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RESEARCH ON VARIOUS ASPECTS OF ATMOSPHERIC FLIGHT.(U)
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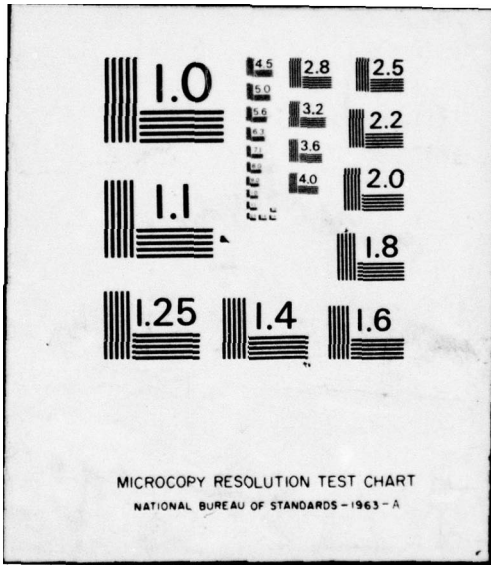
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UNIVERSITY OF TORONTO

A-FSR - TR - 76 - 1422

FINAL TECHNICAL REPORT

(12)

"RESEARCH ON VARIOUS ASPECTS OF ATMOSPHERIC FLIGHT"

See 1473
by

J. H. DELEEUW

and

L. D. REID

AFOSR Grant 71-2091

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"RESEARCH ON VARIOUS ASPECTS OF ATMOSPHERIC FLIGHT"

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SUMMARY

AFOSR GRANT NO. 71-2091

This The research has *studied* been devoted to the study of aerodynamic problems in upper atmospheric flight and the disturbed flight of aircraft due to low level turbulence during the approach phase. Individual project summaries are as follows: → *include:*

- (1) Calculations have been made for low speed sphere drag in transition flow; *Experiments* have been performed which confirm the theoretical predictions;
- (2) An electron beam doppler profile apparatus has been used to delineate the shape of the distribution function in a heat transfer problem indicating its progressive nonequilibrium nature *as* and the degree of rarefaction increased;
- (3) An electron beam fluorescence instrument has been designed for rocketborne use to measure upper atmospheric *concentrations* of nitrogen, molecular oxygen, atomic oxygen, rotational and vibrational temperatures; *A* number of launches have been made on Black Brant rockets from Fort Churchill *(AD 033680)*;
- (4) A laser-doppler instrument has been constructed and checked out as a means of remotely measuring turbulence in the atmospheric boundary layer; *and*
- (5) Wind tunnel measurements in a controlled turbulent shear flow have been made along representative flight paths for STOL vehicles to provide an input to predict dispersions of the landing point.

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1. INTRODUCTION

The research supported under AFOSR Grant 71-2091A has covered a number of experimental, as well as a few theoretical, investigations of a diverse nature. All of the projects are relevant in one way or another to the aerodynamics of vehicles traversing the atmosphere, but they address themselves to conditions ranging from ground level to altitudes of several hundred kilometers.

Much of the work reported here is concerned with rarefied gas-dynamics. Research in this field has been an important element in the spectrum of interests at the Institute for Aerospace Studies almost throughout its entire history and steady support from AFOSR through a number of preceding grants has been all important. The emphasis of our work is devoted to the development and delineation of various techniques to make aerodynamic measurements under the difficult low density conditions of the regime of interest.

One of the major innovations in this regard was the introduction of the electron beam fluorescence technique. It has become a widely used, versatile tool to measure gas density, species concentration and rotational temperature without significant perturbation of the flow field. This technique was extensively used in our own work to study in the laboratory the behaviour of flow fields of low density free jets in which rotational non-equilibrium and diffusive separation of gas species occurred, as well as the study of these effects in flows around bodies of various shapes. The culmination of such a laboratory study on diffusive separation in front of a blunt body is reported here.

A further project measured detailed aspects of the non-equilibrium distribution function in the heat transfer problem between two flat plates under transition flow conditions and has recently been completed.

The advantage of the electron beam fluorescence method is to provide measurements from an undisturbed flow, because the test volume can be arranged to be far enough away from the instrument hardware to be outside the zone of aerodynamic disturbance. This feature of the method was exploited in the development of a series of rocket instruments for sounding measurements in the upper atmosphere from about 80 to 200 km altitude. A series of flights on Black Brant rockets, launched from the Fort Churchill rocket range, were made to measure atmospheric temperature, and the partial densities of the major constituents, molecular nitrogen, and molecular as well as atomic oxygen. This work is described in further detail in this report. To interpret the measurements of atomic oxygen concentration in the rocket flights, laboratory measurements were made of the fluorescence intensity induced in accurately known sample flows of this gas.

The intensity of the laboratory work in low density aerodynamics decreased toward the end of the grant period, when emphasis was placed on experimental work on the turbulence in the atmospheric boundary layer. One approach in this regard was the development of the laser-doppler technique for making turbulence measurement in the actual atmosphere, or in the wake behind vehicles, at substantial distances from the apparatus. A second line of approach was directed toward the production and measurement of simulated turbulent atmospheric boundary layers in the Institute's Controlled Turbulence Wind Tunnel. The final objective here is to define the turbulence experienced along approach paths through the non-uniform conditions that are representative of landing approaches of STOL aircraft.

As is clear from the text of the report, many of the projects supported under the AFOSR grant have been completed and have been reported in final form. The rocket work and the studies of atmospheric turbulence

are continuing with AFOSR support under a new AFOSR grant.

This report is organized in brief sections, summarizing the status and results of each project with references to the reports that contain the detailed description of the work.

2. DIFFUSIVE SEPARATION IN FRONT OF A BLUNT BODY

An electron beam densitometer was used to measure diffusive separation in rarefied helium-argon bow shocks and in the vicinity of the stagnation point of a flat ended cylinder. Species partial densities were determined by measuring the intensity of certain spectral lines in the fluorescence produced by the beam and these measurements were augmented by measurements made with a large-angle scattered electron densitometer. In addition to the expected partial density dependence, the intensity of the spectral lines was found to be static temperature dependent in the case of helium, and velocity dependent in the case of argon. After a systematic investigation of the beam fluorescence, it was possible to reduce the uncertainty of the partial density measurements to acceptable levels by using different calibration curves in different regions of the flow. The bow shock measurements show significant argon enrichment in the region between the shock and the body for the Knudsen number range investigated, 0.04 Kn 0.18. At the body, the measurements are in reasonable agreement with the sampling probe measurements of Chang and Fenn. The argon mole fraction at the body was found to increase with increasing Kn and for Kn = 0.18 the argon enrichment was 50% greater than that expected for free molecule flow. The details of this investigation were published in Refs. 1 and 2.

3. ELECTRON BEAM EXCITATION OF N₂, O₂ AND O₁

Characteristic emission spectra in the 2000Å to 6000Å wavelength range, induced by 0.6-3 keV energy electrons, were obtained for molecular nitrogen, molecular oxygen and atomic oxygen. To study the atomic oxygen fluorescence, it was desirable to produce ground state O₁ atoms in the absence of O₂ molecules in order to avoid contribution to atomic oxygen line radiation by O₂ molecules dissociated upon electron impact. This was achieved by the N + NO → N₂ + O titration reaction. Absolute excitation cross sections were obtained for some of the prominent spectral features of N₂, O₂ and O₁; the emissions were selected on the basis of their applicability for upper atmospheric diagnostics with electron beam fluorescence probes (Refs. 3, 12).

