N91-18998

1990

NASA/ASEE SUMMER FACULTY RESEARCH FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
THE UNIVERSITY OF ALABAMA

# THERMAL ANALYSIS SIMULATION FOR A SPIN-MOTOR USED IN THE ADVANCED MAIN COMBUSTION CHAMBER VACUUM PLASMA SPRAY PROJECT USING THE SINDA COMPUTER PROGRAM

Prepared by: Gary H. McDonald, Ph.D., P.E.

Academic Rank: Assistant Professor

University and Department: The University of Tennessee at Chattanooga
Mechanical Engineering - Mechanics

NASA/MSFC:

Laboratory: Propulsion

Division: Component Development

Branch: Turbomachinery and Combustion Devices

NASA colleague: Kathy S. Tygielski

Date: August 16, 1990

Contract No.: NGT 01-002-099
The University of Alabama

## INTRODUCTION

In the space shuttle main engine (SSME), the mixing of liquid hydrogen (LH2) fuel and liquid oxygen (LOX) oxidizer occurs in the main combustion chamber (MCC). Stored in separate compartments inside the external tank, the LH2 and LOX are pumped by high and low pressure fuel and oxygen turbopumps into the MCC for ignition and combustion. By expelling its combustion products through the nozzle, thrust is produced to propel the shuttle from earth.

The current MCC construction consists of welding many components to form the converging - diverging chamber shape. This process takes about four years to complete at a cost of 3.2 million dollars per chamber. The advanced main combustion chamber (AMCC) is designed to simplify the process for construction and reduce any critical-failure modes by reducing the number of welds. The proposed construction time is about one year with a cost of 1.2 million dollars per chamber.

The proposed improvements are to cast the AMCC jacket out of weldable hydrogen resistant superalloy. In order to line the casting, the vacuum plasma spray (VPS) process will be used to spray Narloy Z, a copper based alloy, inside the casting. This process will be performed by three plasma guns spraying Narloy Z at 1500 $^{0}$F inside a vacuum chamber. The AMCC will be bolted to a turntable driven by a spin-motor and spindle assembly inside the chamber in order to keep the plasma guns perpendicular to the inside surface throughout the duration of the spraying. Three spray guns are necessary for the spraying process. One gun will spray the top section, one will spray the bottom section and one will spray the critical throat section of the AMCC. This system is shown schematically in Figure 1. The proposed benefits of the VPS process are to reduce the number of welds and eliminate all blind welds, to eliminate copper plating from the hydrogen barrier, to reduce maintenance and need for weld inspections and to decrease manufacturing time and thereby reduce the cost.

One of the many design challenges of this project is predicting the thermal effects due to the environment inside the vacuum chamber on the turntable and spin-motor spindle assembly. The objective of this study is to model the spin-motor using the computer program SINDA, System Improved Numerical Differencing Analyzer. By formulating the appropriate input information concerning the motor's geometry, coolant flow path, material composition, and bearing and motor winding characteristics, SINDA should predict temperatures at various predefined nodes. From these temperatures, hopefully, one can predict if the coolant flow rate is sufficient or if certain mechanical elements such as bearings, O-ring seals or motor-windings will exceed maximum design temperatures.

## THE PROBLEM DEFINITION

The spin-motor turntable assembly is schematically shown as a one-half scale drawing in Figure 2. The spin-motor housing is approximately 11.25 inches in height and 13.25 inches in diameter. The motor is composed of the housing, coolant water flow path, two ball bearings, rotor-stator-resolvers, silver slip-ring for electrical conductance, and a central hollow shaft. The spin motor material is 304 stainless steel, the bearing material is 440C steel, the motor windings are AISI 1010 steeland vanadium steel, and the coolant is water. The motor will have 60 $^{O}$F and 60 psi water flowing into it. The chamber temperature will be 300 $^{O}$F and the three VPS guns will bring the AMCC turntable and spin-motor spindle assembly up to 1500 $^{O}$F. The Narloy Z liner will overspray from the AMCC onto the turntable and spin-motor housing. This overspray will effect the heat transfer into the motor and temperatures inside the housing. However, it will not be considered in this initial study. The modes of heat transfer present will be conduction, both axial and radial to the central shaft, convection between the motor components and coolant flow, and radiation of the vacuum chamber and AMCC-VPS environment to the motor housing. The spin-motor is proposed to turn the turntable at 100 RPM throughout the period of spraying. The estimated load of the AMCC and turntable on the spin-motor is approximately 1000 pounds. The bearings are a 95 mm bore diameter top bearing and a 80 mm bore diameter bottom bearing. Both bearings are SKF single-row deep groove ball bearings. [1] The motor components are Inland motor model number BMS-7101. [2]

