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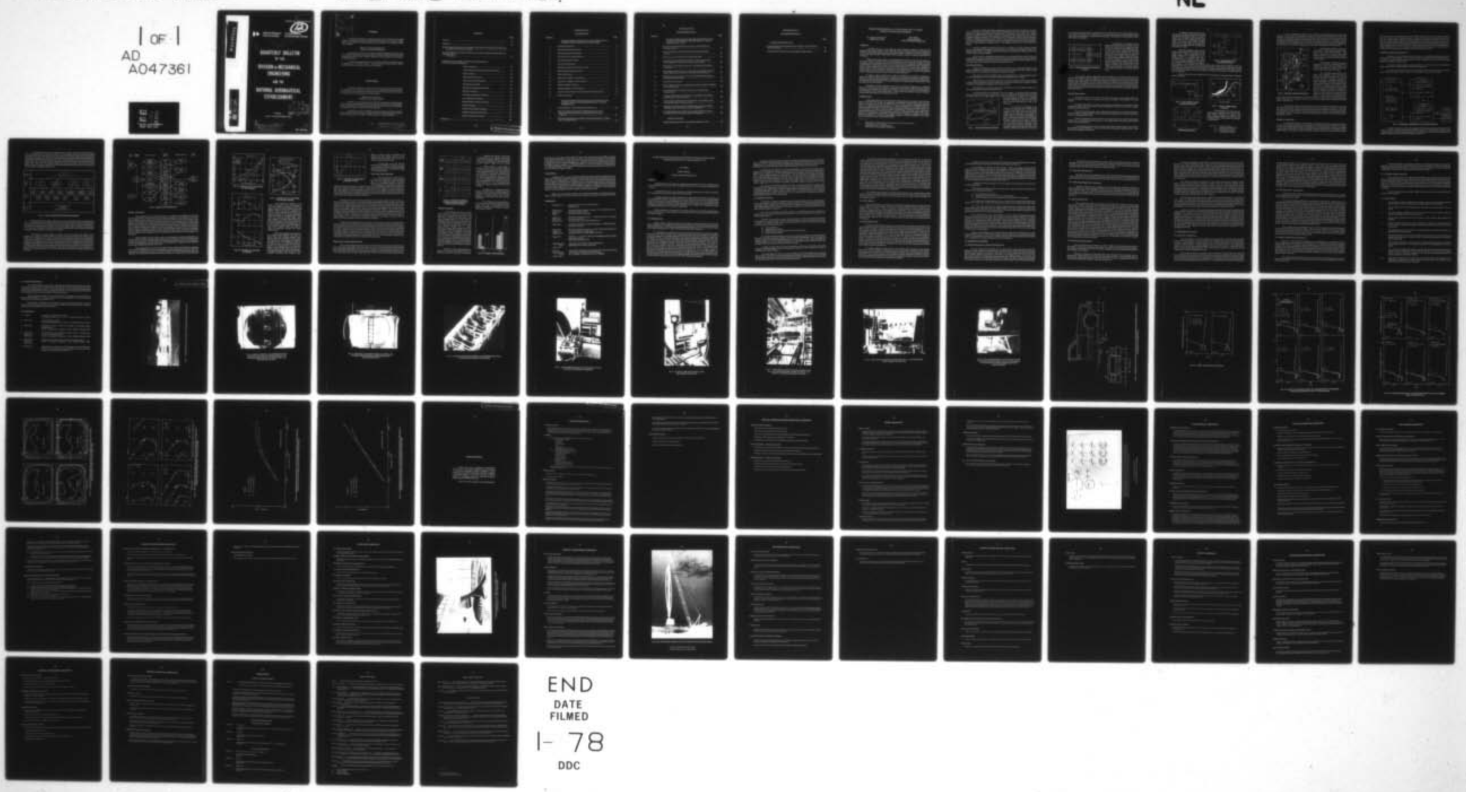

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FOREWORD

The Quarterly Bulletin is designed primarily for the information of Canadian industry, universities, and government departments and agencies. It provides a regular review of the interests and current activities of two Divisions of the National Research Council Canada:

Division of Mechanical Engineering
National Aeronautical Establishment

Some of the work of the two Divisions comprises classified projects that may not be freely reported and contractual projects of limited general interest. Other work, not generally reported herein, includes calibrations, routine analyses and the testing of proprietary products.

Comments or enquiries relating to any matter published in this Bulletin should be addressed to: *DME/NAE Bulletin, National Research Council Canada, Ottawa, Ontario, K1A 0R6*, mentioning the number of the Bulletin.

AVANT-PROPOS

Le Bulletin trimestriel est conçu en premier lieu pour l'information de l'industrie Canadienne, des universités, des agences et des départements gouvernementaux. Il fournit une revue régulière des intérêts et des activités actuelles auxquels se consacrent deux Divisions du Conseil national de recherches Canada:

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Quelques uns des travaux des deux Divisions comprennent des projets classifiés qu'on ne peut pas rapporter librement et des projets contractuels d'un intérêt général limité. D'autres travaux, non rapportés ci-après dans l'ensemble, incluent des étalonnages, des analyses de routine, et l'essai de produits de spécialité.

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HYBRID COMPUTER MODELS AS AN AID IN DESIGN OF GAS TURBINE CONTROL SYSTEMS FOR HELICOPTERS†

R. Langton*, R.M. Evans**
Aviation Electric Ltd.

B.D. MacIsaac
Analysis Laboratory
Division of Mechanical Engineering

ABSTRACT

A detailed model of a twin engine gas turbine helicopter propulsion system has been assembled. The primary purpose of the model was to provide a design tool for aid in evaluation of controls for helicopter propulsion systems. Emphasis, therefore, was placed on accurate representation of the power train with only enough detail of the helicopter to provide an adequate environment for the engines.

Design of the model is based on a thermodynamic description of the physical modules of the system. Extensive use was made of experimentally derived data to describe the major non-linear components such as compressors, turbines, and the helicopter rotor. Considerable emphasis was placed on modularity of model design because it was anticipated that several different engine configurations would be required during the course of the project. Implementation of the model was completed on a hybrid computer. Initial emphasis in this effort was on model accuracy with no particular regard to solution time, however, the model was designed so that separate frequency "bands" of information could be handled under interrupt control once the model was validated.

In order to ensure accuracy and to build up creditability, it was decided to implement a model of an existing control system prior to evaluation of control systems design. A standard hydro-mechanical control system was modeled in complete detail and validation both statically and dynamically indicated excellent agreement between the model and the actual hardware. This was true of both the engine and the control system.

Currently the model is operated in real time in an interrupt environment. A considerable amount of experience has been amassed in evaluating control concepts using the hybrid computer model and one configuration of control system has been committed to hardware. The flexibility and cost effectiveness of the modeling approach to control design has resulted in computer models becoming an essential design tool for Aviation Electric Ltd.

INTRODUCTION

Technological advances in the field of gas turbine propulsion has permitted wider and wider ranges of operation of all aircraft. The ruggedness and reliability of the gas turbine power plant has resulted in its application to many and diverse duty cycles. Today aircraft are flying higher and faster and it is no longer acceptable for helicopters to be simply operational lift units. Stable platforms are essential for applications such as search and rescue and make new demands on propulsion system control to achieve it. In order to keep pace with the technological development in the engine itself, continued development of controls technology is required. In response to this market need, Aviation Electric Ltd. has embarked on a program of advanced controls technology development. The primary goal of this program is to develop the technology necessary to respond successfully to the control systems requirements in the decade beginning 1980.

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† This paper was presented at the Summer Computer Simulation Conference, Chicago, July 1977.
* System Analyst – Aviation Electric Ltd.
** Advanced Concepts Group – Aviation Electric Ltd.
Aviation Electric Ltd. is a Subsidiary of the Bendix Corp.

Part of the controls technology development program involves the development of analytical tools necessary for the design process. Several factors lead one to the decision that computer models are an essential element of the design process. The helicopter with its very close couplings between the airframe and the propulsion system is technically one of the most difficult and complex propulsion controls problems in the aeronautical field. Furthermore, airframe manufacturers subcontract to propulsion manufacturers who would in turn subcontract to control system specialists. This chain of responsibility in the design puts the control designer in a position where he is required to provide a control system for hardware which is not finalized until very late in the development process.

Computer simulation technology does much to allieviate the logistic problems brought about by this situation. Providing the control designer with a flexible and accurate model of the complete system and its environment allows him to predict control system performance before the results of hardware tests are available.

In 1974, a joint collaborative program between the National Research Council Canada and Aviation Electric Limited was undertaken: its primary aim being to develop detailed computer models of helicopter propulsion systems that could provide information leading to control design. The purpose of this paper is to describe the progress on this program to date.

SYSTEM DEFINITION

Fixed wing aircraft rely on the lift forces generated on the aerodynamic surfaces of the wings and tailplane to maintain stable flight. To achieve this condition, the aircraft requires enough forward speed to keep the lift forces and gravitational forces in balance.

The main task of the propulsion system in this application is to provide sufficient thrust to overcome drag forces so that the required forward speed through the air is obtained.

Manoeuvering of a fixed wing aircraft can be readily achieved without involving changes in engine power; modulation of elevator, aileron and rudder control surfaces cause changes in aircraft attitude thus modifying the aerodynamic forces acting on them.

The helicopter, on the other hand, relies continuously on the propulsion system for its lift, forward speed and manoeuvering requirements.

A schematic picture of the helicopter is shown in Figure 1. A lifting rotor may be thought of as a disc with a thrust vector perpendicular to it; lift and forward speed being achieved by tilting the thrust vector at some angle relative to the vertical as indicated in the figure. Yaw control and rotational stability are achieved by controlling the thrust generated by the tail rotor wnich spins in a plane perpendicular to that of the main rotor.

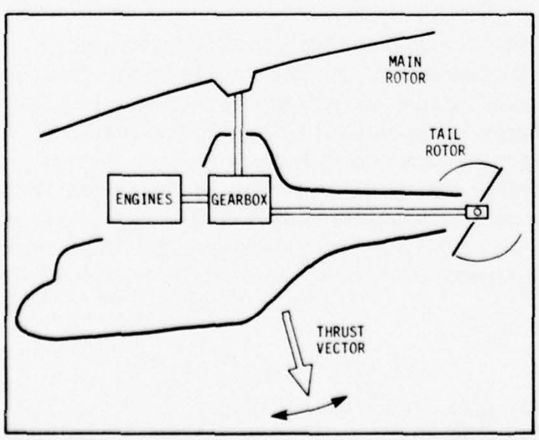


FIG. 1: HELICOPTER DRIVE SYSTEM

It is clear that any changes in the orientation or magnitude of the thrust vectors of these rotors makes direct and immediate demands on the engine for more or less power. Engine response is therefore a particularly important factor in the helicopter application and this is complicated further by the installation. Shafting to the high inertia rotors is typically long and compliant and can result in the presence of torsional resonant frequencies within the required power response bandwidth of the propulsion system. This aspect of engine power control is particularly troublesome in the area of rotor speed governing where the operational need for tight control of rotor speed during manoeuvres implies a requirement for a high governor loop gain which cannot be easily achieved without inviting governor instability at torsional mode frequencies. This particular control problem is dealt with in detail in Reference 1.

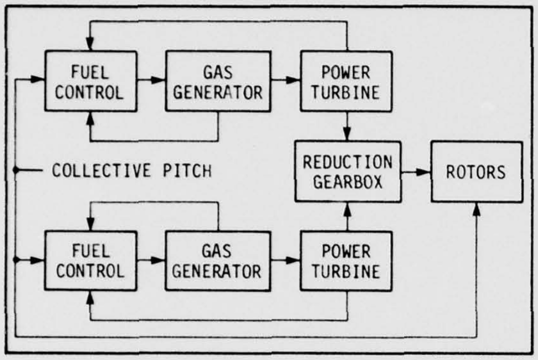


FIG. 2: PROPULSION SYSTEM GENERAL LAYOUT

A breakdown of the system into its major components is shown in Figure 2. In this figure it can be seen that the primary input from the pilot is through a lever designated collective pitch. This input determines the magnitude of the thrust vector required and, to a large extent, the power required from the engine. To anticipate power changes resulting from variation of rotor thrust, collective pitch information is usually transmitted to the engine control system. Control system demands, in turn, affect the gas generator units which supply hot gas energy to separate power turbines. The power turbines are connected via a reduction gearbox and transmission shafts to the main and tail rotors.

The propulsion system configuration shown on Figure 2 is a twin engine system which is becoming increasingly popular throughout the world. The primary motivation for the twin engine helicopter is to provide improved operational safety plus the capability of continued operation following a single engine failure. The twin engine installation complicates life yet again for the control system designer. The high installed power can be as much as 50% in excess of the transmission operating limit so that sophisticated power management systems are often required to provide such functions as overload protection, power balancing between engines and automatic compensation following single engine failure.

THE SYSTEMS MODEL

The primary purpose of the model described in this study is control system design. It is therefore necessary to provide an adequate and accurate environment for evaluation of control concepts.

As the gas turbine itself is a complex, non-linear piece of hardware, it is necessary to include considerable detail in the engine model to ensure representative power response over the complete load range and flight envelope.

The gearbox and transmission system, although relatively linear in its functional description, must be modeled in sufficient detail to allow torsional mode stability effects on the fuel control system to be evaluated representatively.

Airframe aerodynamics, while they affect power requirements and, to some extent, system response, have a significantly smaller influence on the propulsion system than direct pilot demands to the engine and rotor systems.

It was considered adequate, for the purpose of providing a realistic design tool for helicopter propulsion system definition, to limit the model detail to machinery operation within a fixed airframe and atmospheric environment.

A breakdown of the helicopter system into its major modules including the rotor and the gearbox and shafting is shown in Figure 3. Torque from each power turbines drives a shaft whose torque is, in turn, transmitted through a gearbox to another shaft which ultimately drives the main and tail rotors. Both the flexibility and the inertial effect of the shafting are included in the model.

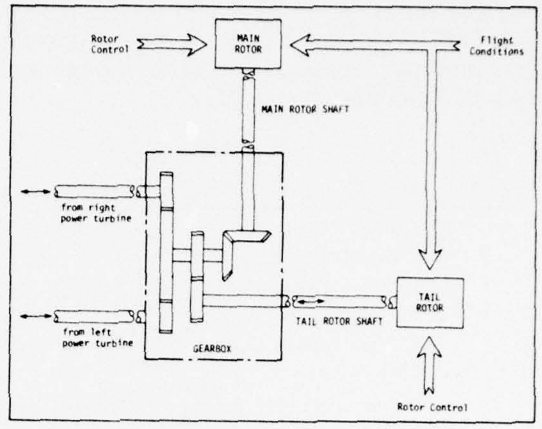


FIG. 3: HELICOPTER LOAD SYSTEM DEFINITION

The turbo machinery which comprise the gas turbine power system is shown in simplified form in Figure 4. Basically, the gas-turbine consists of a compressor driven by a turbine mounted on a common shaft. Air is compressed by the compressor which delivers it to the combustion chamber. In the combustion chamber, the air is heated by burning fuel and is passed on to the turbine. The turbine develops only enough power necessary to drive the compressor; the excess power, in the form of hot gas is passed on to the power turbine which converts it to shaft power to drive the load. The description of the major components of a gas turbine take the form of aerothermodynamic maps which are highly non-linear and rely heavily on experimental data for their definition.

One such data map, which defined the flow characteristics of the gas generator compressor is shown in Figure 5.

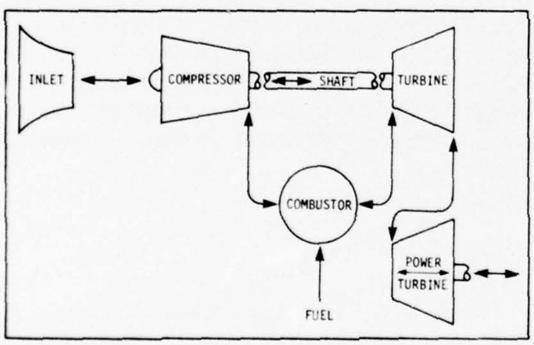


FIG. 4: GAS TURBINE POWER SYSTEM DEFINITION

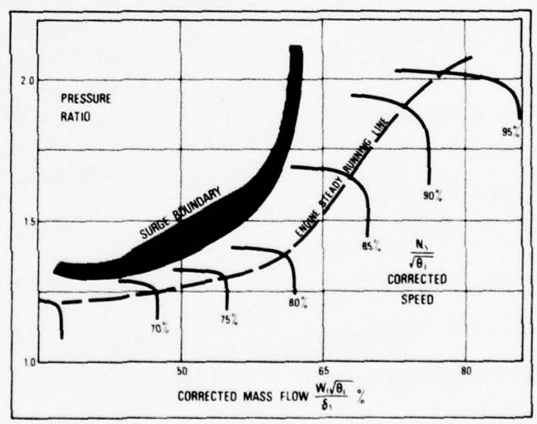
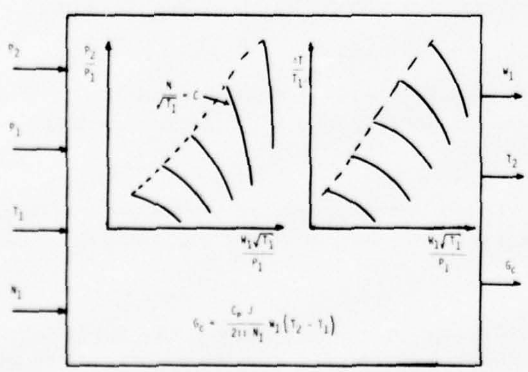


FIG. 5: TYPICAL COMPRESSOR FLOW MAP



COMPRESSOR MODULE

The performance of each major component may be described in the form of a functional module containing the necessary data maps and physical equations as indicated in the following example which defined the compressor performance.

where PR = compressor pressure ratio
N = compressor non-dimensional speed
T_1, T_2 = inlet and exit air temperatures
W = non-dimensional air mass flow
G = torque absorbed by compressor

In order to establish the validity of the complete model through comparison with actual hardware, it was decided to implement a model of a control system currently in operation. The particular control system modeled is shown in simplified form in Figure 6. For this type of control it is useful to distinguish between the fuel-metering and computing sections of the control. The fuel metering section simply supplies fuel to the engine according to the position of a fuel metering valve determined by the computing section of the control. Proportionality is ac hieved by maintaining a constant pressure drop across the metering valve; excess fuel being returned to the pump inlet.

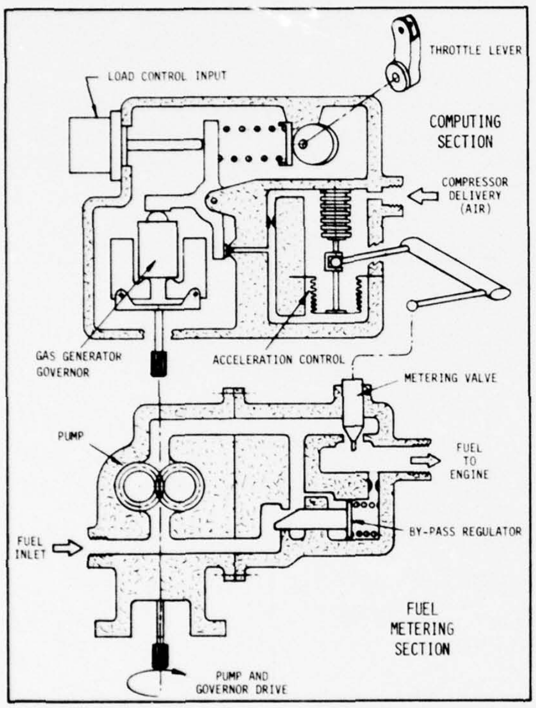


FIG. 6: CONTROL SYSTEM DEFINITION

The computing system in this particular example controls the gas generator power output via a simple speed governor. Safe, smooth control of the engine during power changes is achieved by a pneumatic acceleration control driven by compressor delivery pressure from the engine.

This technique of using actual engine parameters to limit the permissible amount of overfuelling is both simple and effective with altitude compensation of engine performance being inherent in the method of control.

Once the basic building blocks of the system were established, it was necessary to analyze each individual module and to gather the data required to assemble a model. This exercise represented a significant proportion of model development time and it was during this analysis phase that most of the decisions regarding degree of complexity were made. In areas where it was not clear what level of detail would be required, off-line studies were conducted in order to determine the effect of certain phenomena on the operation of that particular module. In particular, the fuel metering section, which is a fluid circuit of extremely fast response, was modeled independently and in great detail. (Ref. 2). Results of this study provided a great deal of insight into the frequency content and the level of detail required for this and subsequent models of a similar type.

As the systems model evolved and the data for each module was gathered, a complete document specifying the equations and the data for the model was produced (Ref. 3). To date, very few changes have had to be made in this systems model insofar as changes in complexity are included. It is important to emphasize that a document was produced at the outset which contained all of the information required to implement the model independently of choice of computer and prior to specification of code.

CHOICE OF COMPUTER

As mentioned previously, several off-line, independent studies were conducted during the course of the analysis to establish the techniques that would be required to implement the model. A model of the fuel-metering system was assembled on an analog computer and also on a digital computer using CSMP (Ref. 2). This study clearly indicated that in order to successfully represent such a system on the digital computer, a timestep of not more than 10^{-4} seconds would be required.

Knowing that some of the shaft dynamics of the system had time constants in the order of seconds gives some conception of the spread in frequency content of the system. It became fairly obvious that the cost of using a digital computer for such a complex model would be prohibitive. At the same time, the analog computer study of the fuel metering system indicated that real time operation of a hybrid computer model would be achievable provided one did not involve a digital computer in servicing circuits which had frequency content of the same order as the fluid circuits. Since evaluation of control hardware was one of the objectives of the program and the system to be modeled was extremely non-linear and complex, the hybrid computer was the obvious choice.

COMPUTER MODEL SPECIFICATION

Adhering to the procedures set down in Reference 3, a complete specification for the computer model was defined (Ref. 4). This document became the blueprint for the implementation of the model. It included program hierarchy, data structure, verification tests and a variety of debug features to facilitate the debug process.

The hybrid computer facility at the National Research Council consists of an EAI PACER digital computer and two fully expanded EAI 680 analog computers.

The model was organized such that the right-hand engine, fuel control and load control were resident on the master console, Console #1, of the analog section as shown in Figure 7.