In parallel with the laboratory investigations of the electron beam induced fluorescence in atmospheric gases, an electron beam fluorescence probe (EBFP) has been developed for rocket flight applications in the 80 to 150 km altitude range. The EBFP is capable of measuring vibrational and rotational temperatures as well as species concentrations in the upper atmosphere. The instrument employs a 2.5 keV, 4 mA electron beam to induce fluorescence in the ambient gas of the atmosphere. The resulting radiation is analyzed with a spectrally selective electro-optical detection system utilizing interference filters, optical fibres, photomultipliers and signal handling electronics. Two versions of the EBFP were flown on Black Brant rockets from Fort Churchill, Manitoba in March, 1971 and March, 1972.

Extensive details of these measurements are available in Ref. 3 and a condensed version was published as Ref. 4. The application of the electron beam fluorescence technique to an early form of the rocket instrumentation is described in Ref. 3 as well.

4. SLOW, RAREFIED FLOW OVER A SPHERE

The rarefied flow over a sphere is studied for the case where the speed ratio, the ratio of the flow speed to the thermal speed is small compared with unity and the conditions are ranging from the continuum to the transition regime. The Bhatnagar, Gross and Krook, and Welander model of the Boltzmann equation is used and modified such that the corresponding Navier-Stokes equations of motion contain the correct value of the coefficient of viscosity. A small perturbation technique is employed to remove the difficulties arising from the nonlinearity still involved in the BGKW model equation, and the fundamental equations as well as the associated boundary conditions are expanded into power series in terms of small perturbations of the velocity distribution function and the macroscopic flow properties. Further expansions are made for the assumed small Knudsen number in the asymptotic field and the full Navier-Stokes equations of motion and the equation of energy are derived.

The method of matched asymptotic expansions is used to obtain the solutions to the Navier-Stokes equations of motion and the equation of energy which are smooth throughout the asymptotic field, and the assumed small Reynolds number and Peclet number are used as the matching parameters respectively, assuming the existence of a small impressed temperature difference between the surface of sphere and the uniform upstream flow. Using the asymptotic solutions as the boundary conditions at infinity in terms of the molecular mean free path, the kinetic equations in the Knudsen layer are solved by means of the kinetic theory analysis, and the solutions are put forward to the second approximation. The results confirm that both flow slip and a temperature jump occur on the surface of sphere, and the asymptotic solutions are modified accordingly.

As a final result, a formula for the drag coefficient for the sphere is calculated, which is accurate to the second order in both the Reynolds number and the Knudsen number indicating the inertial and rarefaction effects, respectively.

An experimental study was carried out to measure the drag coefficient in air for pressures ranging from 0.05 to 20 torr for the speed ratio of 0.003 and ranging from 0.12 to 1.2 torr for a speed ratio of 0.006. In this experimental work, a sapphire sphere of about 400 micron diameter was projected vertically upward by means of an electromagnetic projection device and the drag was determined from the detailed deceleration records. Agreement between the theory and the experiment was found to be good.

The major results of this project are shown in Fig. 4.1, where the theoretical results for the ratio of actual drag to Stokes drag, as indicated by the quantity F , is shown as a function of Knudsen number. The results are shown for two speeds. The low speed ratio is $S = 5 \times 10^{-6}$, and together with the theoretical prediction, Millikan's results are shown. The case of a speed ratio $S = 3 \times 10^{-3}$ shows that even at this quite low speed, the inertial effects are quite noticeable. The experimental results obtained in this project are shown as well.

This work is complete and embodied in the Ph.D. thesis of Mr. M. Tomoeda, listed as Ref. 9. The final report is now in preparation.

5. DISTRIBUTION FUNCTION MEASUREMENTS FOR THE FLAT PLATE HEAT TRANSFER PROBLEM

Measurements of the molecular velocity distribution function between differentially heated parallel plates have been obtained for Knudsen numbers in the transition flow range. The gas used was argon and

the plate temperature ratio was 1.7. The specific distribution in terms of one velocity component, $\int \int_{\underline{v} \ \underline{w}} f(u, v, w, \underline{x}) dv dw$, where the 'u' direction is perpendicular to the plates, was obtained by measuring the Doppler broadening of the 4609.6 \AA AII spectral line emitted as a result of excitation of the gas by an electron beam. Various plate spacing and pressure combinations were used to obtain Knudsen numbers between 0.07 and 3.

The eight-moment linearized model of Gross and Ziering provided the best over-all representation of the data, with the four-moment linearized model of Gross and Ziering and the bimodal solution of Lees predicting a substantially greater degree of asymmetry in the distribution function than was observed at low Knudsen numbers. The constraint placed on the problem by Gross and Ziering to simplify its solution by linearization was that the temperature difference between the plates be much less than the mean temperature, $\Delta T_{\text{plates}}/T_0 \ll 1$. This criterion was not met in our experiment, and the good match between the data and the eight-moment method indicates that the range of validity of linearized solutions may be greater than would be expected based solely on the linearizing condition.

This project has been completed and the description of the investigation is given in the Ph.D. thesis of Mr. D. T. L. Tong, listed as Ref. 10. Typical examples of the major experiments are given in Figs. 5.1 and 5.2, which show the measured distribution function at two Knudsen numbers in comparison with the predictions of three theoretical models.

A concise summary of this work was presented at the 1976 International Symposium on Rarefied Gas Dynamics and will be available in the Proceedings.

6. UPPER ATMOSPHERIC MEASUREMENTS

A major problem in making direct rocket measurements of local properties of the upper atmosphere, especially at altitudes around 100 km, is related to the rocket's high speed motion. This requires interpretation of the aerodynamic effects on the measured quantities, which is particularly difficult at the mentioned altitudes because no reliable aerodynamic theory is available for conditions where the mean-free-path is of the same order of magnitude as the size of the vehicle and precise laboratory simulation and calibration is in most cases impossible.

An experimental method for the measurement of temperature and density to circumvent these difficulties was suggested in Ref. 5.

The basic concept of the method is based on the fact that when a beam of electrons is passed through a pure gas at low pressures (less than 1 torr) optical emission is produced with an intensity proportional to density, and the spectral nature of such induced fluorescence in a mixture of gases, like air, contains information which permits the determination of the partial densities of the constituents of the gas and also provides information on the vibrational and rotational states of these constituents.

The electron beam apparatus when adapted for use as a rocket instrument offers several important advantages that are not found in most of the conventional density and temperature methods in use at the present time. It is possible, with a suitable optical system and guidance of the electron beam, to locate the effective test sampling region at a significant distance from the rocket. This capability alleviates the usual problems of perturbation of the flow by the measuring device and the vehicle itself.

Furthermore, the rotational and vibrational temperatures of the molecules can be accurately interpreted from the measurements thus permitting a direct determination of temperature. The electrons are so fast compared with the flow velocities that the fluorescence radiation is characteristic of the static conditions in the gas even though the flow velocity is hypersonic. Flow velocities up to 10^4 ft/s can easily be tolerated with the isolation of spectral regions in nitrogen, helium, argon, carbon dioxide, and many other gases appropriate to fast transitions, thus affording good prospects for atmospheric diagnosis.

The work done under this AFOSR grant built upon the experience gained on a first rocket flight in the late sixties, in which the principle of the method was proven with a large first version of the apparatus, occupying the major part of a Black Brant's payload capability. These results were reported in Ref. 5. This early version of the electron beam fluorescence instrument was improved in a much more compact 5 channel instrument that could be flown as a passenger experiment as a minor part of the payload of the rockets available to us. Furthermore, payload recovery was successfully introduced in the Black Brant rocket series. Consequently, we have been able to re-use major sections of the electronic instrumentation, while rebuilding and refining the optical-electron beam signal collection part of the instruments.

The apparatus was flown first in March 1971, and again in March 1972, in both cases as passenger experiments. The apparatus was modified subsequently to work with a modulated electron beam with synchronous detection to improve the rejection of extraneous auroral light. In that new version it was flown twice more, once in February 1974 and finally in January 1975.

