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FINAL REPORT

Testing, Analysis, and Code Verification
of Aerodynamics and Heat Transfer
Related to Turbomachinery

Submitted by: Paul I. King Date 7/15/91

Dr. Paul I. King
Mechanical Engineering Department
Cleveland State University
Cleveland, OH 44115

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I. INTRODUCTION

Due to a shortened grant period, work under the subject grant was aimed primarily at the writing of data acquisition code and the installation and testing of new pressure and temperature instrumentation to be used later this year in the testing and evaluation of miniature heat flux sensors. A brief summary of the problem which led to the need for these tests is presented in the background section and is followed by a proposed data acquisition program and the results of investigations of two measurement systems, the Omega OM-900 temperature sensing system and the Scani-Valve Hyscan pressure measurement system.

II. BACKGROUND

The Rotor/General Aviation program at NASA LeRC includes the eventual testing of a compact air-cooled radial turbine for aerodynamic performance, losses, and heat transfer effects. Miniature pressure and temperature sensors will be placed at strategic locations as shown in Fig. 1 with the hope of gaining information which will increase the understanding of the flow physics and improve CFD modeling. One difficulty with the upcoming tests is the thin walls of the turbine blades, only 1.4mm, which makes the use of available threaded, screw-in type heat flux sensors not feasible.

Because of the lack of suitable off-the-shelf heat flux gages NASA program engineers decided early on to measure surface heat flux utilizing special sensors developed earlier at NASA for monitoring turbine blades mounted in the Space Shuttle Main Engine (SSME) turbopump testbed at NASA/Marshall Space Flight Center (Ref.'s 1,2 and 3). Figure 2, taken from Ref. 3, shows the heat flux gage, which for the Marshall tests had an overall depth of 2.18mm. A new gage, 1.4mm thick, is under development and will be constructed with the same technique, i.e., using electrical discharge machining (EDM) to remove material around a cylindrical plug. The new gage will be calibrated in a special test facility currently under construction. A schematic of the test section for that facility is shown in Fig. 3 where it can be seen that a large rectangular duct will supply heated air to an internally cooled small rectangular duct of dimensions equal to a typical cross-section of the turbine rotor. All dimensions and aerodynamic similarity variables (Reynolds, Prandtl, Mach numbers, etc.) are designed to conform to the rotor and its flow field.

A section taken through the gage is shown schematically in Fig. 4. In Fig. 4a. three thermocouples are shown mounted on the surface of the center plug and a fourth is buried in a groove EDMed just beneath the surface of the test surface. The plug stops short of the back wall and is covered by a small cap which traps stagnant air around the plug. The near-cap end of the plug is essentially an adiabatic surface.

If hot air is suddenly applied to the surface containing the embedded thermocouple, temperatures will rise and a time-temperature history for each thermocouple can be obtained as shown in Fig. 4c. (A theoretical 1-D unsteady analysis indicates that in the first second the temperature rise at the surface will be roughly 0.1 degrees (Kelvin) per degree of applied temperature difference.) Temperature-time derivatives can be obtained for each thermocouple from the coefficients of a theoretical curve fitted to the raw time data in Fig. 4c., and the resulting derivatives can be spatially plotted for each point in time as shown in Fig. 4d. The area under any of the resulting curves from zero to L is numerically integrated yielding the instantaneous heat flux. Of particular note is the fact that the foregoing method can be applied at any point in time with no need for accurate knowledge of the run start time. The method is only suitable, however, when the temperatures are varying.

Tests later this year on the new heat flux gage will require a new data acquisition program since two new systems, the Scanivalve Hyscan pressure system and the Omega OM-900 series temperature measurement system (in addition to any other systems, e.g., the laser traversing system) will be operated simultaneously under the direction of a master program. The data acquisition program and the systems for measuring pressures and temperatures will now be discussed.

III. DATA ACQUISITION

A proposed data acquisition program is shown on the flow chart in Fig. 5. The Hyscan pressure system in particular is booted up in local mode, i.e., control of the program is accomplished at the local computer furnished with the system. (The manufacturer, Scanivalve, San Diego, suggests that at least one user has discovered a way to communicate with the system in local mode from a remote site.) After initialization of the systems and a check for proper operation of the sensing hardware, control will be turned over to the remote or host microvax computer. From the host computer any system can be addressed via menu-driven subprograms. Two programs recently developed by the author for the Hyscan system are shown in Fig. 4.