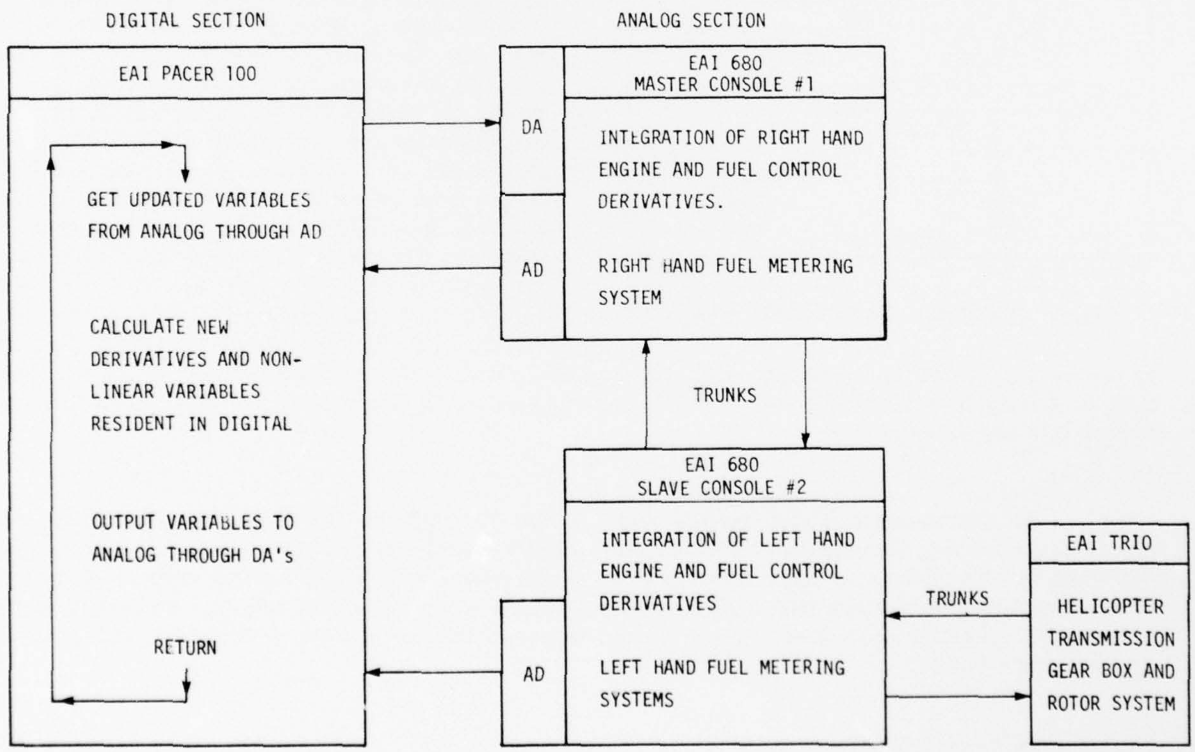


FIG. 7: EQUIPMENT ASSIGNMENT FOR COMPUTER MODEL

Console #2 was used to model the equivalent left-hand components and a free flow of data between the two consoles is achieved through internal trunks. Due to the limited capacity of the computer facility, the transmission, gearbox and rotor inertias were modeled on an external desktop analog computer which was connected via trunks to Console #2.

The hierarchical structure of the digital program is shown in Figure 8. This diagram applies only to the digital portion of the model; however, it is the design of this portion of the model which involves the most effort and usually it is the most difficult to control and debug. The figure indicates four distinct operations at the second level which include problem setup, debug operations, parameter manipulation and finally the high speed loop which is that portion of the code which services the analog circuits. It is recognition of these four distinct operations that has resulted in partition of the digital code in this way. This particular hierarchical structure has evolved over the life of several projects within the Analysis Laboratory of NRC and was further refined in the process of implementing the helicopter propulsion system model.

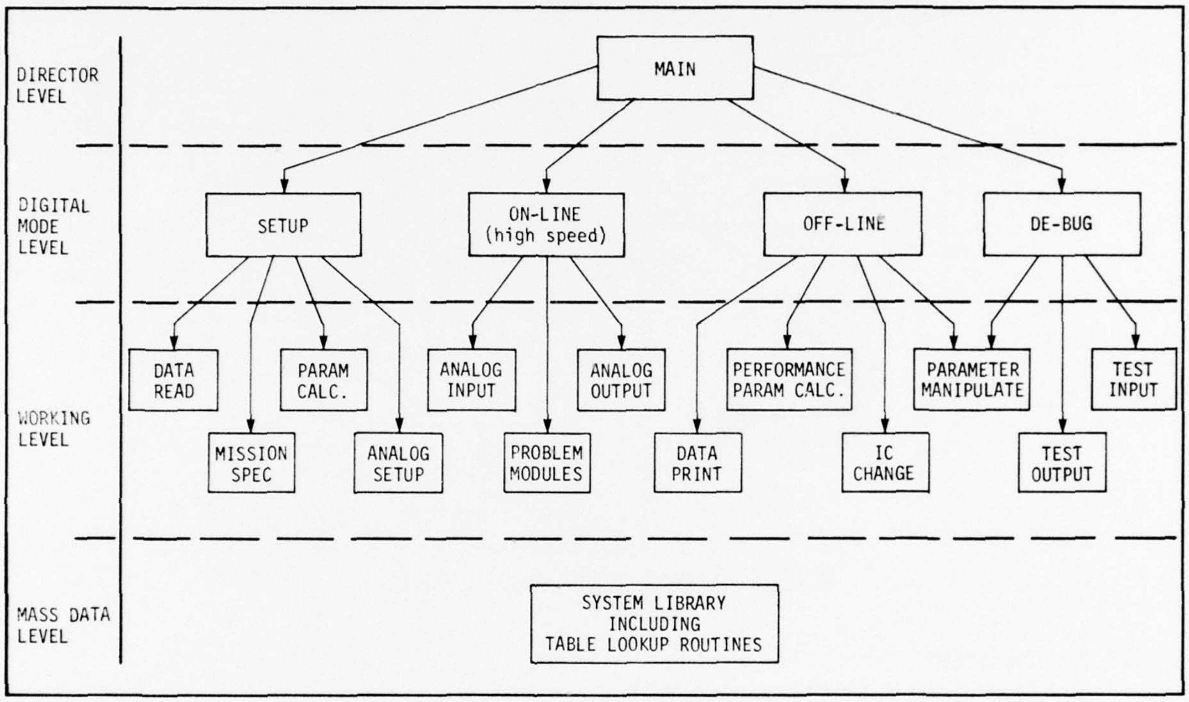


FIG. 8: DIGITAL COMPUTER PROGRAM HIERARCHY

While the hierarchical diagram indicates the levels of responsibility of the various groups of code in the digital computer, they tell nothing about the organization and structure of the data that this code must manipulate. The data structure used in this model is shown in Figure 9. Recognition of the fact that the only mechanism available for checking a digital program is testing it via some given set of inputs and observing the results of the calculations through some output medium has generated the requirement that all data be accessible to the operator.

The decision was made therefore to arrange for all of the information handled by the program to be treated as a global variable stored in a data base accessible by any routine. It has resulted in the development of a system of debug routines which allow inspection and manipulation of this data as required by the operator (Ref. 6). The fundamental principle behind this interactive package is the recognition that say form of debug statements used in a program must themselves be debugged creating additional time and effort required by the operator. Furthermore, removal of these verification tests changes the basic program with the result that it is no longer the same program that was validated. It was required, then, to develop a procedure for checking code in the environment in which it will ultimately operate. It is for this reason that this interactive debugging package was developed.

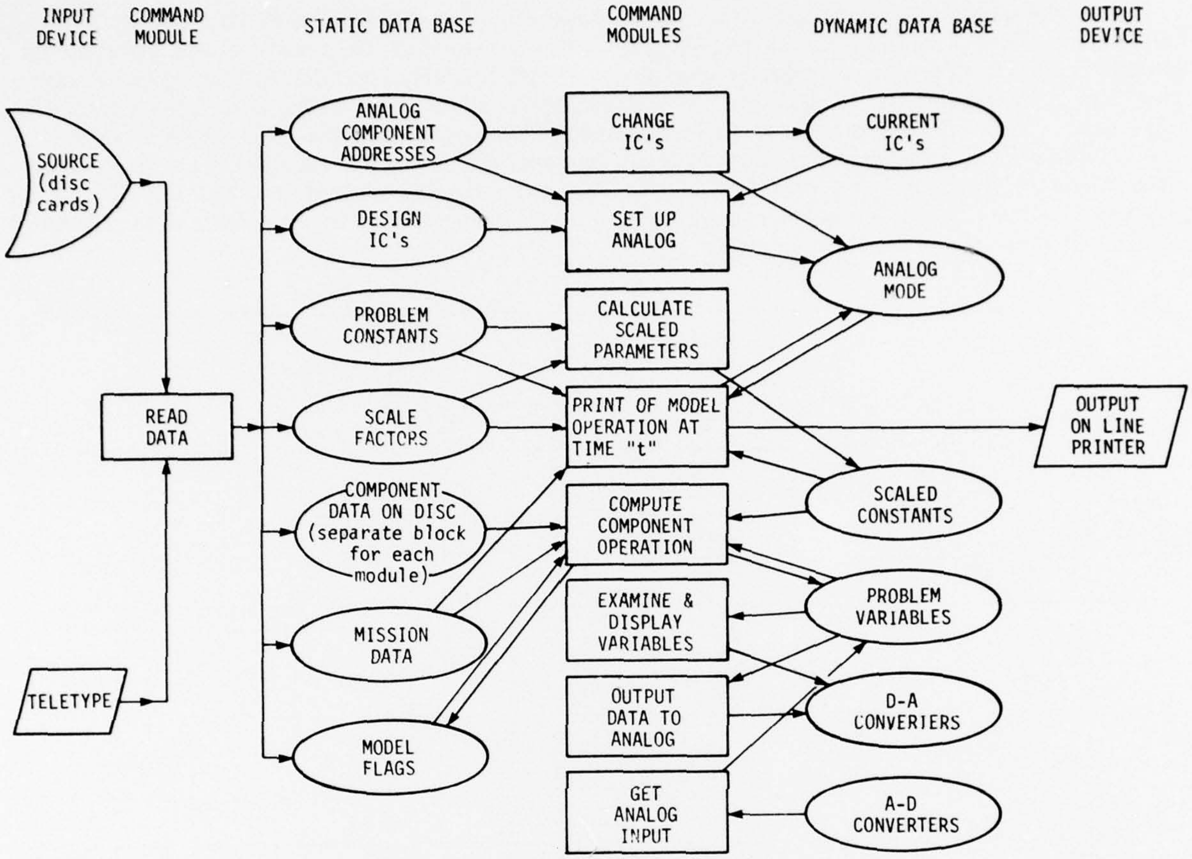


FIG. 9: MODEL DATA STRUCTURE

MODEL VALIDATION

Once verification of the model was complete; i.e.: confidence was established that the code had been implemented correctly and was in fact a true representation of the equations, it was necessary to validate the model against real hardware performance. From the outset of the project, model validation was regarded as an extremely important aspect of the development process. It was for this reason that the decision was made to model existing hardware prior to beginning any control design activity. Previous experience in modeling turbo-machinery systems (Refs. 7 and 8) has indicated that if the aerothermodynamic data defining the major components of the gas turbine were accurately defined, models of acceptable accuracy could be easily developed. Figure 10 shows the comparison between compressor delivery pressure and engine fuel flow as a function of rotor speed; both of these traces indicating excellent agreement with the experimental data provided by the manufacturer of the engine.

Having validated the basic engine model it was necessary to compare the performance of models of the fuel control with hardware. Comparison of performance of the fuel metering section with experiments is shown in Figure 11. While the comparison indicates that there is some discrepancy between the performance of the model and that of the hardware, the comparison is well within the spread in the experimental data from unit to unit.

The computing section of the fuel control was set up using actual production acceptance test procedures; adjustments to values corresponding to spring settings and pneumatic bleed areas being made as though the model were an actual fuel control. It was found that the steady-state performance of the acceleration and governor sections could be set to nominal values without difficulty.

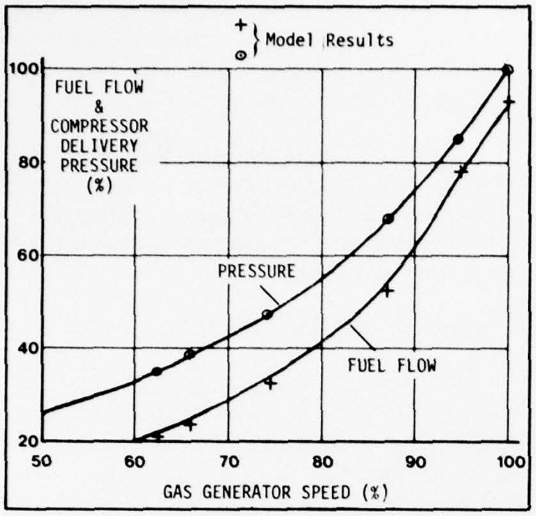


FIG. 10: STEADY STATE VALIDATION OF GAS TURBINE

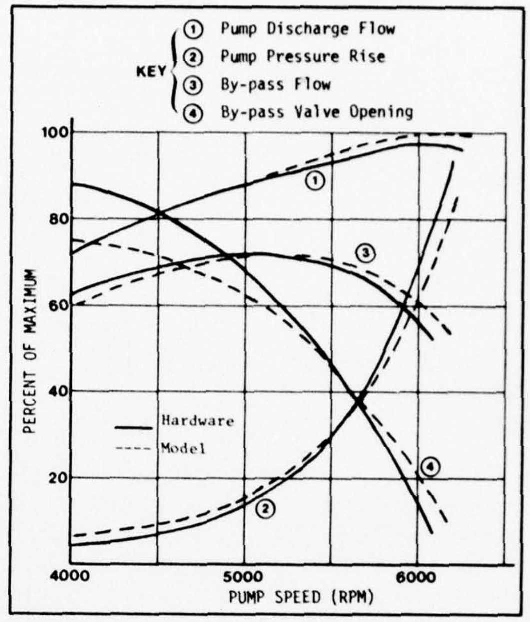


FIG. 11: STEADY STATE VALIDATION OF CONTROL SYSTEM

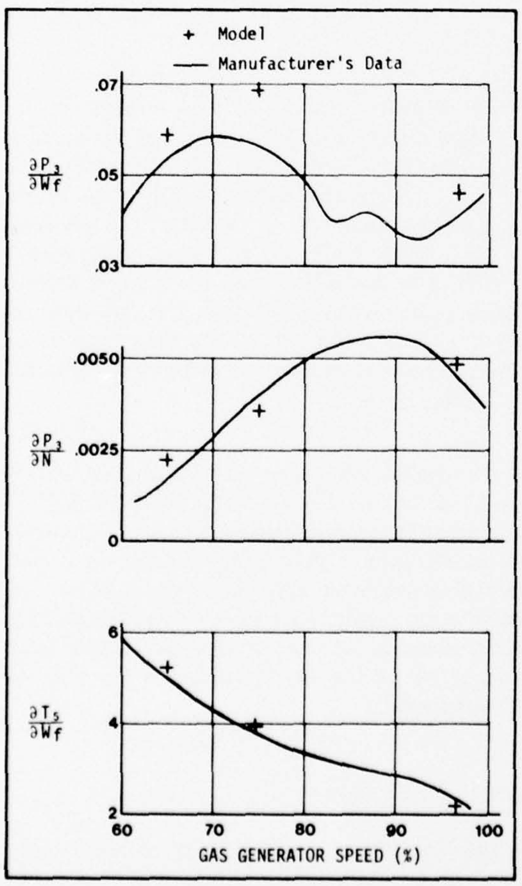


FIG. 12: DYNAMIC VALIDATION OF ENGINE

Once steady-state validation of the model was complete, it was felt necessary to check the dynamic performance of the model against whatever data from hardware tests were available. Figure 12 shows the comparison between the model performance and some of the partial derivatives of the engine performance normally provided by the manufacturer. These curves are considered standard design curves made available to controls manufacturers from engine manufacturers. They have for years been the basis of gas turbine control design and it can be seen that the model provided estimates of these partial derivatives which were quite accurate and completely adequate for control design purposes.

Fuel control dynamics were evaluated by comparing step responses with those obtained from actual hardware dynamic tests. Figure 13 shows the correlation between model and hardware for step changes in compressor discharge pressure. The characteristic shape of the response curve in which fuel flow moves initially in the wrong direction is a well-known feature of the hardware and is seen to be reproduced closely by the model. The discrepancies observed between theory and practice were considered acceptable. Fine tuning of such

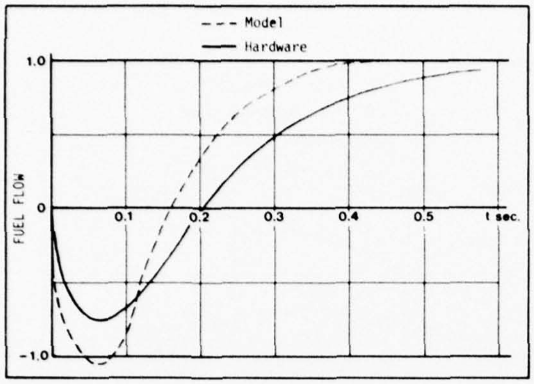


FIG. 13: DYNAMIC VALIDATION OF CONTROL SYSTEM

things as friction values, capacitances and effective fuel bulk modulus could be used to improve the fit; however, this was not considered necessary for the present.

At this point it was felt that the model had demonstrated its ability to operate as an adequate test-bed for control philosophy evaluation which was the main objective behind the simulation program.

THE "REAL TIME" PROBLEM

One of the purposes of the model was to consider the evaluation of control hardware later on in the development. While one realizes that this is essentially restricted to electronic control hardware, it still remained necessary to operate the model in real time. It was decided early in the implementation phase to run the model at 100 times slower than real-time in order to insure accuracy and validity of the model itself. Once these were established, one could separately turn attention to the realization of real time operation. The basic problem of achieving real-time operation in any hybrid computer model is to shorten the length of time required for the digital computer to perform its task and thereby update the D-A converters which service analog circuits more frequently.

Basically, there are two ways of achieving a more frequent update of D-A converters; to shorten the program execution time through improved programming and to arrange to do certain portions of the calculations more often than others through the use of interrupts. Results of experiments with the model indicated that there were three distinct frequency bands that needed to be serviced by the digital computer. Since little or no experience was available in an interrupt environment it was decided to first refine the programming of the model itself. To this end, the highest frequency and the intermediate frequency bands were re-coded in assembly language making use of as efficient calculation schemes as could be devised. Having reduced the execution time of each of these blocks of code to its minimum, it was apparent that the model was still a long way from real-time operation. It was decided that an interrupt environment was necessary in order to solve the problem of achieving real-time operation for hardware evaluation.

Initially, only the highest frequency portion of the model was serviced by interrupt driven code. This served to provide experience with interrupts and also reduced solution times from 100 to 10 times slower than real time. It was found that this speed of solution was convenient for evaluation of control concepts, both in terms of interacting with the model and in producing and documenting the results of simulation runs. Real-time operation, which was achieved with both the highest and intermediate frequency modules serviced by interrupt driven code tends to be so fast that the analyst is kept busy simply "running" the model and has little time to truly interact with it. While real-time is necessary for hardware evaluation, it is anticipated that most of the engineering studies will be conducted at solution speeds that are 10 times slower than real-time.

MODEL USE IN THE DESIGN PROCESS

Once a general purpose tool such as the model described in this paper is developed, many uses of that model are possible. The first and most obvious use to make of the model was to demonstrate operational characteristics that were known to exist in the existing hardware and to use the model to generate techniques for improving system performance. Figure 14 shows strip-chart records of a typical large power excursion while under the control of the power turbine speed governor.

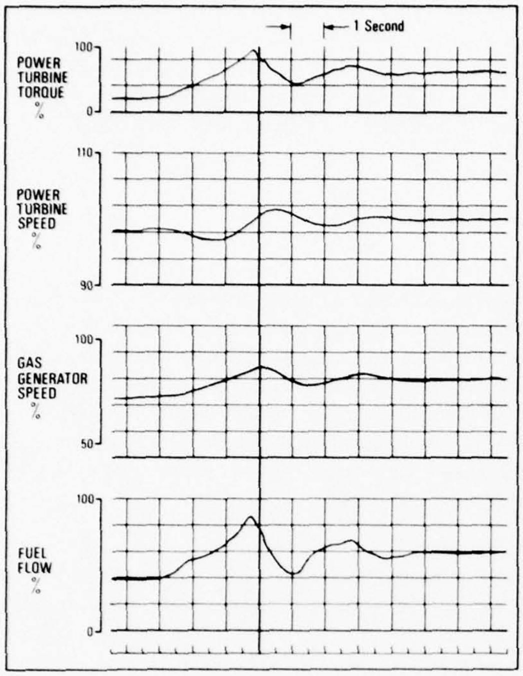


FIG. 14: LARGE SCALE POWER TRANSIENT UNDER CONSTANT ROTOR SPEED CONTROL

PROJECT CONTROL

It is interesting to review the organizational structure of the team involved in this project. This is particularly true in view of the fact that it involved two organizations with widely divergent goals. On the one hand, the National Research Council is interested in the technology of model development and in the use of computers in engineering. On the other hand, Aviation Electric Ltd. is a profit-motivated company whose primary aim is the development of safeable hardware. As a corporate body it is not in a Company's best interest to relinquish control of a project of this magnitude to persons or organizations outside their own. Yet the cost of development of the model, and in particular the amount of development of modeling technique that was required together with the availability of equipment would have made this model extremely expensive to develop in house.

Figure 15 shows an approximate estimate of the project cost sharing in terms of man-hours of effort. It seems fair to say that in

Although not indicated in the figure, it is significant to note that the response frequencies and damping exhibited by the model in this mode of operation are almost identical to recently obtained engine test bed records.

Having achieved a high degree of credibility, both in reproducing the performance of actual hardware, and in the solution of actual operational problems the model was used as an evaluation of a variety of control concepts. The first level of evaluation was in the design of a limited authority power management system to be compatible as an add-on device for the existing hardware. This was felt by Aviation Electric Limited to be an intermediate step towards the eventual evolution of new control concepts.

In addition to the limited authority system, mentioned above, a digitally based full authority control system has been specified by engineers at Aviation Electric Ltd. and the hardware has subsequently been built in breadboard form.

It is intended, in the very near future, to interface this new digital controller with the engine model prior to committing the final design to a hardware form suitable for engine demonstration running.

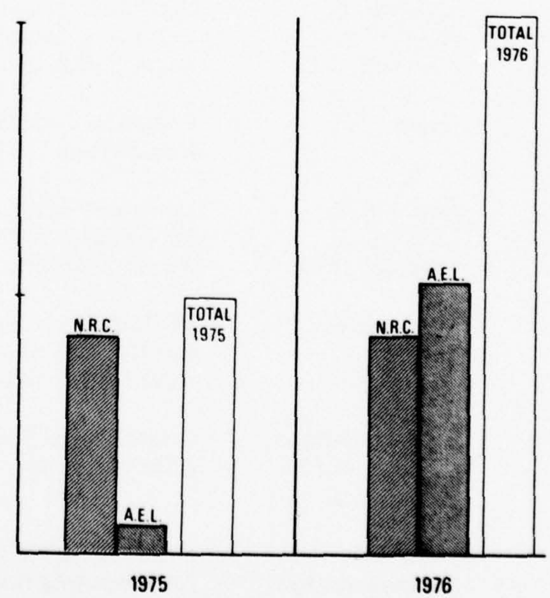


FIG. 15: PROJECT COST SHARING

the initial year of the project, NRC carried the bulk of the effort and the responsibility for pursuit of the model development. It is also fair to say that it was in this year that many of the modeling techniques and many of the problems that were eventually solved, were encountered. This reflects an appropriate role for a research establishment to assume in view of the fact that the ultimate user of the model is a private company. As is indicated in Figure 15, the level of effort by Aviation Electric was considerably higher in the second year. During this year, the model validation was completed and use of the model as a design tool began.

