The Harsh-Environment Initiative – Meeting the Challenge of Space-Technology Transfer

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ESA's Harsh Environments Initiative (HEI) is a programme aimed at transferring space technologies to terrestrial operations in harsh environments. C-CORE is the prime contractor to ESA for implementing the programme, and the Canadian Space Agency is a programme sponsor.

C-CORE's approach to meeting this challenge is to seek out operational priorities in the oil & gas and mining sectors and to develop and implement test-bed projects that apply selected space technologies to demonstrate improved operating efficiencies, lowered risks and enhanced safety. These projects typically involve one or more partners from industries in Canada and Europe, and additional sources of funding that exceed the ESA contribution.

Commercialisation of the space technologies is a key objective. Accordingly, C-CORE and its partners have developed selection criteria that have ensured that only projects with high potential for commercialisation and quick technology transfer (involving the exchange of funds between the space-technology supplier and the end-user) would go ahead.

Introduction

ESA awarded the Harsh Environments Initiative (HEI) contract to C-CORE in August 1997 following an open bidding process in Canada. Supported by the Canadian Space Agency (CSA) also, C-CORE undertook 'The Application of Space Technologies to Operations in Harsh Terrestrial and Marine Environments'. Phase-1 of the Initiative ended in February 1999 and was followed by a seamless transition into Phase-2, which ends on 14 January 2000. The focus of the programme is to transfer space technologies for industrial application in the oil & gas and mining sectors.

The key issues relating to oil & gas and mining operations were identified through specialist workshops as well as one-on-one meetings with potential industry users. New technologies that could enable the targeted sectors to enhance operations in harsh environments, to develop capabilities for more automated operations and provide the ability to operate year round, were determined. Oil & gas and mining development in remote regions such as the Arctic require safe, reliable and efficient operations. Likewise, offshore oil & gas development, particularly in areas invaded by sea ice or icebergs, requires subsea systems that integrate such technologies as robotics and artificial intelligence. Remote operation of subsea systems was identified by the offshore industry as an R&D priority as the need to protect its workers from having to enter high-risk environments becomes ever more critical.

The first 18 months (Phase-1) of the Harsh Environments Initiative brought a number of notable achievements:

- Three operations nodes were established in Canada:
  - Host Node (C-CORE)
  - Oil & Gas Operations Node (C-CORE)
  - Mining Operations Node (Mining Innovation, Rehabilitation and Applied Research Corporation (MIRARCo), Laurentian University, Sudbury, Ontario).
- The European Network was initiated through the Norwegian Geotechnical Institute (NGI) in Oslo.
- An International Advisory Board was established with members from ESA, CSA,

the Spacelink Group, the Province of Newfoundland and Labrador, Small and Medium-sized Enterprises (SMEs), the oil & gas and mining sectors, and Government research agencies.
– Eight demonstration projects were initiated, each with its own partnerships and strategic alliances. Space technologies were introduced into existing projects being undertaken within the oil & gas and mining sectors. The projects were evaluated against five criteria and were approved by the International Advisory Board. They were:

Oil & Gas Node
– *The Consortium for Offshore Aviation Research (COAR)*: This project focussed on the issues associated with operating helicopters on the Grand Banks, with particular emphasis on final approaches to helidecks in low-visibility conditions.
– *Radome Icing*: Microwave communications towers in Labrador develop very large accretions of rime ice, which can disrupt communications. The objective of this project was to evaluate advanced ice-phobic materials able to reduce these ice accretions.
– *Monitoring of Ground Motion using Interferometric Synthetic Aperture Radar from Space*: The objective of this project was to measure ground movements of unstable slopes in which pipelines had been installed so as to be able to take action to relieve stresses before they caused pipeline failures.
– *A Feasibility Study for the Detection of Shallow Gas Hazards in Deepwater Seabeds*: As oil & gas exploration moves into ever deeper waters, the hazard posed by gas hydrates increases. This study was undertaken to develop systems that can identify such gas pockets at depths of more than 3000 m.

Mining Node
– *Sensori-Motor Augmented Reality for Tele-robotics (SMART):* The main objective of this project was to develop systems that would enable the entire mining process to be automated.
– *Geosensing:* To efficiently identify and exploit ore bodies underground, it is essential to be able to determine what lies ahead of the drills. This project focused on developing sensors for ‘geo-probing’ or ‘looking ahead’ in mining operations.
– *Micro-Seismic Pressure Monitoring*: The focus of this project was to monitor the underground environment in order to delineate ore bodies or reservoirs over a period of time.
– *Evaluation of ESA Simulation Tools*: To model the end-to-end mining process, complex simulation techniques are required. The evaluation of ESA-developed simulation software and tools was therefore the focus of this project.

