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INSTRUMENTATION AND RECORDING EQUIPMENT USED IN CONJUNCTION WITH THE ARL TWENTY-INCH HYPERSONIC WIND TUNNEL

D. L. BROWN
K. H. TOKEN
V. HOELMER
R. R. TEPE, JR.
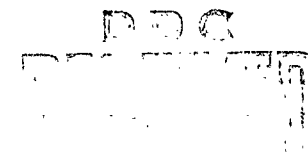
UNIVERSITY OF CINCINNATI
CINCINNATI, OHIO

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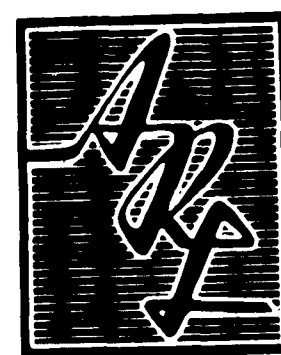
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AEROSPACE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This interim technical report was prepared by the
University of Cincinnati Hypersonic Aerodynamics Research
Staff on Contract AF 33(616)8453, titled "Experimental Aero-
thermodynamic Investigations", for the Aerospace Research
Laboratories, Office of Aerospace Research, United States Air
Force. The work reported herein was accomplished under Project
7064, "Aerothermodynamic Investigations In High-Speed Flow"
during the period between August of 1961 and December of 1962.
Colonel Andrew Boreske, Jr., Deputy Commander of the Aerospace
Research Laboratories, served as project monitor for this work.
Special thanks are extended to Mr. David Murray of the Fluid
Dynamics Research Laboratory of ARL for the suggestions and
advice he extended to the U.C.H.A.R.S. during this task.

ABSTRACT

One of the more serious problems associated with hyper-
sonic wind tunnels of the blow-down variety is the obtaining
of reliable pressure and temperature measurements. This report
reviews the various types of instrumentation investigated for
possible use in the ARL twenty-inch hypersonic wind tunnel and
illustrates the advantages and disadvantages of such instru-
mentation. Various types of flow visualization techniques
are also discussed with emphasis on their applicability to
possible use in the aforementioned tunnel. A description is
also included of the high speed data acquisition system.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I INTRODUCTION

The twenty inch hypersonic wind tunnel at the Aerospace Research Laboratories, henceforth referred to as the HTS-14, is an axisymmetric free jet facility designed to operate at Mach numbers from 8 to 14 over a wide range of free stream Reynolds numbers. The HTS-14 is a "blow-down" type facility employing a set of vacuum pumps and a vacuum sphere on the low pressure side and compressed bottled air (to 3000 psia) on the high pressure side.

The duration of the "blow-down" is limited by the capabilities of the vacuum pumps and the vacuum sphere. Pressure in the vacuum sphere increases throughout the "blow-down", with the run being terminated when the back pressure increases beyond the allowable value necessary to maintain that particular Mach number flow.

A "run" consists of two modes of operation, which are basically the bypass and the normal modes of operation. During the bypass or stabilization mode, air is exhausted from the heater through a water cooled auxiliary nozzle to the atmosphere. This phase of operation allows the total pressure and total temperature to stabilize at the preset values. When stabilization has occurred, the tunnel is put into the normal mode of operation. In this mode, the air flow is directed through the test nozzle and into the test section where the model being tested is located. The air is then exhausted into the vacuum system.

The facility is designed to operate at a maximum stagnation pressure of 2500 psia and a minimum stagnation pressure of 400 psia. The maximum total temperature allowable is 2800° R, which may occur at a maximum air flow of 2.6 pounds per second and at a maximum electrical input to the heater of 1800 KW.

The primary concern of this report is a detailed description of the instrumentation and recording equipment used in conjunction with the above mentioned tunnel, along with an explanation of why such instrumentation was selected.

II INSTRUMENTATION

PRESSURE MEASUREMENT

A prominent instrumentation problem in hypersonic wind tunnels of the blow-down variety, of which the HTS-14 is an example, is the obtaining of reliable pressure measurements. The testing environment of such a tunnel places severe limitations on pressure measuring systems. Two of the more important limitations are:

(1) Short run time -- which necessitates instrumentation with a fast response time.

(2) Low pressure -- which amplifies the time lag problem and requires unique measuring techniques.

Mechanical systems such as manometers, pressure gauges, and diaphragm pressure transducers, which are designed for the 0 to 50 mm of Hg pressure range, normally have too long a response time. Generally, diaphragm pressure transducers which do have a relatively short response time do not have the resolution in the above mentioned pressure range.

Transducers which do have the desired resolution in this pressure range are those that measure some property of the gas, such as heat transfer rates or ionization. These gauges have one serious limitation however, the testing medium must be chemically pure. Contamination of this testing medium sometimes drastically changes the calibration of the instrument. In addition, transducers of this type are generally non-linear.

The principal pressure measuring systems used in conjunction with the HTS-14 are diaphragm pressure transducers, both of the differential and absolute variety, transducers measuring conduction heat transfer rates, and transducers measuring ionization rates.

Due to the aforementioned shortcomings of these systems, considerable research was performed by the U.C.H.A.R.S. in the field of pressure measurements. This research consisted mainly of conducting an intensive literature search into the state of the art and evaluation of existing pressure measuring devices. A short summary of the evaluation program is contained in the

2

following section in an attempt to aid the reader who may have
similar problems.

In addition, because no existing pressure measuring system
satisfied all of the specifications desired, a design of a sys-
tem which did meet these specifications was initiated. This
system will be of a size small enough for forty transducers to
be contained in a volume of 5 cubic inches, have an accuracy of
0.01 mm of Hg in the range of pressures from 0.1 to 100 mm of
Hg, and will have a time response on the order of 5 seconds.
At the present time several models have been built and are
now being evaluated. Details of the design and a thorough
evaluation of the system will be reported as soon as possible.

