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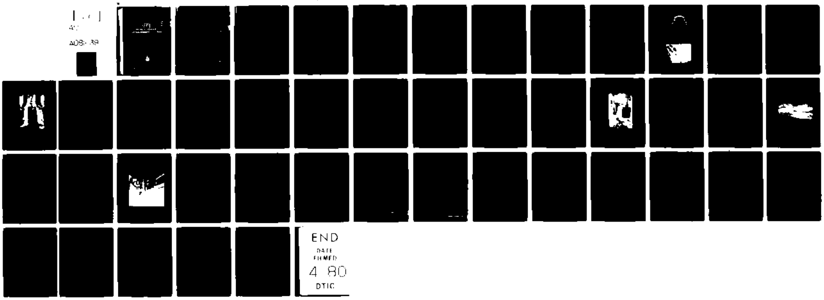

RESEARCH AND DEVELOPMENT BRANCH
DEPARTMENT OF NATIONAL DEFENCE
CANADA

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THE VEHICLE MOBILITY PROGRAM AT DREO, 1972-79

by

I. Lindsay

NOVEMBER 1979
OTTAWA

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FOREWORD

"A historical summary of the type offered in this Report deserves a formal introduction. Not only is it a referenced summary of the philosophy, aims and productivity of DREO/CRAD's research and development effort in the technical area of vehicle mobility on behalf of the Canadian Land Forces, but also it is an interesting story, of human interest, from which many lessons can be learned.

I had the privilege of being the Director responsible for the Technical Program during the period 1 January 1977 to 31 March 1979, the period during which the Program enjoyed its largest annual infusion of resources of manpower and capital funding. I have been deeply impressed with the enthusiasm of this Team, with its attention to things military, with its careful use of its resources, and with its overall productivity.

Vehicle-oriented studies have occurred off and on within the Defence Research community since the early 50's. A formal technical program was initiated in 1970, a program that took off in the period which followed, through external contracting and through an intramural program at DREO.

The author of this report, Mr. Ian Lindsay, was the team leader from 1972 until 1979, when the Program was transferred to the Defence Research Establishment Suffield (DRES). His historical summary of the work of the DREO Team, and his reflections on the evolution of the Program, are noteworthy and instructive."

E.J. Casey
Director,
Energy Conversion Division

ABSTRACT

The vehicle mobility program at the Defence Research Establishment Ottawa (DREO) between 1972-79 is reviewed. Following an outline of the philosophy and principles upon which the program evolved, summaries of the studies supported in universities and industry, and the intramural investigations at DREO, are given. Short outlines of the principal achievements of the various projects are included. The report contains a list of the reports, both intramural and extramural, that were produced as part of the individual studies.

RÉSUMÉ

Ce rapport examine le programme de la section Mobilité de véhicules au Centre de recherches pour la défense, Ottawa (CRDO) pour la période allant de 1972 à 1979. Les grandes lignes de la philosophie et des principes qui ont servis à développer ce programme sont esquissés et sont suivis par des relevés sommaires des projets et études supportés dans l'industrie et les universités et des recherches entreprises au Centre. De plus des résumés succints des principales réalisations de ces projets variés sont donnés. Ce rapport contient une liste de tous les rapports à la fois intra- et extra-muros produits au cours de ces travaux particuliers.

TABLE OF CONTENTS

	Page
FOREWARD	iii
ABSTRACT/RÉSUMÉ	v
TABLE OF CONTENTS	vii
LIST OF FIGURES	ix
INTRODUCTION	1
THE VEHICLE MOBILITY SECTION (VMS)	2
PREFACE	2
THE EXTRAMURAL PROGRAM	3
INDUSTRIAL PROJECTS	3
UNIVERSITY STUDIES	6
VEHICLE TECHNOLOGY (UNIVERSITY)	6
TERRAIN ANALYSIS (UNIVERSITY)	9
THE INTRAMURAL PROGRAM	14
COMPUTER MODELLING	15
SNOW TRAFFICABILITY	16
TERRAIN ANALYSIS	17
VEHICLE TECHNOLOGY	22
MISCELLANEOUS ACTIVITIES	25
APPENDIX A: VEHICLE MOBILITY PERSONNEL AT DREO, 1972-79	29
APPENDIX B: REFERENCES	31
APPENDIX C: CONTRACT REPORTS	35
APPENDIX D: UNIVERSITY GRANTS REPORTS	39

LIST OF FIGURES

	Page
Figures 1 and 2: The passive grouser.	4
Figure 3: The prototype portable penetrometer	7
Figure 4: The Bevameter penetrometer.	18
Figure 5: The DREO terrain temperature probe.	20
Figure 6: Test and recording vehicles for terrain roughness study . .	21
Figure 7: Instrument module for vehicle starting measurements	24

INTRODUCTION

In 1971 the program in vehicle mobility and terrain analysis at the Defence Research Establishment Ottawa (DREO) was significant but limited in scope and size. This was because the requirements of the Canadian Forces (CF) did not stress problems of vehicle technology, winter environments in Canada, and off-road terrain. The program, which had the title, "Geotechnical investigations related to northern operations", was aimed at providing a ready source of consultative support and information to the CF on terrain and mobility problems in Canada. It was conducted at DREO within the Earth Sciences Division (ESD) (Dr. J.H. Greenblatt, Director) by Mr. T.A. Harwood assisted by Capt. D.R. Grant.

Included in the ESD geotechnical program were two relatively small extramural studies at McGill University, Montreal, one by Dr. R.N. Yong which investigated the physics of soil-wheel interaction as a basis for improved vehicle design (1), and another by Dr. J.T. Parry on the development of methods for codifying micro and macro characteristics of terrain based on the need for specialized maps related to vehicle trafficability (2). The progress of the geotechnical program was summarized in a series of quarterly or semi-annual divisional reports beginning in January, 1971 and ending in August, 1979 (3).

In mid 1972, following Mr. Harwood's retirement, Mr. I.S. Lindsay became the leader of the Mobility Research Group with Capt. Grant continuing to contribute. During 1971-72 defence interest in northern Canada had been increasing markedly, a factor which led to a significant expansion of the Group's program both intramurally and extramurally. Included in the influences on the direction the expanded program would take were;

a) Report of the 1971 TTCP Sub-group T conference (4).

b) Report on the terrain conditions and mobility during World War II (5).

c) The Greenblatt Report (6).

Although the latter report was drafted as a basis for a vehicle mobility activity at the projected Defence Research Establishment Manitoba, its recommendations had considerable effect on the DREO program.

The expansion of the mobility research program was gradual as specialist personnel became available for those problems that were selected for study. The program evolved on the basis that;

1. It would largely relate to the CF need for all-weather, all-terrain vehicles for the whole Canadian geographical area.

2. At least initially, the studies would be aimed mainly at producing information that was relevant to the CF interest in an improved Medium Marginal Terrain Vehicle (MMTV).

3. As the program would be limited in scope, it would concentrate on problems that occur at the vehicle-terrain interface, i.e., on those vehicle components that react with the terrain and those terrain factors which affect vehicle mobility.

4. Initially, the program would emphasize extramural projects, i.e., advantage would be taken of the expertise and facilities in universities and industry.

5. As resources permitted the intramural program would be expanded to:

   (a) provide a more rapid response to CF requests, and
   (b) conduct selected studies on specific CF problems.