A master data acquisition program, DAQ, initiates the data scanning. There will be some delay in the initiation of the individual scan programs (measured in microseconds) due to sequential code step execution, so simultaneity of recorded data will not be exact. The program start_scan.exe shown in Fig. 5. was recently developed by the author to initiate the Hyscan data scan sequence.

Much of the code development and hardware checkouts of the Hyscan system was hindered by manufactured-supplied operational software bugs and poorly written documentation with important omissions (profusely apologized for after the fact by the manufacturer), and it is worth reporting here some important operating software clarifications. A new operating system, version 2.12, currently resides with the Hyscan system (the third version supplied by the manufacturer). The following section is intended as a guide for the experienced operator. The precise meaning of the following system-peculiar command language can be found in the

Hyscan 2000 manual.

III.1 Hyscan System

1. Upon initial bootup CALIBRATE/RESTORE must be entered before any data scanning can be initiated. This command recalls into RAM the calibration coefficients for the pressure transducers.

2. All data files generated during a scan have header information which must be stripped prior to processing. The author has written a program titled convert.exe which resides on disk and can be consulted for the way to do this. The syntax for the program is "convert filename1 filename2" where filename1 is the raw binary data file and filename2 is the user-defined target file.

3. All raw data files are in binary format. A manufacturer-supplied program called BIN2ASC will convert any Hyscan generated data file to ASCII data (with the header retained).

4. The manufacturer-supplied program, NOISE, operates on Hyscan binary data files to produce means and standard deviations.

5. The minimum number of scanned channels allowed by the software is two. To achieve a true 20khz sampling rate an a single channel its port location must be entered in the framelist twice.

6. Undocumented commands:

a. CALIBRATOR_COMMAND "Ph" -sets calibrator to +high

b. READ_CALIBRATOR_PRESSURE 1 -reads pressure on calibrator 1.

7. For communicating with the system from the host computer via FORTRAN programs set carriagecontrol='none' in the open statement and use the FORTRAN char operator, char(10), for example,

to transmit linefeed, or other control characters. Char(13) transmits carriage return, char(22) transmits control-V, and char(24) transmits control-x (reset), etc.

8. Scanning is initiated with the command prepare_scan eng char(10),char(22).

9. File transfer is initiated with the command read_file "filename" -note the use of double quotation marks.

In the checkout of the Hyscan and Omega hardware systems some undocumented operational characteristics were noted and are presented in the next section.

IV. HARDWARE SYSTEMS

IV.1 Hyscan System

1. The secondary standard, or Mensor, appears to have a long (several minutes) relaxation period after pressurization and may yield "unstable pressure" errors if calibration is attempted immediately after a hold and test procedure or a power-off condition.

2. Run sequence/time

The run time may be calculated using the following :

if n = number of channels or ports

CI = channel interval (microseconds)

FI = frame interval (microseconds)

N = frame average count

M = frames per scan

then

run time = [n * CI * N + FI] * M

The sequence in which the channels are sampled is:

sequence = sample n channels sequentially (1,2,3,...n) N times; average and store the results as one data point per channel; wait FI microseconds; repeat the foregoing M times.

3. On power up from off condition the data file extension is reset to .000. Thus existing data files can be accidentally overwritten.

4. A/D board resolution = 20v/64k bits (+/- 10v/32k bits)

5. ZOC 16 pressure transducer output = +/- 2.5v with amplification of 2 prior to A/D board. Measured resolution is

0.0008 psi/bit (15 psi transducers)

0.0027 psi/bit (50 psi transducers)

6. Pascals and psi conversions are reversed by changing the Mensor (secondary standard) calibration coefficients and recalibrating the system. The coefficients are changed in TEST/COMMAND portion of Hyscan (see p.25 of lab notebook or refer to p.3 of Mensor calibration procedure.