Evaluation Of Existing Pressure Measuring Systems

The transducers were evaluated in the following manner:

(1) The test transducer was calibrated and checked for
     accuracy against McLeod and Stokes gauges in the
     low pressure range (0-5 mm of Hg), and against a
     Wallace and Tiernan precision calibrating mano-
     meter in the higher pressure ranges. These pri-
     mary standards were first calibrated according
     to the manufacturer's instructions and then
     checked against each other.

(2) The transducer was checked for hysteresis, resolu-
     tion, linearity, and repeatability using simulated
     test conditions. The gauge was then overpressurized
     many times and subsequently checked for repeatabil-
     ity over a period of several days.

(3) The time lag and dynamic properties of the trans-
     ducer were then checked. This was accomplished
     through the use of a calibration stand which sim-
     ulated test conditions in real time, thus enabling
     the time lag characteristics to be evaluated. The
     dynamic properties such as susceptibility to accel-
     eration and electrical noise were also studied.

(4) Compatiability with existing recording systems was
     then determined.

(5) The temperature dependency of the transducer was assumed to be as specified by the manufacturer, and thus no tests were conducted with respect to temperature.

The results of these evaluation tests and a description of the models tested are briefly summarized below:

1. Transducers measuring conduction heat transfer rates.

The transducers of this type evaluated were Hastings Raydist Gauges, models DV-4 and DV-13.

ADVANTAGES	DISADVANTAGES
(1) Low pressure range.	(1) Non-linear output.
(2) Relatively inexpensive.	(2) Difficult to maintain calibration.
(3) Compatible with re-cording system.	(3) Easily contaminated.
(4) Fast response time.	(4) Measures some property of the testing medium other
(5) Low hysteresis.	than pressure, and relates this property to pressure.

The non-linear output and the difficulty of maintaining calibration are the main disadvantages of this type of gauge, but it was found that the DV-13 model does have considerable useful applications when measuring fluctuating pressures in the 0-5 mm of Hg range.

2. Ionization gauges.

The ionization gauges evaluated were Alphatron pressure sensory transducers. At present, there are ten channels of Alphatrons installed in conjunction with the HTS-14. Since such pressure measuring systems are not in wide use, a short description of the Alphatron system will be presented in the following paragraph.

The Alphatron system consists of sensing heads, preamplifiers, and the necessary electronic controls and power supplies. The sensing device makes use of a radium source. The radiation

4

from this source causes ionization of the gas, and the resulting
current is proportional to the density of the gas in the small
chamber of the gauge, and hence, proportional to the pressure.
Since this particular type of gauge is extremely succeptible
to contamination, the chambers are maintained under a vacuum
when not in operation.

ADVANTAGES	DISADVANTAGES
(1) Low pressure range, 0-3 and 0-30 mm of Hg.	(1) Time lag problem.
	(2) Easily contaminated.
(2) Compatibility with recording systems.	(3) Relatively expensive
(3) Linear output.	

The Alphatron pressure measuring system gives excellent
pressure readings in the desired low pressure range, and is
compatible with practically any type of recording equipment.
However contamination does present a serious problem, as does
the time lag problem. The latter problem is magnified due to
the fact that the transducer must be mounted outside of the
tunnel, which necessitates long pressure leads. This system
however, does have definite applications for a blow down
tunnel and is extremely useful in a continuous mode tunnel.

3. Diaphragm Transducers.

(A) Inductance Gauges

The inductance pressure transducer evaluated was a minature
size transducer designed by a group at Langley Field.

ADVANTAGES	DISADVANTAGES
(1) Linear output (3%).	(1) Low resolution in static pressure range.
(2) Small volume.	(2) Zero shift when over pressurized.
(3) Excellent response.	
(4) Compatible with recording systems.	(3) Requires elaborate electronic equipment.

5

The primary advantage of this transducer is that it can be mounted within a model, due to its minature size. Thus the response time is greatly decreased. It is felt that this transducer has application where dynamic pressures of the order of 10 to 100 mm of Hg are under investigation.

(B) Strain Gauges

Although numerous strain gauge transducers were studied, it was found that the Statham Model PA 731TC-1-350 transducer showed the most promise for the pressure ranges under investigation by the U.C.H.A.R.S. staff. Accordingly, ten of these transducers will be installed in the HTS-14 test cabin to be used in conjunction with any test programs. Evaluation of this transducer yielded the following results:

ADVANTAGES	DISADVANTAGES
(1) Linear (within 1%).	(1) Time lag.
(2) Excellent repeatibility.	(2) Large size.
(3) Good resolution in 0-5 mm of Hg range.	
(4) Low hysterisis.	
(5) Low zero shift.	
(6) Relatively inexpensive.	
(7) Does not require elaborate electronic equipment.	
(8) Compatible with recording systems.	
(9) Measures pressure directly.	

The time lag problem is the biggest drawback to this transducer. However this problem has been partially overcome by the U.C.H.A.R.S. by mounting these transducers on the model support in the HTS-14 in a water cooled container. By doing this, the pressure leads have been reduced in length and the time lag decreased to approximately 20 seconds.

In addition to this evaluation program, the possibility of calculating the equilibrium pressure from the transient time lag curve is also presently being investigated. This method, if developed, could lead to drastic reductions in the time lag problem of any of the above mentioned systems.

TEMPERATURE MEASUREMENT

At the present time standard thermocouples are being used in all of the various temperature measuring applications that are encountered. The thermocouples being used are primarily chromel-alumel, or platinum - platinum rhodium type thermocouples. The standard thermocouple technique was decided upon after several feasibility studies were performed on other types of measuring techniques. The other systems investigated, and the results of the investigation are as follows:

(1) Thermistors

Thermistors were discarded as temperature indicating devices in our applications primarily because of their limited temperature range.