A total of 14 European and 33 Canadian industries – from both the space and non-space sectors – had some involvement in these 8 projects, either as potential suppliers of space technologies or as partners. The space technologies evaluated in the various projects included advanced materials, sensors and sensor systems, robotics hardware and software, vision systems, communications and simulation software and tools. The majority of these technologies came from European industries. Ten technologies were incorporated into the demonstration projects.

One of the key thrusts during Phase-1 was to get end-user commitment at an early stage so as to ensure continuous support – either in cash or in kind – for the demonstration projects. ESA had set a number of targets for this funding leverage (0.58 in cash and 0.83 in cash+kind) and all were exceeded (1.12 in cash and 1.82 in cash+kind).

The technology-transfer process
The HEI is continuing to focus its efforts on the oil & gas and mining sectors, where many operations are being conducted in extremely harsh environments. These two Operations Nodes seek either existing projects for which priorities were set, or accelerate those projects that were prioritised at a series of specialist Workshops held in Canada and Europe. The Workshops included Offshore Aviation Research; Mining Operations; Oil & Gas Operations; Deep-Water Operations, Arctic Development and Underground Tunnelling; and the Application of Advanced Space Technologies to Improving Efficiencies in the Petroleum and Mining Industries.

The selection criteria developed ensured that only those projects that meet all of the following requirements were presented to the International Advisory Board for approval:
– *Relevance:* There must be potential major benefits to the project from adapting, or adopting, space-developed technologies, or through developing new technologies that might have applications in space.
– *Support:* The project must have a receptor industry as an end-user, or a partnership of industries as end-users.
– *Timing:* The project must be capable of being substantially demonstrated during the programme activities.

– *Leverage:* The project must have significant potential to lever industrial funding greater than, or equal to, the ESA seed funding.
– *Commercialisation:* The project must have commercial potential and the partners to undertake commercialisation.

The challenges of space-technology transfer
The C-CORE Technology Transfer Model is illustrated in Figure 1. All of the HEI demonstration projects are industry-driven. The key to a successful transfer is to involve industry at an early stage in the demonstration project's development. This will ensure that future commercialisation opportunities can be facilitated.

