operating temperature, conduct a creep analysis of the turbine plenum.
- (d) If the calculated creep life of the plenum is satisfactory for the operating temperature condition, the superalloy selection is satisfactory. However, if the calculated creep life is unsatisfactory then it is necessary to reoptimize by changing either the configuration or the candidate material choice.

The foregoing process will result in a credible assessment of the resulting trade-offs.