Initially a major aim was to reduce the terrain deformation caused by off-road vehicle activity while maintaining a high degree of drawbar pull. Although this objective continued to have high priority, in 1973 the program became strongly oriented to the need for energy conservation, a criterion that remained throughout the period at DREO.

In late 1976, following the disbanding of the Earth Sciences Division, the Vehicle Mobility Group became part of the Energy Conversion Division (ECD). Much of the Group's achievement to this stage was to the credit of Dr. J.H. Greenblatt, the ESD's former Director. The Director of ECD was Dr. E.J. Casey under whom the program continued to prosper.

THE VEHICLE MOBILITY SECTION (VMS)

PREFACE

As the Mobility Research Group acquired more staff and the research program expanded, it was elevated in status, i.e. it became the Vehicle Mobility Section (VMS). As the program already included productive extramural studies in vehicle technology and terrain analysis, whereas the intramural effort was still mainly consultative and advisory, it was decided to place primary emphasis on increased exploitation of the university and industrial potential for conducting applied research. The projects were funded as contracts.

One of the preliminary actions was a reorganization of the Advisory Committee on Military Transportation and Vehicle Engineering. This Committee proved to be very useful in providing advice on both the existing extramural and the proposed intramural research programs. It was also a productive forum for discussion between scientists and military representatives. The Committee was chaired by Dr. R.N. Yong and its Secretary was Capt. D. Grant. It was disbanded with the curtailment of the former Defence Research Board's extramural granting program.

A letter survey was conducted by Capt. Grant on university and industrial interest in mobility resea :h but replies, particularly from industry, were surprisingly few. Subsequent visits to the most promising of these companies indicated that even fewer had specialized facilities and personnel experienced in conducting research. Although the industrial program never became large, it was significant and was usually related to the more applied aspects of some of the university investigations.

A list of the personnel who worked in vehicle mobility at DREO during 1972-79 is given in Appendix A. Not all of them were there for the entire period.

THE EXTRAMURAL PROGRAM

INDUSTRIAL PROJECTS

Most of the industries contacted following the survey stated that they were willing to initiate applied research studies but, if sales of their primary products increased suddenly, or required some redesign and engineering, specialist personnel would be, at least temporarily, reassigned to the production line. One contract was let, to Bombardier Ltd., Valcourt, Quebec, to explore the possibility of incorporating the results of Dr. Yong's laboratory studies into practical vehicle track design. The Bombardier contract which was entitled, "Optimum track configuration for off-road vehicles", continued until 1976 and showed that there was considerable potential for an airfoil shaped grouser, that had been designed jointly by DREO and Dr. Yong, when incorporated into an actual vehicle track. The new grouser was called, "The passive grouser", because field tests showed that it significantly lessened the damage to the terrain surface from track action while minimally reducing vehicle drawbar pull.

The new Arctic Land Use Regulations, to which DND must conform in peacetime, were aimed at reducing the terrain surface disturbance which usually occurs with off-road vehicle operation. The passive grouser (Figures 1 and 2) was designed to have terrain entry and exit angles during motion which would depress but not fracture most soft terrain surfaces as more aggressive grouser-track systems frequently do. The Bombardier contract concluded with the production of a final report (7) which included a new set of criteria for evaluating terrain damage caused by a moving tracked vehicle. The passive grouser is currently being exploited by industry and was incorporated in Bombardier's MMTV 80 concept proposal to NDHQ in 1978.

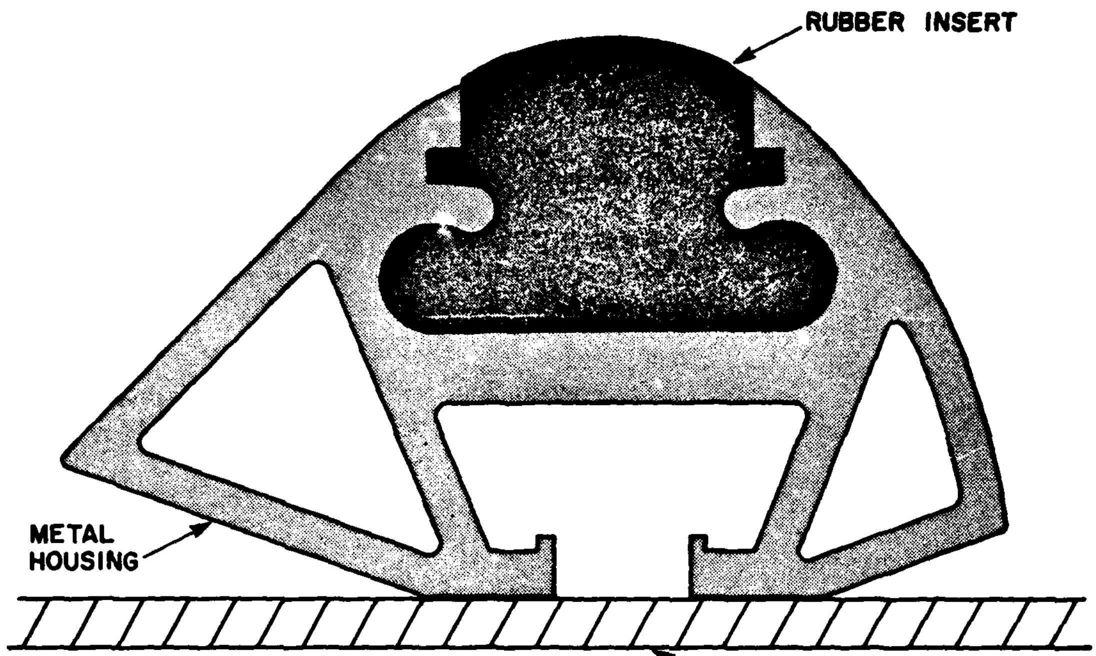
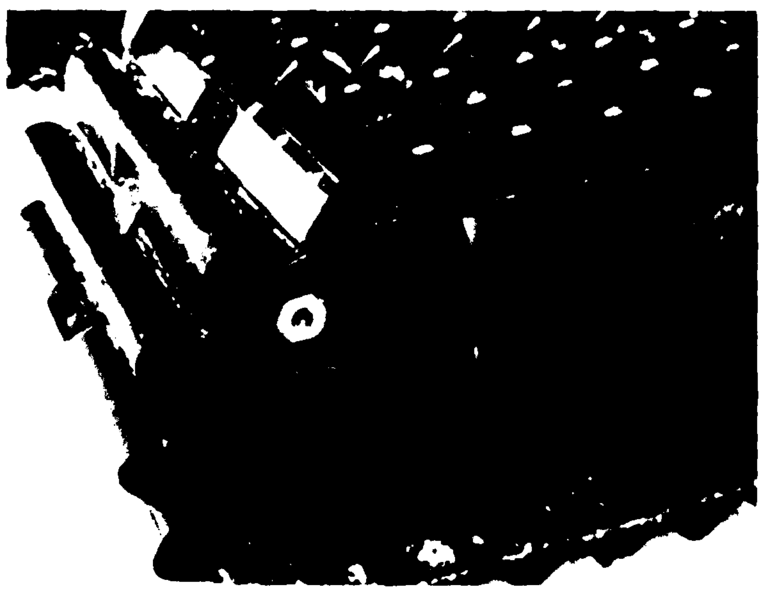


Fig. I The Passive Grouser



Figs. 1 and 2: The passive grouser.

