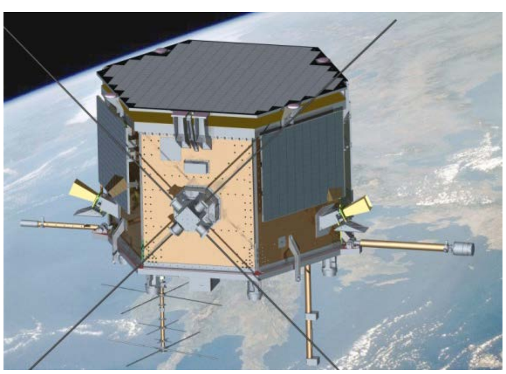

Manitoba Aerospace Technology Road Map

Steering Committee of Manitoba's Aerospace Industry, Academe and Support Sector

MANITOBA AEROSPACE

The Manitoba Aerospace Technology Road Map

Ready to take Flight!

Canada is a world leader in aerospace design, manufacturing, maintenance repair and overhaul, and space systems. Western Canada is a significant contributor to Canada's aerospace industry, with Manitoba being the largest component of the West's aerospace industry, and the third largest aerospace centre in Canada.

To maintain a leadership position and share in the rising market demand for new aircraft, space systems and aircraft servicing over the next 20 years, Manitoba companies must be increasingly successful in the fiercely competitive global supply chain. In an industry driven by technology and innovation, this means identifying and developing key technologies that will provide a sustainable, long-term competitive advantage.

A Technology Road Map (TRM) provides a framework of the key technologies built on consensus of the participants. Over the past year Manitoba's aerospace community have met to consider and propose a series of Technology Thrusts for the industry. The resulting Technology Thrust Reports and the attached Manitoba Aerospace Technology Road Map provide clear direction for our technology development programs.

In industries such as aerospace, in which R&D is a costly, long-term undertaking, collaborative approaches often yield better results for both participants and the economy. Therefore we encourage collaboration and support regional and national efforts, particularly those from the AIAC.

We wish to extend our thanks to the National Research Council for its support of this process and the various elements of that organization that have contributed to this report.

PARTICIPANTS AND SIGNATORIES

StandardAero
Industry Chair, Steering Committee

EMTEQ Canada

Economic Development Winnipeg

Manitoba Aerospace Association
Deputy Chair, Steering Committee

University of Manitoba

Industrial Technology Centre

Magellan Aerospace

Red River College

EnviroTREC

Boeing Canada Operations

Composites Innovation Centre

WestCaRD

Cormer Aerospace

Manitoba Aerospace Human Resources Council

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EXECUTIVE SUMMARY

The Issue

The aerospace sector in Manitoba is a critical and thriving component of Manitoba's and Western Canada's economy. This sector supports over 5,000 jobs and for produces more than $1.6B worth of goods and services annually of which 80% are exported.

There are more than 40 business establishments in this sector, anchored by three global companies: Boeing Canada Operations Ltd.; Standard Aero; and Magellan Aerospace. The industry's primary focus is on complex components design and manufacturing (composites, metallic, and thermoplastics), precision machining, maintenance, repair and overhaul (MRO), and environmental testing of gas turbine engines.

Manitoba has a vibrant and successful aerospace industry that has been built on entrepreneurship, innovation and productivity. **Technology capability and industrial competitiveness are the basis for continuing success.**

The Impetus

Canada's aerospace sector is under increasing threat from a fiercely competitive global aerospace market. Canada's aerospace community, consisting of industry, academia and governments, needs to invest in the development of technology for continuing economic success in this global marketplace. Within an atmosphere of substantial but limited resources, the aerospace community must identify the technology development processes, partnerships and fundamental technology areas of priority to ensure that these resources are invested in the most effective manner.

The Government of Canada's Aerospace Review was launched in February 2012 with the mandate 'to produce concrete, fiscally-neutral recommendations on how federal policies and programs can help maximize the competitiveness of Canada's aerospace industry'. The final report *'Beyond the Horizon: Canada's Interests and Future in AEROSPACE'* was released in November 2012 and has delivered these recommendations. Recommendation #2 was for Canada to "establish a list of priority technologies to guide aerospace-related policies and programs."

Nationally, the Aerospace Industry Association of Canada (AIAC) is coordinating the industrial response to this wide ranging report and Manitoba is well represented on the AIAC Working Groups formulating the responses which will affect the Government of Canada's aerospace program support.