(2) Thermo-Dot

This device is designed to determine surface temperatures by measuring the radiation emitted from a 0.1 square inch area on the surface of the model. To convert this information to temperature, it is necessary to know the effective emissivity of the material at that particular temperature. The effective emissivity being defined as the actual emissivity modified by the attenuation factors introduced by the optical system used in conjunction with this system and the atmosphere surrounding the surface under consideration. Thus it is evident that an iteration process is required to determine the temperature, and then, only nominal temperatures can be obtained. In addition, radiation introduced from extrainious sources must be carefully controlled.

In summation therefore, thermocouples were found to be the desired temperature sensors from consideration of cost, ease of calibration, ease of use, and of the type of temperature measurements planned in the U.C.H.A.R.S. research program.

OPTICAL METHODS

The HTS-14 is presently equipped with a double pass Schlieren System designed to observe the flow field within a 10 inch diameter. A more complete description of this system, along with general operating procedures may be found in Reference 1.

In addition, an investigation was conducted by the U.C.H.A.R.S. into the possibility of using other optical systems either in conjunction with or as a supplement for the Schlieren System. This study was originally motivated by the concern over the possibility that the Schlieren System might not function properly due to the low densities in the HTS-14. Subsequent use of this system has however, proved it to be most reliable in observing the flow field. The other methods investigated were as follows:

(1) Nitrogen After Glow Method:

A great amount of work has been achieved on this method and the results are excellent for the range of densities found in the HTS-14. However geometric considerations of the tunnel makes the use of this method extremely difficult in the HTS-14.

(2) Electric Discharge:

The method of using an electric discharge to excite the flow to a degree so that visible light of varing intensities is emitted by the various density fields has been investigated by various groups and has proved most feasible. The U.C.H.A.R.S. constructed an electric discharge model and proved this method feasible in the HTS-14.

(3) Oxygen Absorption Technique:

Jet Propulsion Laboratory has done some work in this area and the U.C.H.A.R.S. reviewed their results to determine whether the technique was applicable to the HTS-14. The method in principle shows great promise, however, the state of the art in optics and photography has not advanced to a point where this process is practical. The wave lengths of light of the strong absorption bands of oxygen are from $1300A^{\circ}$ to $1750A^{\circ}$, which is in the low ultra-violet range. The optics required to pass this wave length of light are very expensive and photographic

film sensitive to this light is of very poor quality. Because of the two aforementioned problems, it was concluded that this method would be impractical for use in conjunction with the HTS-14.

At present therefore, the only two optical techniques planned to be used by U.C.H.A.R.S. are the Schlieren System and the electric-discharge method.

III RECORDING SYSTEM

INTRODUCTION

The recording systems used in conjunction with the HTS-14 includes both visual recording systems and a high speed data acquisition system.

The Microsadic Mod. II high speed automatic data acquisition system, as shown in Figure 1, was designed and built by Consolidated Systems Corporation for the University of Cincinnati Hypersonic Aerodynamics Research Staff for installation at the Aerospace Research Laboratories. The equipment has been designed to acquire data from the hypersonic wind tunnels located in the Fluid Dynamics Branch of ARL. Figure 2 shows the data flow and the system features of the Microsadic.

The data sampled is in the form of analog signals produced by transducers, thermocouples, or any other device that has an analog output located in the test facilities of the Fluid Dynamics Laboratory.

The "MICROSADIC" samples, digitizes, and stores this data on magnetic tape in a format compatible with the IBM 7094 facility located at Wright-Patterson AFB, which is generally used for all computational work.

OPERATIONAL FEATURES

Figure 3 illustrates the operational features of the Microsadic System. A more complete breakdown and explanation of the components of the system and their operational features is presented in the following paragraphs.

Amplifiers

Forty Sanborn Model 860-1500S preamplifiers are provided for amplifying the low level transducer signals to five volts output for $\pm$ 10 mv, $\pm$ 20 mv, and $\pm$ 50 mv input.