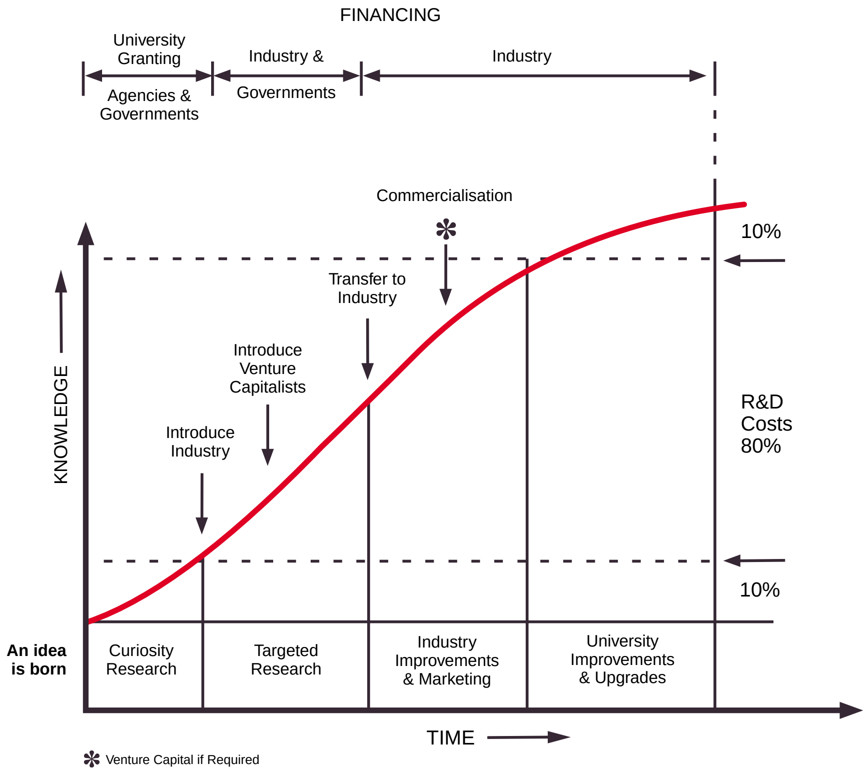

Figure 1. The C-CORE Technology Transfer Model

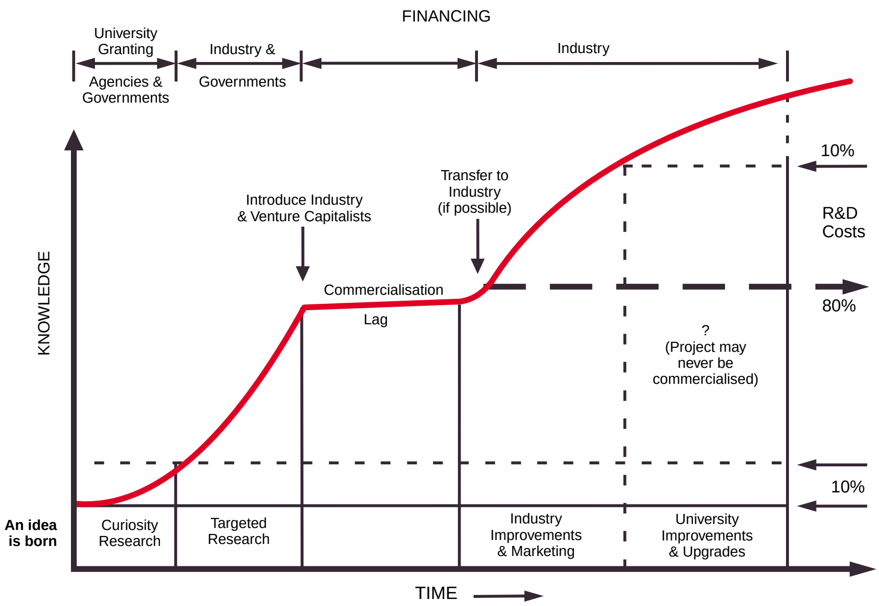

Figure 2. The negative effect of late industry involvement

The consequences of late industry involvement can be seen in Figure 2, where a 'commerciali-sation lag' may delay effective adoption of the technology, or may even result in the project never being commercialised. This is a result of waiting too long to include industry in the project or to seek venture capital where it is needed. The latter should happen very early in the project, as shown in Figure 1, well before the technology is expected to be developed to the point where it can be commercialised.

Based upon the above philosophy for technology transfer, C-CORE established a Commercialisation Committee for Phase-2, to focus specifically on early commercialisation. This Committee requires that the project managers:

– demonstrate a commercial need for the technology
– provide a preliminary assessment of potential market size
– identify the potential to generate new products and services
– describe how space technologies will be integrated
– indicate the involvement of end-users and commercialisers
– furnish a plan for the demonstration of products and services
– focus specifically on the potential mechanisms for commercialisation, and
– assess the impact of the transfer (economic, visibility etc.).

Case studies

Sensori-Motor Augmented Reality for Tele-robotics (SMART)
In mining, large and slow-moving mechanical units such as shovels, drilling rigs, rock breakers, load/haul/dump vehicles, etc. operate under hazardous conditions and at speeds that directly affect the operation's productivity. The tasks to be performed – drilling, scaling, bolting, fragmenting, scooping, etc. – involve complex mechanical interactions with the environment, and require operator skills based upon extensive experience and intuitive knowledge. These skills cannot be modelled easily, precluding at this stage the possibility of full automation. Tele-operation of this equipment can, however, be adopted as an interim technology.

Conventional tele-operation maintains a direct link between the operator and the equipment, which has three major disadvantages:

- the slow motion and the complex machine/environment interactions require continual operator/equipment dialogues, which demand the operator's attention for most of the task; such tasks are typically very tedious, resulting in a reduced attention span
- the task is prone to collisions and control errors, with potentially detrimental consequences to the equipment, the environment or the task itself; and
- transmission delays to and from the operator's site adversely affect efficiency, stability and safety.

The SMART program seeks to alleviate these problems by developing an alternative method of operator/equipment interaction that decouples task specification and task execution. This requires two primary technological advances:

- interactive 3D sensing: minimising the volume and frequency of sensory-data transmitted to the operator and supplementing it with real-time, synthesised information upon request; and
- enhanced sensory-motor interaction: mediating between task specification and task execution using a virtual representation of the equipment in the task representation perceived by the operator.

Both of these areas address the disadvantages associated with the transmission delays, and create a form of operator/equipment interaction that reduces the operator's involvement during the lengthy execution phase. They will also offer the option of simulating the task prior to its execution, considerably reducing risk. Overall, the development will lead to more efficient, safer, and realistic alternatives to present-day operating methods.