One other contract was processed directly with industry although DREO did make a contribution later to a DSS bridge funded commercial study. The contract, negotiated in 1976, was with Innovative Ventures Ltd., Calgary, Alberta and was entitled, "Study of unconventional drive systems, suspensions and modular construction for a light-weight off-road vehicle".

The Innovative Ventures' study began with a review of the literature for vehicle technology. This analysis was sufficiently comprehensive that it was published as a DREO Technical Note (8) consisting of two parts, the first a list of one thousand documents and authors and the other, a compendium of three hundred abstracts and notations. The study was concerned only with current commercial vehicle components. As it progressed it was shown that;

i) Current electro-mechanical drive systems were too heavy for such a lightweight vehicle.

ii) Hytrel plastic tracks abraded quickly on gravel surfaces and cracked at low temperatures.

iii) Hydraulic drive systems were not efficient in lightweight vehicles.

In 1978 the contract was reassigned to Canterra Engineering, Calgary. The final report for the 1978-79 contract year (9) included design drawings for a lightweight experimental, four tracked, two unit vehicle incorporating a self-leveling system, articulated steering and pitch control. The vehicle was modularized so that the components could easily be flown in an aircraft such as a Twin Otter. It would be powered by a Wankel engine.

The jointly funded DSS study with industry was entitled, "A data base system for terrain data computation and map production". As the proposal was a direct outgrowth of an investigation at the University of Guelph that had been supported by DREO for several years, it is summarized under the university section of this report.

Although no other contracts were established with industry, through membership in a Steering Committee, close association was maintained with Hovey Ltd. and Bombardier Ltd. on two MMTV 80 concept NDHQ contracts. Project discussions had been held with Foremost International Ltd. and The Canadian Flextrac Co. but funding requests proved to be difficult obstacles.

Additional contact was continued with industry through VMS participation in the NRC Associate Committee on Air Cushion Vehicles (ACV) and the PAIT Program Review Committee on the Viking Hovercraft. An ACV requirement had not been expressed by the CF but through these associations a familiarity with ACV technology was maintained. A small transfer of funds was made to NRC in 1977 as a contribution to an ACV research project which was being conducted on behalf of industry.

UNIVERSITY STUDIES

In 1972 there were two active university contracts in the vehicle mobility extramural program. Both were with McGill University and were entitled,

1. Field mobility correlation devices and contact mechanisms (Dr. R.N. Yong).
2. Evaluation of terrain (Dr. J.T. Parry).

Dr. Yong's study represented the entire vehicle technology activity and Dr. Parry's the geotechnical program as supported by DREO at that time.

It was decided that limited expansion in both of these categories was warranted using the principle that the projects should be strongly applied research but with some degree of basic work in order to expand the data banks. It was also agreed that;

a) Vehicle technology studies should include the development of computer models where feasible, and

b) The geotechnical field program should emphasize the transect principle, i.e., the selection of representative geographical areas with a description of their surficial environment in digital form (10).

VEHICLE TECHNOLOGY (UNIVERSITY)

In 1973 a contract was negotiated with Dr. R.N. Yong at McGill University entitled, "Vehicle mobility and trafficability on snow covered surfaces". This was related to the need for track design data for CF over-snow vehicles. Initially, it was a laboratory study and resulted in the development of a snow making technique which enabled snow trafficability studies using physical measurements to be conducted throughout the year. Laboratory data were later compared with natural snow data and positive correlations shown. The study also showed the importance of snow age, wind effects, etc., on vehicle mobility. A portable penetrometer (Figure 3), sufficiently simple for field use, was developed as part of Dr. Yong's contract.

Although the study was concluded in early 1976, several of the principles and techniques were exploited by Dr. Yong in subsequent investigations for DND. For example, significant progress had been made with the analysis of the energy dissipation phenomenon through the vehicle's ground contact components and the terrain. The equations were used in the development of mathematical models.

Fig. 3: The prototype portable penetrometer.

The terrain contact mechanism and snow trafficability studies at McGill had now progressed to the point where separate approaches were required for wheeled vehicles and vehicles with tracks in off-road situations. In mid-1976, two contracts were negotiated with Dr. Yong entitled,

a) Vehicle mobility, track systems.

b) Vehicle mobility, wheel systems.

Each included both basic and applied studies aimed at improved vehicle operation, particularly as fuel economy had become an important criterion, as well as with performance prediction techniques. It had become obvious that computer modeling was increasingly important in vehicle mobility problems so there was a need for the development of component sub-models, complete modeling systems and, of course, the basic data on which they were dependent.

The wheel systems project included in its objectives the improvement of off-road vehicle drawbar pull through better wheel, tire, axle and terrain interaction, and the influence of tire construction and properties on energy transfer. The continued development of the vane-cone (VC) penetrometer for vehicle mobility prediction and the modification of the wheel-ground interaction computer model to include flexible tires were also important activities.

These studies continued in 1978-79. The first generation computer model for rigid wheel performance was improved using the data from the flexible tire studies on both firm and soft soils and vane-cone penetrometer sub-model input. Tire performance could now be expressed in terms of energy per unit wheel load and unit travel distance. The characteristics needed for a comparison of tires of different sizes and properties had been identified and defined in detail. With the new data an analytical model for use in the prediction of tire traction and performance was produced. This information was included in a major report presented to DREO as a PhD thesis (52).

In one of Dr. Yong's reports (50) he outlined the development and application of the finite element method (FEM) for the prediction of wheel-soil interaction relative to mobility. In a subsequent paper (51) an improved FEM was described which took into account the effect of the flexibility of a tire carcass, and the resulting energy loss, on mobility. The effect of inflation pressure on the development of tire deformation energy loss was shown for analytically computed values. A start was made during 1979 on the problem of performance prediction for a vehicle with multiple wheels and axles. Eventually tire performance prediction sub-models will be incorporated in AMC 74, a major computer model that was produced in the US.

Dr. Yong's investigation on vehicle track systems included continuation of studies on the effects on performance of grouser spacing, grouser geometry on the track belt, and terrain entry and exit angles. In a presentation (43) to the American Society of Engineers based on this work Dr. Yong showed the importance of belt flexibility in reducing deformation of the soil as a vehicle moved over it. The report also demonstrated that maximum drawbar pull using a rigid track can be obtained with large spacings between the grousers but with lower ride comfort because of irregularity in continuous ground contact. The distance between grousers also affected soil retention between them. The results of road wheel, suspension and sprocket design and location on the vehicle were also considered in relation to drawbar pull, terrain deformation and fuel consumption. As in the wheel study, the potential of various Marks of the vane-cone penetrometer for tracked vehicle performance prediction were assessed. Wherever applicable, the improvement of computer models, including AMC 74, was included in the program.

A number of field tests in snow using the vane-cone penetrometer were also completed by Dr. Yong. The following is a summary of the results of a field test at Alta, Utah, in which the vane-cone penetrometer was used to predict vehicle drawbar pull performance (ft.-lbs) in deep snow. Comparative data for the bevameter are also given.

Vehicle	Prediction		Actual
	Vane-cone	Bevameter	
Thiokol	5300	15000	5500
Bombardier	4000	11400	4200
Spryte	2200	10100	3300

Dr. Yong's study also resulted in considerable basic information on such factors as track-terrain parasitic energies, especially as affected by the vehicle's road wheels.