Upon amplification, the analog signal is transmitted from the amplifier cabinet by use of any or all of the following devices.
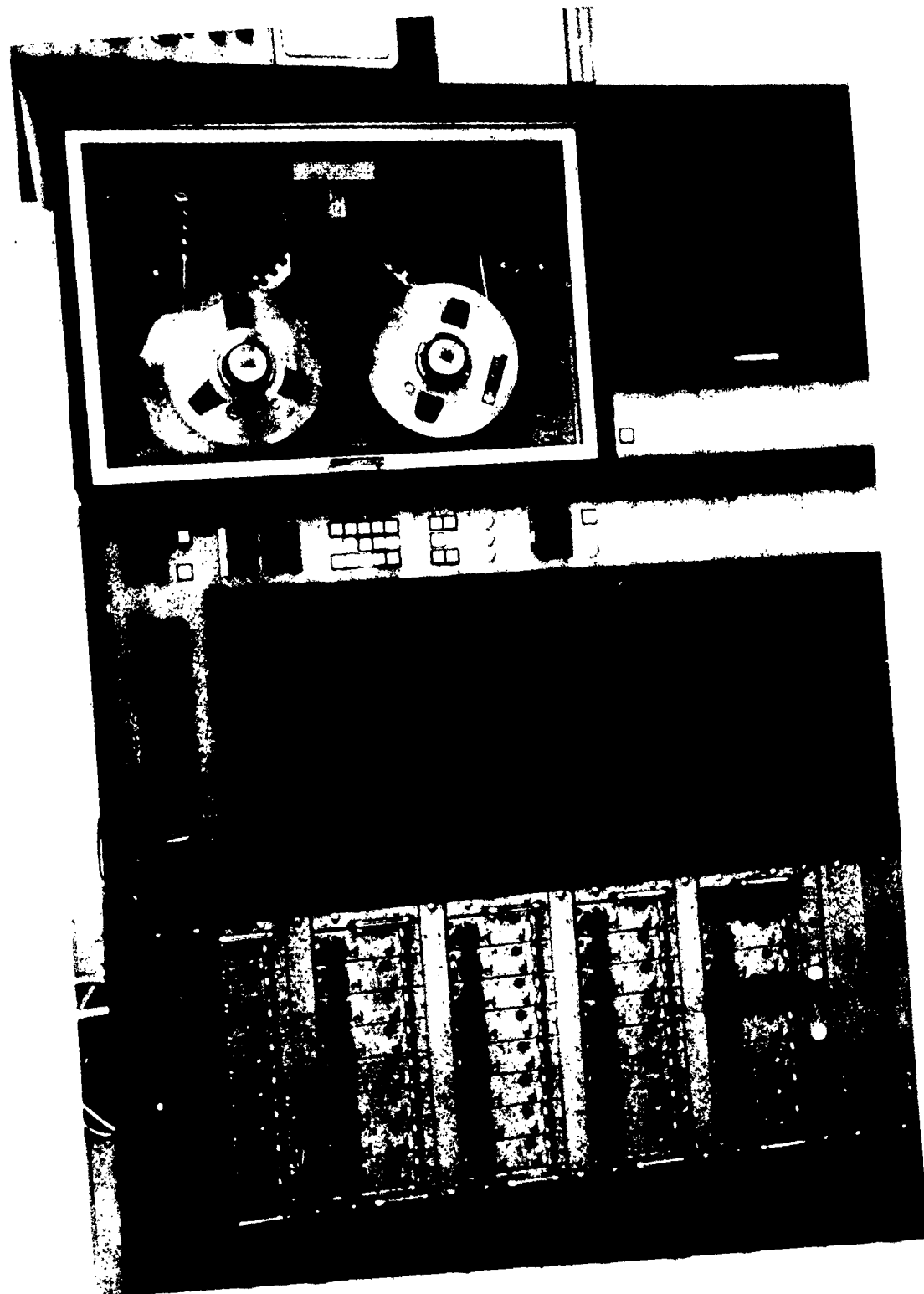
(1) The normal output to the "MICROSADIC" by way of
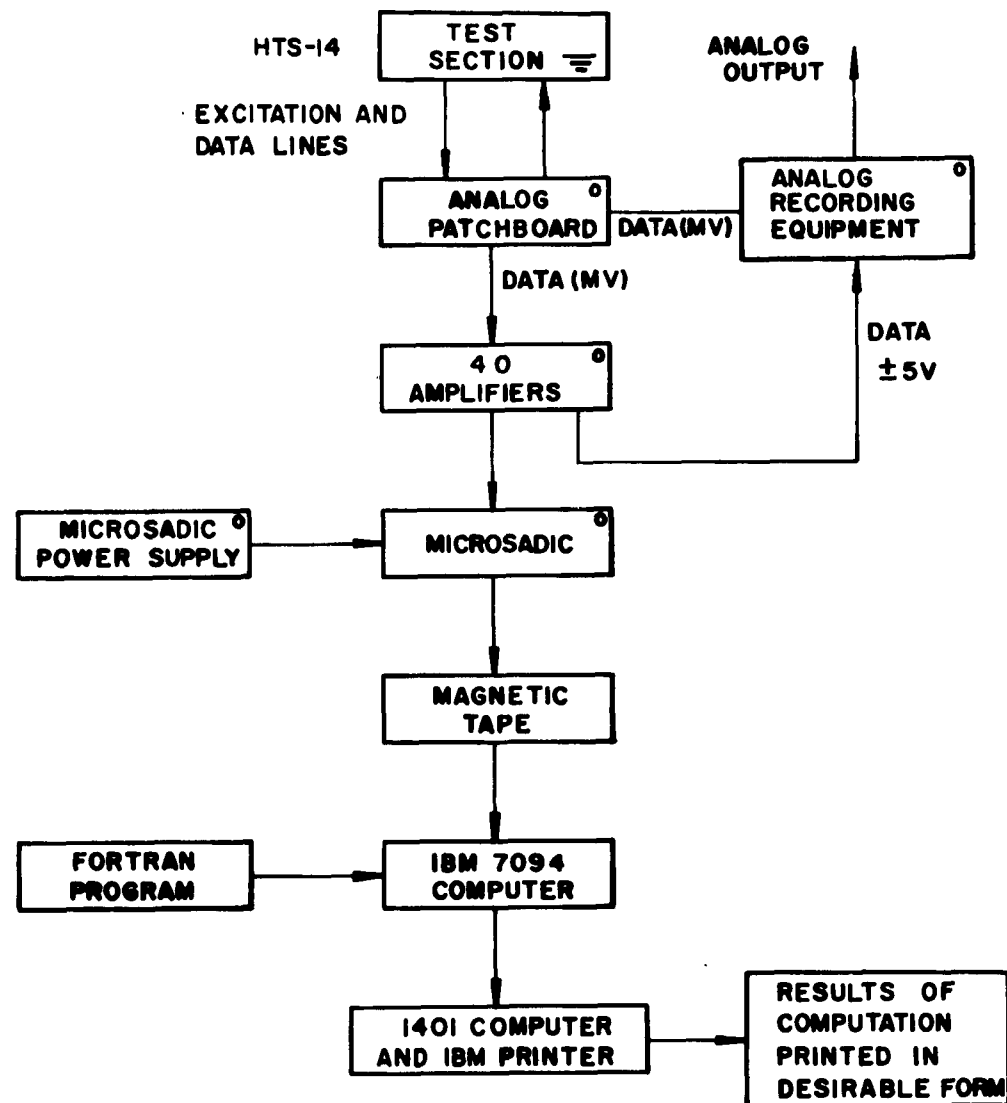
FIGURE 1—MICROSADIC HIGH SPEED DATA ACQUISITION SYSTEM