Project description
The work during the period from February 1999 to January 2000 will consist of in-depth analysis and adaptation of three technologies:
- a head-mounted stereo display system (CASA-Space Division)
- a force-feedback joystick (Matra Marconi Space)
- robot-control software (collaboration with Space Applications Service, Belgium)

which were identified during Phase-1 following an evaluation of 21 space technologies. Adaptations may include hardware modifications and will necessitate substantial software development in order to integrate and test the technologies with the rest of the SMART development, in close consultation with the manufacturers.

The integration of the head-mounted technology in SMART will consist of developing a graphical computation system that could support the real-time overlay of graphics on the head-mounted stereo display system. We will be using a system of two synchronised PC's with enhanced graphical capabilities, each responsible for presenting one of the views in the display system. This requires software and hardware developments for synchronisation and graphical overlaying at video rates. The system developed will not be limited to the SMART application and can easily be extended to similar immersive virtual-reality applications.

The integration of the force-feedback system in SMART will involve developing software for providing force feedback in tele-operated mining operations such as surface drilling or block caving. The feedback should enhance the augmented reality environment created in SMART, and so enable more precise tele-operation of equipment and facilitate improved safety features, preventing the operator from making potentially dangerous movements. The integration software should incorporate additional graphical information, which should be displayed in the enhanced perception environment for further reinforcement of the force-feedback information. The software should also be constructed in a way that allows its easy adaptation to other applications.

The integration of the SAS robot control software (FAMOUS) with SMART will involve developing a link with the discrete-event tool under development in SMART, which will be enhanced to include control-signal generation, system-performance monitoring and facilities for the supervision of human intervention. This tool will include the modelling of both the human operator and the mining operations as discrete-event dynamic systems, including a provision for controlling the interactions between the human operator, mining vehicles and the partially-modelled mine environment. A second, related activity will be the development of a graphical user interface that will provide an appropriate task-specification tool for mine-vehicle operators, with the ability to translate this graphical representation of the task(s) into both FAMOUS scripts and SMART DES representations.

Transfer of FAMOUS into the SMART project
FAMOUS (Flexible Automation Monitoring and Operation User Station) is space-robotics

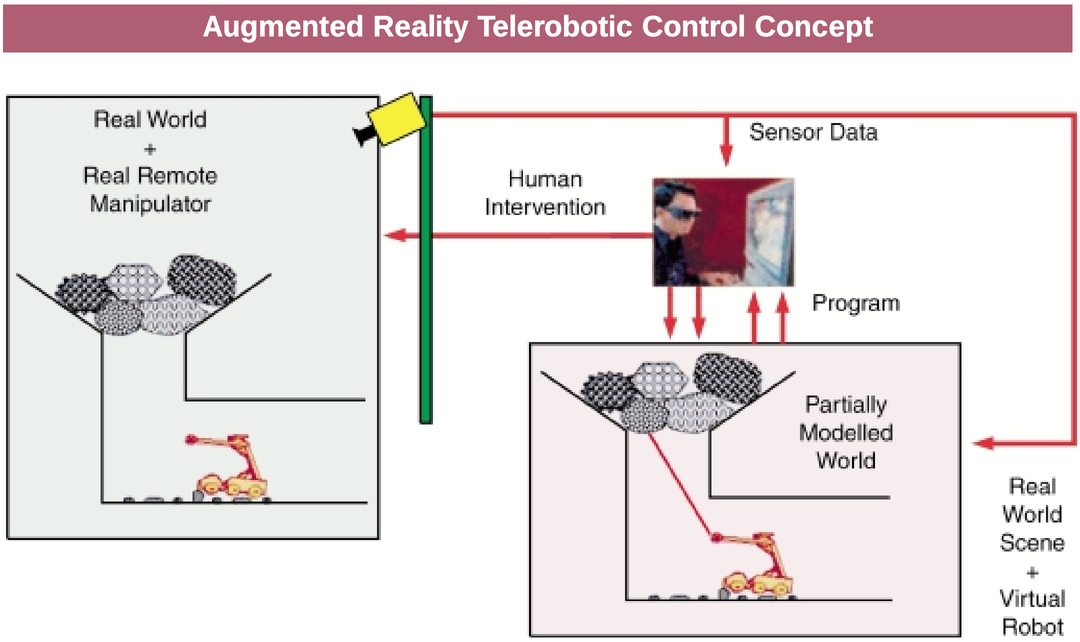

Figure 3. The application of FAMOUS to SMART

software developed by Space Systems Services (SAS, Belgium), under contract to ESA. C-CORE has undertaken work to adapt FAMOUS for use in the tele-operation of mining equipment utilising the SMART concept illustrated in Figure 3.