In 1978 major industries, in the U.S., Canada, and Sweden, adopted features for track systems and modelling procedures for prototype military and agricultural vehicles as derived from published material arising from the DREO-McGill mobility program. Fiel tests and application of many of these features were based on information resulting from DREO extra-mural programs.

Much of Dr. Yong's additional progress was related to mathematical modeling. A visioplasticity model was developed and the decoding of the individual items used in the AMC 74 model was completed. A start was made on the preparation of a User Manual for AMC 74. Titles of reports resulting from Dr. Yong's contracts are listed in Appendix B.

TERRAIN ANALYSIS (UNIVERSITY)

As stated, in 1972 Dr. J.T. Parry, McGill University, had a contract with DND entitled, "Evaluation of terrain". The aim of this study was, "To develop methods for codifying micro and macro characteristics of terrain in such a way that overlay and other special use maps could be produced relating to specific use of terrain". The project was based on air-photo analysis and interpretation supported by complementary terrain proofing in the field. The areas involved were CFB Gagetown and CFB Petawawa. In 1973 Dr. Parry published a report (44) which not only provided a history of the development of air-photo interpretation in Canada but included a comprehensive bibliography on the general subject. A valuable review of terrain classification systems and air-photo interpretation methods, as part of a Defence Research Board research grant, was produced in the same year (45).

Dr. Parry's contract was a continuing one. "False color" was used to study soil and vegetation and infrared imagery was shown to be useful in identifying water channels. Detailed reports and experimental maps were produced for the CF Bases at Gagetown and Petawawa.

As the CF had expressed increased interest in many regions of northern Canada, and funds for terrain research were relatively limited, a series of informal discussions was held with military specialists to define information and mapping requirements plus geographical priorities. These meetings resulted in a number of useful guidelines for the continuation and expansion of the terrain program, for example;

i) As some studies had already been conducted at CFB's Gagetown, Petawawa and in northern Quebec, first priority was given to the Mackenzie delta region of the North West Territories followed by the Churchill, Manitoba and Resolute Bay areas.

ii) Based on these regional priorities, terrain analyses and maps covering areas with radii of 250 miles would be useful.

iii) The needs for a terrain classification system and a mobility mapping method, i.e., information presentation, that met CF requirements were important.

These informal discussions also revealed the complexity of the CF requirements. For instance, the mapping needs of the vehicle commander might be quite different from those of the infantry officer or the military engineer. In fact, some of these requirements were in direct conflict.

In 1974 Dr. Parry completed a report (11) and map series for the Labrador transect (Lac Saffrey). The terrain's geological, hydrological and vegetal characteristic were photo-analysed and ground proofed and the information presented in tables and experimental color map overlays as a basis for estimating CF overland mobility. The terrain data bank was also expanded considerably.

Dr. Parry's project was continued in 1975 with the aim of producing a transect for the Mackenzie delta (NWT) region using his improved photo interpretation, and information ground proofing presentation methods. At the same time, as additional funds had become available, negotiations for a Western university contract on terrain analysis were started.

In early 1976 Dr. L.M. Lavkulich, Dept. of Soil Science, University of British Columbia, began a related study in northeastern British Columbia. A transect was selected in the transition zone of the mountainous and lowland areas for topographical study. Again, photo-analysis supported by ground proofing methods was employed. In addition to general expansion of the terrain analysis program on a regional basis, the UBC investigation used some different parameters than Dr. Parry's and was aimed at the development of an alternative data analysis and presentation technique. It would include a study of both topographic and photobase mapping systems for meeting CF needs.

About the same time a third study, one aimed at developing computer based terrain mapping methods, was initiated. Prof. S.H. Collins, University of Guelph, had, a number of years earlier, received DRB grants to develop an orthophotographic system for use in terrain analysis and mapping. The project had been dormant for a short period but in late 1975 a DREO contract based on the original findings was negotiated with Prof. Collins.

In 1976, as there were now several complementary extramural and intramural studies on terrain trafficability and experimental mapping, a, "Workshop on terrain analysis and mapping", was organized and held at CFB Gagetown. Its aims were to inform the CF of the progress in geomorphology and cartography, to modify the program accordingly, to ensure information exchange between the three university contractors and to field test an experimental mobility map produced by Dr. Parry. The Workshop accomplished these aims and permitted a detailed exchange of ideas between scientists and CF field officers (12). The recommendations of the Workshop report included one on the need for data bank expansion. Comments on photobase versus topographic maps, color coding requirements, and minimum obstacle sizes and separation for mapping purposes were also recorded. It was suggested that individual, special maps were needed for strategic planning, tactical forecasting and vehicle commander use. Finally, it was recommended that additional Workshops of this type be held.

Dr. Parry's report (13) on the Mackenzie delta (NWT) transect was completed in 1977. The terrain analysis maps, which were an important component of the report, were influenced considerably by the comments made by CF officers on the experimental mobility map that was field tested as part of the CFB Gagetown Work Shop. However, it was shown that the "clutter levels" of the experimental maps were close to exceeding the desirable limits when all "essential" mobility information was included.

As part of Dr. Parry's Mackenzie delta study, color, color IR, color UV and thermal IR air photos were compared as a basis for defining vegetation-permafrost relationships and the depth of the active terrain layer. Data for five physiographic regions were used to prepare a photobased vegetation classification for the Mackenzie (Inuvik) transect. Relationships were shown for type of vegetation cover and vehicle mobility, ground visibility to the foot soldier or vehicle driver, and concealment from aerial observation.

Following the completion of the Mackenzie transect study, Dr. Parry extended the project to Fort Churchill, Manitoba, the next region on the geographical priority list. Aerial photography for a transect in a hill-plain transition area west of Churchill was accumulated. On 1 April 1979, the contract became the responsibility of DRES.

As reported, in 1976 Dr. L.M. Lavkulich, University of British Columbia, began a contract study entitled, "Analysis of terrain in north-eastern British Columbia". The investigation was informally coordinated with that of Dr. Parry. The general objectives for the two studies were similar, i.e., production of Canadian data bank information and development of a terrain classification method acceptable to the CF. However, different geographical study areas and data analysis and presentation methods were selected.

The first major progress report was prepared by Dr. Lavkulich and his principal associate, Dr. H. Schrier, in 1977. It included a description of a trafficability mapping technique based on both point measurements and space and linear data, i.e., it was a numerical terrain classification scheme. The method was also an attempt to overcome the CF's objection to map overlays through the use of a multi-dimensional system based on a "data clustering" process rather than the multi-parameter approach. In 1978 a report (14) describing improvements to the numerical terrain classification system was compiled by the contractor. Data from soil surveys, topographic maps and aerial photographs had been used to develop a transect near Fort St. John in northeastern British Columbia. It included terrain data for both dry summer and frozen ground conditions. The technique had the advantage of treating both physical and environmental parameters simultaneously.

By late 1978 two distinct experimental terrain classification systems aimed at meeting CF needs had evolved, one by Dr. Parry and the other by Drs. Schrier and Lavkulich. A contract had already been established with Dr. Parry to develop a transect near Fort Churchill, Manitoba based on his classification system. As this region was large and complex with several distinct terrain transitions, a complementary contract was negotiated with Dr. Lavkulich to:

a) Analyze an area adjacent to Dr. Parry's study site so that a larger joint transect could be produced, and

b) Include a zone in common with Dr. Parry's on which the two experimental terrain classification systems could be compared.

Responsibility for Dr. Lavkulich's contract was transferred to DRES effective 1 December 1979.