In terms of technology development priorities, it is imperative that Manitoba identify its own strategic technology requirements to ensure that these priorities are reflected in any response to government by the AIAC and by any implementation plans by the government. In this highly competitive industry, it is critical that Manitoba be prepared to ensure its priority technologies are properly documented and marketed.

The Manitoba Aerospace Technology Road Map was undertaken to respond to these national requirements and to build a Manitoba consensus on how to proceed.

Manitoba Technology Road Map Process

An industry led Technology Road Map Steering Committee (Appendix A) was established to formulate a Manitoba Technology Road Map.

The first step was to define the major technology thrust areas as identified by industry. Inputs to this process included the technology priorities identified during the January 2013 Technology Strategy Workshop as well as more direct inputs from the Steering Committee membership and the wider Manitoba aerospace community.

Based on these inputs, six Thrust Area Working Groups (TAWG) were formed with 50 participants (Appendix B) from the community. Each TAWG was chaired by an industrial member with a deputy chair from the Not-For-Profit Organization (NPO) community to support the chair both administratively and technically. Over the period May to September 2013, these TAWGs met to critically review Manitoba's technology needs and to prepare, a Critical Technology Report for each critical technology within their thrust area based on the format set by the Steering Committee (Appendix C).

External resources, primarily Environmental Scan Reports prepared by NRC Knowledge Management as well as NRC subject matter experts, were used by the TAWGs to ensure a broad understanding of the national and international state of technology development of the critical technologies before formulating a Manitoba-centric Critical Technology Report was well understood before formulating a Manitoba centric Critical Technology Report. The NRC Knowledge Management - Environmental Scans are attached to this report as Appendix D.

Collectively, these Critical Technology Reports represent Manitoba's Aerospace Technology Road Map and are included in the Technology Road Map Report as Appendix E.

To maintain momentum on implementing the recommendations potential Implementation Strategies are included in the Discussion section of this report. Finally, a series of conclusions and recommendations are presented to provide a mobilization and immediacy to implementing this Technology Road Map (TRM).

MANITOBA TECHNOLOGY ROAD MAP REPORT

Background

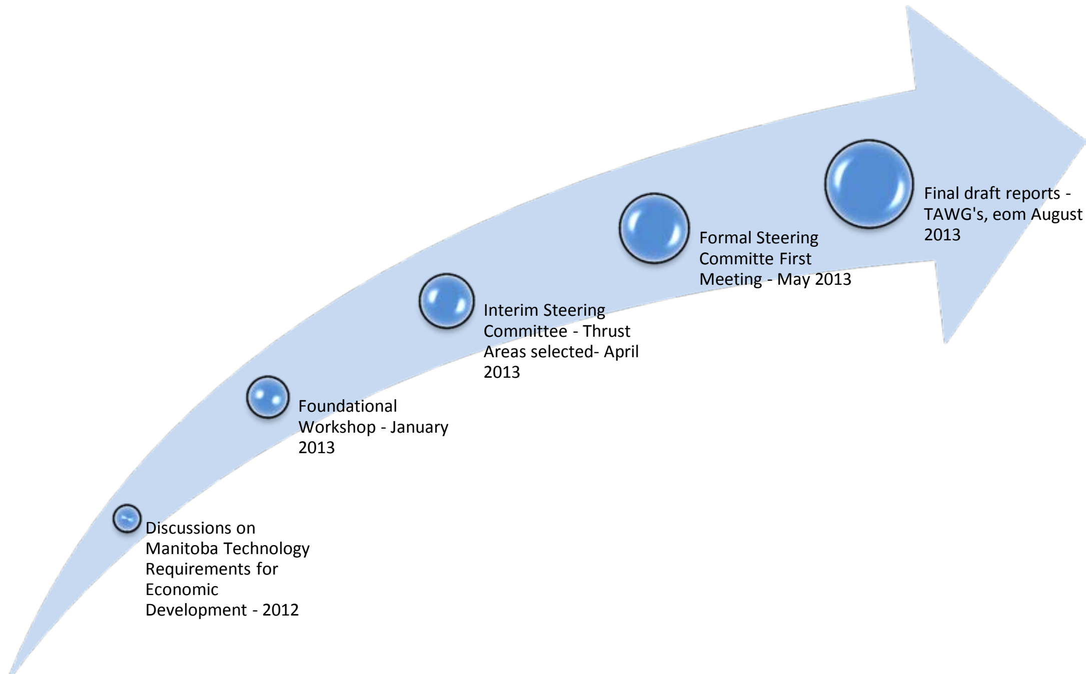
Discussions were initiated in September 2012 on the need to develop an overall Technology Strategy to ensure investments were made in the technologies most critical for Manitoba's aerospace community's economic growth. To explore this further, a Technology Strategy Workshop was planned for January 2013. The focus of this Workshop grew to include discussions of Manitoba's response to the recommendations in the Federal Government's report *'Beyond the Horizon: Canada's Interests and Future in Aerospace'* tabled in November 2012. Manitoba's Technology Roadmap process began in January 2013 as a recommendation arising from this Workshop.