The plan for transferring FAMOUS to mining applications involves:

Figure 4. NewTel's microwave tower at Monkey Hill, Labrador

- establishing the requirements, specifications and architecture for the FAMOUS/SMART control station
- prototyping a selection of FAMOUS/SMART components
- proof-of-concept demonstrations to ensure that the functional-capability targets can be achieved
- demonstrations to potential customers in the mining sector
- completion of the FAMOUS/SMART control station
- determination of pricing policy and the preparation of marketing material, and
- customer development for worldwide exploitation.

The use of advanced ice-phobic materials for anti-icing

NewTel Communications microwave communication towers and antennas located in Labrador develop very large build-ups of rime ice during wintertime. These ice accretions frequently result in the loss of communications or, worse still, can cause extensive physical damage to the towers and antennas.

Likewise, Cougar Helicopters Inc., who provide helicopter transportation services to and from the Hibernia Platform on the Grand Banks, frequently encounter in-flight icing conditions. Although their helicopters are the only ones in North America cleared to fly in known icing conditions, the penalty of having to install electrical anti-icing equipment is a reduced payload capability and lowered aircraft performance. Any means of eliminating this heavy equipment through the use of lightweight ice-phobic materials will lead to more efficient operation.

Project descriptions

The objective of these projects is to evaluate the effectiveness of state-of-the-art ice-phobic materials, developed initially for space applications, for anti-icing applications in the telecommunications and aviation sectors.

High buildups of rime ice on the NewTel microwave towers can cause loss of communications. The worst sites are located at Sand Hill near Cartwright, and at Monkey Hill near Makkovik, where ice thicknesses of more than 1.5 m have been measured. Figure 4 shows the ice accumulation on the tower at Monkey Hill in January 1998.

NewTel has upgraded its facilities to operate at 6 GHz, rather than the current 900 MHz, and this increased frequency is of concern since the decreased wavelength is likely to result in increased sensitivity to ice accumulation.

C-CORE is currently designing and installing a mechanical system to prevent radome ice accumulation, and also installed a new test panel at Monkey Hill in May 1999 to further evaluate the ice-phobic properties of various advanced materials. Figure 5 shows snow/ice accretions produced in the laboratory on some of the material samples obtained from Daimler-Benz and RST Systemtechnik (Germany), Diavac (UK) and Cametoid Ltd. (Canada). These samples are listed in Table 1.

In addition, the electromagnetic transmissivities of these materials will shortly be measured at