CONCLUSIONS

A detailed model of a gas turbine powered helicopter system has been developed. The complexity and wide range of frequency content of signals involved made the hybrid computer the obvious choice for implementation. Comparison of the model with existing hardware has indicated excellent agreement between theory and practice and it is generally agreed that the model has now been accepted as a viable design tool. Real-time operation of such a complex model was only possible through extensive programming in assembly language together with interrupt driven routines which service the higher frequency circuits. The model has exhibited its capability to solve operational problems of current equipment and also to rapidly evaluate design concepts.

Finally, the entire program provides an excellent demonstration of Government and industry working together to solve a complex control problem in the sphere of advanced technology.

REFERENCES

1. Peczkowski, J.L. — *Automatic Control of Free Turbine Engines.* Bendix Report.

2. MacIsaac, B.D., Gagne, R.E., Inrig, C. — *Analog and Digital Computer Models of the Metering Section of a Gas Turbine Fuel Controller.* NRC LTR-AN-22, 13 May 1975.

3. Langton, R., Evans, R.M., MacIsaac, B.D. — *Helicopter Propulsion Controls — System Model for Twin Engine Helicopter Power Plant.* Aviation Electric Ltd., AETR 36586, Mar. 76.

4. Gagne, R.E. — *Computer Modeling and Simulation Handbook — MKIII Simulation.* May 1976, p. 147-154.

5. Evans, R.M., Langton, R., MacIsaac, B.D. — *Helicopter Propulsion Controls — Computer Model Specification for Twin Engine Helicopter Power Plant.* Aviation Electric Ltd., AETR 36588, Apr. 1976.

6. Gagne, R.E. — *BUGOFF — An On-Line Interactive Debugging Package for Digital and Hybrid Computers.* NRC LTR-AN-30, Sept. 1976.

7. Saravanamuttoo, H.I.H., Fawke, A.J. — *Simulation of Gas Turbine Dynamic Performance.* ASME Paper No. 70-GT-23, April 1970.

8. Falk, A.J., Saravanamuttoo, H.I.H., Holmes, M.W. — *Experimental Verification of a Digital Computer Simulation Method for Predicting Gas Turbine Dynamic Behaviour.* Proc. I. Mech-E., Vol 186 27/72, 1972, P. 323-329.

ON THE INVESTIGATION OF THE RAM AIR EFFECTS ON THE AIR SIDE COOLING SYSTEM PERFORMANCE OF A NORTH AMERICAN CAR

U.W. Schaub

Engine Laboratory

Division of Mechanical Engineering

SUMMARY

Road tests alone do not suffice in providing the manufacturer with the necessary information on cooling fans to meet the new and stringent efficiency and noise reduction requirements of customers.

Appreciable fuel savings may be possible by carefully optimizing the air side of the automotive cooling system with respect to vehicle speed and heat load.

A research study on how these variables affect cooling system and component performance of a typical North American passenger sedan has been started with the support of Canadian Fram Limited. Datum road tests and preliminary wind tunnel testing in the 3m X 6m Propulsion Wind Tunnel of the Division of Mechanical Engineering have been completed. This work has resulted in establishing a wind tunnel test section/vehicle configuration that is suitable for investigating the design and off-design performance of the air side cooling system.

Novel techniques for controlling the engine bay pressure and for deriving cooling fan pressure rise with the fan in its normal engine bay surroundings and with the vehicle inside the wind tunnel are being investigated.

1.0 INTRODUCTION

Present customer enphasis on better fuel consumption and noise reduction places new and difficult demands on the cooling fan under all operating conditions. The greatest loads the automotive engine cooling fan has to cope with under normal operating conditions occur at hot idle and at 50 km/h as the vehicle is driving up a 7.2% grade, when full air conditioning is being used.

In considering the overall fuel economy of operating the vehicle it is important to realize that much of the vehicle operation takes place at partial load when the heat loads to be dissipated are less than maximum. The energy required to achieve engine cooling can be significant. Energy must be provided in order to overcome drag losses of the cooling air captured from the approach flow (ram air), which can be as much as 15% of the total aerodynamic drag of the vehicle (Ref. 1), and to power the cooling fan. Although aerodynamic drag is only one factor affecting resistance of the vehicle to motion, the fuel consumption needed to overcome cooling air drag can be as large as 5% (Ref. 2). While the power required to drive the cooling fan may appear small relative to the installed engine power, full engine power is required only intermittently during the life of the engine. Most of the time the power requirements are much less than the installed power, such as during cruising at 100 km/h, and then the power used by the fan can be as high as 5% of the brake horsepower. Depending on how efficiently the cooling air flow is managed, how high the system resistance is, and how the cooling effort is split between the available ram effect and the cooling fan, the fuel necessary to achieve engine cooling may be as much as 10% of the total fuel consumption.

Appreciable fuel savings may be possible by carefully optimizing the air side of the cooling system with respect to vehicle speed and heat loads. One method of improving the fuel economy, and reducing noise, is to decrease fan torque as engine speed increases; but, in order to achieve the best advantage it is important to determine the cooling fan performance with and without ram air.

At present the fan designer does not know beforehand to what extent the available ram air changes the fan characteristic, causes air to bypass the fan, and how the cooling fan air flow should be matched to the available ram air. The existing procedure of using static test stand fan performance data — without actually knowing the ram air effects — and then verifying the adequacy of performance for each application under road conditions cannot be relied upon to lead to optimal fan designs in the short time normally available. Nor does it lead to easy transfer of knowledge from one fan design to the next. This problem can be examined thoroughly only in the wind tunnel, where the relevant parameters can be controlled and where the vehicle's engine bay pressure can be varied.

The Division of Mechanical Engineering of N.R.C. is uniquely equipped in Canada to assist in research in this problem area. This Division has a wind tunnel facility, the 3m X 6m Propulsion Wind Tunnel, that is large and fast enough to accommodate a full scale vehicle in its test section and is designed specifically to operate with live engines. It has a removable test section for convenient model installation and a suitable overhead crane. It is now equipped with loading ramps, automobile lifting slings and will have a wheel dynamometer.

2.0 PROGRAM OUTLINE

The Division of Mechanical Engineering and Canadian Fram, Ltd. (C.F.L.), a leading manufacturer and supplier of fans for the highly competitive car market in North America, have initiated a co-operative research program that is intended to relate cooling system (air side) performance and the system operating point to such important independent variables as: fan speed, back pressure, ram air flow, and heat exchanger temperature.

Since C.F.L. had already considerable experience in conducting instrumented road tests, its contribution to this research program has included both a test vehicle and some previously used in-vehicle instrumentation.

Full size motor cars had not been tested previously in N.R.C.'s Propulsion Wind Tunnel, consequently it was necessary first to obtain a datum performance record from road tests, and second to examine and establish suitable wind tunnel conditions with a typical North American passenger vehicle in the test section with respect to:

1) tunnel steadiness,
2) approach velocity profile,
3) distribution of cooling air velocity behind the radiator and,
4) engine bay back pressure.

The weather conditions existing at the time of the road tests precluded generating maximum head loads, and both the weather conditions and the available instrumentation were not suitable for making accurate and detailed measurements. The ones made were, however, quite appropriate for indicating whether or not the wind tunnel/vehicle test configuration and conditions represented cooling air flows under actual road ram air conditions correctly.

In order to know what the velocity distributions at the front of the vehicle, the air flow conditions behind the radiator, and the fan performance should be in the wind tunnel, a number of road tests were at different speeds.

The wind tunnel test section was of the closed type and was provided with an elevated ground plane on which the test vehicle was placed. Several vehicle positions along the ground board were evaluated with respect to the external aerodynamic reference data logged during the road tests. The best compromise position was then used for all further tests.

To study the aerodynamic performance of the cooling system under ram air conditions involves measuring component and system resistances under ambient temperature and maximum heat load conditions. Component resistance will be obtained by sequential removal of such elements as the engine and the air conditioner heat exchangers, the intake grill, the bumpers, etc. It will be necessary to determine the cooling fan characteristics under ram air conditions while the fan is in its normal congested surroundings. This is not a simple task if one considers the number of openings in the engine bay compartment, and the clutter of structural and machine parts underneath the engine bay. The discharge cooling air flow will be collected inside a special catchment pan underneath the vehicle, and the pressure level inside the engine bay above and below ambient static pressure will be controlled by means of remotely placed plant exhauster machinery. Because there are large unsupported body panels, such as the hood, it will not be possible to cover as large a range of back pressures as is normally deemed necessary for mapping fan performance characteristics. Nevertheless, the pressure differentials obtainable (+0.8 to −0.2 k Pa) will provide sufficient range to off-design operations on either side of the running line with and without ram air. Providing a greater back pressure range appears to be beset with hardware complications and, at any rate may give rise to unrepresentative flow distribution problems. Direct measurement of fan pressure rise is recognized to be difficult in view of engine bay space constraints. It is planned therefore to determine fan pressure rise indirectly through measurements of fan thrust and air temperature.

The present article describes the purpose and technique of quite a large research program which has only just been started. Only a few typical results of the early work involving road and initial wind tunnel tests, by means of which correct tunnel/vehicle ram air conditions were established, are being presented herein.

3.0 TEST VEHICLE

Since the distribution of cooling air at the radiator strongly dependent on shape and detail of the vehicle's front end, generality in a study of the air side cooling system can probably not be realized. There is, however, a strong requirement to assure relevancy to current North American automotive engineering practice, and consequently it is important to use a representative cooling fan type, heat exchanger air velocities, temperature distributions, fin and tube detail, engine bay temperature levels and space constraints. This requirement was satisfied in choosing a 1976 Ford Granada as the test vehicle. The test vehicle is shown in Figure 1. It was equipped with air conditioning because most of the fans made by C.F.L. are sold in the U.S. market and are fitted on cars equipped with air conditioning.

4.0 INSTRUMENTATION

During the road and early wind tunnel tests the radiator through flow was indicated at the hot air side by a fixed array of nine small diameter propeller anemometers obtained from C.F.L. The array is shown in Figure 2. Propeller anemometers were chosen for air speed measurements because the cooling air was known to move very slowly and to be highly nonuniform (Ref. 3), there was only a minimum of axial space available between the heat exchanger and the cooling fan, and because the automotive industry had already considerable experience with this type of measuring instrument. These fixed position anemometers were unable to sense flow direction and were of insufficient number to provide the detailed information necessary for a reliable quantitative determination of air flow. The fixed array was later replaced with a traversing vertical array of propeller anemometers made by NRC and shown in Figures 3 and 4 for detailed air flow measurements. The NRC anemometers can be removed individually and rearranged in the array, and the array indexing can be changed to suit different sampling requirements.

To measure cooling air temperature and total pressure thermocouples and total pressure probes were mounted alongside the anemometers and a short distance downstream of the radiator core (to allow for as much velocity profile smoothing as possible). One total temperature probe was mounted on top of the front fender of the test vehicle to enable measurement of ambient temperature. The temperature and pressure data were used to calculate the properties of state at the anemometer locations and for correcting local to standard day conditions.

Coolant water flow rate was logged with a turbine flow meter and a digital read-out. Radiator water inlet and outlet temperatures were indicated by thermocouple probes.

Fan performance measurements made included: engine bay pressure, rotational speed, torque and thrust. Engine bay pressure, or back pressure in the case of shrouded cooling fans, was sensed by means of a single static pressure tap located on top of the engine block. Fan speed was indicated by means of an infrared light sender and receiver unit and a frequency meter with digital display similar to those used to sense anemometer propeller frequency. A torque/thrust meter, specially made and provided by C.F.L., was inserted between the production cooling fan and its drive pulley in the space normally taken up by the distance piece. The strain gauge signals were transmitted via a slip ring assembly to a manually balanced strain indicator.

A calibrated fifth wheel mounted on the rear bumper of the test vehicle was used to measure vehicle road speed.

Three pitot-static pressure probes were employed to measure total and static pressure distributions in the external approach flow:

a) one metre ahead of the vehicle
b) underneath the front bumper on the car centreline, and
c) under the engine bay in the cooling air exit and underside flow mixing region.

These rakes were casually referred to as the one metre, front, and rear boundary layer rakes, respectively. All three were oriented vertically and each comprised of six individual pitot-static heads.

The "one meter" rake served to indicate centreline approach air speed and profile under road and also tunnel conditions, where the solid blockage effects were expected to be large (some 11% for the vehicle and 9% for the support structure). The six pitot static heads were spaced 12.7 cm apart and the lowest was 23.5 cm above the road surface.

The "boundary layer" rakes were intended to yield the velocity distribution underneath the vehicle during the road and wind tunnel experiments. Road clearance changes due to surface asperities and normal vehicle vertical motion dictated probe road clearances of 8 and 9 cm for the front and rear boundary layer rakes, respectively. These clearance requirements were established through use of lead rubbing strips during repeated calibration runs on federal roadways. The pitot-static head spacings of these rakes were 6 and 2.5 cm for the front and the rear boundary layer rakes, respectively. While there was no measurement of flow direction, the probe data were considered sufficiently accurate for evaluating how serious the underside blockage effects in the wind tunnel might be relative to the road test results.

Figures 5 and 6 illustrate how the instrumentation read-outs were arranged in and carried by the vehicle. The back rest of the front passenger seat was removed so that the instrument console could be accommodated and viewed by an operator in the back seat. The equipment was powered by a C.F.L. supplied dc-ac converter drawing from two 12-volt batteries.

5.0 EXPERIMENTAL METHOD

5.1 Pressure Measurements on Board the Moving Vehicle

To avoid pressure level problems due to external effects (wind and vehicle motion) the differential pressure transducer was backed with a reference pressure. Rather than carrying a constant reference pressure supply in the vehicle, which meets with many practical problem, the technique used by Hucho, Janssen and Schwartz of VW (Ref. 4) was adapted and used. VW overcame the back pressure problem by backing all measured pressures with a reference static tap located on a sting mounted pitot-static probe carried ahead and above the vehicle. The NRC method uses the approach total pressure indicated by a Kiel probe instead of the static pressure of the VW pitot-static probe.

The pressures were then referenced to stream static by averaging the measured differences indicated by runs in both directions and adding the approach stream dynamic pressure computed from fifth wheel data. In the wind tunnel the method was similar except, of course, that the tunnel dynamic pressure was used directly instead of the fifth wheel data.

5.2 Torque/Thrust Measurements

The thrust and torque straingauge circuits were null balanced after the engine had achieved a stable temperature (sump mounted thermocouple) just prior to each test run. Data readings were made during the runs by manually balancing the indicator. Null balance was verified after each run.

5.3 Cooling System Equilibrium Temperatures

During the early road tests on Highway #17 the cooling system thermostat operated normally and resulted in normal temperatures in the engine and comfortable temperatures for the test crew inside the vehicle. At low ambient temperatures this also caused inlet and outlet temperatures to the radiator to fluctuate wildly. To avoid spurious heat flow data because the relevant data was not recorded simultaneously the thermostat was removed and a small orifice plate was placed into the inlet hose.

5.4 Road Testing Procedure

Three nominal road speeds were chosen: 0, 50 and 100 km/h. Using a test vehicle crew of three (driver, observer, scribe) each test pass required ten minutes, excluding warm-up and traffic clear-up time. A total of 22 passes, or 11 complete return trips (test runs) were made. Only dry weather conditions with reasonably stable ambient temperatures (-4 to -24°C), barometric pressures, and with wind speeds of no greater than 8 km/h were selected. To minimize wind effects the test data were averaged from at least one pair of "return" passes in the same geographical area. Two highways of the Province of Ontario near Ottawa served as test sites: an unopened but paved section of Highway #17, just outside Renfrew, and Highway #417, a recently opened four-lane divided roadway. For reasons associated with the timing of the whole program the testing was done during winter. While Highway #17 was snow covered most of the time, Highway #417 was in a typical dry operational state, i.e. with an occasional sprinkling of road side gravel of less than 3 cm in diameter together with some traction sand and salt. Whereas Highway #17 was bordered with dense tree stands and outcrops of rock, Highway #417 was in open country with a median separation varying between 10 m and 50 m. Test runs on Highway #417 were taken inside a vacated traffic window of one km — all traffic was held back at least one car length behind the test vehicle and the distance to the last vehicle in front of the test vehicle was 1 km. The oncoming traffic flow was not controlled but very light. All test runs were made with the assistance of an NRC pacer vehicle which prevented following traffic from overtaking the test vehicle. All 50 km/h test runs on Highway #417 were co-ordinated through the Ontario Provincial Police and assisted by a patrol car. On completion of each pass the captured traffic trailing the test vehicles was released.

5.5 Wind Tunnel Testing Procedure

The wind tunnel tests were made in the NRC — DME 3m × 6m Propulsion Wind Tunnel. This facility is of the open circuit type, which made it possible to operate the test vehicle's engine at all conditions. Although this wind tunnel is capable of wind speeds of up to 250 km/h only speeds of up to 100 km/h were needed.

Because the loading bay of this wind tunnel was too short for the test vehicle a set of inclined entry ramps leading to the second floor was made, see Figure 7. A special lifting sling was fabricated for various test vehicles to hoist them from the incline and inserting them into the test section. Figure 8 illustrates the present test vehicle being loaded.

To avoid unrepresentative tunnel floor boundary layer build up that could bias the distribution of cooling air entering the vehicle's engine bay, an elevated ground plane was erected inside the test section 1.8 m above the tunnel floor. This 11 m long ground board was supported on several slender columns and trusses, all in the air stream between the board and the fixed tunnel floor. A large (0.5 m thick) fairing with a truncated trailing edge directly underneath the test vehicle connected the ground board with the tunnel floor and housed an exhauster duct for drawing off the entire cooling air that is collected by a catchment pan specially made for the test vehicle's engine bay. Figure 9 shows the test vehicle inside the tunnel's test section on the ground board. The leading edge of the ground board was located in the throat of the contraction preceeding the working section of the wind tunnel.

The vehicle was placed and anchored on the ground board with its suspension locked firmly to provide ground clearance dimensions identical to road test conditions. Different vehicle positions along the ground board were studied in order to find one that would generate velocity profiles in front of the vehicle and underneath its engine bay similar to those measured on the road whilst approximately representative cooling air flows were maintained. It was not considered essential to generate exactly matching ground boundary layers in the wind tunnel; but, underside blockage (boundary layer and catchment pan) was tailored by means of shape and slot suction to reproduce road test cooling air flow distributions behind the radiator.

The rake velocity distributions were studied for three vehicle positions: 0.13, 2.23, and 4.75 m from the leading edge of the ground board, two cooling fan speeds (1500 and 2800 RPM), and a range of tunnel air speeds. Although matching road (air) speeds were known these could not be set in the wind tunnel directly because significant vehicle and ground board blockage nullified known empty tunnel flow calibrations. It was, however, possible to establish velocity profiles at the one metre rake similar to those on the road, and this determined appropriate tunnel speed settings.

In order to be able to control and adjust engine bay pressure level a special cooling air flow catchment duct was fabricated for attachment underneath the engine bay region, see Figure 10. This catchment was connected by way of transition pieces and ducts to remotely placed exhauster machinery. To achieve good sealing, the power steering cylinder and linkages were removed and all clearance spaces between the structural, suspension members, engine, exhaust, driveshaft, heat exchanger cores, firewall, etc., were sealed off tightly with foam rubber strips and uncured rubber paste. All engine bay panel holes were sealed and the hood was taped down. The rear boundary layer probe was now contained inside the catchment duct. The exhauster was started and set to match the road test engine bay pressure while the tunnel and engine speeds were set to match road conditions. Radiator through flows were examined by means of the velocity anemometers and compared with corresponding road test data.

6.0 EXPERIMENTAL RESULTS

6.1 Road Tests: External Flow

The total amount of air that is displaced by the test vehicle is reduced by the amount of cooling air entering the grill. At zero forward speed the cooling fan draws air in from still surroundings and makes this displacement a negative quantity, but as forward speed builds up the displacement becomes a positive quantity. At large forward speeds the cooling air flow is a very small quantity relative to the total air mass displaced laterally by the body of the vehicle — somewhat less than 10 percent. The air approaching the front of the vehicle therefore slows down relative to the moving vehicle before it speeds up alongside the vehicle.

The average velocity at the one metre rake was observed to be only 0.88 of the actual road speed. While the velocity ratio should obviously increase and tend to infinity as the road speed tends to zero, the observed data scatter (±7%), presumed to be associated mostly with gust effects, masked any clear possible speed dependence of this ratio. Figure 11 shows that velocity calculated from the one metre rake data diminishes towards the ground — as expected from the previous considerations.

Though partially obstructed by the license plate, the front boundary layer rake directly underneath the grill showed further air speed reductions relative to the vehicle. The rear boundary layer rake, located below the engine bay alongside the engine, experienced the discharging cooling air flow in addition to the approach flow passing underneath the vehicle. To satisfy continuity requirements the average velocity here should be, and was actually observed to be, higher than that observed under the front bumper. While flow angles were not measured in the present case, the measured static pressures at the rear boundary layer were actually slightly positive relative to ambient (10 to 20% of approach flow dynamic), and very close to the measured engine bay pressure, where the air velocities were known to be small. Consequently the velocity distribution at the rear boundary layer rake, while subject to some misalignment errors, were not greatly in error, and in any event proved to be useful data for comparing wind tunnel results with road test results. Some of the observed velocity difference between the front and rear measuring stations is presumed to be associated with the displacement effect of the front wheels. The cooling air discharge from the engine bay is associated with the reduced velocities in the upper portion of the profiles.

6.2 Wind Tunnel Tests: External Flow

Although the total vehicle and supporting structure blockage was large relative to normally encountered wind tunnel blockages (it was nearly 20%) the test section flow rate was as steady as for the completely empty test section.

In view of the reported difficulties in simulating the road boundary conditions (Refs. 5, 6) a fixed ground board was used and the test vehicle's wheels were stationary on it. The velocity profiles were then studied at three different distances from the leading edge of the ground board. Some of these are shown in Figure 12. No major differences in the one metre rake position velocity profiles from those measured on the road were evident at distances of 0.13 m and 2.23 m, but at a distance of 4.75 m the velocity seemed actually more uniformly distributed. On the other hand, the profiles indicated by the boundary layer rakes were appreciably different in the wind tunnel. The maximum underside air velocities were for instance as much as 7% greater in the wind tunnel, and the engine bay static pressure, while still positive, was correspondingly less. The best match for the front boundary layer rake data was obtained with the test vehicle in the most rearward position (4.75 m). Neither position on the ground board nor tunnel/engine speed settings significantly altered the shape of the rear velocity distributions. Discounting evident differences in rake height settings, velocity profile comparisons and practical considerations suggested that the mid position (2.23 m) seemed like the best compromise vehicle position along the ground board.