The basic instrument layout is shown in Fig. 6.1 which shows schematically how the electron beam is oriented with respect to the 5 channel optical fibre light collecting system. The optical backstop serves to reduce unwanted auroral background light in first instance. The beam is collected on the backstop structure to provide a well defined return path for the electron beam current back to the rocket. The channel selection has varied somewhat from launch to launch. However, in general, two such instruments have provided 10 channels of information, which were assigned to a variety of spectral bands sensitive to molecular nitrogen, molecular oxygen and atomic oxygen, in addition to rotational temperature and vibrational excitation.

A detailed description of the features of the design of the fluorescence probes, the calibration techniques, and typical results from various flights is given in Ref. 6. A paper summarizing measurements on the thermospheric N_2 and O_2 concentrations has been published as Ref. 7.

This research is continuing and during this grant period, the instruments were refurbished once again for a further flight in January 1977.

7. LASER DOPPLER VELOCIMETRY

Although the laser doppler (LD) method is gaining wide acceptance in laboratory use, there has been a much smaller number of reports in the literature relating to applications of the LD technique to outside measurements. Few investigators have detailed findings on the quality of LD signals at large distances ($\approx 20m$) using naturally occurring scatterers, or commented on the fringe visibility during their observations.

Using the forward scatter differential doppler mode and a 2mw He-Ne laser, the fringe quality and beam wander has been investigated for a range of beam separations (.3, 1 and 2m), with concomitant variations

in the beam transit distance (up to 350m). The transit terrain contained portions of asphalt and grass and the observations covered a wide range of temperature, wind and humidity conditions. Tests were conducted at all times of the day and night and are being continued to cover winter conditions.

A sketch of the optical arrangement is shown in Fig. 7.1; by scanning a large portion of the beam's overlap region the quality of the LD fringe pattern could be established quickly and without reliance on a possibly varying scatter source. The scanning method also enabled data to be obtained quickly in conditions of high turbulence when beam wandering produced a fringe pattern for only ~ 0.3 duty cycle.

It was found that despite the disparity in path quality, usable fringe patterns were obtainable under all observing conditions (a typical record of the fringe visibility is shown in Fig. 7.2. For beam separations of a few tens of centimeters two beams wander nearly independently so the results may be regarded as valid for even larger beam separations.

Final data reduction will enable limits to be set regarding the spatial resolution obtainable at large ranging distances since this is linked to the beam wander. A report on this work is in preparation.

A first application involving the use of the LD system with natural scatterers was made to define the wake region behind an air cushion model vehicle on the Institute's circular track.

One of the objections raised against the use of a tethered hovercraft running on a circular track when operating in close proximity to a confining circumferential wall, is that the vehicle may travel in its own aerodynamic wake. The circulation or stirring effect caused by the repeated passage of the vehicle over the same paths has been investigated by qualitative tuft testing showing that the wake spills radially. The

problem of quantifying the residual wake velocity is one that is well suited to the laser doppler (LD) method, indeed at most locations in the trajectory of the vehicle this is probably the only viable technique.

The LD method provides a capability for remotely sensing the velocity of scatterers passing through an observation region whose spatial extent is defined by the common overlap region of two beams, derived from the same laser. Using natural air contaminants under a variety of conditions it has been shown elsewhere that flows can be accurately monitored with the LD method where velocity changes are 200 ms^{-1} in $1 \mu\text{s}$. Although seeding from a fixed source at track level could have been employed for the tests described here, the use of natural air is more flexible and provides experience for cases where seeding is impractical.

A sketch detailing the optical configuration is shown in Fig. 7.3, the forward scatter differential doppler mode was employed although the scatter signals were sufficient in the back scatter mode if the collecting lens had been placed at track level.

The LD signals during all runs were recorded on the video track of a Sony 3650 audi-video TV tape recorder, voice annotation and timing signals were inserted on the audio channel. This procedure gave considerable flexibility in data reduction enabling three different methods of signal analysis to be intercompared. The doppler frequency could be determined directly from storage oscilloscope traces, through a spectrum display in the frequency domain, or using a commercial digital frequency tracker (DISA 55L).

The results of this study show that fears of a noticeable circulation developing due to repeated passes by the vehicle are unfounded. The details of the experimental configuration and data analysis techniques

are described in Ref. 8. The successful use of the laser doppler method for a transient flow phenomenon using only natural scatterers constitutes a useful step toward its use in the study of wind turbulence.

8. THE INFLUENCE OF TURBULENCE ON STOL APPROACH MANEUVERS

Safe and reliable landings of STOL and VTOL aircraft on steep descent paths in congested environments, low visibility and strong wind must be achieved if the all-weather air transport systems envisaged for the future are to become a reality. A central feature of the overall problem is the design of vehicle control and terminal guidance systems that will result in small enough dispersions of the flight path and vehicle attitude at some decision height.

The approach taken to the analysis of this problem at our laboratory involves the use of a boundary layer wind tunnel simulation of the earth's planetary layer. Two-point space/time correlations among the three turbulence velocity components in the flow are obtained along a glideslope setup in the tunnel. These measurements of the so-called 'flight path correlation matrix' are combined with a linear aircraft model using a fixed probe theory developed by Etkin in Ref. 8.1. This generates estimates of the RMS dispersion of the aircraft's state vector about a reference flight condition resulting from the presence of turbulence.

Figure 8.1 indicates the landing approach geometry employed. The wind conditions simulated represent the flow over smooth open terrain. The flow field parameters simulated were velocity profile (power law with an index of 0.16), turbulence intensity profile (see Fig. 8.2) and turbulence spectral shape. Typical longitudinal flight path correlations are shown in Fig. 8.3.

The aircraft model employed represents a typical twin engined STOL transport. The nominal landing approach is assumed to be along a straight glideslope at an angle of 15° . The vehicle longitudinal equations of motion have been linearized about an equilibrium condition corresponding to flight along this glideslope in the presence of a constant headwind. The computer codes required to combine the experimentally derived flight path correlation matrix with the linearized aircraft model have been written and are presently undergoing debugging. In the present approach to the problem the effects of both wind shear and turbulence are treated as perturbations about the equilibrium flight case. The initial runs are being performed in an open-loop manner. It is anticipated that future efforts will be made to close the loop with a pilot or autopilot model.

When employing the wind tunnel to generate the flight path correlation matrix two labour intensive areas emerge. One enters when the initial flow conditions are being set in the test section. This requires the use of a conventional traversing rig to position a velocity probe. The present rig is not acceptable and as a result a replacement is being designed (see Fig. 8.4). This new rig will be driven by stepping motors under the control of our on-line digital minicomputer. Initially two degrees-of-freedom will be under computer control with the rig being positioned along the tunnel by a hand crank.

The second area of concern is the positioning of the two velocity probes along the glideslope. The number of locations employed is large and repositioning is presently quite time consuming. A stepping motor driven glideslope rig is being built to overcome this problem (see Fig. 8.5). It will be under minicomputer control also. It is anticipated that these devices will allow greater amounts of data to be handled and thus expand the range of study undertaken in the aircraft response program.

In an attempt to obtain some full scale data for comparison with the above laboratory generated results some flight tests were flown for us by the National Research Council of Canada, National Aeronautical Establishment. Their Bell 205 helicopter has been instrumented to measure the three velocity components of atmospheric turbulence. This system is based on α and β probes combined with an airspeed indicator to give the instantaneous airspeed vector and an inertial platform updated from a radar doppler system to determine the groundspeed vector. From these two vectors the windspeed vector is computed.

Using this system several landing approaches were made along a 15° glideslope and the time history of the three turbulence velocity components recorded. These data are presently being used as input to our STOL transport landing approach simulation in order to generate aircraft state vector dispersions for comparison with the wind tunnel results.