## BUILDING THE SINDA MODEL

SINDA is a software system which possesses capabilities that make it well suited for solving lumped parameter representations of physical problems governed by the diffusion-type heat equation. The system was designed as a general thermal analyzer accepting resistor-capacitor (RC) network representation of thermal systems. SINDA consists of three main parts: (1) the preprocessor, (2) the execution (integrating heat transfer equations), and (3) operation (post-processing and output). In the preprocessor, the lumped capacitance of a region is called a node assigned by some arbitrary reference number. A node represents capacitance of defined region which is the product of density, specific heat and volume. The three types of nodes are diffusion nodes, arithmetic nodes, and boundary nodes. The heat conduction paths between the defined nodes are considered conductors which are also assigned some arbitrary reference number. The types of conductors available are linear conductors, radiation conductors, and one-way fluid conductors. A linear conductor can be either axial, radial or convective conductances. Axial conductance is the product of thermal conductivity and area perpendicular to heat flow divided by the length of flow path. Radial conductance is the product of 2 times pi times length of path divided by natural logarithm of the outer radius divided by the inner radius. Convective conductance is the product of the convection heat transfer coefficient and area perpendicular to heat flow. A radiative conductance is the product of emissivity, surface area, Stefan-Boltzmann constant and a surface configuration view factor. A one-way fluid conductance is the product of mass flow rate and specific heat. Other parts of the preprocessor are source data and constant or array data. Source data represents any internal heat generation source within the system imposed on a particular node. The constant data represent material properties that are constant throughout the simulation. Array data represent material properties that are either a function of time or temperature in the simulation. The execution uses forward finite differences to solve the heat transfer equations to find temperatures. The operation blocks are unique to each simulation representing FORTRAN statements controlling iterations and output. [3]

The construction of the preprocessor data took most of the time in this study. First, the motor was subdivided into 30 regions defined by diffusion nodes. Next, arithmetic nodes were defined between differing materials inside the motor and boundary nodes defined the exterior of the motor housing. Next, volumes of each region were calculated. Then, capacitances of each region were determined where specific heat is a function of temperature from the array data.

Once the capacitances were defined, axial and radial conductances were determined. For both cases, the length of heat flow path is represented by variable L, and the thermal conductivity is a function of temperature from the array data. For axial conductance, area A, is perpendicular to the heat flow and for radial conductance, $r_o$ and $r_i$ are outside and inner radii, respectively.

Convection conductances were found by calculating the appropriate liquid-solid contact surface areas. Then, the convective heat transfer coefficient, h, was found using a turbulent correlation for circular cross-section (Dittus Boelter correlation). The convective heat transfer coefficient is a function of temperature using the appropriate material properties at the desired temperatures.

The convective heat transfer coefficient versus temperature data were found in the array data for the coolant flow rates of 10 and 20 gallons per minute (gpm). One-way fluid conductances were calculated using either the 10 or 20 gpm converted to mass flow rate and the specific heat as a function of temperature from the array data.

Radiative conductances were found by setting emissivity to 0.9, calculating total housing surface area to be 455.4 square inches and view factor to be 1. This conductance equalled $0.1714 \times 10^{-8}$ Btu/hr-ft$^{2-0}$R. The only heat generation sources were due to the motor windings and bearings. After extensive calculations, the top and bottom bearing heat generation rates were 14.6 and 10.3 Btu/hr, respectively. The motor-winding heat generation rate was 755.5 Btu/hr.

The array data consisted of thermal conductivity and specific heat versus temperature for 304 stainless steel, 440C steel, AISI 1010 steel, vanadium steel and water. Also, for water, viscosity, density and Prandtl number versus temperature were listed. For two coolant flow rates, 10 gpm and 20 gpm, convective heat transfer coefficient versus temperature were formulated using the Dittus-Boelter correlation.

At this time, no significant solution from SINDA has been determined.

## RECOMMENDATIONS

Several recommendations can be made to further this study.

1. To complete the operation blocks and debugging of the SINDA codes to obtain verifiable results.

2. To add the effect of Narloy Z overspray from the AMCC-VPS on the motor housing.

3. After detailing of the design is complete and some preliminary chamber tests occur, try to correlate experimentally determined data with model predictions to obtain confidence with the model constructed.

4. To perform some parametric studies of the effects of coolant flow rate variation, chamber temperatures variations and other necessary parameters to better understand the thermal environment of the AMCC-VPS support equipment.

Hopefully, based on these recommendations, a useful numerical model of the AMCC, turntable and spin-motor spindle assembly can be constructed. These models could become an important source of information when comparing the results to future experimental AMCC test data. Also, parametric studies using this model can provide a relatively economical means to predict possible problem areas. However, for the SINDA model results to be a reliable predictor of the thermal effects, it must have reliable input data based on experimental or empirical formulations. As the AMCC develops from the design and development phases into the construction and test phases, the SINDA model can become an important evaluation tool for predicting motor, turntable, or even AMCC thermal conditions.