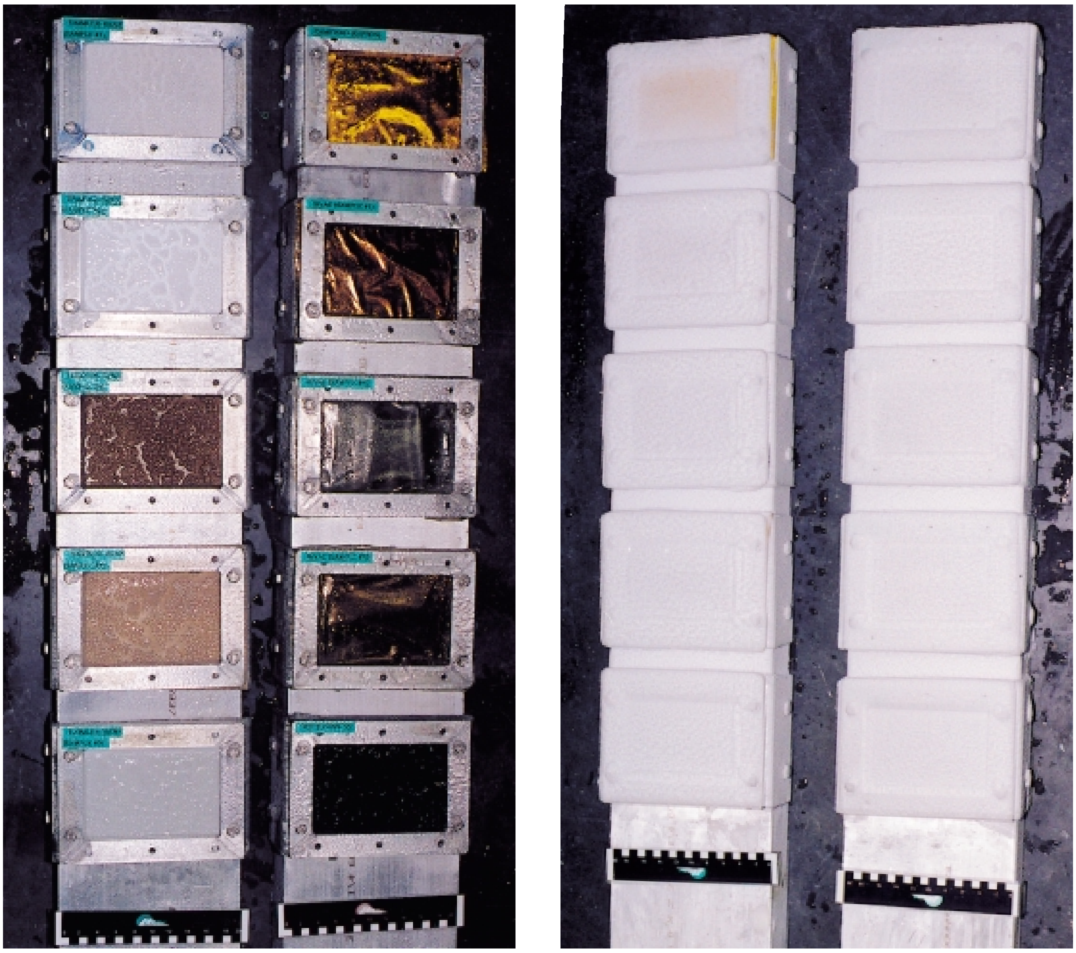

Figure 5. Advanced materials with ice-phobic properties subjected to ice (left and below) and snow (right) accretions in the laboratory

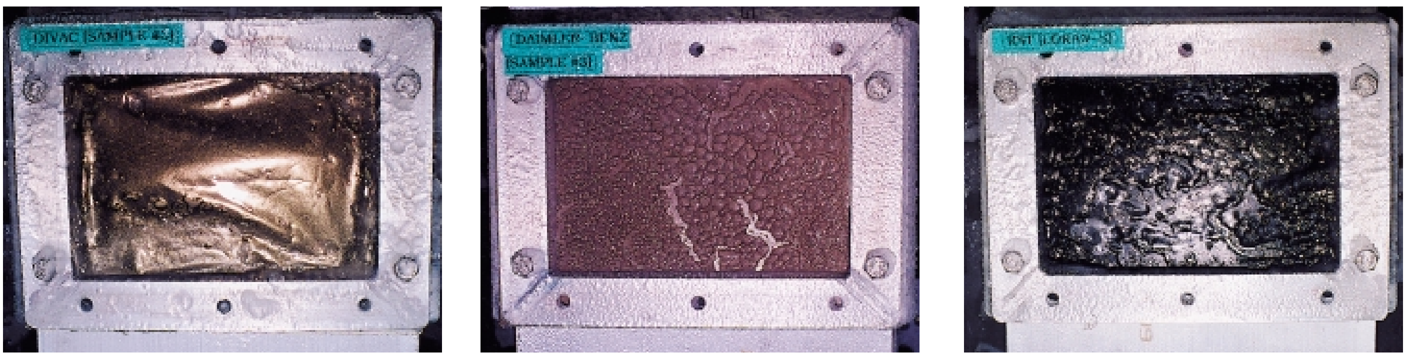

Table 1. List of samples obtained to date

Company	Material Type	Comments
Cametoid Ltd. (Canada)	Kapton-coated aluminium	Flexible
Raumfahrt Systemtechnik GmbH (Germany)	Loran-S	Rigid
Daimler-Benz (Germany)	PTFE-coated glass fabric	Flexible
	PTFE-coated PTFE fabric	Flexible
	TFM-coated glass fabric	Flexible
	TFM-coated aramide fabric	Flexible
	Fluor-elastomer-coated glass	Rigid
Diavac ACM Ltd. (UK)	DLC coated Mylar film:	All samples flexible
	5 min at 200 V one side	
	20 min at 200 V one side	
	5 min 300 V one side	
	10 min 300 V one side	
	5 min 300 V both sides	