Prof. S.H. Collins, University of Guelph, had developed a stereo-orthophotographic technique for use in some aspects of terrain analysis and mapping under the former DRB grant system. He described orthophotos as processed air photos linked to a map grid. A contract entitled, "An improved terrain trafficability system", was negotiated with Prof. Collins in 1975. Its objectives were to apply the stereorthophoto system, photogrammetric imagery, digital terrain analysis and an algorythm for computing terrain parameters, to terrain trafficability mapping using a computer as an intermediate step for data treatment, storage and presentation. The computer inputs were digital elevation data which were processed by slope, roughness and interpolation subroutines. Data display on the computer was by way of an offline map plotter.

A major progress report (14) was presented in May, 1978 by Prof. Collins to DREO entitled, "Development of an improved mobility model". It included a diagramatic outline of the stereorthophoto system plus prototype computer-plotter produced overlays on a computer drawn orthophoto trafficability map of CFB Petawawa. One overlay showed off-road terrain which an APC could traverse easily, the second overlay, terrain of greater difficulty, and the third, areas which were considered untrafficable. The overlays were based on data supplied by Dr. J.T. Parry, McGill University following one of the terrain mapping symposia. The results indicated the feasibility of a computer based trafficability mapping system to absorb and process a large amount of terrain data from points on orthophotos, in this case points that were 4.5 metres apart. They also showed the rapidity with which terrain trafficability maps could be produced using this technique. The system was not yet applicable to heavily treed terrain.

Prof. Collins' experimental method had reached the stage where fairly large amounts of funds for development were needed. Consequently, it was suggested to him that multi-departmental support should be explored. As a result, a DSS "bridge-funding" contract for 1978-79 was negotiated in which DREO, D Carto and EMR were to be contributors. Responsibility for CRAD participation in this project was transferred to DRES in April, 1979.

The final terrain analysis contract, negotiated in 1977, was with Dr. J-Y. Wong, Carleton University. It was entitled, "The design and evaluation of a bevameter for field application". The aim of the study was to modify the bevameter, a type of penetrometer, in which the load is mechanically rather than manually applied, as a scientific instrument for field use. The device measured compression and shearing resistance in terrain, including snow, as an indication of the surface's vehicle trafficability. The time required for the analysis of bevameter measurements usually delayed the application of the data during vehicle field tests so Dr. Wong proposed some automation. The suggestion for the contract originated with DST(OV) and CRAD funds were used for its support.

As part of the study a field data automatic recording and processing component was designed and incorporated into a vehicle mounted bevameter. It included a module for analyzing the pressure-sinkage and shear stress-displacement data obtained from the bevameter. Following completion of the hardware for the data processing component, the bevameter system was field tested in sand, muskeg and snow. Drawbar pull measurements using a CF APC (M113) vehicle were the basis for assessing the predictive capability of the bevameter system. Also evaluated was the consistency of bevameter data under a variety of well defined environmental conditions and the relative merits of several theoretical approaches. A series of reports was received from Dr. Wong including those entitled;

a) The design and evaluation of a bevameter for field applications (16), and,

b) An automatic data processing unit for a bevameter (17), and,

c) Evaluation of various methods for processing data obtained using a bevameter.

The final report includes the software for the data processing system. A detailed, "User's Manual", was also produced. Included were drawings for the bevameter assembly, the hydraulic circuits, the hydraulic drive and loading mechanisms for the shear head and for the sinkage reference pad.

Dr. Wong and his associates also produced a report (46) which relates the characterization of the mechanical properties of muskeg to vehicle mobility. Included are results of the load-sinkage and shearing characteristics from a muskeg site near Ottawa. Mathematical models for the bearing capacity and the shearing properties of muskeg were developed and methods for predicting the punching load, critical sinkage and shear strength for the substrate were proposed.

THE INTRAMURAL PROGRAM

As stated, in 1972 the intramural program in vehicle mobility was primarily administrative and planning with Mr. Lindsay and Capt. Grant being the main participants. The Mobility Research Group expanded as positions were acquired and specialist personnel hired. Eventually, the Group became the Vehicle Mobility Section (VMS) headed by Mr. Lindsay.

A new study by Capt. Grant was started in 1972 entitled, "Snow stabilization", which was aimed at producing techniques for hardening loose snow surfaces by applying liquid spray to reduce visibility and drifting problems particularly at airfields. A spraying system on a mobile platform was designed and a prototype used in field assessments. Small scale winter field tests of physical variables such as spray rate, droplet size, density, etc., had shown that colored water applications had more potential than chemical additives or organic solvents. During this period Mr. G.T. Booker joined the project and worked with Capt. Grant.

The results of the field tests indicated that it was not feasible to treat large areas of snow surface in very cold conditions. Dyed spray could be used to identify the boundaries of airstrips, taxi ways and roadways in winter.

After additional field tests of different colored sprays under various visibility conditions, plus many modifications to the mobile spray system, the study was completed. A DREO Technical Report (22) covering the tests was produced. During the study it had become necessary to include a fifth wheel component as part of the mobile spray platform to measure a number of surface parameters as the vehicle moved over the snow. The existing device did not perform acceptably until a number of improvements were made by Mr. Booker. They were reported in a DREO Technical Note (23).

During his secondment at DREO, Capt. Grant was active in many phases of the mobility program. He conducted the survey of industry and universities for interest in mobility research and was the Secretary of the DREO Advisory Committee on Military Transportation and Vehicle Engineering. He also did a short tour in Viet Nam in 1973. In 1974 Capt. Grant was transferred to CFB Borden.

Mr. Booker retired from DREO in the same year. He had been one of the project officers for the contract study by the Bombardier Co. entitled, "Optimum tractive element configurations for an articulated marginal terrain vehicle".

COMPUTER MODELLING

One of the areas in which it was decided the VMS could play a role was in computer modelling and vehicle mobility simulation. In late 1973 Mr. W.K. Ng joined the group and began expanding the computer modelling capability. DREO had previously received a copy of a comprehensive report (24) entitled, "The AMC Army Mobility Model 71", from the Tank Automotive Research and Development Command (TARADCOM), US Army, Warren, Mich. It provided detail on a prototype computer model designed to estimate the maximum feasible speed of an off-road vehicle over a section of analyzed terrain. It was also based on vehicle-terrain-driver interactions in a specified operational environment. A later experimental model, known as AMC 74, was produced using data from US test sites, a variety of conditions and several vehicles. In order to make it useful for CF purposes, equivalent Canadian data had to be produced and incorporated in the model. Also, the basic US model did not include data for vehicle performance in snow nor for articulated tracked vehicles, subjects of major CF interest.

The AMC 74 model, which consisted of a series of complex mathematical modules including the Areal, Ride Dynamics and Obstacle Crossing sub-models, was written in Fortran language and coded for a CDC 6600 computer. One of the early requirements, following receipt of the AMC 74 tapes from TARADCOM, was to convert the job-control-language and input-output codes so that the model could be installed in DREO's Sigma 9 computer. This was done by Mr. Ng and Dr. J.E. Neilson of Carleton University. A formal report of the conversion was prepared (25).

Following the installation of AMC 74 in the DREO and then the McGill University computers (the latter by Dr. R.N. Yong), a number of errors were detected in the model which had resulted from changes in the basic mathematical equations and in the experimental programming. Corrections were made which improved the computational capability of AMC 74. These changes were formally reported by Mr. Ng (26).