11

HTS-14

TEST
SECTION ⏚

ANALOG
OUTPUT
↑

· EXCITATION AND
DATA LINES

ANALOG
PATCHBOARD ° DATA(MV) ANALOG
RECORDING
EQUIPMENT °

DATA (MV)

DATA
±5V

40
AMPLIFIERS °

MICROSADIC °
POWER SUPPLY

MICROSADIC °

MAGNETIC
TAPE

FORTRAN
PROGRAM

IBM 7094
COMPUTER

1401 COMPUTER
AND IBM PRINTER

RESULTS OF
COMPUTATION
PRINTED IN
DESIRABLE FORM

o-DENOTES SINGLE POINT GROUND THROUGH GROUNDING BUSSES
⏚-DENOTES SINGLE POINT GROUND

FIGURE 2 -BLOCK DIAGRAM SHOWING DATA FLOW FROM
HTS-14 TO USEABLE FORM

12

40 LOW LEVEL
TRANSDUCER INPUTS

40
AMPLIFIERS

OPTIONAL
HIGH LEVEL
OUTPUTS ±5V

DATA SWITCH

OVERVOLTAGE
PROTECTION

MULTIPLEXER

A/D
CONVERTER

CONSTANTS

FORMAT
CONTROL

TIME
PROGRAMMER

TAPE
TRANSPORT

REPRODUCE
HEAD

PERFORMANCE
ANALYZER

DECIMAL LIGHT
DISPLAY

IBM 7094 TAPE
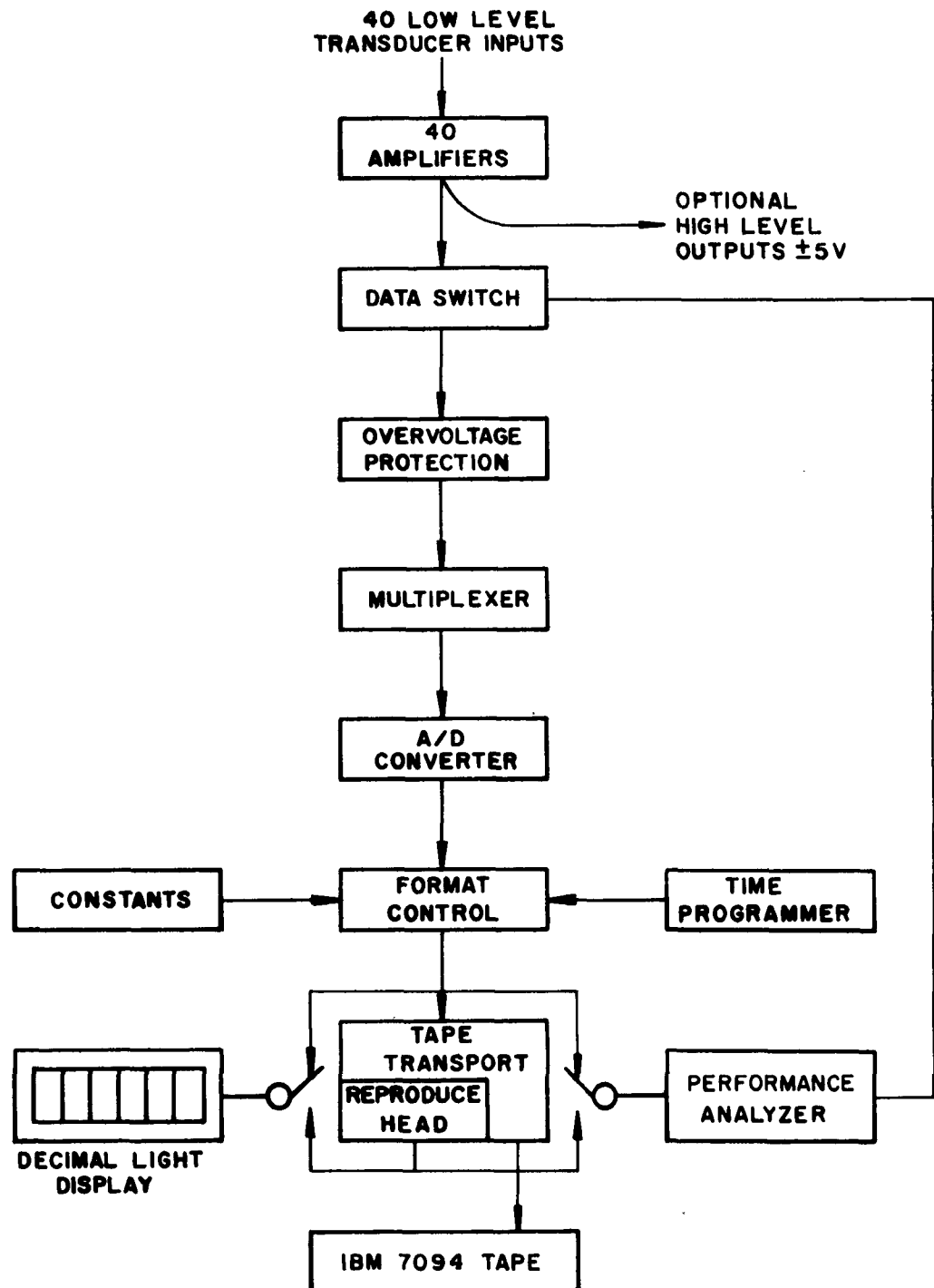
FIGURE 3 –MICROSADIC SYSTEM BLOCK DIAGRAM

13

a rear connector.

(2) A second rear output connector which would be used in conjunction with analog equipment.

(3) A phone jack monitor is provided on the front panel of the amplifier cabinet and is to be used during calibration and adjustment of the amplifiers.

Sampling Modes

Four sampling modes are provided, which are as follows:

(1) 10 Kc continuous sampling mode.
In this mode the "MICROSADIC" operates at its highest sampling rate and places data on the tape in a gapless format (3 digit - 10 Kc or 4 digit - 5 Kc).