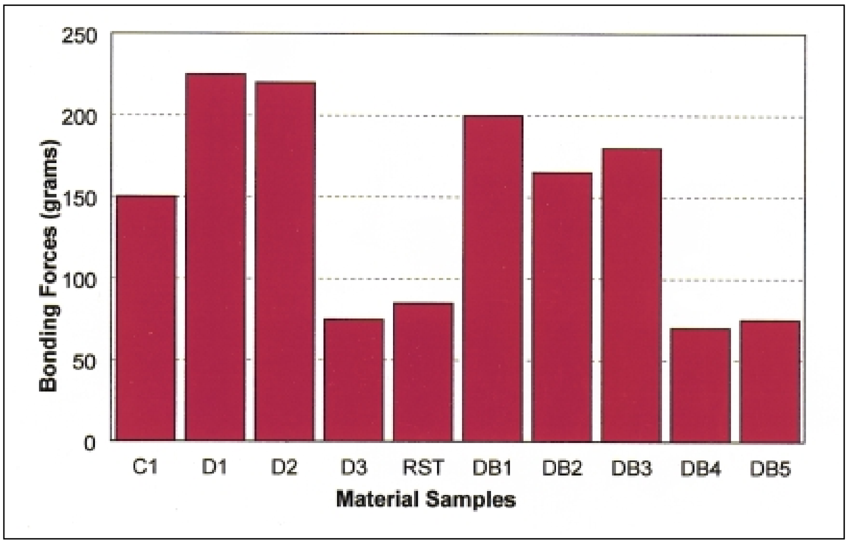

Figure 6. Ice-phobic properties of the sample materials

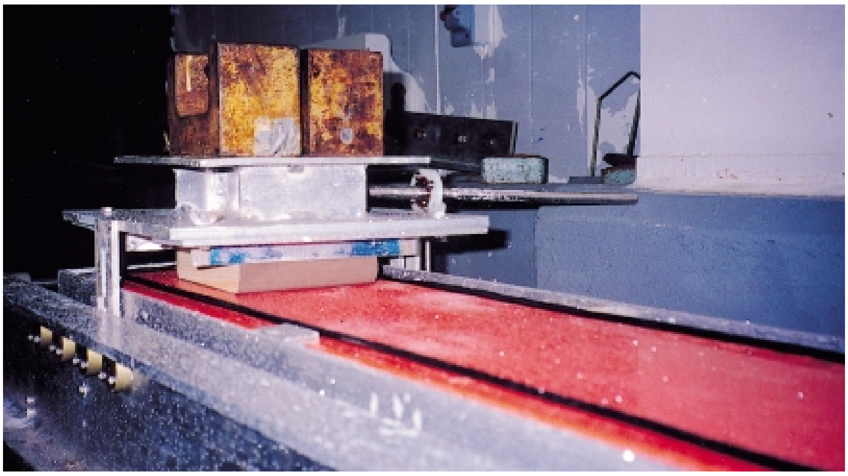

Figure 7. Experimental set-up for measuring static and dynamic friction coefficients between the test materials and ice

frequencies ranging from 900 MHz to 6 GHz. The propagation of microwave signals through ice of various thicknesses has already been characterised over this range of frequencies.

The ice-phobic properties of these materials, measured through a simple scratch test, are indicated in Figure 6.

Laboratory tests to determine both the static and dynamic coefficients of friction between ice and the test materials were also undertaken by C-CORE at the National Research Council of Canada's Institute for Marine Dynamics. The experimental set-up is shown in Figure 7, and the friction coefficients measured are reported in Figure 8.

Figure 9 shows the test site with the panel (next to the person standing) covered in rime ice built up over a six-week period. Access to this remote site is by helicopter only and, as such, visits are made on an opportunistic basis. Figure 10 shows the test panel cleared of the rime ice that had built up around the edges of the test frame and then completely covered the test samples. The clear areas on the samples indicate lack of adhesion of the ice to their surfaces.

The materials being tested for ice-phobic properties at the Labrador site were also mounted at strategic points on Cougar Helicopter Inc.'s Super Pumas (Fig. 11) to evaluate their potential for in-flight icing. Trips to and from the Hibernia Platform from St. John's, Newfoundland involve low-level flying (typically at 1500 m) and the probability of encountering icing conditions, particularly during the winter months, is high. The electrical anti-icing (or de-icing) system currently installed on the helicopters results in a 6 knot reduction in cruising speed and a 115 kg reduction in payload. When all flights are operating at their payload and range limits, any means of eliminating these drawbacks is welcome. It is recognised that the introduction of new materials onto the aircraft structures will require approval from the relevant certification authorities (Transport Canada for Canadian operations) and that this may take time. Nevertheless, enhancing the performance of the aircraft will be an ongoing task.

The technology-transfer process

Unlike the transfer of software, or a specific technology, the use of advanced materials in new terrestrial applications is a joint endeavour between the supplier and the end-user. In the current applications, C-CORE became the R&D provider to industry. Testing of the advanced materials under operational conditions, through the demonstration projects initiated by C-CORE under the HEI, proved to be of significant commercial value to the suppliers. Furthermore, the use of these materials in non-traditional sectors opened up new market opportunities for the suppliers. Two types of technology transfers were undertaken:

- a straightforward purchase of sample materials from the suppliers for testing purposes, and
- the negotiation of a cooperative agreement between C-CORE and the suppliers, whereby C-CORE conducted the materials testing under operational conditions and in the laboratory and provided the results to the suppliers. As C-CORE opened up new market opportunities for the suppliers, both C-CORE and ESA (through its investment in the development of the advanced materials in the first place) stand to recover royalties.