## REFERENCES


1. SKF Product Guide Manual, SKF Industries, Philadelphia, PA, 1988.

2. Inland Motor, Kollmorgen Corporation, Brushless D.C. Motor and Servo Amplifiers, Radford, VA, 1988.

3. SINDA User's Manual with Sinflo addition, COSMIC Program # GSC - 12671 Computer Software Management and Information Center, Athens, GA (revised by Sperry Support Services), Huntsville, AL, 1980.

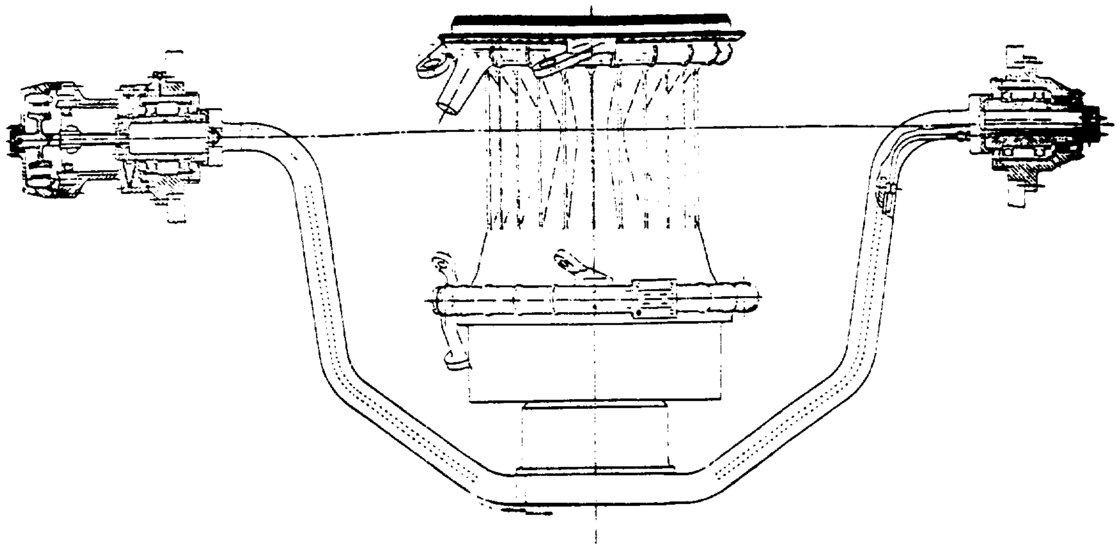

Figure 1: The AMCC, Turntable, Spin-Motor with Spindle

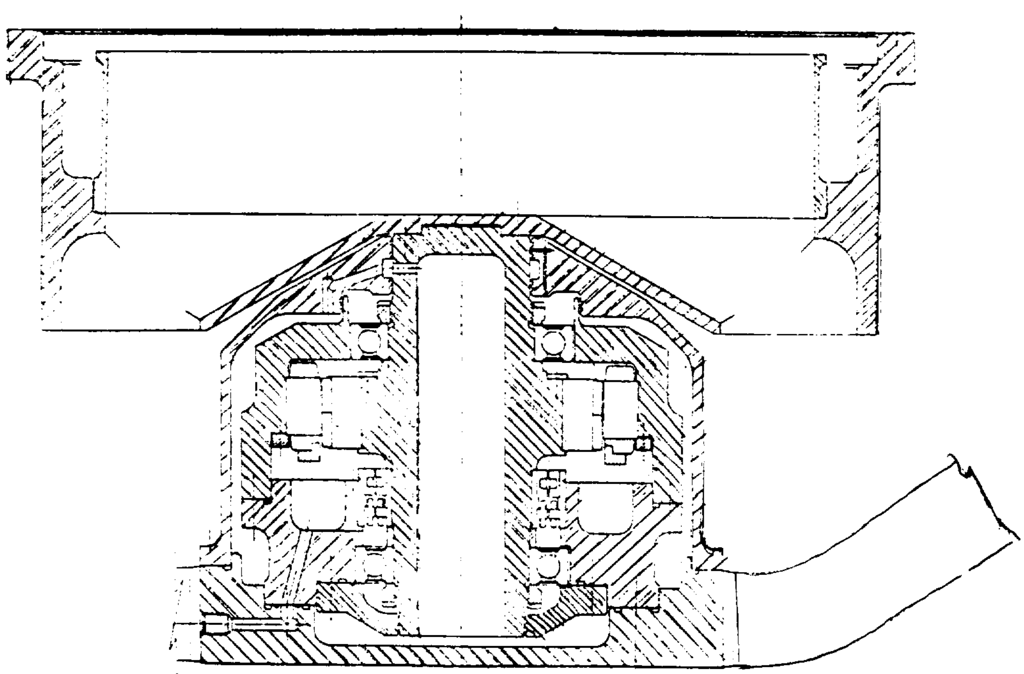

Figure 2: The Spin-Motor and Turntable Assembly