(2) Intervelometer mode.
The intervelometer or gapped mode involves the loss of data as 3/4 inch gaps are placed on the output tape between whole sweeps. These tape gaps require approximately 5 milliseconds to generate. The advantage to this mode is that the IBM 7094 ancillary equipment, the 1401 computer, can print the data directly if quick checks are essential to the particular test program involved.

(3) Single scan mode.
In this mode, the "MICROSADIC" scans all input channels selected at a frequency determined by the clock rate patched into the system (10 Kc, 1 Kc, 100 cps, 10 cps, or 1 cps).

(4) Single channel mode.
In this mode a selected channel can be recorded at a selected frequency determined by the clock rate patched into the system (10 Kc, 1 Kc, 100 cps, 10 cps, or 1 cps).

Constants Selector

Twelve ten position thumbwheel switches (0 through 9) are provided for purposes of entering constants into the magnetic tape record. In addition to being entered manually, these constants can be patched into the record along with test data.

Commutator

The "MICROSADIC" commutator is in effect an automatic, high speed, multiposition, solid state, single pole switch. Any number of channels may be selected and commutated in increments of one channel, through the use of the channel capacity thumbwheel switch. Presently this unit is capable of sampling a maximum of forty channels.

A/D Converter

The 9999 bi-polar binary-coded-decimal digitizer performs the conversion function for all of the data channels. The digitizer can accept and digitize samples from the commutator at a 15 Kc rate, however, in its present application the digitizer works at a maximum rate of 10 Kc.

The method used to determine the digital value of a particular sample is the successive approximation technique, starting with the most significant digit and proceeding to the least significant bit.

Format Control

This unit accepts digital data from the A/D converter, the time accumulator register, and the identifying constants, and sequences it for recording in IBM 7094 tape format.

Two basic formats are provided, gapped or gapless. In the gapped mode an IBM record contains time and the number of channels being recorded proceeded by a 3/4" gap, which facilitates data reduction, however, causes the loss of some data. In the gapless format the IBM record contains time and as many samples as make up a full run.

Data Switch and Performance Analyser

The 40 input channels can be removed from the input circuit

and in their place a precision test voltage can be introduced
via the data switch. The test voltage operates in conjunction
with the performance analyser which compares the digitized
value of the precision voltage with the analog value.

In addition, an allowable limit of the magnitude of the
digitizer error can be selected and any over-error will be
displayed on the front control panel. Optionally the "MICRO-
SADIC" can be stopped if the error exceeds the chosen magnitude
and the erronious channel identified and displayed.

Counters and Timers

The "MICROSADIC" derives its basic time count from a
270 Kc crystal located in the digitizer. This 270 Kc clock
rate is reduced to 30 Kc which constitutes the system clock.
Further frequency reduction is accomodated to 10 Kc, 1 Kc,
100 cps, 10 cps, and 1 cps intervals. These time bases are
then available for triggering other functions in the system
such as the commutator for slow speed scanning in the inter-
velometor mode. Provision is also made for accumulating
time in a 6-decade, BCD counter which utilizes either the
10 Kc or 1 Kc clock rates.

Digital Patching System

The digital patching system employed by the "MICROSADIC"
allows a great deal of flexibility in determining the record-
ing format. At this digital patch board, all primary data
and control lines are terminated along with many auxiliary
logic lines, i.e., (time counts, constants, etc.)

Digital Display And Tape Transport

The digital display is capable of displaying all data
digitized (with identifying channel number), time, and all data
written on tape with the exception of time. The last function
is accomodated through a read head in the tape transport and
the associated conversion electronics.

The record-reproduce tape unit operates at a tape speed
of 150 in./sec. with a bit packing density of 200 bits/inch.
All electronic circuitry is completely solid state.

Power Supply And Grounding System

Power is supplied to the "MICROSADIC" system by a 440/110 volt isolation transformer with Electrostatic shielding. The power supply lines also are equipped with 15 ampere slow blow thermal overload relays for protection purposes.

Since the signals obtained from the majority of the transducers utilized, is in the low D.C. millivolt range; precautions must be taken to insure that no extrainious signals are introduced to the system. This is best accomplished through single point grounding and adequate grounding cables. In the case of the "MICROSADIC", all transducers are grounded at the test facility in use, along with all recording devices and their associated equipment, i.e., (power supplies, analog patch board, etc.).

## IBM 7094 Tape Editing Program

The data tape generated by the "MICROSADIC" system, although compatible with the 7094, is not compatible with 7094 Fortran language. Although the individual bit combinations represent the proper BCD number, they do not add up to the correct signed magnitude when read into the IBM 7094 computer. This is because ancillary information is added by insertion of extra bits in convenient, already used, data characters which make up a data point, so that the sampling rate will not be decreased due to the addition of this information. These bits are needed to indicate sign and "end of channel sweep". A second problem is the gapless tape which the "MICROSADIC" can generate if the highest possible sampling rate and no loss of data is required.

U.C.H.A.R.S. has written two FAP subroutines which will accomplish the following:

1. Gap any 3 BCD or 4 BCD gapless tape.

2. Edit any gapped tape to make it Fortran compatible. Figure 4 shows the data flow in the IBM 7094 when it receives the data tape from the MICROSADIC. Figure 5 is the flow diagram for generating a gapped tape from a gapless one, while Figure 6 illustrates the steps necessary for making the data compatible with Fortran language.