Much of Dr. Yong's contract work on vehicle components and mobility at McGill University involved the development of computer models and the production of data for them. He and his associates produced mathematical models for visio-plasticity (soil and snow) analysis and for the prediction of wheel-terrain interaction, vehicle track action and flexible tire performance. These models were designed so that they could be easily incorporated into AMC 74. At the same time Dr. Yong made code identifications and listed the functions of individual items for AMC 74. Eventually, he wrote a detailed User Manual for the model. The McGill program was informally coordinated with Mr. Ng's work at DREO.

In 1976 a series of meetings were held with CF representatives to determine interest in and guidelines for the DREO computer modelling program. It was agreed that all-season terrain information, including snow, and Canadian vehicle performance data, particularly for the ride dynamics, would be required. This influenced the VMS plans for both the intramural and extramural mobility programs. The CF were also interested in computer simulation as a means for preliminary screening of candidate commercial vehicles and Medium Marginal Terrain Vehicle (MMTV) concepts. One of Mr. Ng's principal objectives was the improvement of AMC 74 to help to meet these needs.

During this period Canada became a participant in an evaluation of AMC 74 as an experimental, "NATO Reference Mobility Model". The aim was to develop a computer model which each of the NATO countries could use as a simulation and analysis tool for comparative mobility and equipment evaluation. Mr. Ng attended meetings of the relevant NATO Panel and reported on DREO experience with AMC 74 and on corrections, improvements and modification of the model for meeting Canadian requirements, particularly for a winter scenario.

In late 1978, following the drafting of additional reports, Mr. Ng transferred to the Dept. of Transport. A contract was negotiated with Dr. J.E. Neilson, Carleton University, to keep the computer modelling program viable until its formal transfer to DRES in 1979.

SNOW TRAFFICABILITY

Following his transfer from ice research to the VMS in late 1974, Dr. G.J. Irwin initiated a study of snow trafficability relative to CF requirements. As well as concentrating on vehicle mobility problems in northern regions of defence interest, he informally coordinated his field work with the laboratory studies of snow being conducted by Dr. Yong at McGill University. Several of the NATO countries, particularly the USA and England, had stated reliance on Canada for snow trafficability information.

Dr. Irwin's initial field work was conducted near Schefferville, Quebec, in 1975 where, using snow pits, measurements were made of snow profiles, snow density, moisture content, particle characteristics and bearing strength. An experimental vane-cone penetrometer was assessed and several modifications initiated. A second visit to the Schefferville area resulted in considerable data on wet snow qualities. Some of these data were used by Prof. Collins, Guelph University, during the development of the stereorthophoto process.

Reports of the Schefferville results were given at the second DREO Symposium on terrain analysis and mapping. The snow data were also used by Dr. Irwin in the development of a formal classification for snow relative to off-road vehicle performance (27). This classification system was based on studies of deposited and metamorphosed snow in several Canadian regions. Information was included in another report (28) on the value of a plate penetrometer, modified by Dr. Irwin, for making snow measurements. Another snow classification system, developed by Dr. Parry for the Mackenzie delta region, was used as a basis for some of Dr. Irwin's work.

Additional snow investigations were conducted by Dr. Irwin at the Land Engineering Test Establishment (LETE), Orleans, Ontario, and at DREO in

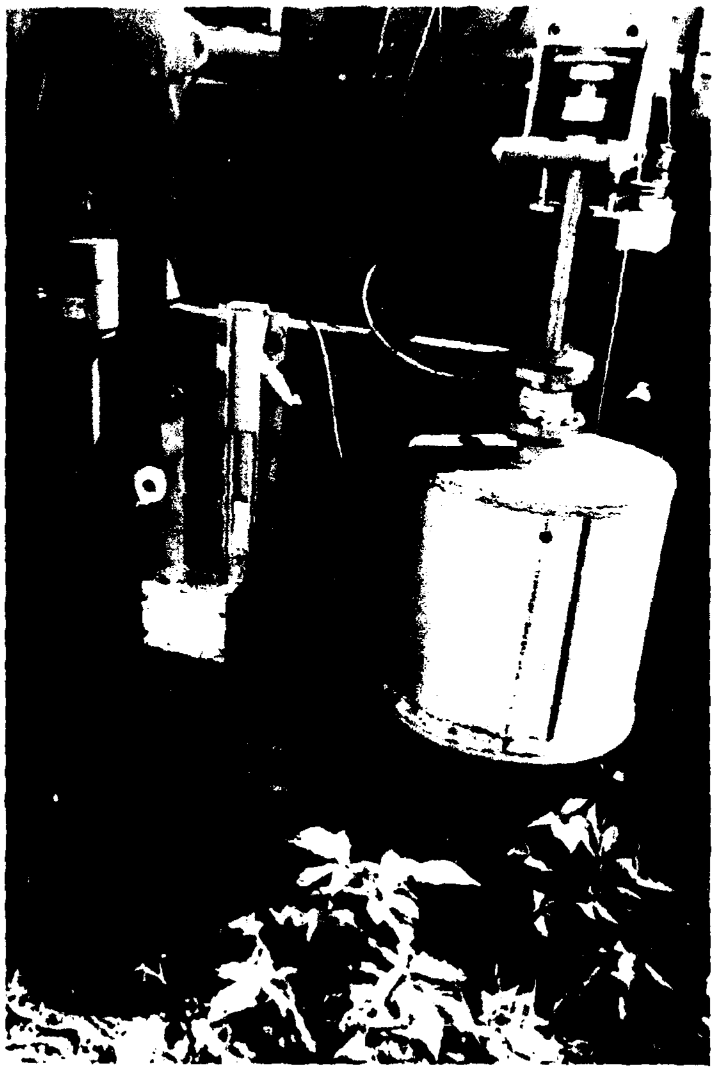


Fig. 4: The Bevameter penetrometer.

d) Obstacle direction as a function of terrain surface linearity.

e) Terrain matrix cohesiveness, which is a factor in the subarctic because of seasonal changes in the terrain.

The classification was divided into mathematical description and surface roughness definition categories.

Mr. Pilon was assisted by Mr. D. Pichette throughout the terrain roughness program at DREO. During the geotechnical field work near Tasiujaq (49), northern Quebec, it became obvious that the standard soil temperature probe was not sufficiently rugged. Mr. Pichette designed a lighweight probe (Figure 5) with much better durability. Field tests showed that the new probe (35) rapidly reached equilibrium with ambient temperature in the active terrain layer. Patent processing for the device has been initiated.

Some of the difficulties with field analysis in northern Canada have been the country's vastness, degree of surface variation and the time consuming measurement process. In 1977 an airborne terrain surface data acquisition system was designed at DREO. The principal components were a Laser Profilometer, a Time Interval Counter, a 3-axis Stabilized Platform, a Video Recording TV Camera and a digital Tape Recorder (47,48). A short term contract was negotiated with Davis-Eryou Ltd. for an engineering and systems analysis of the laser profilometer which had been procured from a US source and modified considerably at DREO. Following this the equipment was to be transferred to DRES for flight testing and application.

Another series of tests was conducted at LETE in 1977 on the effect of surface roughness on the performance of a CF APC 113. The roughness course, which consisted of randomly spaced obstacles, and the test program were designed and conducted by Mr. J-P. Bacle, an experienced scientist on term employment at DREO. Velocity changes, pitch, yaw, heave and roll were electronically and graphically recorded during tests at various vehicle speeds. The driver's comments were also recorded. Unfortunately, Mr. Bacle left DREO before completion of this project but significant data were obtained, a valuable study method was developed and the data bank increased. Figure 6 shows the test and data recording vehicles.