It is well known that severe wind shear in the region of the approach path at an airport can cause aborted landings and accidents. Aircrew and safety boards have called for the measurement of wind shear conditions at airports and the reporting of this information to the aircrew. Our current review project in this area is intended to assess the technical difficulty of obtaining the necessary data and to determine how it might be displayed in the cockpit. In the latter case it is observed that the cockpit radio-telephone link is already overloaded and this suggests that a visual display of some type might be required. At the present time a ground based system employing a network of acoustic-doppler wind shear detectors is being studied in conjunction with a visual cockpit display employing a pictorial representation of current conditions. The ultimate goal of this system is to alert aircrew to possible dangers and

to aid them in making decisions concerning the advisability of attempting a landing approach.

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9. ION TEMPERATURE MEASUREMENTS

An experimental verification of the end effect theory of long cylindrical Langmuir probes in a high-speed collisionless plasma flow has been studied. This effect is observed as a sharp departure from the predicted 'infinite probe' current when a strongly negative probe is aligned with the flow. Both the height and the width of the ion current peak measured about the zero-degree attitude are strongly sensitive to ion temperature. The effect is verified for a mesothermal argon plasma with probe radius to Debye length ratio $0.005 < \epsilon < 0.5$ and for ion to electron temperature ratios close to unity. A scheme is developed to obtain a self-consistent measurement of the ion temperature using the basic characteristics of the finite-probe angular response after a modification of J. R. Sanmartin's theory.

A versatile ion source was constructed after a state-of-the-art electrostatic ion thruster. It provides, together with a large size vacuum chamber, a simulation facility for which the plasma stream characteristics can be tailored and the ion speed ratio easily modeled for diagnostics purposes.

A range of flow conditions and of probe parameters are investigated and the overall applicability and reliability of the method to measure T_i are assessed. Potential areas of applications are outlined. This work has been fully reported in Ref. 11.

10. PUBLICATIONS OF GRANT-SUPPORTED WORK

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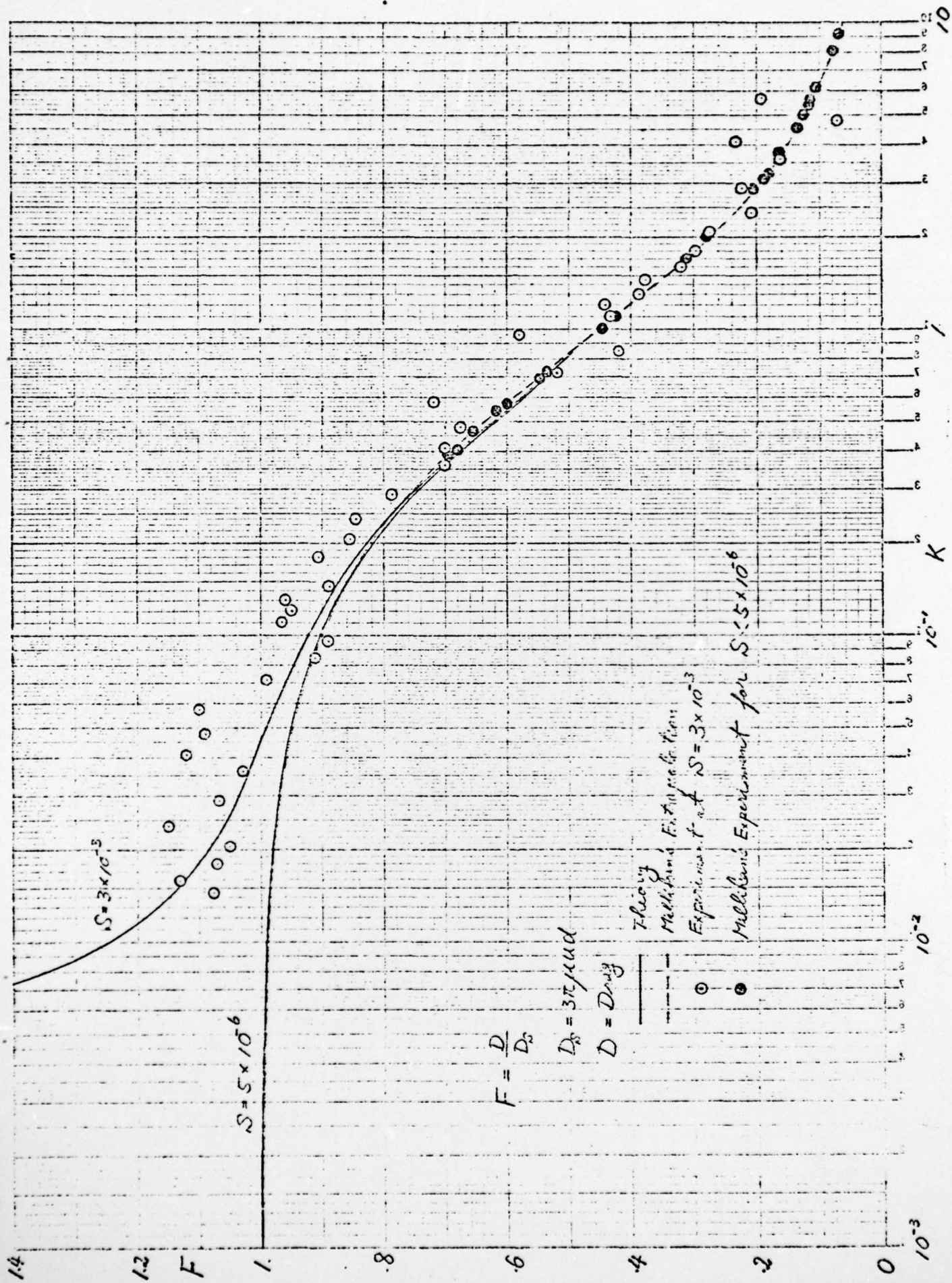