IV.2 Omega 900 System

1. The thermocouple modules default to type T thermocouple conversions upon power up from off condition.

2. The OM931 TC Modules contain 16 bit A/D boards with one sign bit (effectively a 17 bit machine).

3. A/D is accomplished via dual-slope integrators with 50 ms conversion time (0.05 s) (and the signals are grounded after each A/D cycle). Acquisition is multiplexed using one sample and hold amplifier per module. The modules can be run simultaneously, but true simultaneity is not achieved due to the slight time shift in interpretation of the "go" commands within the command code.

4. Total CPU storage is 32k bytes; each temperature reading occupies three bytes of memory.

5. The reference temperature is the temperature of the rear terminal strips which are not heated but which are monitored with thermistors. It is important to keep these strips covered and isolated from room air currents.

6. The command conv <ch> = <num> initiates the A/D sequence.

V. SUMMARY

Roughly five months of full time work were spent on this project by the author. The state of the project is such that less experienced engineers may now step in and complete the software development and become familiar with the hardware. A skeleton data acquisition program resides on disk. Peculiar calls to the Hyscan system and the Omega system have been identified and can be obtained from the code written by the author. Trouble spots with the hardware have been identified and are documented here and in the lab notebook on site.

VI. REFERENCES

1. Liebert, C.H., "Measurement of Local, High-Level, Transient Surface Heat Flux," NASA TP-2840, 1988.

2. Liebert, C.H. and Weikle, D.H., "Heat Flux Measurements," ASME Paper 89-GT-107, 1989.

3. Liebert, C.H., "Heat Flux Measurement in SSME Turbine Blade Tester," NASA TM-103274, 1990.

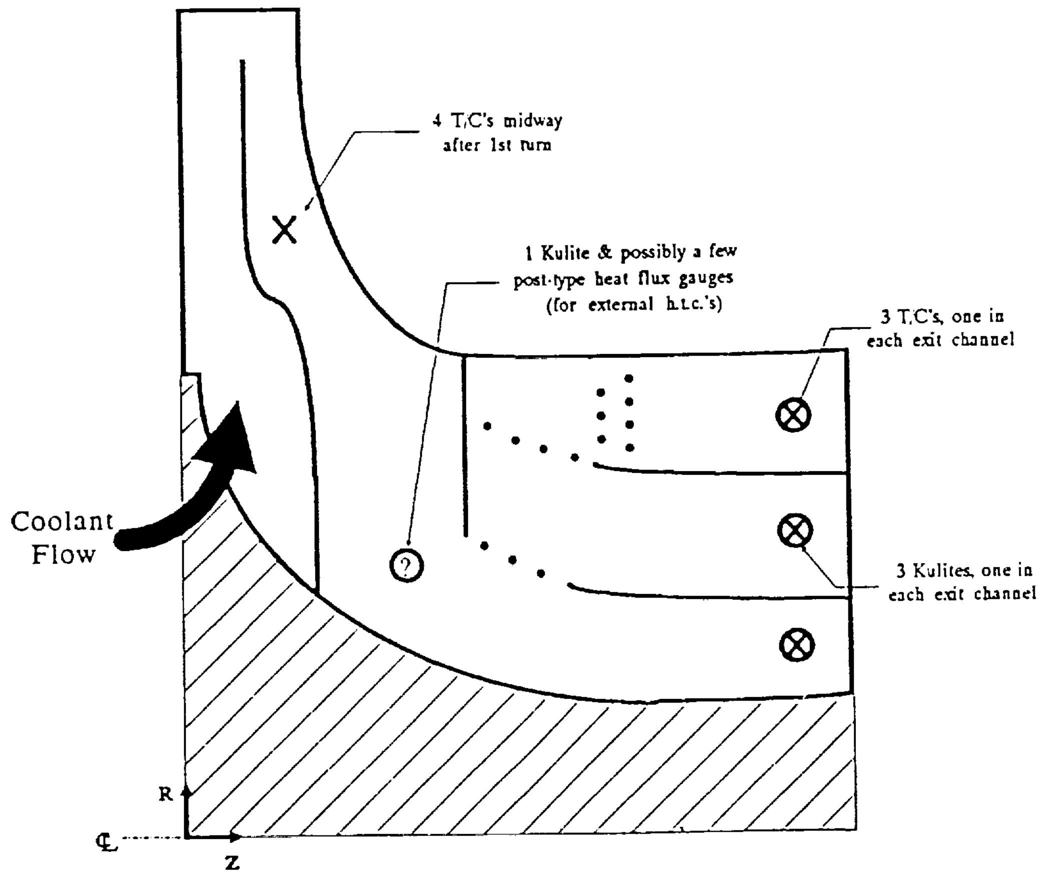


Fig. 1. Internal Instrumentation

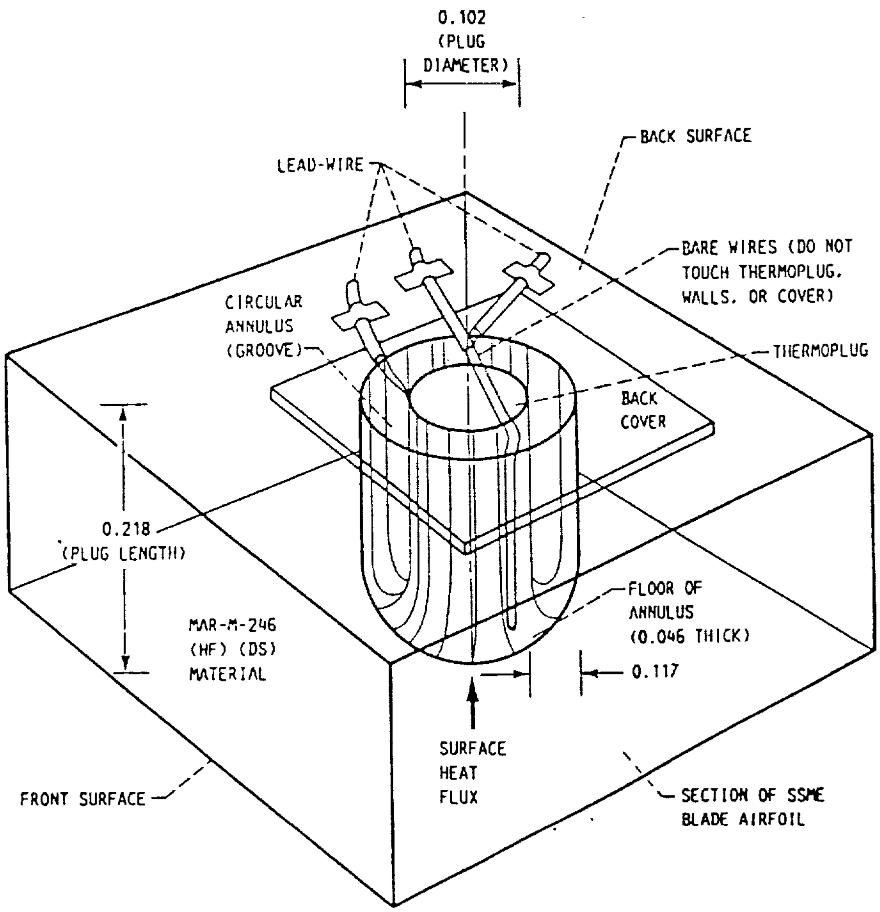


Fig. 2. Plug Heat Flux Gage (from Ref. 3.)