In 1978 the CF were conducting evaluations of a number of candidate trucks as the 2.5 Ton replacement vehicle. As part of the field assessment the VMS had been asked to conduct surface soil analyses relative to the performance of the candidate vehicles at LETE and CFB Petawawa on a variety of wet and dry substrates. Soil bearing strength was the main parameter to be measured so the opportunity was taken to compare the WES cone penetrometer (the standard) with the experimental McGill University vane-cone device. Soil water content and density were also measured.

Participating in these tests were Mr. Pilon, Dr. Irwin, and Mr. Hutton of the VMS, plus summer students Mr. Y. Bégin and Ms. C. Mougeot. Mr. Bégin was given the responsibility, with supervision, for the conduct of the soil assessments. Several reports of these tests were prepared (29,30,31, 32 and 33). The reports, with Mr. Bégin as the principal author, described not only the physical properties of the test area terrain at LETE but also the proportions of soil voids, solid components and carbonates as well as the shape and size of pores and grains. Comparisons of terrain deposits and

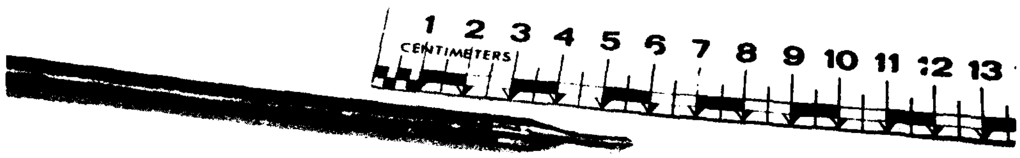


Fig. 5: The DREO terrain temperature probe.

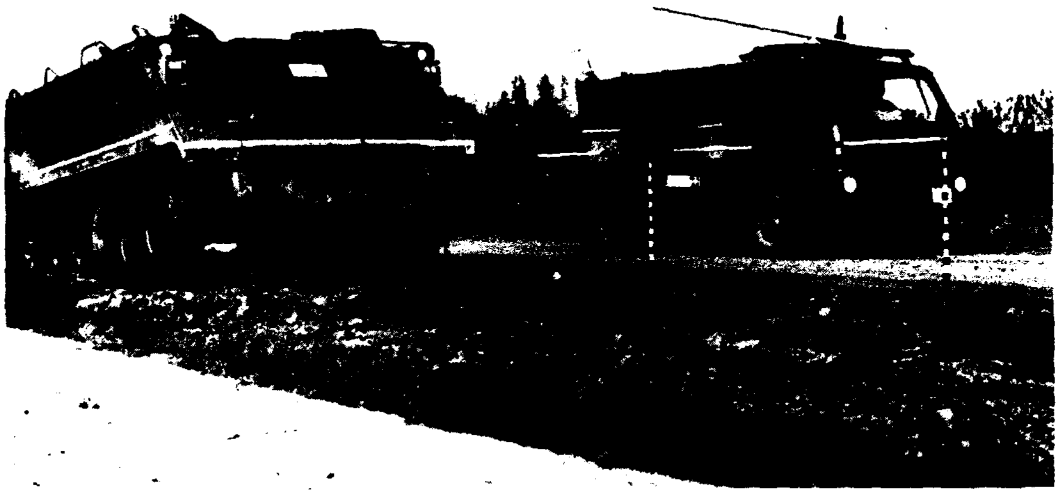


Fig. 6: Test and recording vehicles for terrain roughness study.

obstacle types were given for the experimental sites at LETE and CFB Petawawa. The relationship of the mechanical properties of the substrates, based on their physical properties, to the mobility of the candidate vehicles was demonstrated. Comparisons of the bevameter, the WES penetrometer and the McGill vane-cone penetrometer indicated that the first was the most representative of the mechanical interactions of vehicle and terrain for research purposes.

Annual Symposia on Terrain Analysis and Military Mapping were organized by the VMS to review CF requirements, informally coordinate the intramural and extramural research investigations and keep the CF aware of progress and difficulties. In addition to a general information exchange, there were specific benefits to the overall program. For example, although developing different terrain classification and data representation methods, there was considerable collaboration between the McGill University and University of British Columbia projects. Also, Prof. Collins, in evaluating a prototype system for digital terrain modelling, used actual field data produced as part of Dr. Parry's study. At the third Symposium, several US specialists expressed interest in closer ties between their program and the CRAD terrain analysis investigations.

Mr. Pilon left DREO in late 1978. The remainder of the intramural terrain analysis program at DREO consisted primarily of report processing.

VEHICLE TECHNOLOGY

In 1975, when it had become apparent that intramural expansion in vehicle mobility research was warranted, talks were held with CF personnel on the type of effort which should be given priority by DREO. During a visit to DLMSEM discussions (I.S. Lindsay-Col. E. Kuffner) indicated that serious starting and operating problems existed for CF vehicles in the low temperature environment. DREO was subsequently tasked (DLMSEM 14) to study the problem and arrangements for a relatively small project were initiated.

Mr. G.J. Hutton joined DREO in early 1975 and took responsibility for the study entitled, "Operation of land vehicles and equipment at low temperatures". The main objective was to determine low temperature operating limits for materials, components and systems as a base for the improvement of specific CF vehicle performance. After a literature review and a number of preliminary discussions, it was confirmed that the problem was too complex to be solved through a one year study. Mr. Hutton was now assisted by Mr. W.G. Ferguson and in September 1977, Mr. G.D. Webster joined the Vehicle Technology (VT) group.

In preparation for the low temperature study, CF vehicle winter operations at a number of northern sites, including CFS Alert, Ellesmere Island, were observed. Civilian experience, particularly the petroleum industry's in the north, was also reviewed. Time was spent with CF maintenance crews who were preparing vehicles for winter exercises at Camp Wainwright, Alberta. At Churchill, Manitoba some preliminary measurements were made on the starting and warm-up temperatures of cold-soaked vehicles including an APC 113, an RM 110 and an Alpine snowmobile. Reports on the observations and measurements made in this preliminary phase were given to DGLEM and other relevant NDHQ agencies. A review paper based on these findings was presented at the 7th QWG (Armour) Conference at FMC HQ (36).

As a result of this field experience, it had been determined which vehicle components in the electrical system and drive train required detailed study in low temperature conditions. Instrumentation to measure component temperatures and electrical system behaviour during the engine start and warm-up from the cold soaked condition was designed and tested. This was a difficult task as sensor attachments at a number of different points during vehicle motion on rough terrain were required. Nevertheless, a field portable module (Figure 7) for monitoring and recording component performance, fuel and air flow and cylinder pressure with a quick-disconnect system, for either gasoline or diesel powered engines, was developed. Automatic recording of 24 component temperatures and 12 electrical measurements was now possible. At a Land Ordnance Engineering Conference in May, 1978, Mr. Hutton reviewed these low temperature-vehicle starting studies. He outlined the problems (37,38) of intermittent vehicle operation and the advantages and disadvantages of engine heating and reheating. At the same conference Mr. Webster described tests at CFS Alert which indicated the M113 cold soaked no-start temperature as -22°C. He also outlined a technique for the identification of combustion phases like "first fire" and "actual start" and discussed the eventual probability of vehicle self-monitoring of these processes using micro-processors (38).