FIG. 4.1 DRAG FACTOR AS A FUNCTION OF MODIFIED KNUDSEN NUMBER

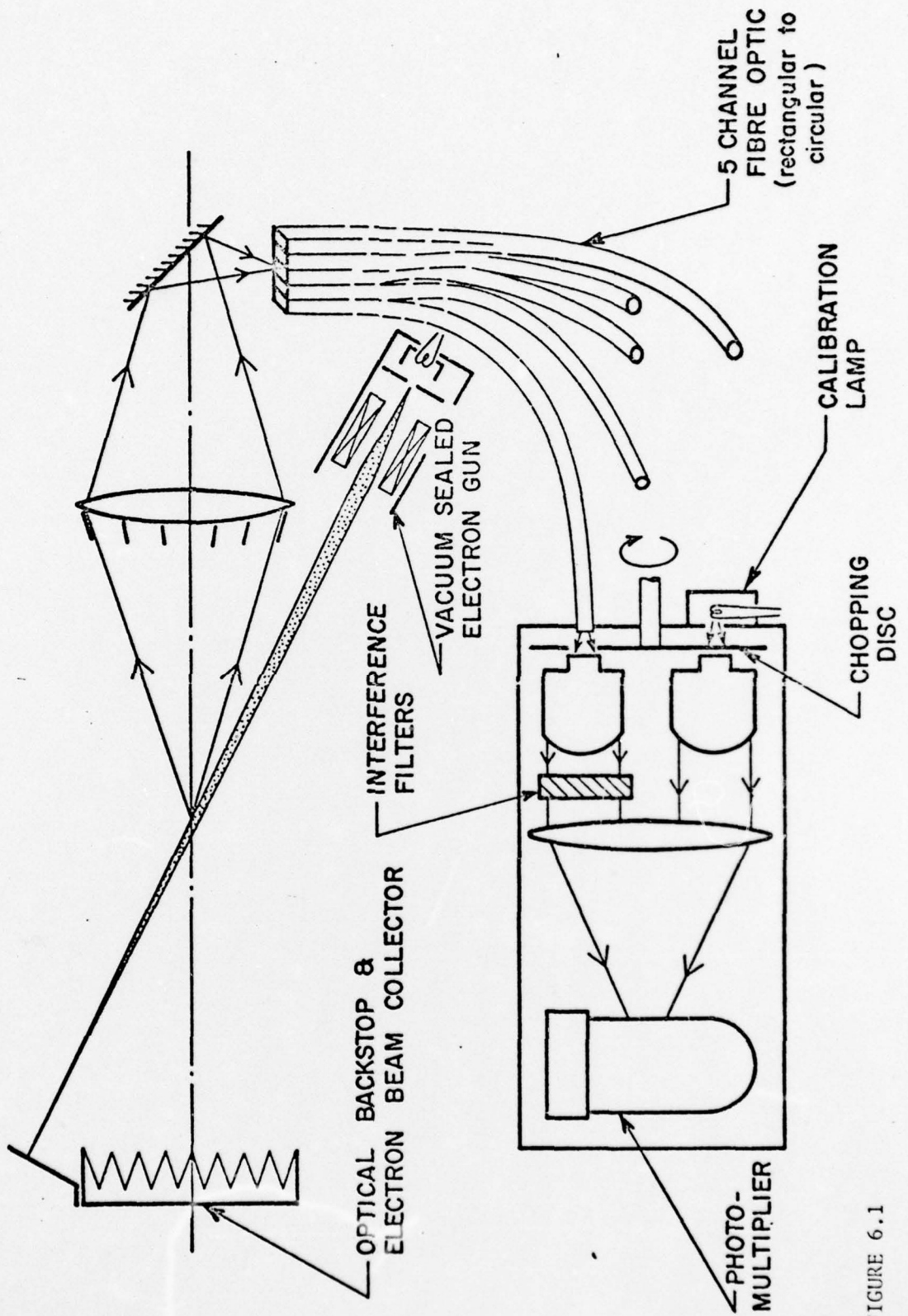


FIGURE 6.1

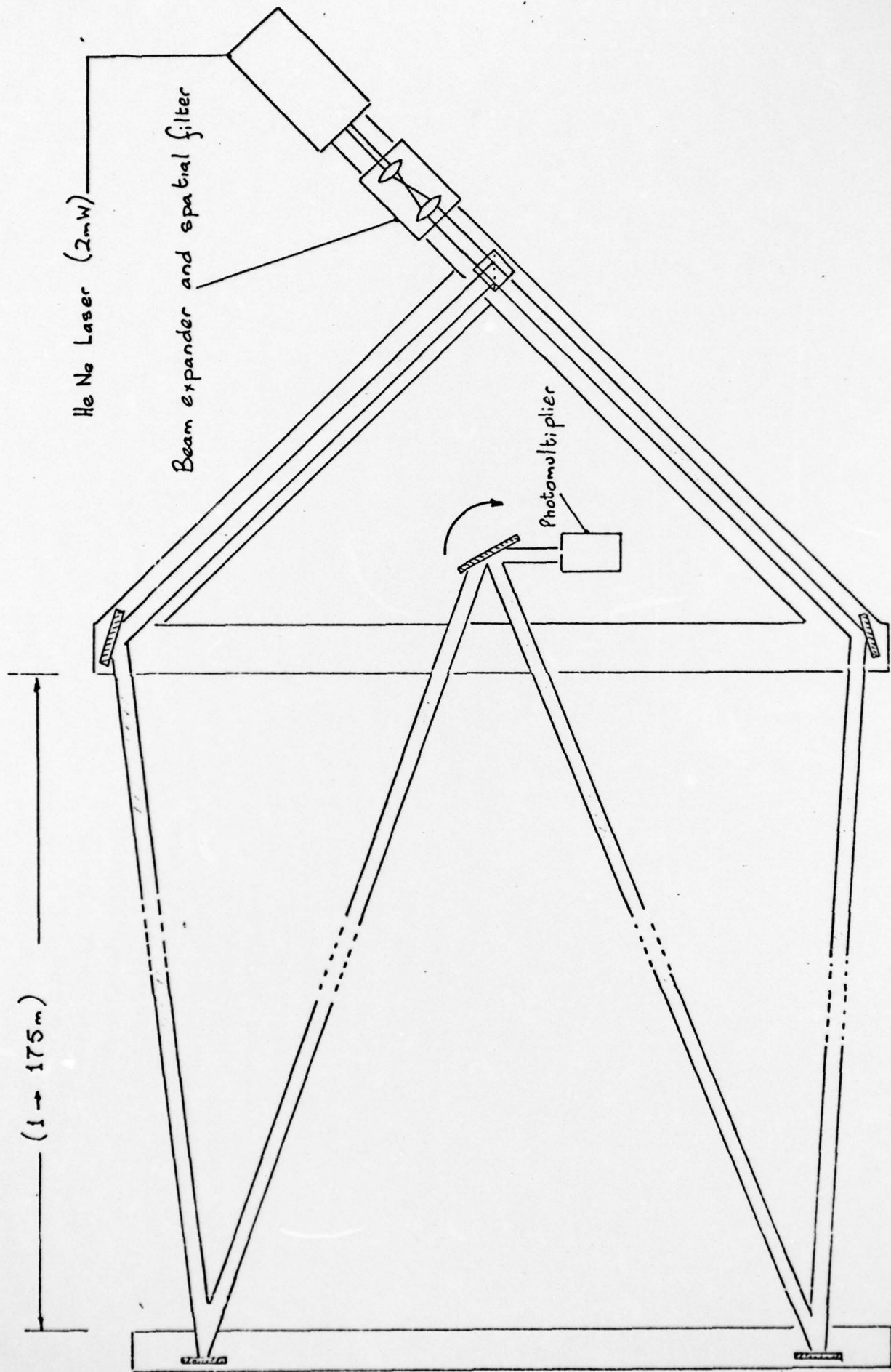


FIG. 7.1 LASER DOPPLER FRINGE QUALITY EXPERIMENT

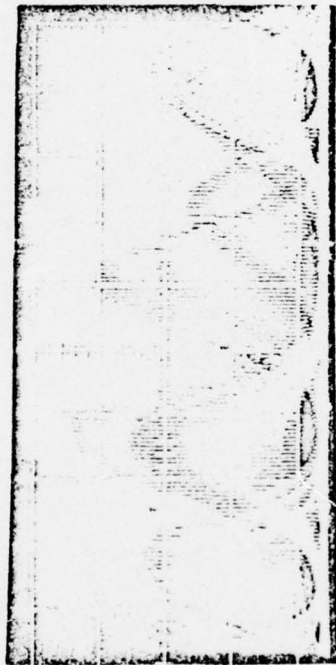


FIG. 7.2 FRINGE QUALITY RECORD

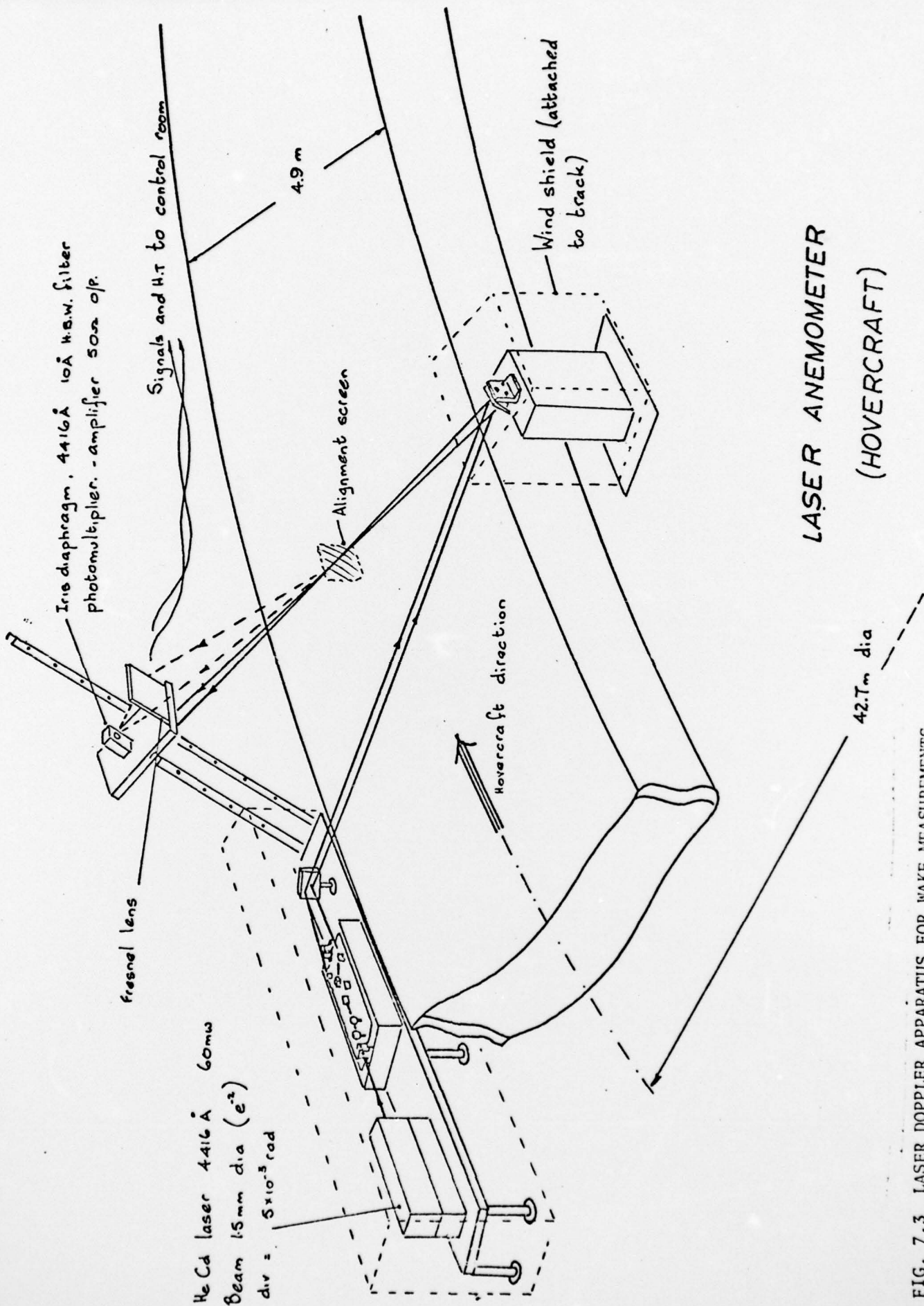


FIG. 7.3 LASER DOPPLER APPARATUS FOR WAKE MEASUREMENTS

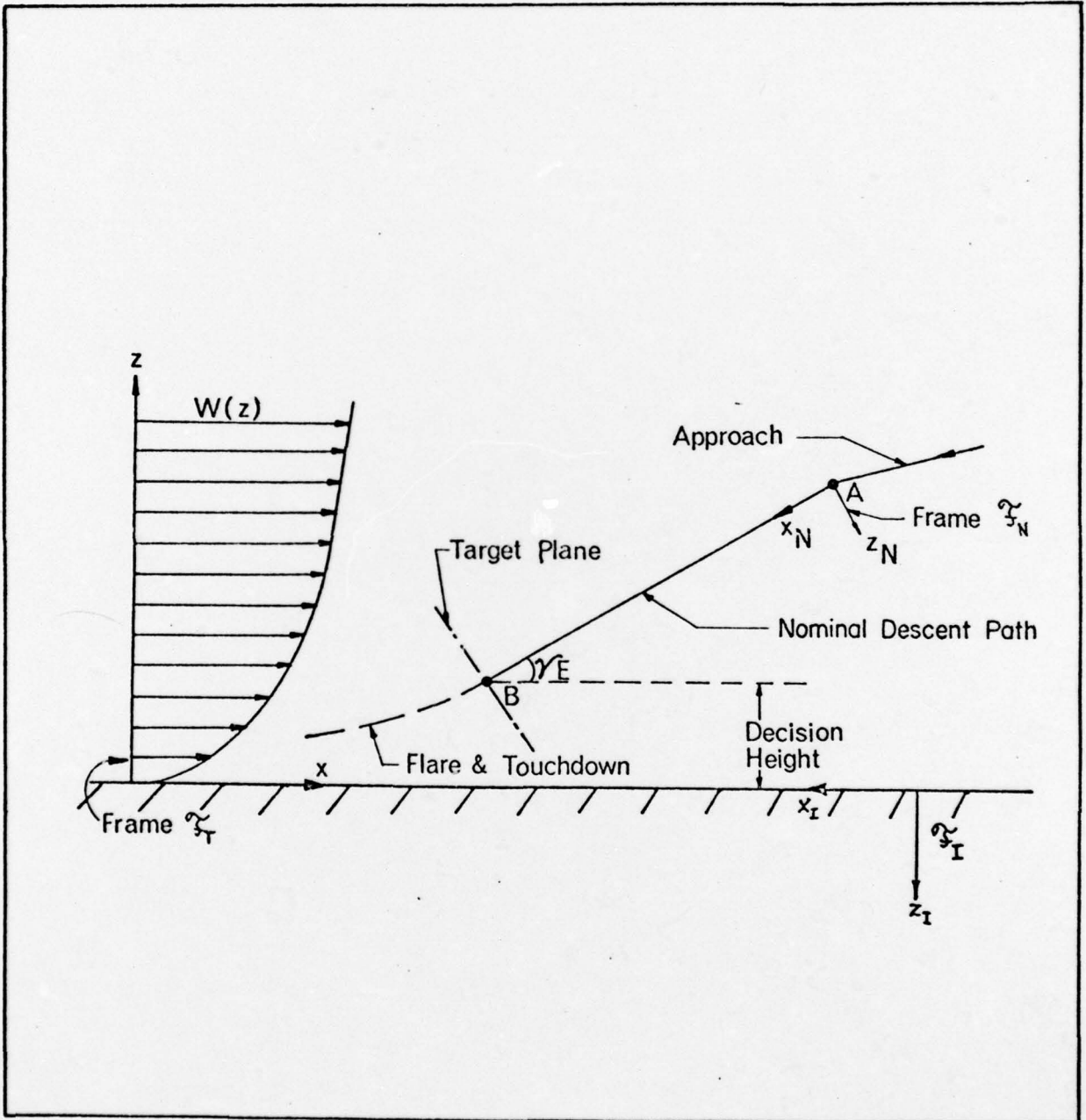


FIG. 8.1 TYPICAL AIRCRAFT DESCENT THROUGH THE PLANETARY BOUNDARY LAYER

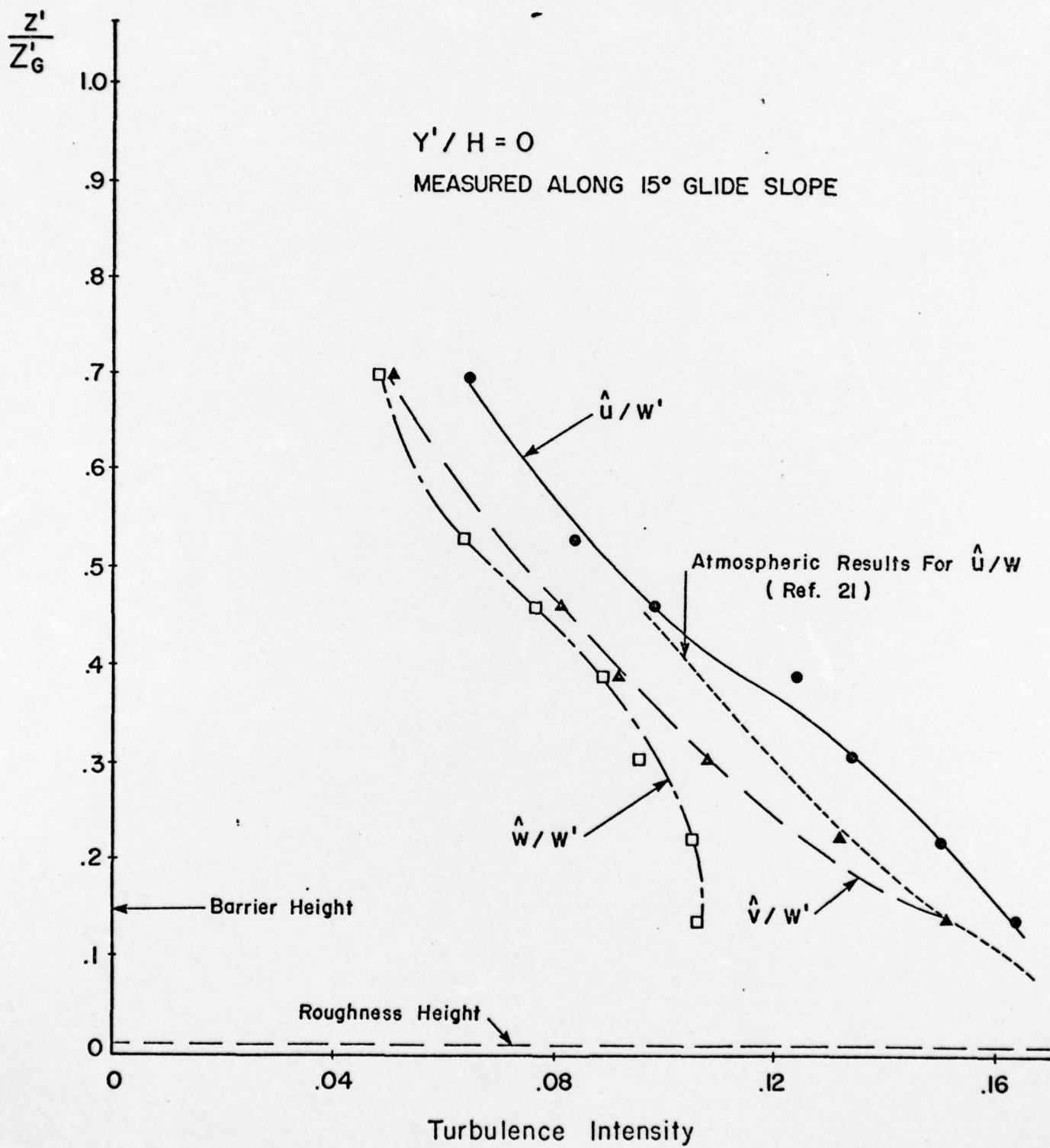