The catchment pan, which bridged the gap between the engine bay and the ground plane, did offer noticeable additional blockage locally, but not one metre ahead of the vehicle, as indicated by the centreline velocity data shown in Figure 13. For example, there was a 5% decrease in maximum velocity underneath the front bumper. Slotting the ground board just ahead of the catchment pan appeared to cancel this additional blockage effect.

6.3 Internal Aerodynamic Data Comparisons

The C.F.L. anemometer measurements were, as explained above, not suitable for quantitative assessments, but did constitute an important basis for comparisons between road and wind tunnel results. Figure 14 facilitates typical comparisons at the 50 km/h and 100 km/h operating conditions. The cooling fan speeds and engine bay back pressures in the wind tunnel were the same as measured on the road. Although one anemometer directly underneath the cooling fan became inoperative during the wind tunnel experiments reasonable contours of local velocities could be derived. These indicated that the cooling air flow distributions generated in the wind tunnel were sufficiently similar to those on the road.

In both cases the air speeds near the top of the radiator exceeded those near the bottom, and the close proximity of the fan hub caused air speeds at the centre of the radiator exit area to be less than at the sides.

Figure 15 illustrates corresponding temperature rise distributions. Although the heat loads generated in the wind tunnel were lower than on the road, the isotherms of Figure 15 indicate reasonably good agreement between the tunnel and road data. This evidence is at least a qualitative substantiation of the observed cooling air velocity distribution likenesses.

6.4 Cooling Fan Operating Line Data

The running line static (zero road speed) performance data and superposed road operating data at 50 and 100 km/h are shown in Figures 16 and 17. Each figure features "warm" and "cold" ambient temperature conditions of 20°C and -9°C, respectively. The road tests were done at temperatures of -9°C and less. The cooling fan thrust and power appear to have a temperature dependency that cannot be accounted for by air density changes alone; but, these results must be interpreted cautiously because neither ambient nor radiator temperature effects have been studied systematically at this time.

The limited preliminary data available suggest that the ram effect on fan thrust and power is much less than expected.

7.0 CONCLUSIONS

1. The centreline air speed averaged over the distance equal to hood height minus ground clearance is 88% of the true vehicle speed one metre upstream of the test vehicle.

2. The air speeds below the front bumper were lower than at one metre ahead of the test vehicle.

3. The static pressures underneath the engine bay were very close to pressures inside the engine bay and slightly positive relative to ambient.

4. Coolant system resistance had to be held constant in order to achieve stable radiator temperatures.

5. Cooling air flows, fan thrust and torque appear to show dependence on temperature and ram air speed. The temperature dependence apparently cannot be accounted for by density changes alone.

6. The combination of the test vehicle and the ground board structure did not produce unsteadiness in the wind tunnel flow.

7. The blockage effects due to the vehicle and ground board structure in the wind tunnel are significant and dependent on vehicle position on the ground board relative to the ground board's leading edge.

8. The air speeds underneath the vehicle without its catchment pan tended to exceed those observed during road tests. The engine bay pressure was correspondingly low, but still positive.

9. The cooling air catchment duct caused a local blockage effect that reduced the maximum velocity overshoot underneath the front bumper observed for the clean vehicle configuration. Use of slot suction just upstream of the catchment pan facilitated adjusting this velocity maximum to match road test data.

10. Representative distributions of cooling air flow behind the radiator can be produced in the wind tunnel provided that the correct engine bay pressure and velocity maximum in the profile below the front bumper are generated.

8.0 ACKNOWLEDGEMENTS

The research program is being aided considerably by Canadian Fram Limited, who, among other things, provided the test vehicle, much of the in-vehicle road test instrumentation, and considerable road testing know-how. N.R.C. also acknowledges the co-operation between Canadian Fram Limited and the Ford Motor Company in Dearborn, Michigan, for the extended load of the 1976 Ford Granada test vehicle, and for the release of company test data.

Much assistance was given by the Ontario Ministry of Transport and Communication in making available suitable test sites for road testing and for providing O.P.P. escort and supervision during some of the road tests on Highway #417.

The Ministry of Transport of the Federal Government kindly provided some of the road test instrumentation, and the Township of Gloucester is thanked for authorizing the use of township roads to move test equipment to and from test sites.

9.0 REFERENCES

1. Costin, F. *Aerodynamics of the Modern Car Pt. 2.* Automotive Engineer, Vol. 1, No. 2, December 1975, pp. 16-18.

2. Carr, G.W. *Add-Ons Reduce Air Drag.* Automotive Engineering, Vol. 84, No. 2, February 1976, pp. 33-35.

3. Olson, M.E. *Aerodynamic Effects of Front End Design on Automobile Engine Cooling Systems.* Society of Automotive Engineers, S.A.E. 760188, February 1976.

4. Hucho, W.H., Janssen, L.J., Schwartz, G. *The Wind Tunnel's Ground Plane Boundary Layer — Its Interference with the Flow Underneath Cars.* Society of Automotive Engineers, S.A.E. 750066, February 1975.

5. Beauvais, F.N., Tignor, S.C., Turner, T.R. *Problems of Ground Simulation in Automotive Aerodynamics.* Society of Automotive Engineers, S.A.E. 680121, January 1968.

6. Fackrell, J.E. *The Simulation and Prediction of Ground Effect in Car Aerodynamics.* Department of Aeronautics, Imperial College of Science and Technology, I.C. Report 75-11, November 1975.

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FIG. 1: FORD GRANADA TEST VEHICLE INSTRUMENTED FOR ROAD TESTS

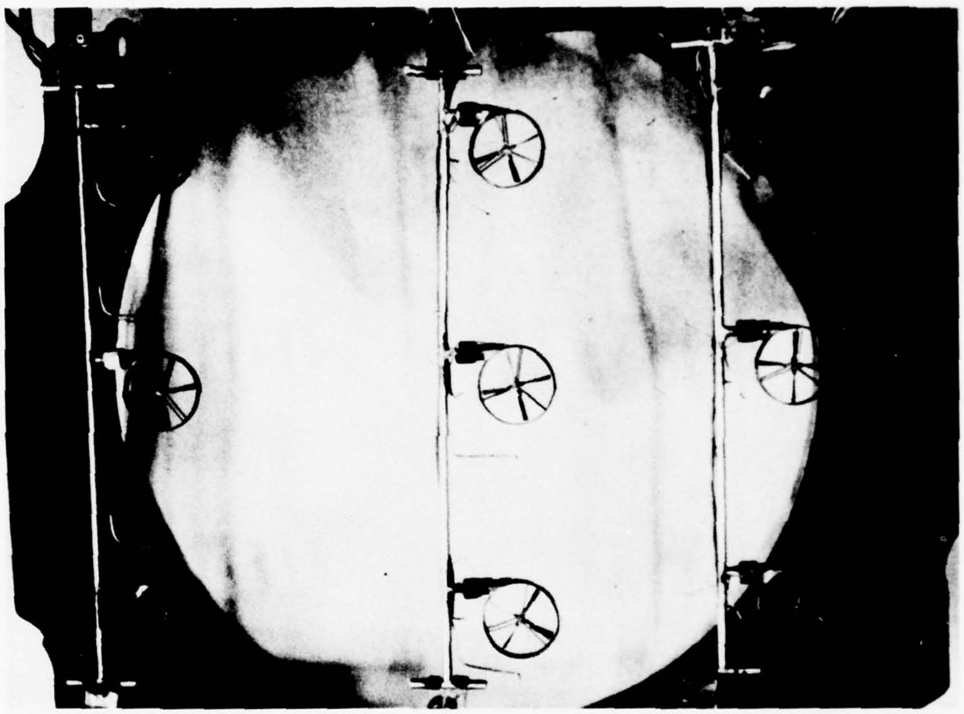


FIG. 2: ARRAY OF PROPELLER ANEMOMETERS FOR MEASURING COOLING AIR FLOWS THROUGH THE RADIATOR PROVIDED BY CANADIAN FRAM, LTD. FOR THE INITIAL TESTS

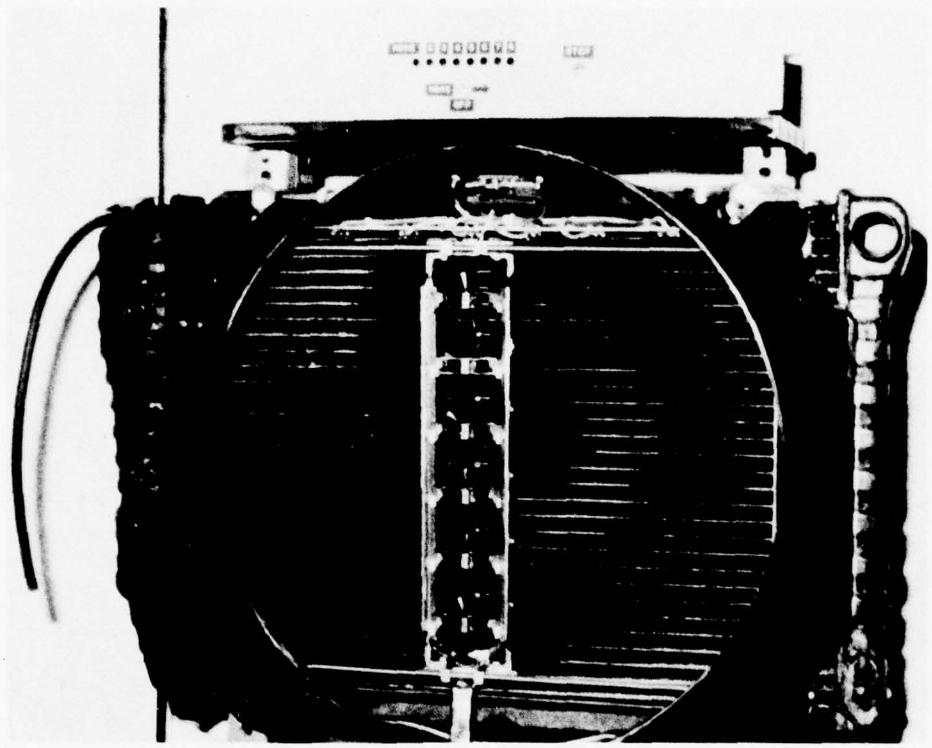


FIG. 3: NRC-MADE TRAVERSING ARRAY OF PROPELLER ANEMOMETERS MOUNTED IN POSITION NEXT TO THE RADIATOR CORE

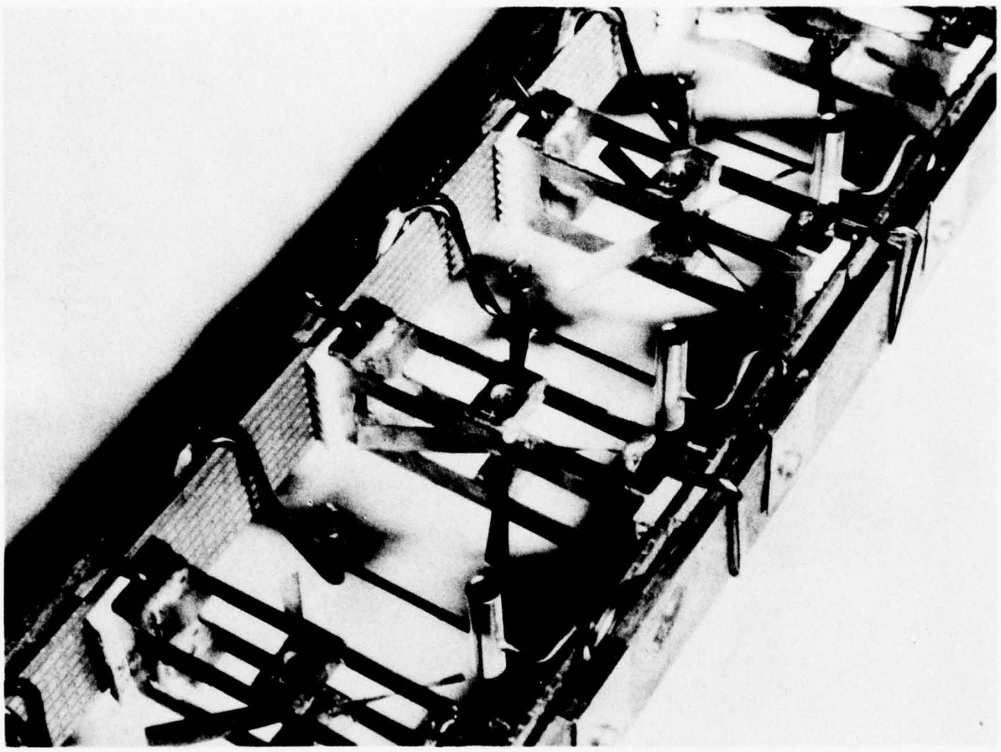


FIG. 4: CLOSE-UP OF NRC-MADE PROPELLER ANEMOMETERS, TOTAL PRESSURE AND TEMPERATURE PROBES

FIG. 5: VIEW FROM BACK SEAT OF TEST VEHICLE OF THE IN-VEHICLE INSTRUMENT CONSOLES

FIG. 6: CLOSE-UP VIEW OF IN-VEHICLE TEST INSTRUMENT READ-OUTS

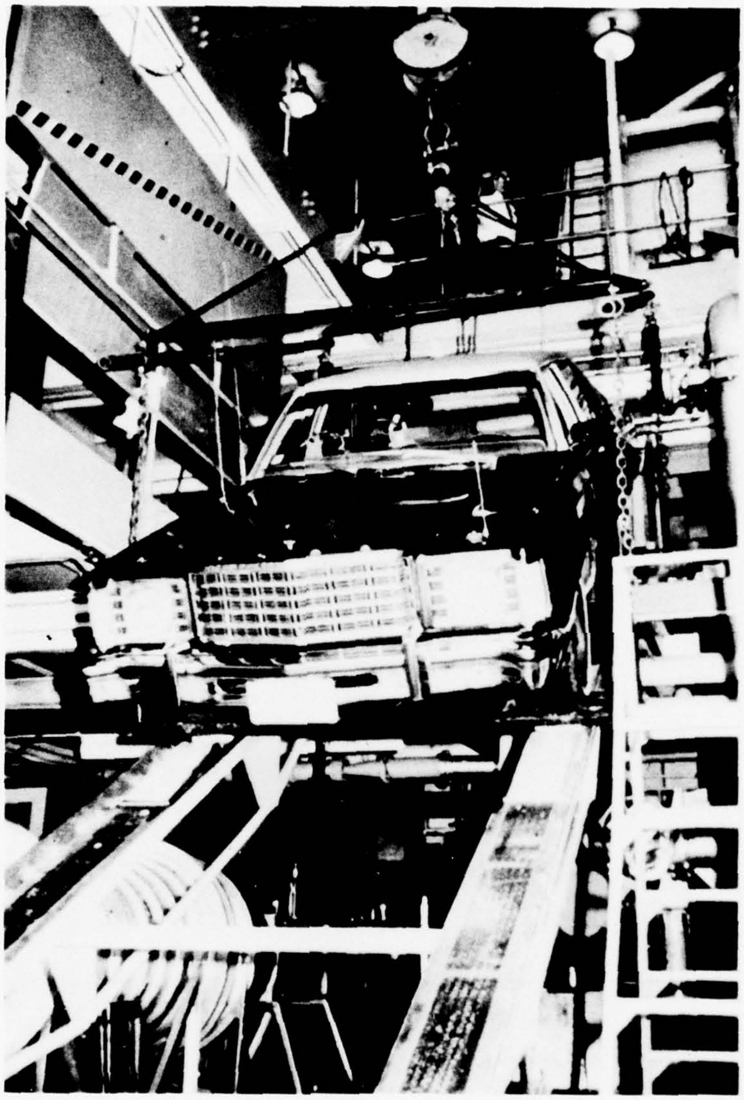


FIG. 7: TEST VEHICLE ON THE INCLINED RAMPS IN THE 3m × 6m PROPULSION WIND TUNNEL BUILDING. THE VEHICLE IS IN POSITION UNDER THE SLING

FIG. 8: TEST VEHICLE IS BEING LOADED INTO THE 3m × 6m PROPULSION WIND TUNNEL TEST SECTION

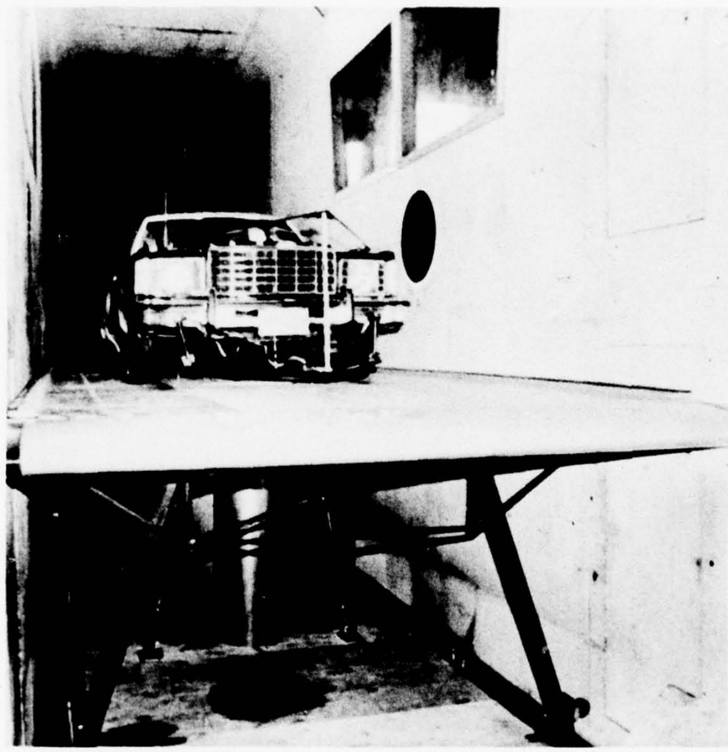


FIG. 9: FULLY INSTRUMENTED TEST VEHICLE ON THE ELEVATED GROUND BOARD. WITH THE ENGINE BAG EXHAUSTER DUCT SHOWN UNDERNEATH THE GROUND BOARD