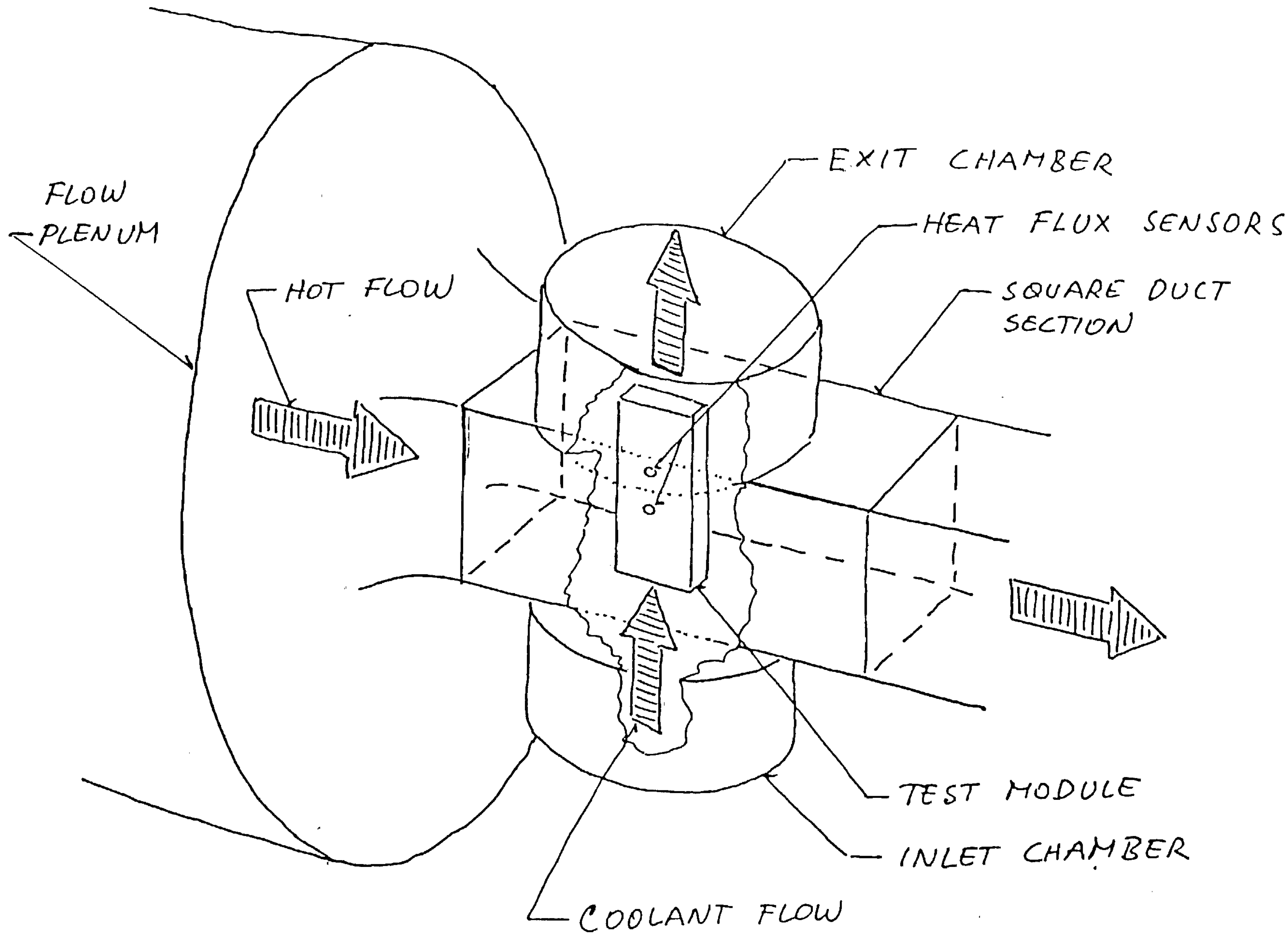
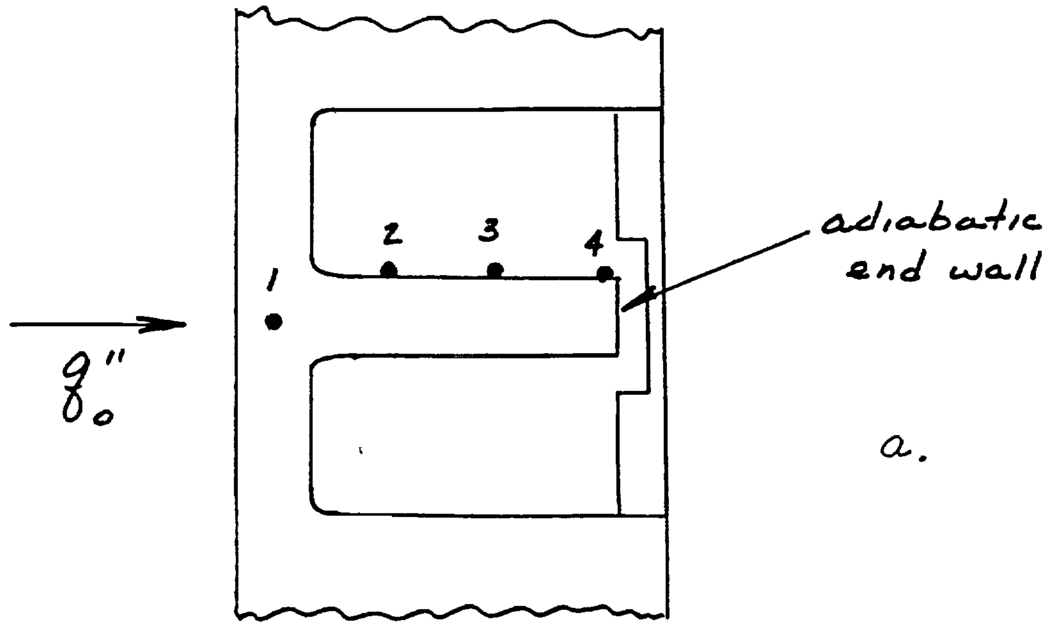