In late 1977, Mr. Rainer Glass, a mechanical engineer from West Germany with design experience with combat vehicles, joined the VT group on a Canadian Defence Research Fellowship. During his year at DREO, Mr. Glass participated fully in both the laboratory and field studies of the group and provided considerable assistance. He also helped the terrain research team with penetrometry assessment and modification. Mr. Glass returned to West Germany in October, 1978.

The portable recording module was used in the next series of vehicle starting and operation tests in February, 1978 at CFS Alert. The diesel engined APC 113 and the gasoline powered CF 1.25 T truck were tested in temperatures ranging from -22°C to -40°C. In May the starting performance of candidate and standard vehicles for the CF 2.5 T truck replacement program was evaluated in the NRC Cold Chamber using the portable module. Reports (37,38,39 and 40) of these low temperature tests were presented at the Land Ordnance Engineering Conference, CFB Borden, in late May, 1978.

A second series of low temperature vehicle starting tests using the NRC Cold Chamber was conducted in December 1978 and a third in March 1979. They were attended by DRES personnel to become familiar with the equipment and methods that had been developed. The results proved the reliability of the new systems and techniques. Minimum temperatures for starting a vehicle, for marginal start, marginal no-start and no-start were established. The effects of variations in airbox heater operation, coolant heater changes and different vehicle operators, and the use of several synthetic oils were shown. Battery cooling rates after vehicle shutdown were determined for a range of ambient temperatures. With the assistance of personnel from the DREO Energy

Fig. 7: Instrument module for vehicle starting measurements.

Conversion Division, battery discharge and charge rates, and starter and alternator currents and voltages during the APC 113 engine starting sequence, were measured at low temperatures. Both Mr. Webster and Mr. Hutton have drafted reports (41,42) of the various tests conducted in this series.

In late 1978 Mr. Webster was transferred to other duties in DREO. In the spring of 1979 the VT materiel inventory was checked and the equipment, tools, instruments, etc., shipped to DRES. Alas, Mr. Hutton accepted a position in NDHQ (CRAD) soon after.

MISCELLANEOUS ACTIVITIES

The Vehicle Mobility Section took part in a number of miscellaneous activities related to off-road CF vehicle research and development. As the Section was relatively small even at its peak, it was easy to maintain direct contact with the extramural contractors. Section personnel frequently co-operated with the organization and conduct of extramural field investigations, particularly when CF facilities and equipment were involved.

Although the CF had not stated a requirement for Air Cushion Vehicles (ACV), the principle was considered to be sufficiently interesting as an off-road system that a familiarity with ACV research and development should be maintained. From 1972 to 1974, Mr. I.S. Lindsay was responsible for ACV familiarity and was a member of the NRC Associate Committee on Air Cushion Vehicles. This committee was a valuable contact with industrial, university and government R and D in the ACV field. Mr. Lindsay was appointed to the Dept. of Industry, Trade and Commerce's PAIT Program Review Group for the Viking Hovercraft. He and Capt. Grant also participated in the PAIT Review Group for the Martin Track, an experimental vehicle track design.

In 1975 Dr. Irwin became responsible for ACV technology at DREO and joined the NRC Associate Committee. He was also involved in the negotiation of a DREO transfer of funds to NRC to assist with the CASPAR ACV research project.

Mr. Lindsay was a member of the NDHQ Steering Committee on the Medium Marginal Terrain Vehicle (MMTV) (1980) which had the aim of stimulating designs for such a vehicle for the CF. Following an, "MMTV 80 Bidders Conference", which was arranged by NDHQ, Mr. Lindsay was appointed by the Steering Committee to a technical evaluation team to analyze and grade the subsequent MMTV 80 concept proposals from industry as a basis for selection and funding. Eventually, two contracts were awarded totaling 250K, one with Bombardier Ltd. and the other with Hovey Ltd., for separate MMTV 80 concept studies.

Mr. Lindsay was a member of the DND team which attended the monthly progress review meetings for the Hovey and Bombardier contracts. The final reports for the two MMTV 80 concepts were submitted to NDHQ in 1978. The VMS contributed to the arrangements for their analysis using computer modelling.

In 1975 the VMS joined NDHQ in the initiation of a Swedish-Canadian Correspondence Group on Vehicle Mobility and Terrain. Several briefings on the VMS intramural and extramural programs were given to Swedish representatives during subsequent information exchanges.

An invitation paper (52) on the DREO mobility program was given by Mr. Lindsay at an NRC Symposium on needs for cold region research and development. In attendance were representatives of universities, industry and other government agencies.

Dr. Greenblatt left DREO in mid 1975 and from then until the Earth Sciences Division was disbanded in late 1976 Miss I.M. Dunbar was the acting director. In early 1977 the VMS became a component of the Energy Conversion Division which was directed by Dr. E.J. Casey.

Following the formal announcement in July 1978 that the VMS would be moved to DRES effective 1 September 1979, the transfer of the Section's staff to other duties was gradual but relentless. Only Dr. Irwin of the original personnel became a member of the new Section at DRES. Naturally, there was disappointment among the VMS staff in the decision to transfer the Section but all continued to contribute fully to the Section's program as long as possible. They were a group of which to be proud.

Once the decision to move the Section had become firm, it was decided that the transition period would be eased if there was minimal need for DRES to process new research contract demands immediately. Therefore, those DREO extramural contracts which warranted continuation were renegotiated for two and three year terms which would carry them well beyond the transition phase. The contractors cooperated completely with this scheme even though forecasting programs and administrative needs so far in advance was difficult. On 1 April 1979, the responsibility for the VMS extramural program was transferred to Defence Research Establishment Suffield.

A total of 122 research reports and scientific papers resulted from the vehicle mobility program. Of these, 35 were intramural and 87 from the extramural contract or grant programs. The references referred to in the text are listed under Appendix B. Appendix C lists the other papers and reports which were produced by contractors as part of the extramural program. Appendix D is a list of mobility reports which resulted from the university grant program prior to its cancellation.

ACKNOWLEDGEMENT

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APPENDIX A

VEHICLE MOBILITY PERSONNEL AT DREO, 1972-1979

Section Head - Ian Lindsay

- Vehicle Technology

  G.J. Hutton - Leader
  * Capt. D. Grant
  ** G.T. Booker
  G. Webster
  *** R. Glass
  W. Ferguson

- Terrain Analysis

  J.A. Pilon - Leader
  D.R. Pichette
  J-P. Bacle
  **** Y. Bégin
  **** C. Mougeot, Miss

- Snow Research

  Dr. G.J. Irwin - Leader
  E. Zweck von Zweckenburg, Miss

- Computer Simulation

  W.K. Ng - Leader

- Secretary

  Mrs. R.M. Carroll

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* Seconded *CF* Officer
** Retired in 1974
*** West German NATO Fellow
**** Summer Student

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APPENDIX D

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13. ABSTRACT

The vehicle mobility program at the Defence Research Establishment Ottawa (DREO) between 1972-79 is reviewed. Following an outline of the philosophy and principles upon which the program evolved, summaries of the studies supported in universities and industry, and the intramural investigations at DREO, are given. Short outlines of the principal achievements of the various projects are included. The report contains a list of the reports, both intramural and extramural, that were produced as part of the individual studies.

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