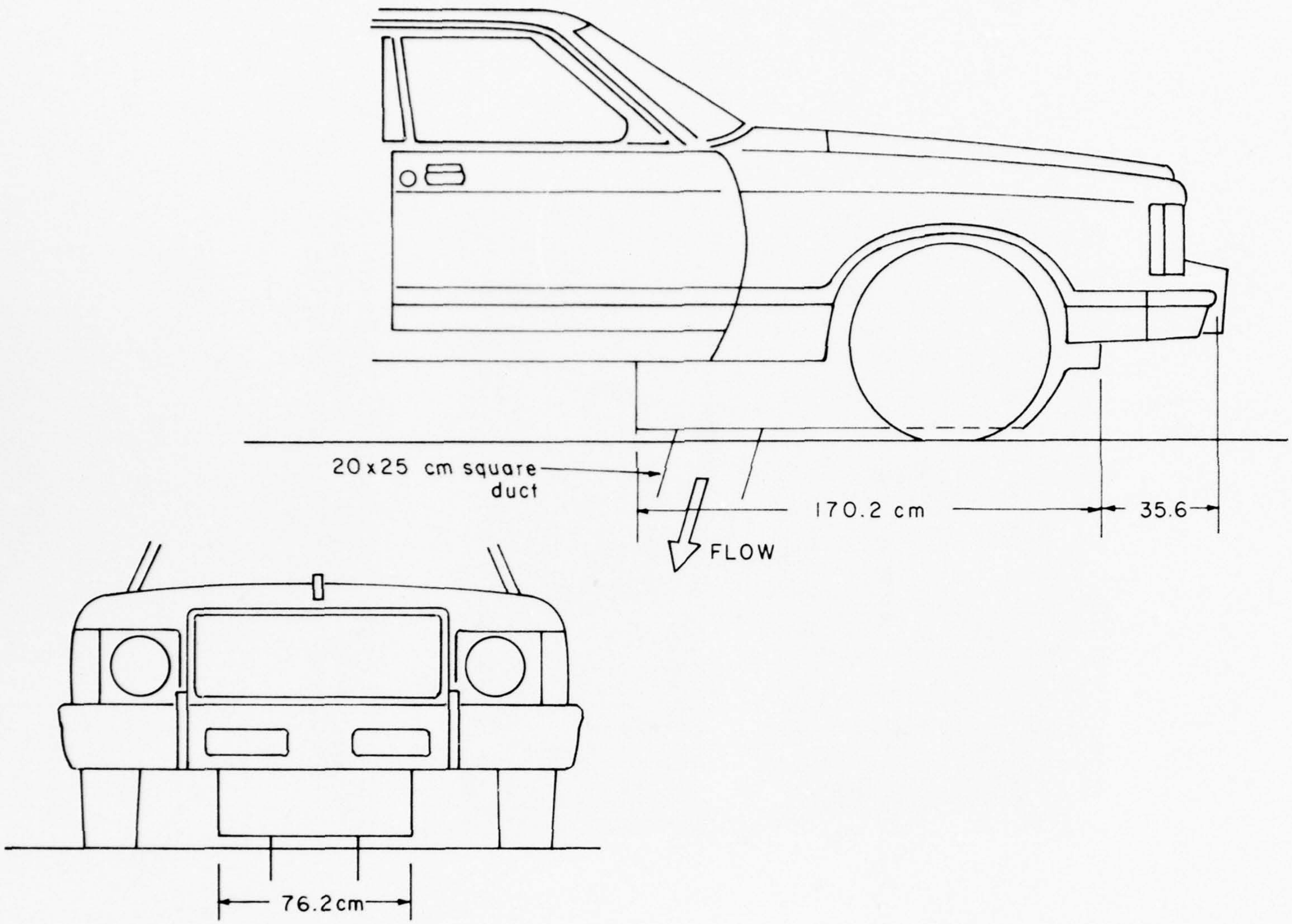


FIG. 10: SCHEMATIC OF THE TEST VEHICLE ON THE GROUND BOARD SHOWING THE ENGINE BAG DISCHARGE CATCHMENT PAN

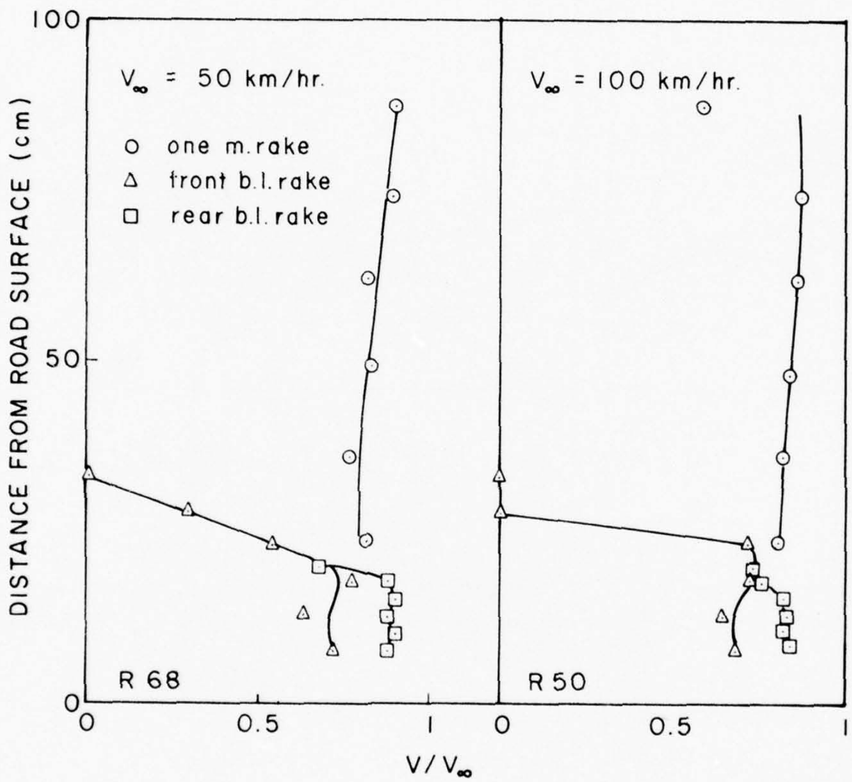


FIG. 11: ROAD TEST VELOCITY PROFILES

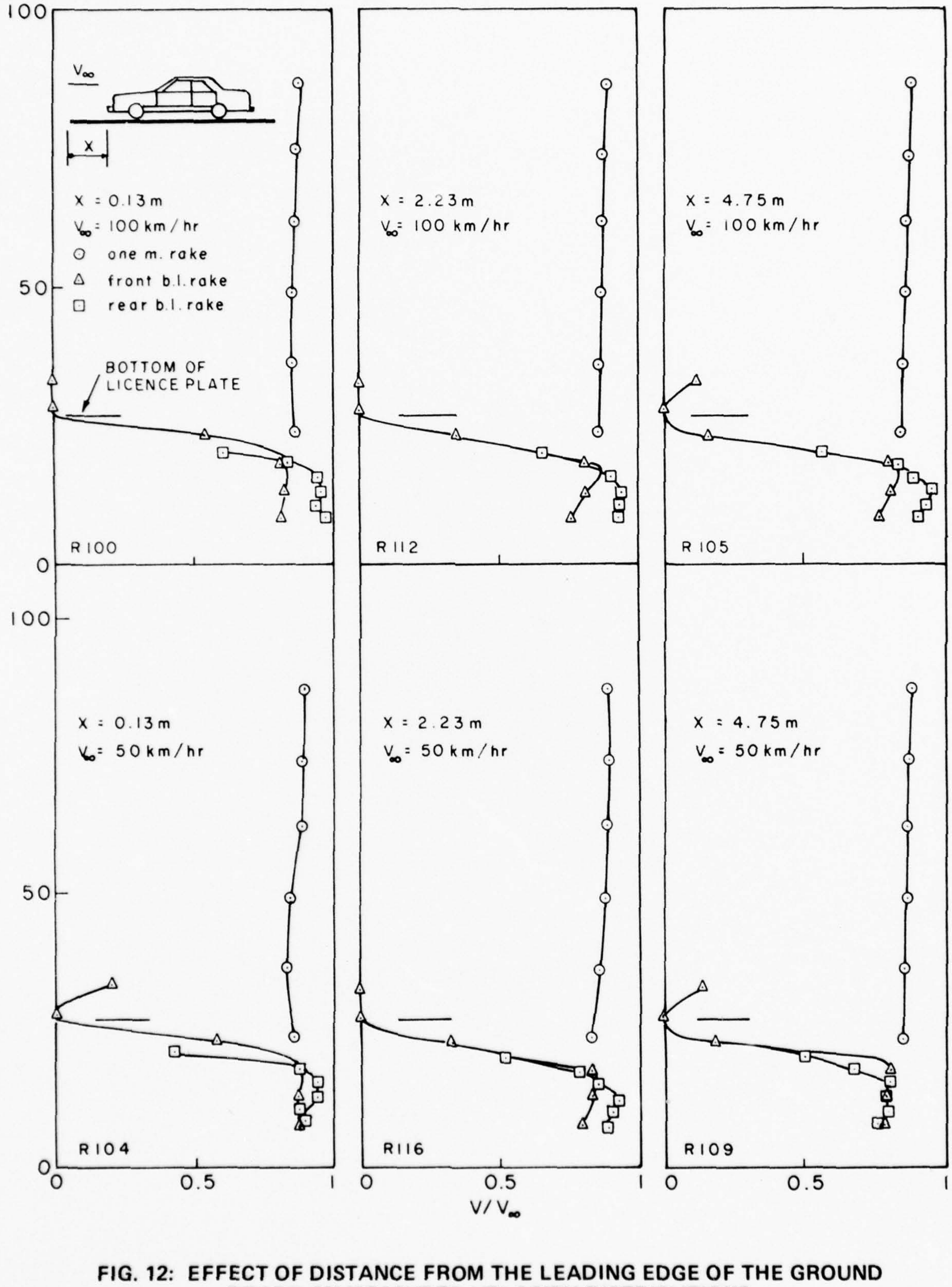


FIG. 12: EFFECT OF DISTANCE FROM THE LEADING EDGE OF THE GROUND BOARD ON MEASURED VELOCITY DISTRIBUTIONS

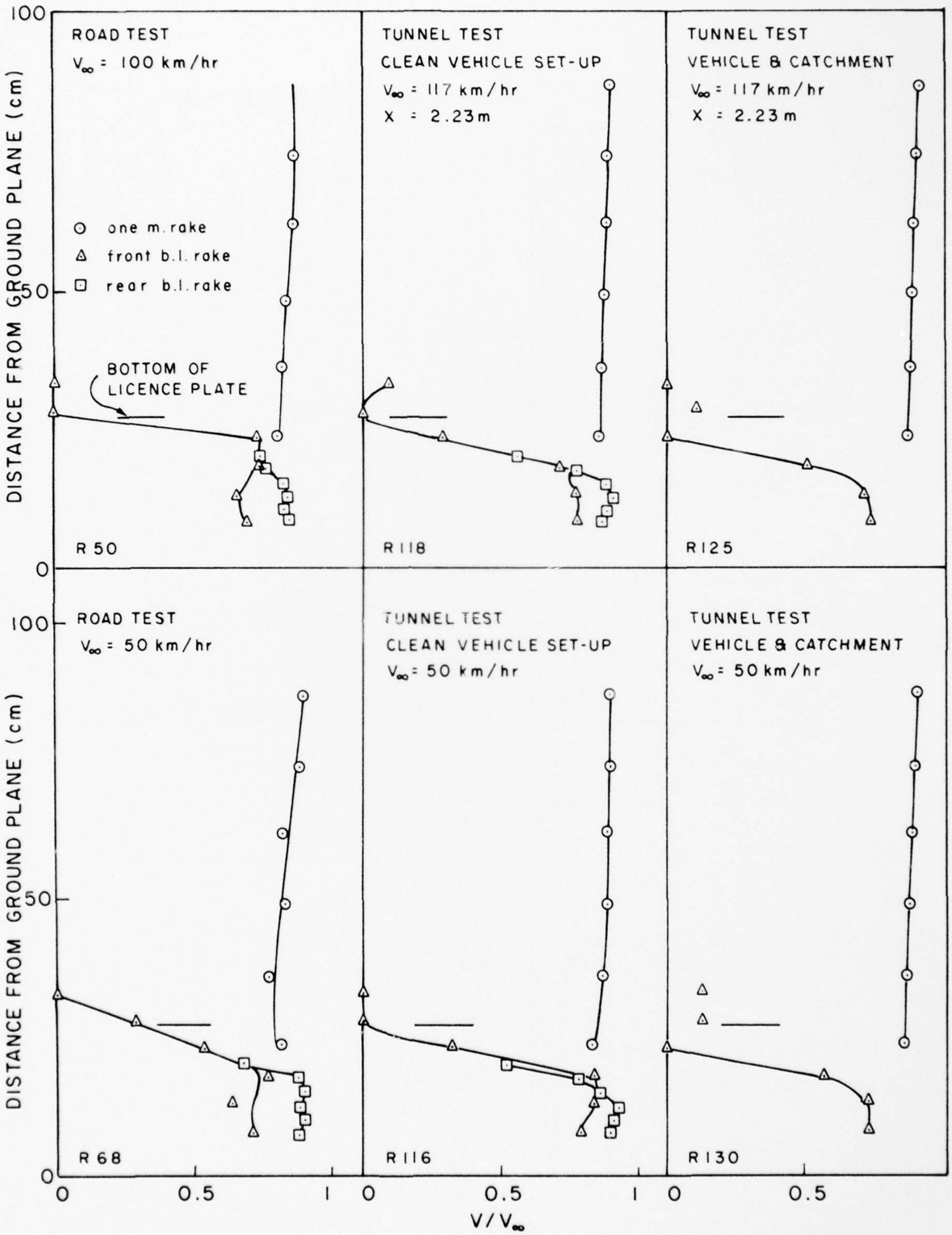


FIG. 13: FLOW BLOCKAGE EFFECT IN THE WIND TUNNEL DUE TO THE ENGINE BAG CATCHMENT PAN

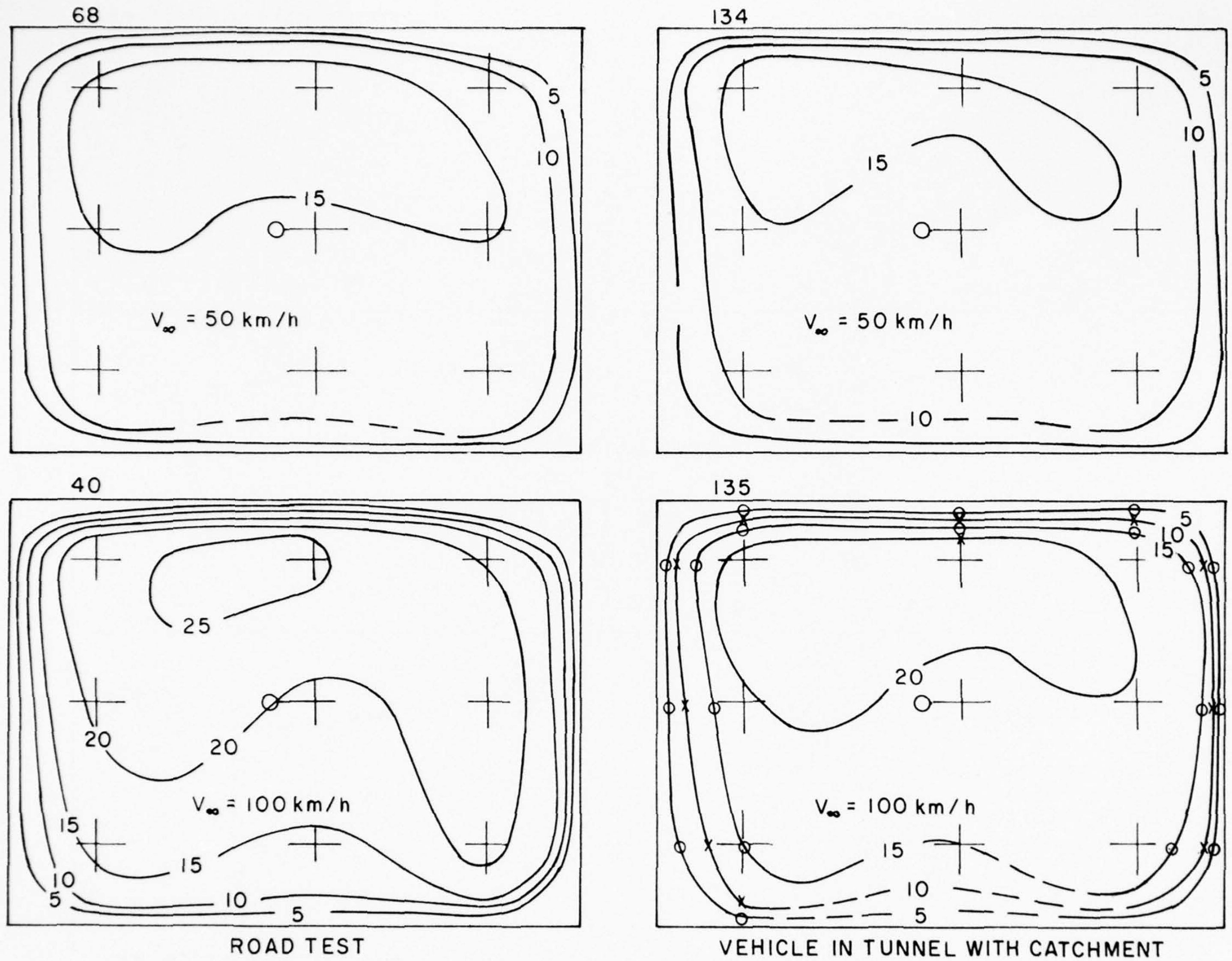


FIG. 14: AIR SPEED DISTRIBUTIONS IN THE OUTLET PLANE OF THE RADIATOR UNDER ROAD AND WIND TUNNEL TESTING CONDITIONS

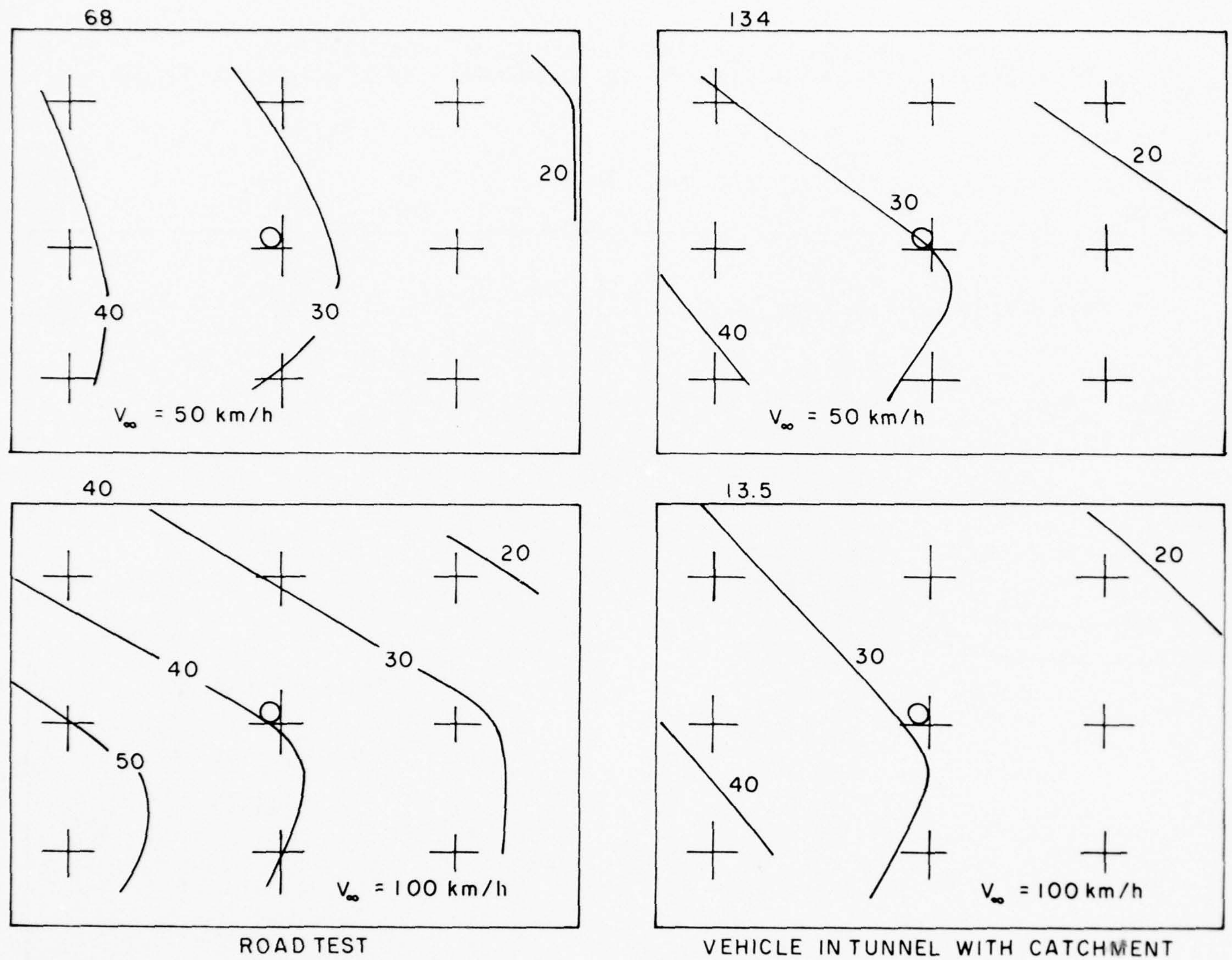


FIG. 15: AIR TEMPERATURE DISTRIBUTIONS IN THE OUTLET PLANE OF THE RADIATOR UNDER ROAD AND WIND TUNNEL TESTING CONDITIONS

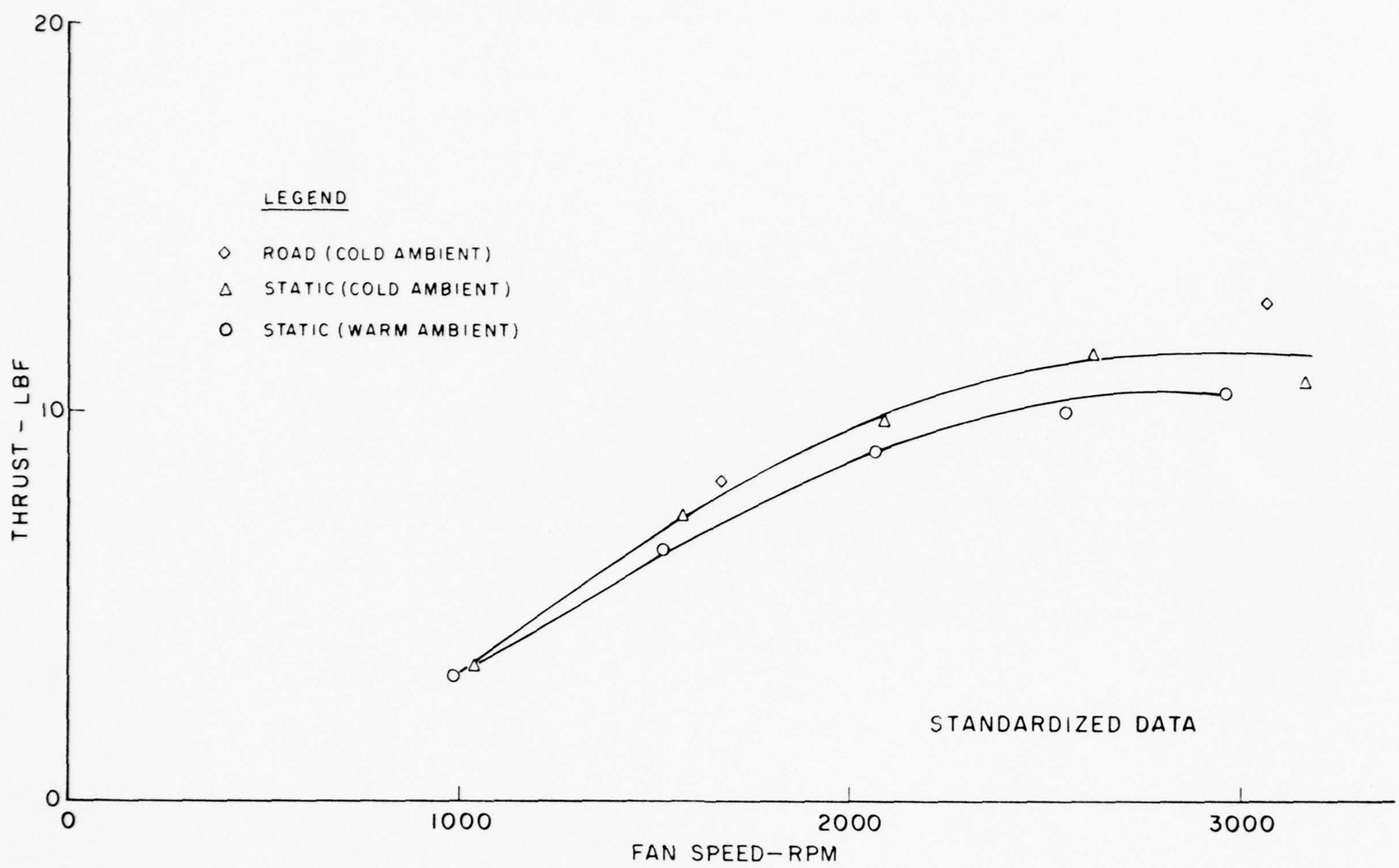


FIG. 16: THRUST/SPEED RELATIONSHIP OF THE TESTED COOLING FAN WITH AND WITHOUT RAM EFFECT AND AT TWO DIFFERENT AMBIENT TEMPERATURES

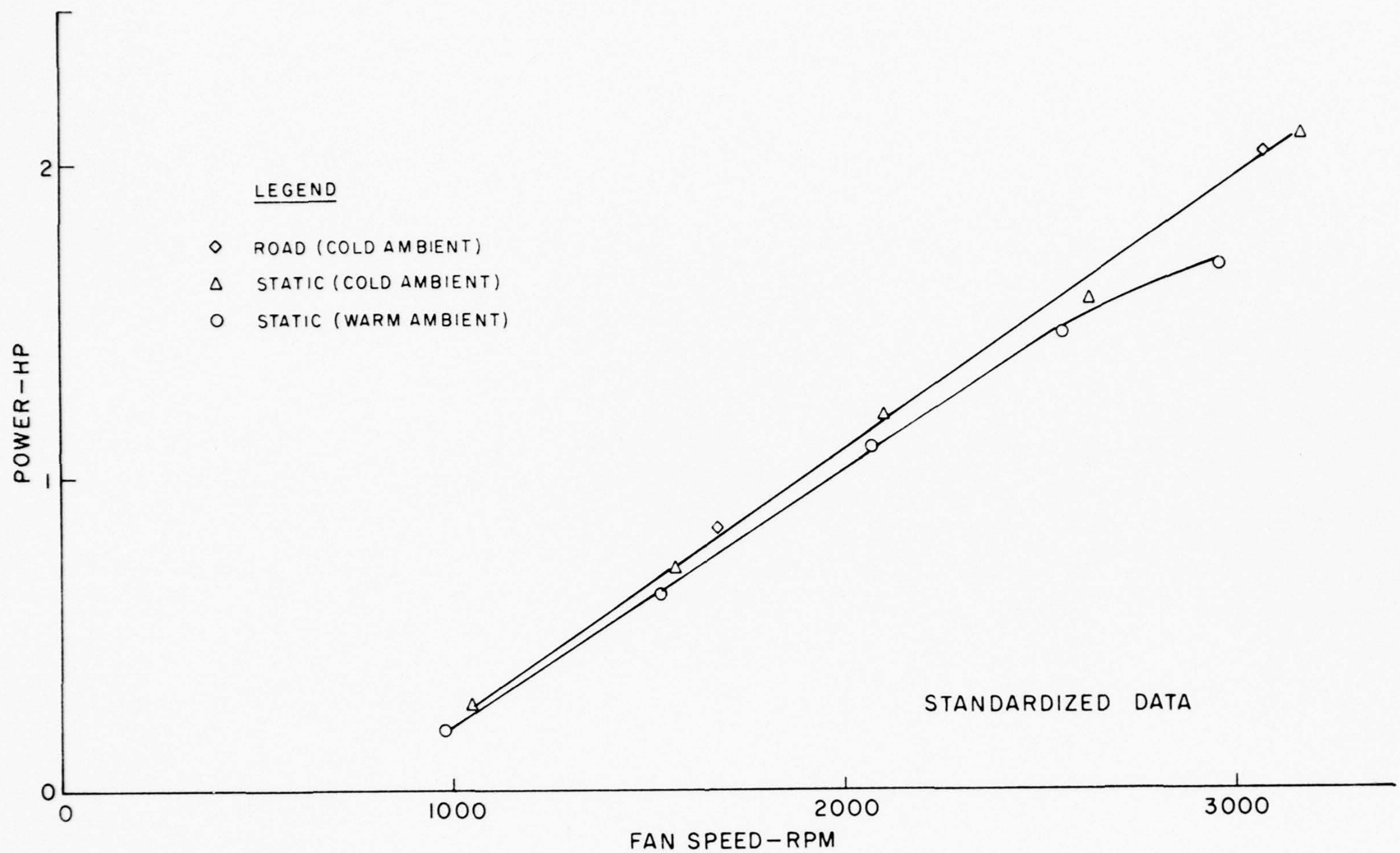


FIG. 17: POWER/SPEED RELATIONSHIP OF THE TESTED COOLING FAN WITH AND WITHOUT RAM EFFECT AND AT TWO DIFFERENT AMBIENT TEMPERATURES

CURRENT PROJECTS

Much of the work in progress in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering includes calibrations, routine analyses and the testing of proprietary products; in addition, a substantial volume of the work is devoted to applied research or investigations carried out under contract and on behalf of private industrial companies.