In the former case, if the suppliers seek to increase their market opportunities resulting

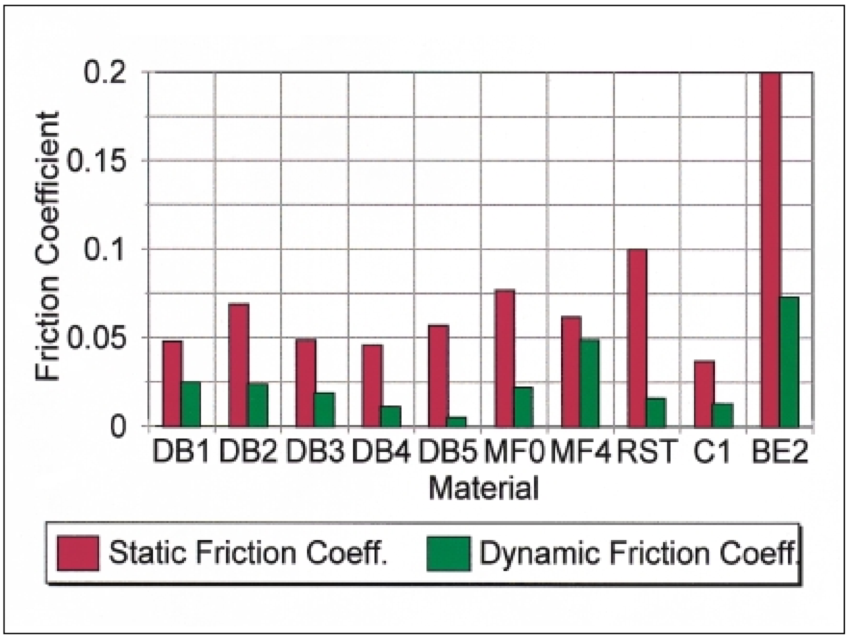

Figure 8. Static and dynamic coefficients of friction between the test materials and ice. DB1-5, MF0-4, etc. are codes for the various test samples

Figure 9. The Monkey Hill test site showing the rime-ice-encrusted test panel (left)

Figure 10. The test panels partially cleared of rime ice (right)

Figure 11. A Super Puma operating under typical weather conditions on the Grand Banks

from the demonstration projects, then C-CORE will enter into a ‘commercialisation agreement’ whereby royalties from sales flow to both ESA and C-CORE. Since the testing of the materials was not conducted under a true partnership agreement (test samples were purchased from the supplier rather than being provided free of charge), the foreground technology (foreground intellectual property) would rest with C-CORE and its partners in the demonstration projects, and the royalties flowing back to C-CORE would be set at a higher level than those under a true partnership.

In the latter case, the foreground technology (foreground intellectual property) would belong to all partners, since each would be contributing to the project. In effect, C-CORE would be acting as the manager of an R&D consortium conducting materials research for the industry suppliers and the end-users. However, any out-of-pocket expenses incurred by C-CORE would need to be covered by the industrial partners.

As with the FAMOUS/SMART project described earlier, the partners would seek wider markets worldwide in order to fully commercialise the results.

In addition to the aviation sector, the power and communications utilities are very interested in applying ice-phobic materials to their transmission and communication towers. The disastrous ice-storm of January 1998 in Ontario and Quebec has highlighted the need for such advanced ice-phobic materials. Likewise, drilling ships, oil rigs and fishing fleets operating in regions prone to spray icing can also benefit considerably from using materials more resistant to ice build-up. The enhancement in operational safety is significant.

Conclusion

Phase-1 of the Harsh Environments Initiative (HEI) resulted in the activation of eight projects in the oil & gas and mining sectors. The main objective is to improve terrestrial operations in these sectors by improving both efficiency and cost-effectiveness, without incurring any reduction in safety or unacceptable environmental consequences. A technology-transfer model that was developed by C-CORE more than a decade ago has been adopted to provide a smooth flow of technologies developed for space to terrestrial applications.

Automation has a very high priority with mining companies and several space technologies are being explored to assist in meeting the goal of full mine automation within the next few years. Offshore aviation is a major issue for oil & gas development in cold oceans. Means for improving efficiency and safety are being researched, one aspect being the use of ice-phobic materials to improve flying operations in icing conditions. The materials tested to date have shown a wide variation in their ability to shed ice. The work also has relevance for power-transmission and communications towers and for shipping operations in northern waters.