Fig. 3. Test Section for Gage Calibration



<u>1-D</u>

$$\frac{dq''}{dz} = \rho c_p \frac{\partial T}{\partial t}$$

b.

$$q''_o = \int_0^L \left(\rho c_p \frac{\partial T}{\partial t} \right) dz$$

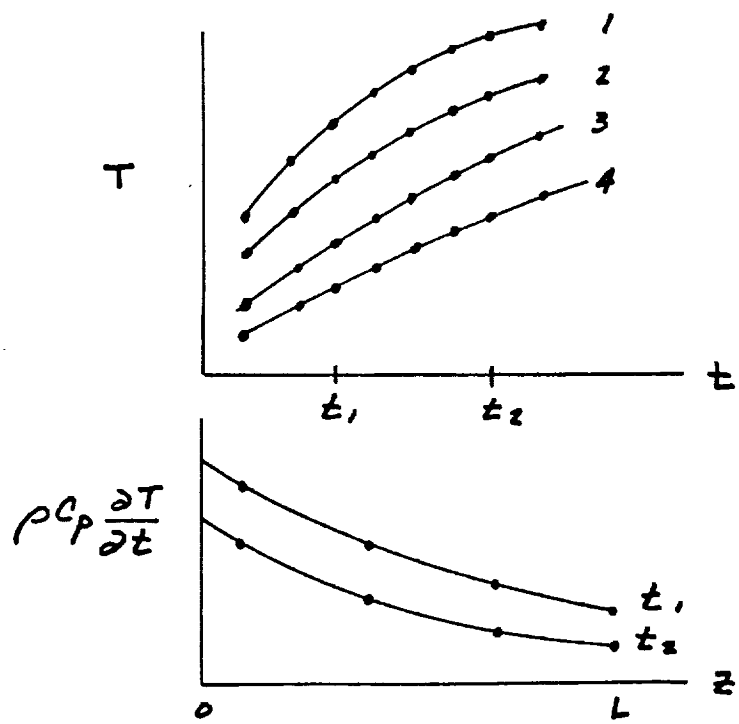


Fig. 4. Heat Flux Gage Theory

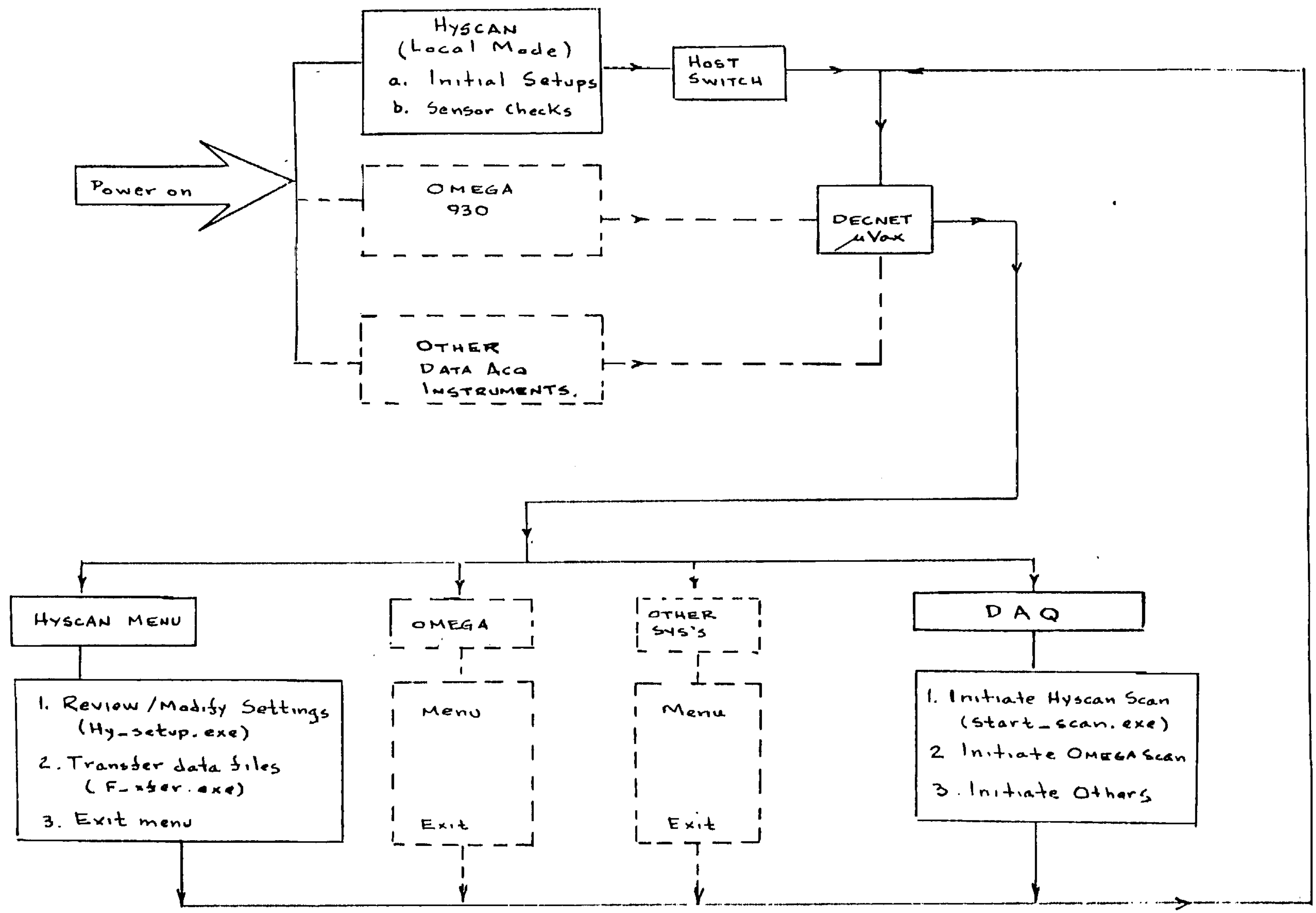


Fig. 5. Data Acquisition Program

NEW TECHNOLOGY REPORT

I General Information

1. Type of Report: ( ) Annual (X) Final

2. Did any nonpatentable items result from the work perfomed under this grant?
( ) yes (X) no

3. Did any subject inventions result from the work performed under this grant?
( ) yes (X) no

4. Are new technology items being disclosed with this report?
( ) yes (X) no

II New Technology Items

Please provide the title(s) of all new and previously disclosed new technology items conceived or first actually reduced to practice under this grant.

	Title	Internal Docket Number	Patent Appl. Filed	Patentable Item	Nonpatentable Item
1.	(None)	______	( )	( )	( )
2.		______	( )	( )	( )
3.		______	( )	( )	( )
4.		______	( )	( )	( )

III Subcontractors

Please complete the following section listing all subcontracts issued to date. Include each subcontractor's name, address, contact person and telephone number.

(None)

Attn:________________ tel. ( ) ____-______

Attn:________________ tel. ( ) ____-______

Attn:________________ tel. ( ) ____-______

Attn:________________ tel. ( ) ____-______