FIG. 8.2 TURBULENCE INTENSITY PROFILES IN SIMULATED FLOW.
44" x 66" TUNNEL

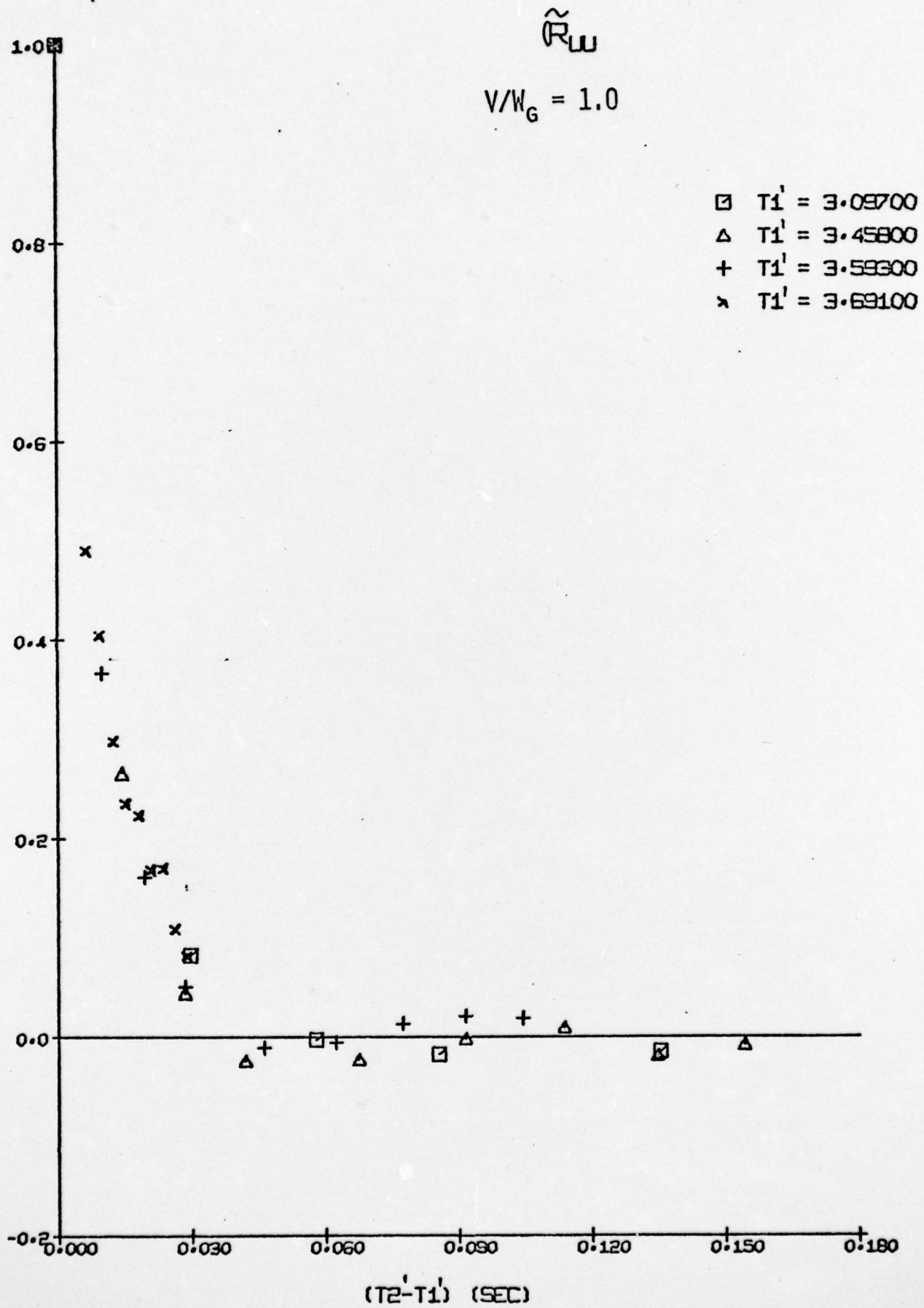


FIG. 8.3 FLIGHT PATH TURBULENCE CORRELATION, 44" x 66" TUNNEL

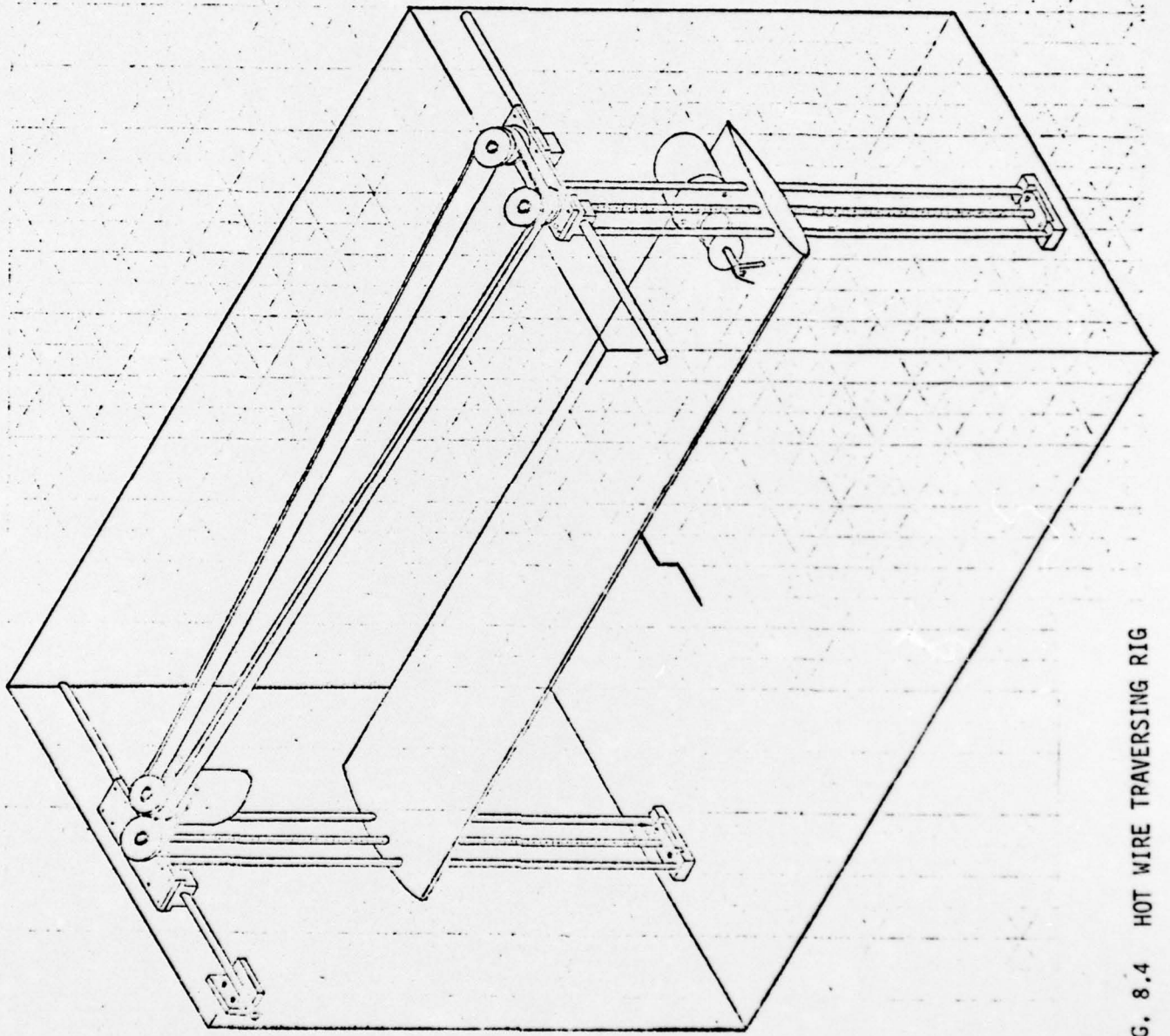


FIG. 8.4 HOT WIRE TRAVERSING RIG

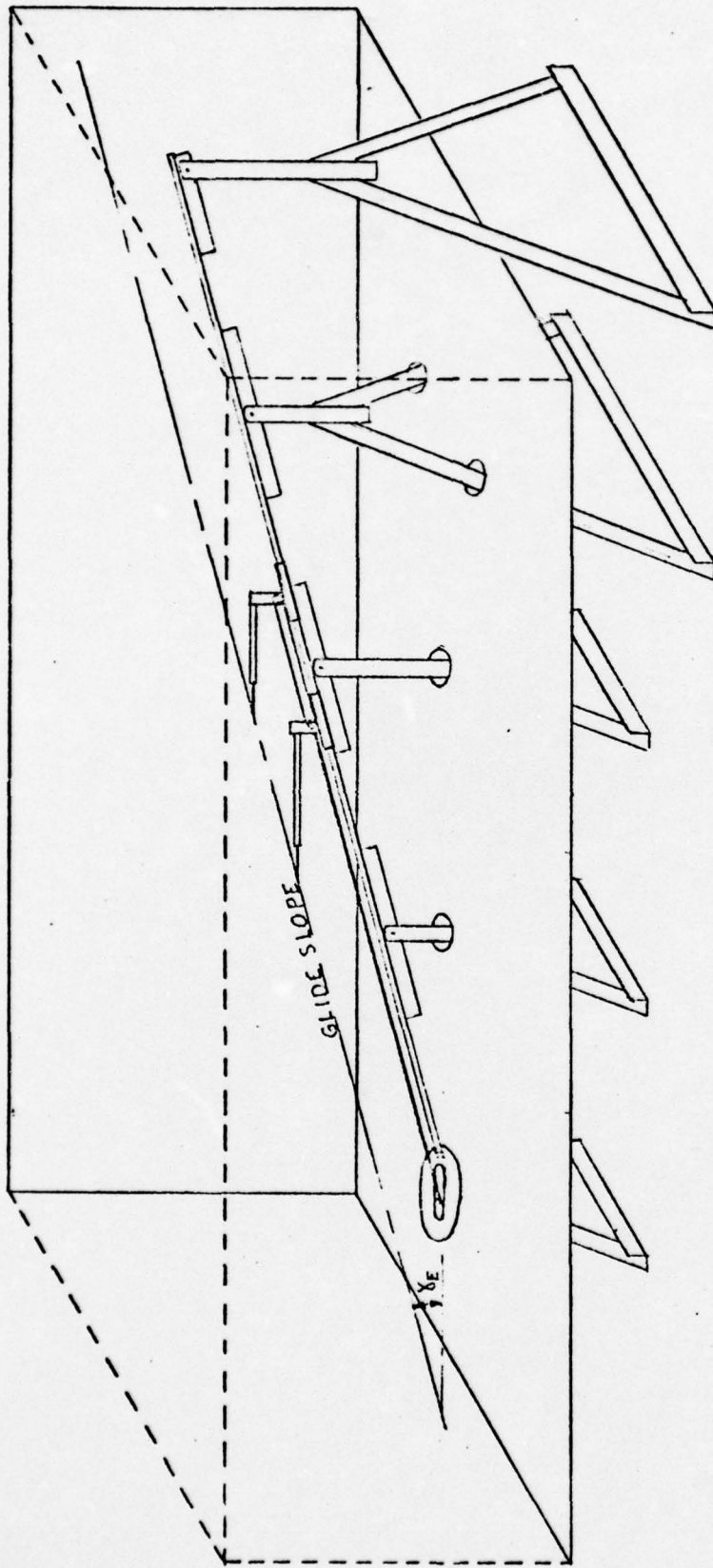


FIG. 8.5 GLIDE SLOPE RAIL, 44" x 66" TUNNEL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The research has been devoted to the study of aerodynamic problems in upper atmospheric flight and the disturbed flight of aircraft due to low level turbulence during the approach phase. Individual project summaries are as follows: 1. Calculations have been made for low speed sphere drag in transition flow. Experiments have been performed which confirm the theoretical predictions. 2. An electron beam doppler profile apparatus has been used to delineate the shape of the distribution function in a heat transfer problem indicating its progressive nonequilibrium nature as the degree of rarefaction increased. (cont)		

3. An electron beam fluorescence instrument has been designed for rocketborne use to measure upper atmospheric concentrations of nitrogen, molecular oxygen, atomic oxygen, rotational and vibrational temperatures. A number of launches have been made on Black Brant rockets from Fort Churchill. 4. A laser-doppler instrument has been constructed and checked out as a means of remotely measuring turbulence in the atmospheric boundary layer. 5. Wind tunnel measurements in a controlled turbulent shear flow have been made along representative flight paths for STOL vehicles to provide an input to predict dispersions of the landing point.

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