None of this work is reported in the following pages.

ANALYSIS LABORATORY

AVAILABLE FACILITIES

This laboratory has analysis and simulation facilities available on an open-shop basis. Enquiries are especially encouraged for projects that may utilize the facilities in a novel and/or particularly effective manner. Such projects are given priority and are fully supported with assistance from laboratory personnel. The facilities are especially suited to system design studies and scientific data processing. Information is available upon request.

EQUIPMENT

1. An Electronic Associates 690 HYBRID COMPUTER consisting of the following:
   (a) PACER 100 digital computer
   - 32K memory
   - card reader
   - high speed printer
   - disc
   - digital plotter
   - Lektromedia interactive terminal

   (b) Two EAI 680 analogue computer consoles
   - 200 amplifiers including 60 integrators
   - 100 digitally set attenuators
   - non-linear elements
   - x-y pen recorders
   - strip chart recorders
   - large screen oscilloscope

   (c) EAI 693 interface
   - 24 digital-to-analogue converters
   - 48 analogue-to-digital converters
   - interrupts, sense lines, control lines
2. Hewlett Packard Model 3960 FM instrumentation tape recorder. IRIG standard, 4-track, 1/4-inch tape. Speeds: 15/16, 3-3/4 and 15 inches per second.

GENERAL STUDIES

Study of methods for obtaining a mathematical model of a flexible articulated manipulator arm.

Curve fitting using cubic splines.

APPLICATION STUDIES

In collaboration with Aviation Electric Ltd., a hybrid computer model of an advanced turbo-fan engine is being put together in order to investigate the expected performance of its control system.

In collaboration with the Railway Laboratory, a pilot hybrid computer model of the NRC roller rig for railway vehicle testing is being built as an aid in the design of the roller rig and its controls.

In collaboration with Aviation Electric Ltd., modeling work is underway in support of their advanced control concepts for both the small business jet engine and the helicopter engine. At present, a validation of a detailed model of a twin engine helicopter model is complete. Several detailed design studies have been completed and evaluation of one hardware configuration is underway.

In collaboration with the Control Systems and Human Engineering Laboratory and the International Nickel Co., Ontario Division, an interactive computer model of a copper-nickel smelter is being developed to study material handling and scheduling in the plant.

In collaboration with R.L. Crain Ltd., an interactive order streaming program for a print shop has been developed and is currently being evaluated by the press co-ordinators.

In collaboration with Canadian Westinghouse Ltd., a study is being made of the fuel controller requirements for a new family of industrial gas turbines. A hybrid computer model has been assembled and is being used in the development of control system hardware.

In collaboration with Kendall Consultants Ltd., and SPAR Aerospace Products Ltd., a hybrid computer model of the remote manipulator arm being designed for the space shuttle is being assembled. The model is to include all allowable motions in three dimensions as well as arm flexibility effects.

In collaboration with the Urban Transit Development Corporation and G.F. Crate Ltd., a model of an Intermediate Capacity Transit System is being developed in order to study various system designs and resulting operational performance.

In collaboration with Northern Telecom Ltd., an interactive computer program is being developed to schedule cable orders on cable stranding machines.

In co-operation with Concordia University, a model of a heavy railroad freight vehicle is being assembled. Simulations of vehicle response to periodic and random excitations are to be conducted.

In co-operation with Carleton University and Engine Laboratory a preliminary study is underway of a heavy equipment propulsion system using a co-rotating compressor.

SYSTEM SOFTWARE STUDIES

An interactive package for setup and checkout of analogue computer circuits in a hybrid environment.

A simple graphics package for the LEK-104 terminal.

A preprocessor for hybrid computer model digital programs.

CONTROL SYSTEMS AND HUMAN ENGINEERING LABORATORY

INDUSTRIAL CONTROL PROBLEMS

Industrial systems and agricultural applications of fluidic circuits.

Fluid sensor and control component research and development.

Interactive computer modeling applied to operations scheduling of large scale industrial plants and processes.

Development of CAMAC instrumentation for industrial control applications.

Engineering support to specific firms for the implementation of schemes for control and mechanization.

HUMAN ENGINEERING – BEHAVIOURAL STUDIES

Investigation of the control characteristics of the human operator and the basic phenomena underlying tracking performance.

Investigation of the nature of sensory interaction in human perceptual-motor performance.

Investigation of the factors involved in the presentation and processing of information, particularly in relation to simulator design.

HUMAN ENGINEERING – MEDICAL AND SURGICAL

Development of heat exchangers for localized cooling of the spinal cord.

Measurement in-vivo of the mechanical impedance characteristics of skin and healed wounds.

Development of models of tissue sections, organs, and whole organisms.

Development of stereo-taxic and allied apparatus for clinical procedures involving the spinal column.

ENGINE LABORATORY

HOSPITAL AIR BED

A hospital air bed designed and built by NRC has been delivered to the Hotel Dieu Hospital in Kingston, Ontario for clinical evaluations of treatment of burn patients. The function and performance specifications of the bed were devised in collaboration with Canadian medical authorities to satisfy Canadian needs.

A second air bed was purchased in England by the Victoria Hospital in London, Ontario, and was adapted by NRC to meet Ontario Hydro requirements.

Several modifications were made to the NRC air bed as a result of the early testing experience. Both beds are being used very successfully for clinical evaluation. A study and an evaluation of the through flow characteristics of various support fabrics has been completed and has led to an improved air bag structure. The new concept is now being evaluated in Kingston.

GAS TURBINE OPERATIONS

An investigation of aircraft gas turbine engine operating characteristics is being conducted in conjunction with the Canadian Forces.

Assistance has been given to the Canadian Forces in the development of an inlet protective system for sea-borne gas turbines operating in icing environments.

AEROACOUSTICS

A 12-inch diameter ducted fan model has been tested aerodynamically for the purpose of making performance comparisons between a standard 19-bladed stator and a 19-bladed stator with stepped leading edges. Comparative noise studies of the same configurations in an acoustically treated test cell have recently also been completed.

These experiments are made by the Engine Laboratory in co-operation with the Division of Applied Physics with the intent of evaluating special noise reducing features in ducted fan design. Publication is in preparation.

A study of the noise characteristics of centrifugal fans and blowers is in progress. The effect of casing geometry on a 15 horse power blower is recently completed. A new five horse power fan test rig to study the effects of various elements of the fan on aerodynamic performance and noise generation has been recently commissioned.

ENGINE COOLING SYSTEM PERFORMANCE

In collaboration with Canadian industry an experimental study is being made of automotive cooling fan performance with the fan in its actual engine bay environment and subject to normal ram air conditions. The study involves both road and wind tunnel tests at full scale under hot and cold radiator conditions. The test vehicle is typical of an intermediate size North American passenger car, and along with considerable in-vehicle instrumentation, is being provided by the industry for test purposes.

A good simulation of the road test cooling system aerodynamics has been achieved in the 10′ × 20′ test section of the Propulsion Wind Tunnel of the Division of Mechanical Engineering. Component and system aerodynamic performance is currently being studied in the wind tunnel for the ambient temperature radiator condition. Publications are in preparation.

ROTOR DYNAMICS

An experimental rig has been constructed to investigate techniques for improved vibration signal diagnosis from rotating machinery under a variety of operating and support conditions. Test rotors are being designed.

The laboratory's torsional vibration calibrator is being modified to allow study of the effect of translational vibration on the performance of a belt-driven torsiograph.

On behalf of a Canadian manufacturer, the power absorption characteristics of a centrifugal fan have been determined for a unit to be used on the spillway gates of a hydro power station.

AIR CUSHION VEHICLES

An analytical study of ACV drag overland is continuing. Advances in the theory have been formulated, and an experimental program is in progress, to explore the validity of these theories and provide numerical values for the coefficients proposed.

An associated study of skirt element structural stability and response to transient disturbances during forward motion is proceeding.

Research vehicles HEX-1B and HEX-4 are being used for static stability tests, and drag measurement at various speeds and lift airflows over a range of porous terrain. Special instrumentation for this work is carried on the vehicles. A trailer is being built and equipped with additional devices for measuring terrain porosity.

HYDROSTATIC BEARINGS

The fabrication and testing of an oil-lubricated hydrostatic bearing support system for the railroad roller test rig is in progress.

Experimental and analytical work on air lubricated bearings and seals is continuing. Attention is being focused on aerostatic thrust bearings with one compliant surface.

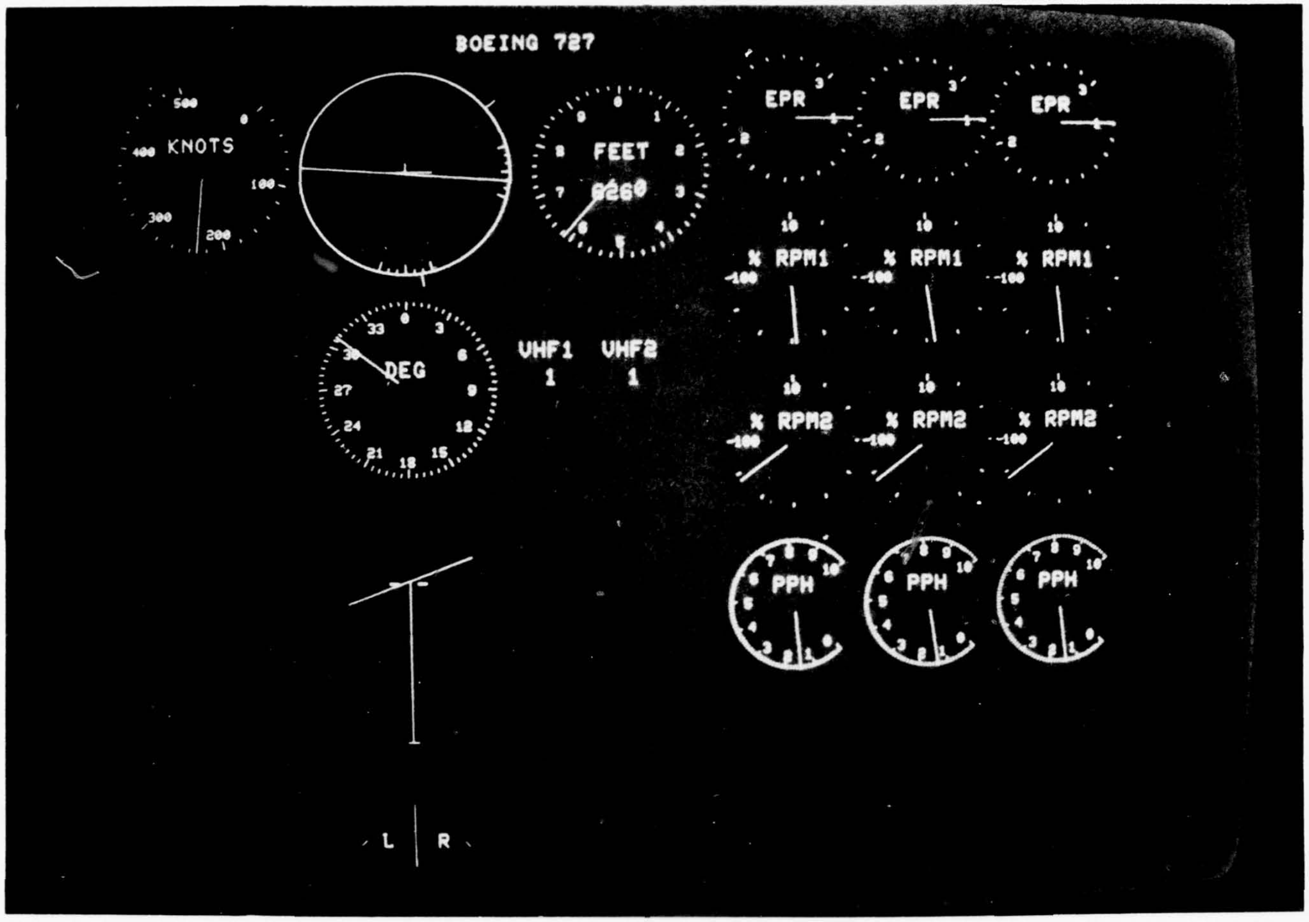
HYBRID DRIVE VEHICLE SIMULATION

An all-digital computer simulation of hybrid drive vehicles is being developed. A model of the accumulator system has been prepared and is being verified against an actual accumulator. Initially, a heat engine-hydraulic drive system will be modeled and verified against a prototype system installed in the Fuels and Lubricants Laboratory. At present, the model can handle a spark ignition engine coupled to an automatic transmission in an automobile.

The use of the automotive computer model as a aid in developing improved traffic signal control strategies is being investigated. The fuel consumption of float vehicles operating in traffic under different signal control patterns will be determined.

NRC – PRATT AND WHITNEY HIGHLY LOADED TURBINE

The test cell has been prepared and the instrumentation of the test section is in progress. The data acquisition and reduction system is being 'de-bugged' and the appropriate control algorithms are being written.



At the Flight Research Laboratory, the value of flight data recorder information in accident investigation has been greatly enhanced by feeding the data to real time displays of the flight instruments and pilots control inputs generated on a CRT as shown above. With synchronized audio information from the cockpit voice recorder, the flight deck environment can be realistically re-created.

FLIGHT RESEARCH LABORATORY

NATIONAL AERONAUTICAL ESTABLISHMENT

FLIGHT RESEARCH LABORATORY

AIRBORNE MAGNETICS PROGRAM

Experimental and theoretical studies relating to the further development of airborne magnetometer equipment and its application to submarine detection and geological survey, are currently in progress. The North Star flying laboratory has now been retired but analysis of magnetic data taken over east, west and Arctic coasts of Canada will continue for some time to come. Studies are continuing in very low frequency (VLF) and other navigation methods to support long range geophysical surveys. A Convair 580 aircraft to replace the North Star is currently being equipped with new magnetometer and computing systems.

INVESTIGATION OF PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT OPERATIONS

The Laboratory's Bell 205A1 variable stability helicopter is being employed in programs to investigate terminal area operational problems which are most severe for or peculiar to aircraft capable of low approach speeds. The 205, which is capable of measuring and recording the magnitude of the three components of motion of the atmosphere through which it flies, is employing this capability in a program of terminal area wind and turbulence documentation at the Rockcliffe STOLport. In a related program the 205 is being configured to simulate the flight characteristics and handling qualities of a powered-lift STOL transport aircraft. The effects of severe turbulence and strong wind shears on the approach handling qualities and operational envelope of such an aircraft are being evaluated by flying the simulated vehicle through naturally occurring atmospheric disturbances.

INVESTIGATION OF ATMOSPHERIC TURBULENCE

A T-33 aircraft, equipped to measure wind gust velocities, air temperature, wind speed, and other parameters of interest in turbulence research, is used for measurements at very low altitude, in clear air above the tropopause, in the neighbourhood of mountain wave activity, and near storms. Records are obtained on magnetic tape to facilitate data analysis. The aircraft also participates in co-operative experiments with other research agencies, in particular, the Summer Cumulus Investigation (see below). A second T-33 aircraft is used in a supporting role for these and other projects.

AIRCRAFT OPERATIONS

The Flight Recorder Playback Centre is engaged in the recovery and analysis of information from the various flight data recorders and cockpit voice recorders used on Canadian military and civil transport aircraft. The military systems are being monitored on a routine basis. Civil aircraft recorders are being replayed to investigate incidents or accidents at the request of the Ministry of Transport. Technical assistance is being provided during incident and accident investigations and relevant aircraft operational problems studied.

INDUSTRIAL ASSISTANCE

Assistance is given to aircraft manufacturers and other companies requiring the use of specialized flight test equipment or techniques.

INVESTIGATION OF SPRAY DROPLET RELEASE FROM AIRCRAFT

Theoretical and experimental studies of spray droplet formation from a high speed rotating disc have been conducted. Flight experiments utilize a Harvard aircraft modified to carry external spray tanks. Automatic flying spot droplet and particle analysis equipment is in operation for processing samples obtained in the laboratory and in the field by various agencies. The equipment has potentialities for the analysis of many unusual configurations provided that these may be photographed with sufficient contrast.

AUTOMOBILE CRASH DETECTOR

There is a need for a sensing device to activate automobile passenger restraint systems in incipient crash situations. Investigations are in progress to determine the applicability of C.P.I. technology to this problem.

SUMMER CUMULUS INVESTIGATION

At the request of the Department of the Environment flight studies of Cumulus cloud formations over Quebec and Ontario were instituted during the Summer of 1974. Instrumented T-33 and Twin Otter aircraft with a Beech 18 are being used to determine the properties of Cumulus clouds which extend appreciably above the freezing level. The measurements are being made to assess the feasibility of inducing precipitation over forest fire areas by seeding large cumulus formations. During 1975 a variety of cloud physics instruments were added to the Twin Otter, and special pods for burning silver iodide flares were attached beneath the wing of the T-33 turbulence research aircraft. The effects of seeding on the microstructure of individual cumulus clouds were studied in the Yellowknife area during the summers of 1975 and 1976 and in Thunder Bay in 1977. This project is planned to continue for several years.

FUELS AND LUBRICANTS LABORATORY

COMBUSTION RESEARCH

Experiments on fuel spray evaporation.

Investigation of handling and combustion problems involved in using hydrogen as a fuel for mobile prime movers.

Evaluation of the use of mixtures of methane and carbon dioxide as automobile fuels.

Co-operative studies with Advisory Group for Aerospace Research and Development (AGARD) Working Group 11 to produce a report on aircraft fire safety.

EXTENSION AND DEVELOPMENT OF LABORATORY EVALUATION

Development of new laboratory procedures for the determination of the load carrying capacity of hypoid gear oils under high speed conditions and under low speed high torque conditions.

Evaluation of filter/coalescer elements for aviation turbine fuels.

Evaluation of longlife filter/coalescer elements from aviation turbine fuel service.

Water separation characteristics of aviation turbine fuels.

PERFORMANCE ASPECTS OF FUELS, OILS, GREASES, AND BRAKE FLUID

Investigation of laboratory methods for predicting flow properties of engine and gear oils under low temperature operating conditions.

Investigation of the electrostatic charging tendency of distillate fuels.

Evaluation of static dissipator additives for distillate fuels.

Evaluation of properties of re-refined oils and by-product sludges.

Investigation of the use of anti-icing additive in aviation gasoline.

MISCELLANEOUS STUDIES

The preparation and cataloguing of infra-red spectra of compounds related to fuels, lubricants, and associated products.

The application of Atomic Absorption spectroscopy to the determination of metals in petroleum products.

Investigation of the stability of highly compressed fuel gases.

Analytical techniques for analysis of engine exhaust emissions.

Participation in the Canadian (CGSB), American (ASTM) and International (ISO) bodies to develop standards for petroleum products and lubricants.

The design and development of an internal combustion engine/hydraulic transmission hybrid power plant for the energy conserving car.

Further developments of specialized pressure transducers for engine health diagnosis and the development of diagnostic techniques and consultation with licencee in developing production methods for patented transducers.

Evaluation of various products, fuels, lubricants and hardware in respect of their effects upon overall vehicle fuel economy and energy conservation properties.

GAS DYNAMICS LABORATORY

V/STOL PROPULSION SYSTEMS

A general study of V/STOL propulsion system methods with particular reference to requirements of economy and safety.

INTERNAL AERODYNAMICS OF DUCTS, DIFFUSERS AND NOZZLES

An experimental study of the internal aerodynamics of ducts, bends, diffusers and nozzles with particular reference to the effect of entry flow distortion in geometries involving changes of cross-sectional area, shape, and axial direction.

SHOCK PRODUCED PLASMA STUDIES

A general theoretical and experimental investigation of the production of high temperature plasma by means of shock waves generated by electromagnetic and gasdynamic means, and the development of diagnostic techniques suitable for a variety of shock geometries and the study of physical properties of such plasmas.

NON-DESTRUCTIVE SURFACE FLAW DETECTION IN HOT STEEL BILLETS

An eddy-current surface flaw detector is being developed, using a special coil system by which a three-phase modulated R.F. signal is being electrically rotated round the billet at a rate given by the modulation frequency. The system displays the angular position of the flaw on a polar oscilloscope sweep or numerically, while the signal amplitude represents the depth of the flaw.

HIGH PRESSURE LIQUID JETS

High speed water jets generated by pressures in the range of 1000 to 60,000 psi can be used for cutting a wide variety of materials, e.g. paper, lumber, plastics, meat, leather, etc., and for cleaning surfaces such as masonry, rocks, tubular heat exchangers, etc. Nozzle sizes, depending on the application, are in the range from 0.002 to 0.15 in. diameter. A technique for manufacturing small nozzles in the range 0.002 to 0.015 has been developed using standard sapphire jewels available from industry. Larger orifices are manufactured and polished using standard shop procedures.

At present, the following investigations are active in the laboratory:

1. Intensive development of a rotating seal designed and developed in the laboratory. It appears to have great potential, especially for industrial cleaning, quarying and possibly for drilling operations.

2. Experiments on the fracturing of rocks using continuous and cavitating jets.

3. Experiments for clearing ice off runways and for cutting through thick ice ridges.

4. Experiments on the production of intermittent jets with high stagnation pressures.

Emphasis is now being placed on the study of effects produced by cavitating jets, how best to produce them and where they may be usefully applied.