17
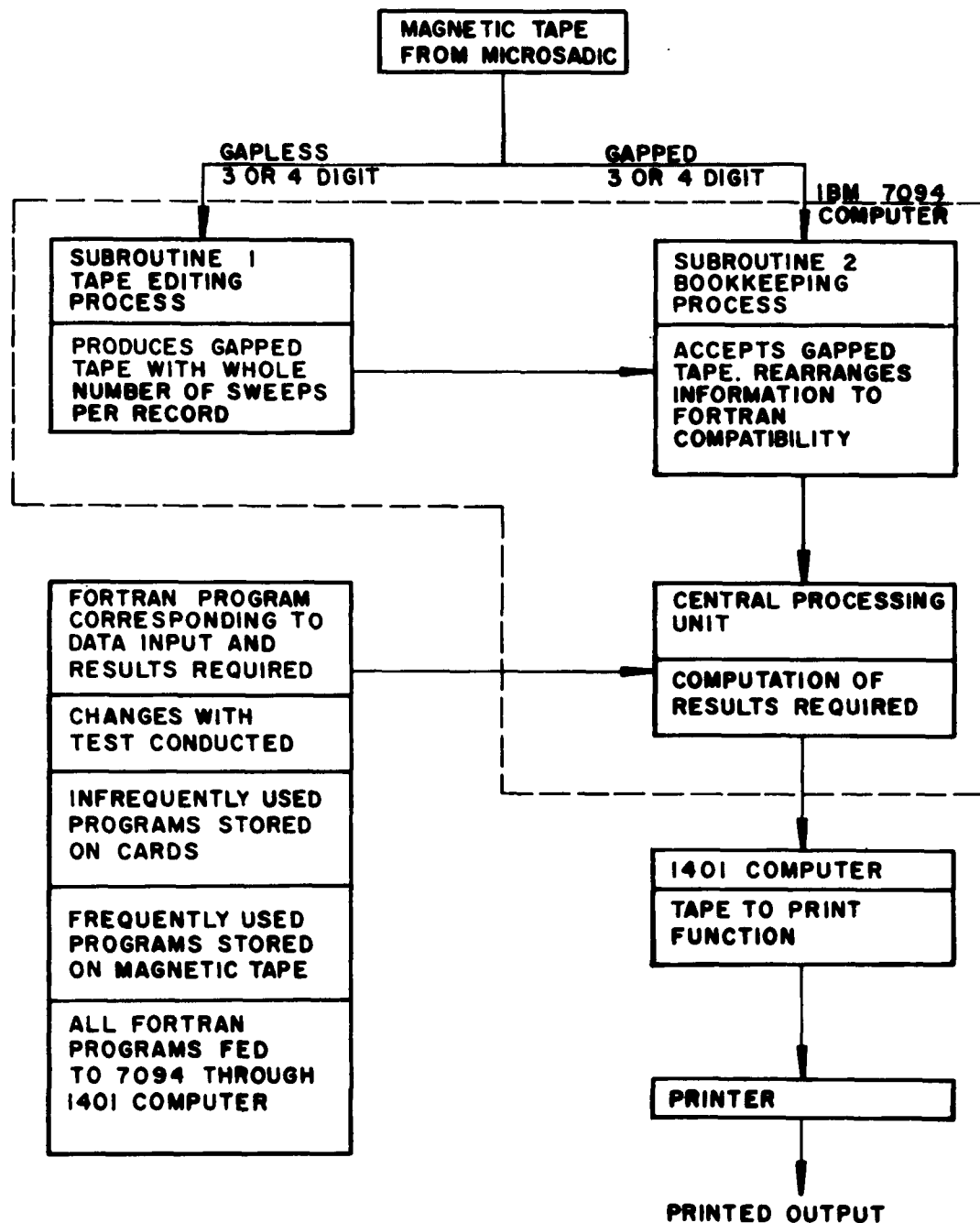
FIGURE 4 -BLOCK DIAGRAM SHOWING FLOW
IN IBM 7094

18
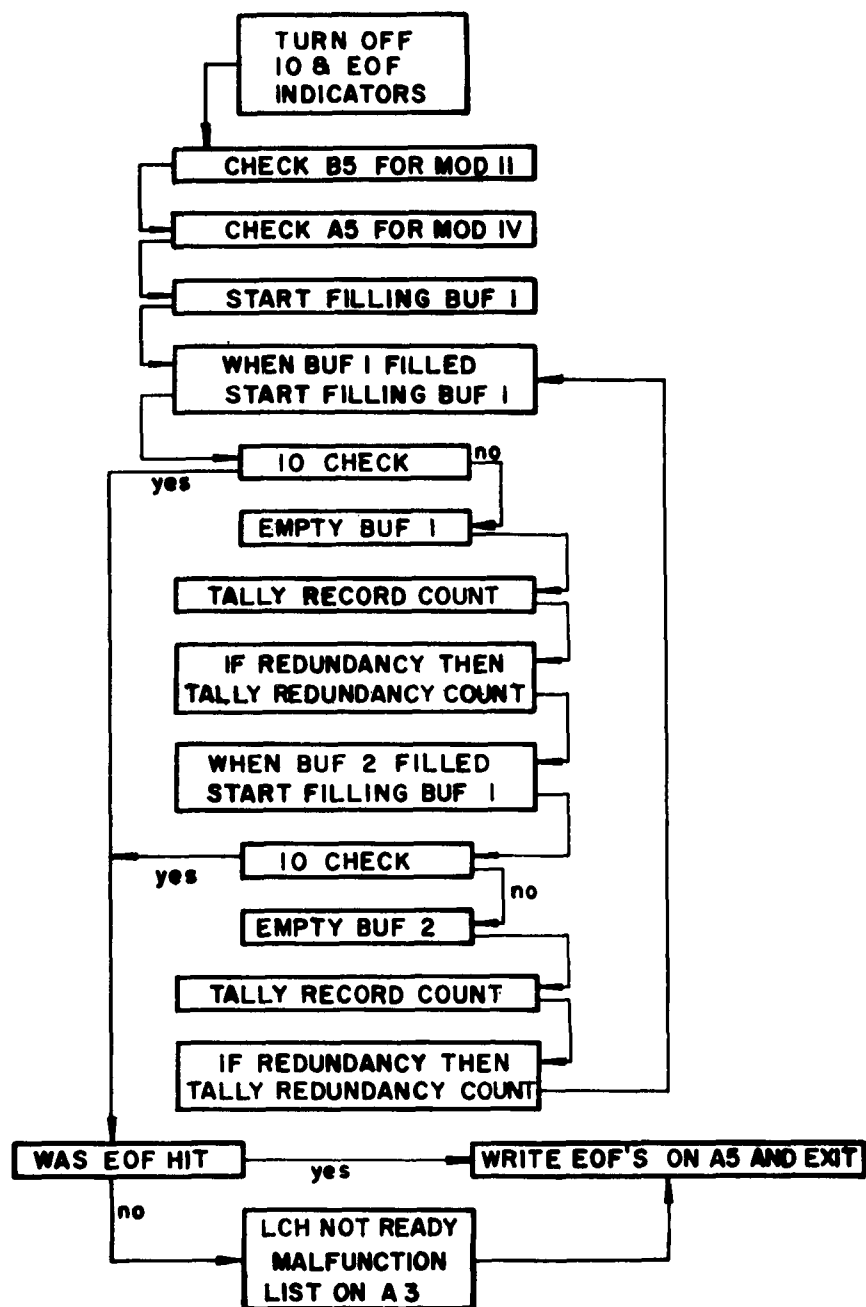
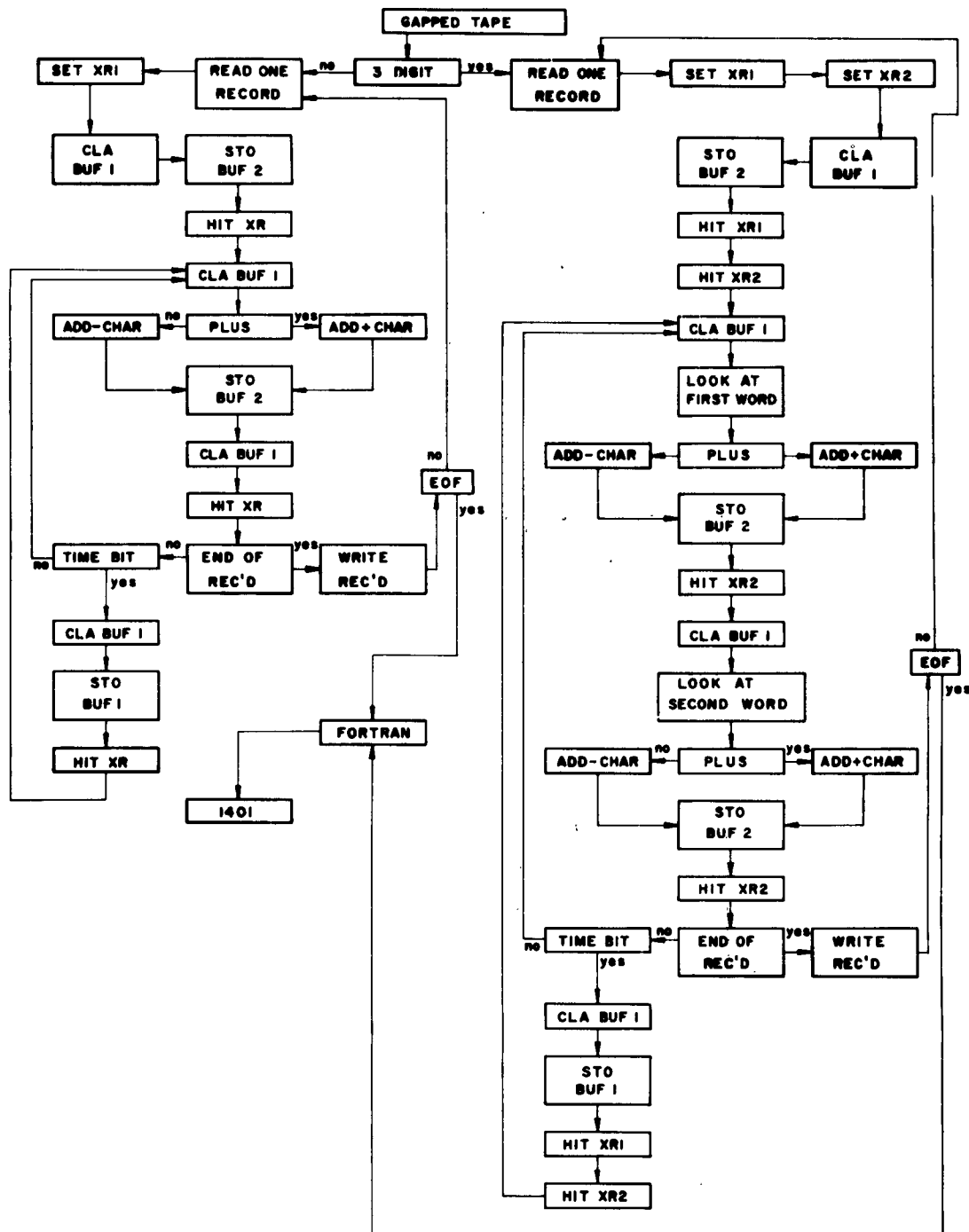**FIGURE 5 –FORTRAN ASSEMBLY PROGRAM NECESSARY TO GAP A GAPLESS TAPE**

FIGURE 6 —FORTRAN ASSEMBLY PROGRAM NECESSARY TO YIELD FORTRAN
COMPATIBLE DATA FROM A GAPPED TAPE

IV REFERENCES

1. Goll, M. E. and Lapenas, T. A.; "Operation and Maintenance Instructions for Off-Axis Double Pass Schlieren System", A.R.L. 62-463.