HEAT TRANSFER STUDIES

Initial development of a temperature control thermosiphon for an electronic package has been successfully concluded. Life testing of this device has commenced.

An investigation of methods of increasing boiling and condensing heat transfer coefficients by treatment of the heat transfer surface has begun.

A co-operative project with the Division of Building Research will determine the usefulness of the thermosiphon as a ground heat source for a heat pump.

Work has started on extending the range of design information for use in air-to-air heat recovery units.

COMPUTATIONAL FLUID DYNAMICS

To support the experimental work, numerical simulations are being developed in three areas.

Single-pulse jets from vertically-accelerated liquid-filled rotating cones. This is a two-dimensional, axisymmetric, unsteady, incompressible flow problem with a free surface, where the liquid is subjected to large body accelerations.

Fluid dynamics of laser-produced plasmas. The phenomena are considered as two-dimensional, axisymmetric, unsteady, compressible flow problems in which real gas behaviour is considered. The approach, which uses Lagrangian formulation, has been used to calculate two cases:

(a) The fluid dynamics of a laser breakdown plasma, with the objective of explaining the mechanism of beam re-entry into the plasma when beam intensity is reduced.

(b) The interaction of a CO_2 laser beam with magnetically confined plasmas. This major problem is currently being studied numerically as part of a co-operative effort with the Aerospace Research Laboratory of the University of Washington.

Shock dynamics and fluid dynamics resulting from synchronized spark discharges on the axis and discharges on the perimeter of a cylindrical vessel containing hydrogen, to achieve high gas temperatures on the axis of the vessel.

GAS TURBINE BLADING STUDIES

A program on the theoretical and experimental study of the performance of highly loaded gas turbine blading has been undertaken as a collaborative program with industry and universities.

INDUSTRIAL PROCESS, APPARATUS, AND INSTRUMENTATION

There is an appreciable effort, on a continuing basis, directed towards industrial assistance. This work is of an extremely varied nature and, in general, requires the special facilities and capabilities available in the laboratory.

Current co-operative projects with manufacturers and users include:

(a) Flow problems associated with industrial gas turbine exhaust systems (Foster Wheeler).
(b) Combustion studies for industrial gas turbine applications (Westinghouse and Rolls-Royce).
(c) Application of thermosiphon as an energy conserving device in industrial applications (Dept. of Agriculture, Ministry of Transport, Farinon Electric, Chromalox Canada Ltd).
(d) Scaled model studies on steel and copper converters to establish relative performance and ceramic liner deterioration rates (Canadian Liquid Air and Noranda).
(e) High pressure water jet applications in industry (High Pressure Systems Ltd.).
(f) Power turbine nozzle vane studies (Westinghouse).
(g) Scaled model studies to establish the performance of complex industrial flue systems with a view to establishing specific design and performance criteria. (Noranda and Inco Canada Ltd).

HIGH SPEED AERODYNAMICS LABORATORY

RENEWAL OF THE TURBULENCE DAMPING SCREENS IN THE 5-FT. × 5-FT. WIND TUNNEL

The task of dismantling the settling chamber of the tunnel was commenced in July 1977.

Manufacture of the replacement screens is well advanced now with three being complete by the end of September.

Slippages in the estimated completion date have occurred and it is now expected that the re-assembly will not be complete until December.

CALIBRATION OF THE 5-FT. × 5-FT. WIND TUNNEL'S TRANSONIC TEST SECTION

Measurements of flow angle and stagnation pressure distribution across the width of the test section and mid height were made prior to the dismantling of the wind tunnel. The measurements provided steady state values of the flow angularity and stagnation pressure at nine lateral stations and also r.m.s. values of the fluctuating components of flow-angle and stagnation pressure at these stations. The data is currently being assessed.

Following the rebuild of the tunnel the measurements will be repeated. Further to these measurements the longitudinal distribution of static pressure along the centre line of the transonic test section will be measured by means of a new 4-inch diameter sting mounted probe.

SETTLING CHAMBER STUDY IN 5-IN. × 5-IN. WIND TUNNEL

Model tests have been conducted in the NAE pilot facility, to determine the effect of increasing the resistivity of the second porous (dished) baffle in the wide angle diffuser ahead of the stilling section, and the installation of "trimming" screen at the exit of the acoustic baffle geometry. Furthermore, studies of the effect of modifications to the cruciform-cone structure at the entrance of the wide angle diffuser on the settling chamber flow have also been conducted. Based on the results of these studies, certain revisions to the settling chamber of the 5-ft. × 5-ft. wind tunnel will be made, which we expect to considerably improve the flow distribution and to decrease the level of pressure fluctuations at the entry to the stilling section.

TWO-DIMENSIONAL TRANSONIC FLOW STUDIES

Efficient computer programs based on finite difference procedures are available for the design of supercritical airfoils and for the analysis of supercritical flow. A small disturbance transonic program is being developed and will include wind tunnel wall effects.

HIGH REYNOLDS NUMBER PIPE FLOW

This investigation is carried out at the request of and in co-operation with Laval University, Quebec.

The object is to obtain turbulent skin friction data at very high Reynolds number (Re_d up to 20×10^6) in an 8-in. pipe. The investigations to date include calibration of a range of Preston and razor blade surface pitot tubes and mean velocity traverses. Turbulence and noise measurements are also being considered. Analysis of the Preston tube calibration data has been carried out and the results agree well with semi-empirical theory based on the logarithmic wall law.

A floating element skin friction balance has recently been supplied by Laval University and initial tests have been carried out.

THEORETICAL AND EXPERIMENTAL STUDY OF JET NOISE

Further investigations of internal noise in a low speed jet are in progress. More detailed studies of the interaction of the transmitted sound with the jet flow and some statistical investigation of the multiple wave scattering by the turbulent eddies will be carried out. Some experiments on co-axial jets have been performed and measurements of pressure fluctuations in the turbulent shear layer have been undertaken. Turbulence measurements will be carried out by laser Doppler velocimeter.

REYNOLDS NUMBER EFFECTS ON TWO-DIMENSIONAL AEROFOILS WITH MECHANICAL HIGH LIFT DEVICES

A multi-component airfoil model, based on a supercritical airfoil, has been designed and manufacturing is in progress. The model will be equipped for pressure measurements on all components and provision is also made for boundary layer-wake surveys in the vicinity of the airfoil surface. The model is part of a program aimed at a detailed analysis of 2-D high lift flow and the effect of Reynolds number on the optimum flap settings.

Work on an iterative solution of the compressible boundary layer flows about multi-element airfoil is continuing at the University of Manitoba.

TESTS FOR OUTSIDE ORGANIZATIONS

Pratt & Whitney Aircraft of Canada

Three temperature recovery probes were calibrated in the 5-in. × 5-in. pilot tunnel in the Mach number range $.12 \leq M \leq .8$.

HYDRAULICS LABORATORY

ST. LAWRENCE SHIP CHANNEL

Under the sponsorship of the Ministry of Transport, a study to improve navigation along the St. Lawrence River, using hydraulic and numerical modeling techniques.

NUMERICAL SIMULATION OF RIVER AND ESTUARY SYSTEMS

Mathematical models have been developed to simulate tidal propagation in estuaries, wave refraction in shallow water and littoral drift processes.

DEVELOPMENT OF SPECTRAL ANALYSIS PROGRAMS

For use in the analysis of wave records and on-line analysis of turbulent diffusion data produced in the laboratory.

WAVE FORCES ON OFF-SHORE STRUCTURES

Wave flume study to determine design criteria for off-shore mooring structures.

RANDOM WAVE GENERATION

A study of random waves generated in a laboratory water wave flume by signals from a computer.

LOCK MODEL STUDY ON VESSEL SIZE

In co-operation with the Marine Dynamics and Ship Laboratory a model study has been undertaken to determine the effect of vessel and lock dimensions on the entrance and exit speeds of ships in locks of the St. Lawrence Seaway.

STABILITY OF RUBBLE MOUND BREAKWATERS

A flume study for the Department of Public Works to determine stability coefficients of armour units and the effect of a number of wave parameters on the stability of rubble mound breakwaters.

WAVE LOADS ON CAISSON TYPE BREAKWATERS

A flume study for the Department of Public Works to determine the overall loading, as well as the pressure distribution on various Caisson-type breakwaters.

WAVE POWER AS AN ENERGY SOURCE

A general study to assess the wave power available around Canada's coast and to evaluate various proposed schemes to extract this energy. International co-operation is taking place through the International Energy Agency of OECD.

MOTIONS OF LARGE FLOATING STRUCTURES, MOORED IN SHALLOW WATER

A mathematical and hydraulic modeling program will be carried out to develop techniques and methods to forecast motions of, and mooring forces on large structures moored in shallow water.

SAULNIERVILLE HARBOUR MODEL STUDY

A hydraulic model study and wave flume study to relocate a breakwater at Saulnierville, N.S. to give better protection.

THORNBURY HARBOUR MODEL STUDY

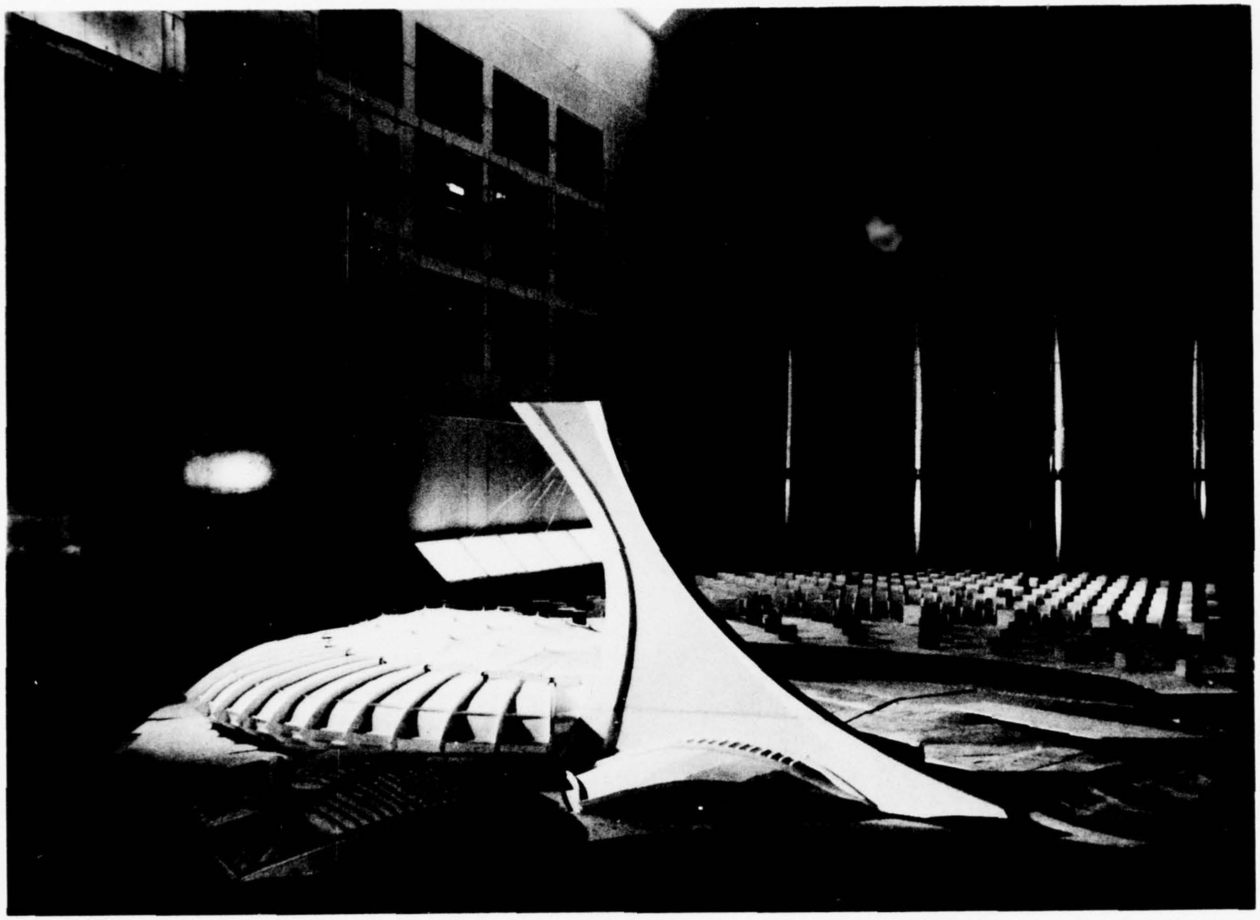
A hydraulic model study to investigate wave agitation in the harbour basin at Thornbury, Georgian Bay, for Public Works, Canada.

CALIBRATION OF FLOW MEASURING DEVICES

Facilities to calibrate various types of flow meters up to a maximum capacity of 5,000 gpm are regularly used for/or by private industry and other government departments.

COLESON COVE MODEL STUDIES

Flume studies are being conducted to determine stability criteria of a rubble mound breakwater protecting the intake channel at the Coleson Cove Thermal Generating Station, N.B., and wave loads are measured on a model of the diffuser cap for the same station for New Brunswick Power Commission and Eastern Designers, Fredericton, N.B.



1:100 SCALE MODEL OF THE MONTREAL OLYMPIC STADIUM
IN THE NAE 30-FT. × 30-FT. WIND TUNNEL

LOW SPEED AERODYNAMICS LABORATORY

NATIONAL AERONAUTICAL ESTABLISHMENT

LOW SPEED AERODYNAMICS LABORATORY

WIND TUNNEL OPERATIONS

The three major wind tunnels of the laboratory are: the 15-ft. diameter, open jet, vertical tunnel; the 6-ft. × 9-ft. closed jet horizontal tunnel; and the 30-ft. V/STOL tunnel. During the quarter, 13 programs were undertaken which included work for Canadair Ltd., DeHavilland Aircraft of Canada Ltd., and the Wind Engineering Group of the Laboratory. Performance specifications are being prepared for a new wind tunnel data acquisition and control system to replace the present system which has been in service for 20 years. A request for proposals will be submitted to suppliers within the next month.

WIND ENGINEERING

The construction of a 1:100 scale model of the Olympic Stadium was completed and installed in the 30-ft. × 30-ft. wind tunnel. Surface pressure measurements were made on the stadium mast and the aerodynamic forces on the structure due to the proposed removable roof were measured. A second series of measurements is to be undertaken in 1978.

Measurements of wind properties are being made on the Lions' Gate Bridge, Vancouver as part of an aerodynamic investigation of the bridge. There are four anemometers distributed along the span and two accelerometers to measure bridge motion. A fully automated recording system has been installed. Site assistance is being provided by Buckland and Taylor Ltd., Vancouver.

In collaboration with the Division of Building Research an aerodynamic investigation of Commerce Court, Toronto is being undertaken. The purpose is to obtain wind tunnel comparisons with full scale measurements of surface pressures. A 1:200 scale model has been constructed and testing has begun in the 30-ft. × 30-ft. wind tunnel.

A second configuration for the renovated widened version of the Lions' Gate Bridge is to be investigated in the 30-ft. × 30-ft. wind tunnel. A 1:100 full aeroelastic model is now being constructed. The work is being done for Buckland and Taylor Limited.

FLUIDICS

Co-operative studies with D.G. Instruments of a 3-axis air velocity sensor are continuing using both NRC and industry developed concepts. Studies of vortex excitation of velocity sensor probes have been carried out in co-operation with FluiDynamic Devices Ltd. A program of applications of laminar flow in thin passages is being carried out in co-operation with the Control Systems and Human Engineering Laboratory of DME.

NUMERICAL METHODS

A correlational theory for the prediction of boundary layer transition has been devised and successfully demonstrated in some simple cases which are of interest for the design of airfoils.

The numerical methods are applicable to compressible flows involving heat and mass transfers at the boundaries.

VERTICAL AXIS WIND TURBINE

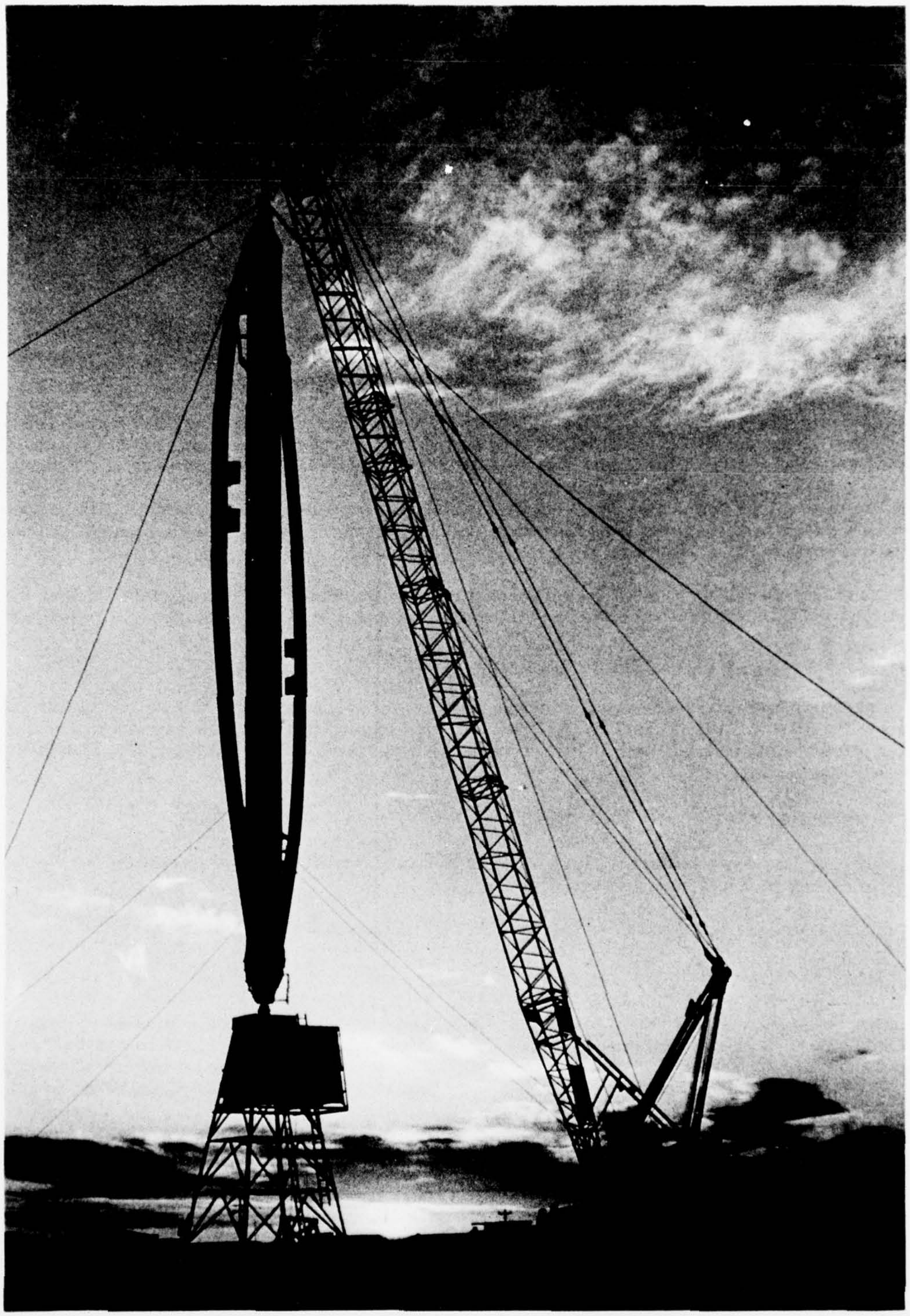
The 230 kW demonstration wind turbine, designed and built by Dominion Aluminum Fabricating Ltd has been erected by Hydro Quebec and has begun experimental operation on the Magdalen Islands. DAF are now developing commercial turbines in the power range from about 5 to 50 kW. A small turbine built by Bristol Aerospace has been operating successfully, without maintenance, for over one year at an automatic meteorological station on the Beaufort Sea Ice. Bristol are continuing development of turbines as power sources at remote sites.

AERIAL SPRAYING OF PESTICIDES

A co-operative program between NAE and the University of New Brunswick, to determine the droplet size distribution of standard nozzle configurations, is continuing. The experimental method consisted of photographing droplets in the 50 to 250 micron range using a narrow depth of focus, and a high intensity flash. An electronic detector was also placed in the spray; its function was to count the number of droplets in a given size range. The second stage of the experiment has been completed with measurements of droplet emissions from a Micronair rotary atomizer being made. Further wind tunnel testing will continue during the latter part of 1977.

A new spray boom designed has been tested in co-operation with Conair Aviation (Abbotsford, B.C.). This configuration will have significantly less aerodynamic drag than the present installation which is used on the DC-6B aircraft and is expected to save several hundred horsepower. The spray emission from the new configuration is currently being evaluated in flight.

Theoretical and experimental studies are continuing on the effects of the vortex wake and other factors on the swath width of spray left by a low flying aircraft.



VERTICAL AXIS WIND TURBINE SITUATED ON MAGDALEN ISLANDS, QUEBEC

LOW SPEED AERODYNAMICS LABORATORY

NATIONAL AERONAUTICAL ESTABLISHMENT

LOW TEMPERATURE LABORATORY

RAILWAY CLIMATIC PROBLEMS

Under the auspices of the NRC Associate Committee on Railway Problems, Sub-Committee on Climatic Problems, a variety of analytical and experimental work is conducted on a continuing basis.

THERMAL PROTECTION OF TRACK SWITCHES

The use of heat to eliminate switch failures from snow and ice is a standard approach to this problem. Work has been carried out on improving the efficiency of forced convection combustion heaters and the means of distributing heat to the critical areas of a switch.

HORIZONTAL AIR CURTAIN SWITCH PROTECTOR

A non-thermal method of protecting a switch from failure due to snow has been undergoing development and evaluation. This method consists of high velocity horizontal air curtains designed to prevent the deposit of snow in critical areas of a switch. The tests conducted to date are especially encouraging with respect to yards and terminals. Additional evaluation is required for the line service application.

NEW RAILWAY SWITCH DEVELOPMENT

The ultimate solution to the existing problem of snow and ice failure of the point switch would appear to be replacement by a new design that is not subject to failure in this way. A switch has been designed, fabricated, laboratory tested and has now completed one winter season of field trials. The design involves only shear loading from snow and ice.

LOCOMOTIVE SANDING EQUIPMENT

An investigation into the various possible modes of failure of a locomotive sanding system resulting from low temperature has been undertaken. In addition to the expected failures resulting from moisture freezing in various parts of the pneumatic equipment, two other modes of failure are being investigated further.

HELICOPTER DE-ICING

A study of helicopter icing protection involving the evaluation of various systems (thermal, fluid, and self-shedding materials) and the development of de-icing control systems including ice detectors. The principles for a dynamic ice detector with high sensitivity to be used on helicopters are being investigated. Investigation of methods of establishing a rate function with the dynamic icing detection principle is being conducted.

MISCELLANEOUS ICING INVESTIGATIONS

Analytical and experimental investigations of a non-routine nature, and the investigation of certain aspects of icing simulation and measurement.

TRAWLER ICING

In collaboration with Department of Transport, an investigation of the icing of fishing trawlers and other vessels under conditions of freezing sea spray, and of methods of combatting the problem.

AIR CUSHION VEHICLE ENVIRONMENTAL PROBLEMS

A study has been started on the deposition of snow on sections representing possible tracks for guided ACV's. Snow and ice deposits are being measured and recorded during each winter storm.

A study of snow removal by unconventional methods is being undertaken for high speed transit systems.

AIRBORNE SNOW CONCENTRATION

To provide statistical data on the airborne mass concentration of falling snow in order to define suitable design and qualification criteria for flight through snow, measurements of concentration and related meteorological parameters are being made.

SEA ICE DYNAMICS

Analytical and experimental work on the techniques of forming low-strength ice from saline solutions is being carried out in connection with proposed modeling studies of icebreaking ships and arctic port facilities.

MARINE DYNAMICS AND SHIP LABORATORY

HIGH SPEED CRAFT

Several models in a systematic series have been studied and others are being prepared to determine their performance in still water and in waves.

YACHTS

A continuing program of sailing yacht model studies is underway using equipment and techniques developed in the laboratory.

BULK CARRIER

A model of a dry cargo vessel was constructed in the laboratory and an investigation made to determine the feasibility of its unique design. A new bow was made and fitted and additional studies carried out with various bulbs.

HYDROFOIL PROGRAM

An experiment program is to be conducted on a model of a hydrofoil main foil, for which program a special dynamometer has been built by the laboratory.

HYDROFOIL DESIGN SERIES

A series of five hydrofoil models is being considered and two have been built for investigation of their hull lift and drag, foil lift and drag and seakeeping performance.

BEHAVIOUR OF SHIPS IN LOCKS

Three radio-controlled Great Lakes cargo vessel models with varying beams were built in the laboratory. A study of their behaviour is being carried out in a Seaway lock model in cooperation with the Hydraulics Laboratory. Investigation has been made of the hydrodynamic forces acting on the vessels during approach and passage through the locks with a view to recommending modifications to the existing lock structures and defining the effect of ship beam on entry and exit times. Experiments were conducted to determine safe navigation speeds in the channel with respect to avoiding collision with the lock entrance walls. As well, basic turning rate data was obtained when the vessel was guided by marine shunters. Some full-scale measurements have also been made on board a ship.

Y-PASS SYSTEM

A model, equipped with a Y-Pass system, has been tested for resistance and propulsion and its performance evaluated.

DEVELOPMENT OF NON-AQUEOUS SOLUTION SYNTHETIC MODEL ICE

As is well known, the properties of full scale ice must be scaled down when carrying out model tests. To this end, extensive studies are being carried out, of the physical characteristics and procedures for the manufacture of non-aqueous solution synthetic model ice for ship model experiments.

GREAT LAKES BULK CARRIER

A model of an 1100-ft. bulk carrier has been constructed in the laboratory and its resistance and propulsion characteristics studied.

DOUBLE-ENDED FERRY

A model of a double-ended, quadruple-screw ferry has been constructed in the laboratory and its performance is being evaluated.

PATROL VESSEL

A model of a very high speed patrol vessel has been built in the laboratory for investigation of its resistance.

PATROL VESSEL

A model of a patrol vessel has been manufactured in fibreglass. It will be fitted with various stabilizers and extensive seakeeping experiments are to be carried out at various stabilizer configurations. A computer analysis will then assist in finding the optimum stabilizer configuration.

COMBINATION FISHING VESSEL

A model of a 70-ft. West Coast almon and herring fishing vessel is to be constructed in the laboratory and its resistance, propulsion and seakeeping characteristics investigated.

RAILWAY LABORATORY

RAILWAY STUDIES

Two experimental axles with spin controlled geometric properties have been manufactured and are being tested under a 100-ton grain car at Uplands Test Centre. Trackside instrumentation is being improved and one type of fully steered truck is being tested as a preliminary to tests on steering trucks to be carried out for CP Rail.

The dynamometer car supplied by CP Rail for use as a mobile instrument car is being refurbished. The pocket to contain the coupler and draft gear is being modified. Instrumentation has been prepared for tests on rail corrugations, the effect of unsprung weight and bolster strength to be carried out on CP track.

The Laboratory continues to provide assistance to the Canadian Government in the assessment of the performance of passenger trains at high speed. An instrumented wheelset is being prepared for a reference vehicle. Consideration is being given to a test program on a Canadian train for the American Federal Railroads Administration.

RAILWAY DYNAMICS BUILDING (U-89)

The floor and control room have been completed. Rooms and services have been erected to house the electric power plant to the roller and vibration rigs. This complex includes a small workshop.

The vibration stands have been designed and the hydraulic power supply purchased for the building. The actuators have been delivered. The rail structure to support vehicles in the building is being manufactured.

Dynamometers have been connected to a pair of roller rig electric motors to aid in the development of their control. Initial testing is underway. A hybrid computer model has been developed in conjunction with the Analysis Laboratory.

Hardware for the roller rig is being developed and made by the Manufacturing Technology Centre. A design for the position controls has been carried out in the Railway Laboratory.

GENERAL INSTRUMENTATION

The laboratory is co-operating with the Marine Dynamics and Ship Laboratory in the development of the micro-processor controlled ship motion analyzer.

A non-contacting transducer is being developed to measure speed and displacement of ferromagnetic surfaces by correlating two magnetic noise signals.

Development of a non-contacting servo gauge using stepping motor drive for the measurement of tidal levels in hydraulic models.

MECHANICAL AIDS TO THE HANDICAPPED

Two Canadian firms have been licensed to build and market the NRC Page Turner.

MECHANICAL AIDS TO SURGERY

Experiments are being conducted using the Vascular Suturing Instrument on the joining of umbilical veins for possible use in future implant work.

The NRC pigmentation injector and various vascular suturing instruments have been overhauled for use in clinical surgery.

STRUCTURES AND MATERIALS LABORATORY

FATIGUE OF METALS

Studies of the basic fatigue characteristics of materials under constant and variable amplitude loading; fatigue tests on components to obtain basic design data; fatigue tests on components for validation of design; studies of the statistics of fatigue failures; development of techniques to simulate service fatigue loading.

RESPONSE OF STRUCTURES TO HIGH INTENSITY NOISE

Study of excitation and structure response mechanisms; study of panel damping characteristics and critical response modes; investigation of fatigue damage laws; industrial hardware evaluation; investigation of jet exhaust noise.

OPERATIONAL LOADS AND LIFE OF AIRCRAFT STRUCTURES

Instrumentation of aircraft for the measurement of flight loads and accelerations; fatigue life monitoring and analysis of load and acceleration spectra; full-scale fatigue spectrum testing of airframes and components.

ELECTRON FRACTOGRAPHY

Qualitative determination of fracture mechanisms in service failures; fractographic studies of fatigue crack propagation rates and modes.

METALLIC MATERIALS

Structure-property relationships in cast and wrought nickel-base superalloys. Studies of the consolidation and TMT processing of superalloy powders and compacts by hot isostatic pressing, hot extrusion and upset forging; studies on mechanical properties. Mechanics of cold isostatic compaction of metal powders, properties of hydrostatically extruded solids and compacts, extruded at pressures up to 1600 MN/m^2. Studies of the oxidation/hot corrosion behaviour of coated and uncoated refractory metals and superalloys.

MECHANICS AND THEORY OF STRUCTURES

Stresses in multi-cell caissons for marine structures. Stress concentrations at corners of box structures. Behaviour of plates under high-speed impact, with reference to bird resistance of aircraft windshields.

FLIGHT IMPACT SIMULATOR

Simulator developed and calibrated to capability of accelerating a 4-lb. mass to velocity of 1000 ft./sec. and an 8-lb. mass to velocity of 760 ft./sec.; operation on year-round basis achieved and includes use of temperature controlled enclosure from $-40°$ to $+130°F$; in addition to airworthiness certification program includes assessment of resistance to impact for materials and structural design for most types of viewing transparencies.

CALIBRATION OF FORCE AND VIBRATION MEASURING DEVICES

Facilities available for the calibration of government, university, and industrial equipment include deadweight force standards up to 100,000 lb., dynamic calibration of vibration pick-ups in the frequency range 10 Hz to 2000 Hz.

COMPOSITE MATERIALS

Studies of composites including resins, crosslinking compounds, polymerization initiators, selection of matrices and reinforcements, application and fabrication procedures, material properties, and structural design.

FINITE ELEMENT METHODS

Development and application of finite element methods to structural problems. Development of refined elements with curved edges. Development of methods for non-linear problems. Studies on the analysis of cracked members.

MOTOR VEHICLE SAFETY

The mathematical model of the redirection of a vehicle by a cable barrier has been validated experimentally and effort is now being concentrated on the development of a facility for the dynamic measurement of the inertial properties of automobiles by suspending them on air bearings. Engineering charts for the design of flexible road barriers are being prepared.

In collaboration with Ministry of Transport, Road and Motor Vehicle Traffic Safety Branch, studies to determine the performance of headlights in the driver passing task are being carried out. Work is continuing on a system for studying driver performance and traffic quality by the analysis of automatically recorded vehicle control input and response data.

POLICE EQUIPMENT STANDARDS

The NRC/CACP Technical Liaison Committee on Police Equipment is a bilateral arrangement for bringing together police and government personnel to review police equipment requirements, equipment performance specifications, and conformance testing procedures. Work of the Committee is expedited by a permanent Secretariat which has a primary responsibility for continuity in the activities of a number of Sections, each dealing with a particular area of expertise, and for co-ordinating work and specialist contributions from various participating Departments and organizations.

UNSTEADY AERODYNAMICS LABORATORY

DYNAMIC STABILITY OF AIRCRAFT

Development of new techniques for dynamic stability experiments.

Determination of cross-derivatives on an aircraft-like configuration at high angles of attack.

Exploratory measurements of vertical acceleration derivatives.

Development of an electro-mechanical calibrator for the existing dynamic cross-derivative apparatus.

ATMOSPHERIC DISTRIBUTION OF POLLUTANTS

Analysis of the downwind vertical spread of gaseous and aerosol pollutants from sources near the ground, with special emphasis on the effect of atmospheric stability.

Instrumentation of a small mobile laboratory to measure airborne particulates and of an aircraft to detect atmospheric tracers.

Use of the above detection system to measure the vertical spread of a pollutant in a polar atmosphere during the AES pilot study of polar meteorology on Lake Simcoe.

TRACE VAPOUR DETECTION

Development of highly sensitive gas chromatographic techniques for detection of trace quantities of vapours of pesticides, explosives and fluorocarbons.

Sensitivity evaluation of commercially available explosive detectors.

Airborne and ground-vehicle based measurements of the spread and distribution of various aerosols and tracer gases.

Development of techniques for conditioning and testing of biosensors.

WORK FOR OUTSIDE ORGANIZATIONS

Dynamic moment measurements and flow visualization studies for NASA, using wind tunnel facilities at NAE and at NASA Ames.

Feasibility and design studies for NASA.

Aircraft-security feasibility studies for Transport Canada.

Scientific assistance to interdepartmental Explosives Detector Evaluation Program, Montreal.

Feasibility Studies for DSMA, Toronto.

WESTERN LABORATORY (VANCOUVER)

PRACTICAL FRICTION AND WEAR STUDIES

Various laboratory simulations of practical tribological systems to study friction, wear and lubrication behaviour of lubricants and bearing materials in response to specific external requests. For example, a recent project was concerned with investigations of the lubricity of water/glycol-based hydraulic cylinder fluids for use in Arctic undersea drilling rigs.

FUNDAMENTAL STUDIES IN TRIBOLOGY

Continuing study of the abrasive wear behaviour of glassy and other carbons and several hard ceramic materials.

LUBRICANT ANALYSIS

Periodic analysis of used marine oils to assess their degree of deterioration as an aid to engine failure prevention.

PRACTICAL STUDIES OF BEARINGS AND SEALS

Design of a machine to test the effectiveness of the lubrication system of locomotive traction motor support (journal) bearings at low temperatures.

Continuing experimental investigation of the efficacy of various seal arrangements in a static model of a ship's hydraulic rotary steering gear.

INSTRUMENTATION STUDIES

The development and construction of further instrumentation for the Division of Building Research for the automatic tape recording of velocity and pressure measurements in snow avalanches in the Rogers Pass.

Modifications and improvements are being designed and made for the laboratory's mini-computer. These include a high speed 'selector channel' and a new micro-electronics core memory.

Work has been completed on a distributed light source and sensor for use in the automatic bus passenger counter previously developed.

NUMERICALLY CONTROLLED MACHINING

Technical assistance on this subject is being provided to firms and other institutions in Western Canada which are considering the purchase of numerically controlled machines to improve their production efficiency. Seminars are held to explain the fundamentals of numerical control and programming and the laboratory's three-axis NC milling machine is used to machine demonstration batch quantities of typical components for interested companies.

Plans are being made to demonstrate the use of computer assisted programming and punched tape preparation as a means of reducing manual programming time for items requiring a large number of geometrical statements.

PUBLICATIONS

MECHANICAL ENGINEERING REPORT

MS-140 A SYSTEMS ENGINEERING STUDY OF NIGHT VISIBILITY WITH AUTOMOBILE HEADLIGHTING.

H.F.L. Pinkney, A.A. Ayad, P. Huculak, A.L. Harrison, National Aeronautical Establishment, August 1977.

The question of night visibility with automobile headlighting is studied using a systems approach.

A methodology has been developed to isolate all the independent variables affecting night driving visibility such as sources, reflective surfaces, transmission media and observer.

It is shown that correlation was achieved between the results obtained from field experiments for the unopposed roadway obstacle detection task and corresponding calculations based on accurate field illumination engineering data and observer laboratory visual performance data.

Using the luminance difference method developed during the visual performance studies, the report demonstrates how the illuminance characteristics of the source interacting with the scene luminance factors can affect the luminance difference signal *available* for detection (ΔL_A) with respect to the luminance difference signal *required* by the observer (ΔL_R).

Examples of the application of this type of approach are also given to analyze the unopposed car and the interaction with other sources of illuminance such as moonlight, dusk skylight and opposing headlights. By means of these examples the sensitivity of visibility to the field, source and task parameters is also shown.

Extension of the methodology to statistical population performance evaluations is outlined and current research in progress for obtaining a statistical measure of the parameters affecting headlamp population behaviour is briefly outlined.

LABORATORY TECHNICAL REPORTS

National Aeronautical Establishment

LTR-FR-60 MacPherson, J.I.

A Cumulus Cloud Seeding Experiment for Forest Fire Control – NAE Participation and Results for 1976.
August 1977.

LTR-HA-30 Lee, B.H.K.

Some Measurements of the Properties of a Co-Axial Jet.
September 1977.

LTR-ST-913 Harrison, A.L.

Measured Illumination Characteristics of the 1974 Headlamps. Part 2 – The ECE Headlamps.
5 May 1977.

Division of Mechanical Engineering

LTR-CS-174 Buck, L., Green, G., Hyde, F., Isnor, C.D., Leonardo, R.

NRC Stressalyser Operating Handbook.
June 1977.

LTR-CS-176 Hayes, W.F.

Maglev Guided Ground Transportation System Conceptual Design Study.
September 1977.

LTR-ENG-65 Dudgeon, D.H.

Performance Measurements on a Power Absorption Fan from the Long Spruce Power Station.
August 1977.

MISCELLANEOUS PAPERS

Buck, L. Defining the Boundary in a Positioning Task. Acta Psychologica, 41, 1977.

Chan, A.W., Hearn, D.W. A Rectilinear Distance Round-Trip Location Problem. Transportation Science, Vol. 11, No. 2, May 1977.

Elias, L., Seman, G., Wilson, D. Detection of Hidden Explosives on Passenger Aircraft. Presented at 2nd International Conference on Crime Countermeasures – Science and Engineering, at Oxford, England, on 23-30 July 1977. Published as a joint NRC/DOT report, May 1977.

Fowler, H.S., Harcourt, C.H. Prairie Weak Road Load Relief Program. Lecture given at CASI 11th Symposium on Air Cushion Technology, Vancouver, September 1977. To be published in Proceedings. Also published by Associate Committee on Air Cushion Technology, Tech Report 4/77, July 77.

Gagne, R.E., Inrig, C.M. An On-Line Interactive Debugging Package for Hybrid Computers. Proc. Summer Computer Simulation Conference, Chicago, July 1977, AFIPS Press pp. 121-126.

Gommers, C.M.J. Some New Forms for Strain Gauge Measurement Elements. Translated by E.R. Funke, August 1977. Laboratory Memo. HY-90.

Hanff, E.S. A Dynamic Calibrating Apparatus for Cross Derivative Experiments. Presented at the 7th International Congress on Instrumentation in Aerospace Facilities in Shrivenham, England, on 6-8 September 1977. Published in ICIASF 77 Record, pp. 125-134.

Hawthorne, H.M., Chow, C.*, Peters, E.*, Warren, I.H.* Evaluation of Gasification Reactivities of Coals by Differential Thermal Analysis. Presented at the 13th Biennial Conference on Carbon, Irving, California, July 1977. (Extended Abstracts pp. 452-453.)

Holt, R.T., Wallace, W. Impurities and Trace Elements in Nickel Base Superalloys. Published in International Metals Review, Review 203, March 1976.

Kekez, M.M., Savic, P. The Glow (Spark) Discharge Electrolysis-Combustion Concept of Ball Lightning. 13th International Conference on Phenomena in Ionized Gases, Berlin, 12-17 Sept. 1977.

Kekez, M.M., Savic, P. Some Comments on the Leader Channel Development. CIGRE International Meeting, Cardiff, Wales, 31 Aug. – 2 Sept. 1977.

Kekez, M.M., Savic, P., Makomaski, A.H. The Use of Shock Tube and Shock Wave Concepts in the Physics of Electrical and Optical Gas Breakdown. 11th International Symposium on Shock Tubes and Waves, Seattle, Washington, 11-14 July 1977.

Kind, R.J.**, Wardlaw, R.L. The Development of a Procedure for the Design of Rooftops Against Gravel Blow-Off and Scour in High Winds. Proceedings, Symposium on Roof Technology National Bureau of Standards, Gaithersburg, Maryland, U.S.A., 21-23 September 1977.

Langton, R., MacIsaac, B.D. Hybrid Computer Models as an Aid in Design of Gas Turbine Control Systems for Helicopters. Proc. Summer Computer Simulation Conference, Chicago, July 1977, AFIPS Press pp. 219-227.

Larkin, B.S., Turnbull, J.E.*** The Economics of Heat Recovery Systems for Animal Shelters. 1977 Seminar of the Int. Centre for Heat and Mass Transfer, Dubrovnik, Yugoslavia, Aug. 1977.

Makomaski, A.H., Pietrzyk, Z.A.**** Numerical Simulation of the Laser Solenoid Experiment. 13th Int. Conference on Phenomena in Ionized Gases, Berlin, 12-17 Sept. 1977.

Makomaski, A.H., Scudder, D.A.****, Pietrzyk, Z.A.****, Vlases, G.C.**** A Study of Laser Induced Plasma Motion in a Solenoidal Magnetic Field, 11th International Symposium on Shock Tubes & Waves, Seattle, Washington, 11-14 July 1977.

Orlik-Rückemann, K.J. Experimental Separation of Pitching Moment Derivatives Due to Pure Pitching and Vertical Acceleration. Presented at AIAA Atmospheric Flight Mechanics Conference in Hollywood, Florida, AIAA Paper 77-1159, 8-10 August 1977.

Panarella, E. The REXIMPLO Experiment: High Frequency Pulsed Compression of Pre-Ionized Deuterium Gas. Proc. 8th European Conference on Controlled Fusion & Plasma Physics, Prague, Czechoslovakia, Sept. 19-23, 1977.

Panarella, E. Spectral Purty of High-Intensity Laser Beams. Physical Review A, Vol. 16, No. 2, August 1977, p. 16.

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* Centre for Materials Research, University of B.C., Vancouver.
** Carleton University.
*** Agriculture, Canada
**** University of Washington.

MISCELLANEOUS PAPERS (Cont'd)

Philpott, K.L., Ploeg, J. The Miramichi Channel Study: A Dredging Feasibility Study of an Environmentally Sensitive Estuary. Presented at 24th International Navigation Congress, September 1977. Published in Proceedings.

Rudnitski, D.M., MacIsaac, B.D. Reduction of Gas Turbine Transient Test Data Using a Hybrid Computer. Summer Computer Simulation Conference, Chicago, July 18-20, 1977. To be published in Proceedings.

Wong, J.K.S. Study of Mixtures of Methane and Carbon Dioxide as Fuels in a Simple Cylinder Engine (CLR). SAE Paper 770796, Detroit, September 1977.

UNPUBLISHED PAPERS

Agrawal, R.K., MacIsaac, B.D., Saravanamuttoo, H.I.H. An Analysis Procedure for the Validation of On-Site Performance Measurements of Gas Turbines. Submitted to "Annual Gas Turbine Conf. of American Society of Mechanical Engineers.

Armstrong, G.W., Crabtree, D. The Artifact Subtraction Technique Applied to Spinal Evoked Potential Measurements. Workshop on Spinal Cord Monitoring, Cleveland, 14-16 September 1977.

Gardner, L. Canadian Studies Related to Electrostatic Charging of Aviation Fuels. Presented at U.S. Air Force Electrostatic Symposium, Dayton, Ohio, 30 September 1977.

Immarigeon, J-P., Wallace, W., Kandeil, A*, Van Drunen, G.** Deformation Processing of Hot Isostatically Pressed Superalloy Compacts. Presented at 16th Annual Conference of Metallurgists, Metallurgical Society of the Canadian Institute of Mining and Metallurgy, Vancouver, August 21-15, 1977.

Lowe, I.R.G. Compliant Surface Air Lubricated Bearings. Talk given to the Canadian Tribology Research Seminar at the National Research Council Canada in Ottawa, September 26, 1977.

Ohman, L.H. A Major Refurbishing Program for the NAE 5-ft. × 5-ft. Blowdown Wind Tunnel. Presented at the 48th Meeting of the Supersonic Tunnel Association at Ecole Nationale Superieur de l'Aeronautique, Toulouse, France, September 14 and 15, 1977.

Orlik-Rückemann, K.J. Dynamic Stability Research at the National Aeronautical Establishment in Ottawa. Presented at the 48th Meeting of the Supersonic Tunnel Association in Toulouse, France, on 14-15 September 1977.

Ringer, T.R. Icing Test Facilities in Canada. Presented at Round Table Discussion on Icing – AGARD Fluid Dynamics Panel Meeting, 30 September 1977, Ottawa, Ontario.

Stallabrass, J.R. Helicopter Ice Detection, Icing Severity and Liquid Water Content Measurements. Presented at Round Table Discussion on Icing – AGARD Fluid Dynamics Panel Meeting, 30 September 1977, Ottawa, Ontario.

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* Carleton University, Ottawa,
** Westinghouse of Canada Ltd., Hamilton.