The two day Workshop which was organized as a series of four panels (Manitoba Priority Technologies for Economic Development; Manitoba Priorities related to Technology/Funding; Manitoba Priorities related to Workforce Development, and; Manitoba Priorities related to Technology Development Partnerships). Each panel session consisted of theme speakers, primarily from Manitoba, followed by a panel session. Twenty-seven speakers participated on the panels. This workshop concluded with a final panel-summation session as "Technology Priorities, Economic Development, and the Emerson Aerospace Review".

From this Workshop two key recommendations were reached. The first was to pursue a modified Technology Road Map process to generate a Strategic Technology Document for Manitoba. The second was that Manitoba strongly supports the Emerson Report recommendations. The workshop also identified that Manitoba has specific priorities and concerns related to implementation of the Emerson Recommendations.

Figure 1 demonstrates the process flow for the production for the TRM and the creation of the final TAWG Reports.

Figure 1 – Basic Process Flow for TRM through to production of final TAWG reports.



THRUST AREA WORKING GROUPS

The six Thrust Area Working Groups are listed below. The mandate of each TAWG included refining and prioritizing those technologies within their area that would be critical to future economic development in the aerospace industry in Manitoba.

TAWG1: Advanced Machining

Deputy Chair
Alfonz Koncan, EnviroTREC, Director of Business Development and Government Relations

TAWG 2: Robotics and Automation

Chair
Serge Boulet, Magellan Aerospace, Manufacturing Technology Engineering
Deputy Chair
Myron Semegen, ITC, Manager, Advanced Technologies

TAWG3: Composites

Chair
Loren Henrickson, Boeing Canada, Winnipeg, Engineering Manager
Deputy Chair
Gene Manchur, CIC, Aerospace Sector Manager

TAWG 4: Simulation Modelling and Analysis

Chair
Doug Roberge, StandardAero, Senior Airworthiness Engineer
Deputy Chair
Ken Webb, MAA, Executive Director

TAWG 5: Testing and Certification

Chair
Brent Ostermann, StandardAero, Director, Engineering
Deputy Chair
Vic Gerden, WestCaRD, CEO

TAWG 6: Space and Rocket Systems

Chair
Diane Kotelko, Magellan Aerospace, Space Systems Engineer
Deputy Chair
Wendell Wiebe, MAHRC, Executive Director

THRUST AREA WORKING GROUP REPORT SUMMARIES

This section presents the summaries of the critical technologies identified by each of the six Thrust Area Working Groups using a one-page Quad-Chart summary. Complete TAWG reports available as Appendix E to this report and the digital version can also be accessed through either Manitoba Aerospace Association or EnviroTREC websites.

Thrust Area 1 – Advanced Machining

The Advanced Machining thrust group reviewed adaptive machining and multi-task flexible systems, considered 3-D measurement, fabrication and printing technologies and the role of robotics in inspections.

This group identified the following critical technologies:

- Additive Manufacturing
- Automated Scanning
- High Speed Machining
- 3D Scanning
- Adaptive Machining
- Machining Strategies
- Non-Destructive Evaluation
- Nano Technologies

Thrust Area Working Group #1 considers the development of opportunities in Additive Manufacturing, as related to metals should be pursued as a priority in whatever configuration seems most appropriate to serve the needs of local industry at the time.

Many of the thrust elements presented a 2 – 5 year timeline. This presents many challenges on the available resources to manage multiple research programs over extended time frames. Establishing a pre-competitive environment is recommended to be established which technologies would provide the opportunity to form the partnerships necessary to advance the most thrust elements.

An Advanced Machining Development Centre might be the basis for a collaborative approach. Existing and new OEM's working in Manitoba could become partners with Manitoba's Aerospace industry and as a group they could select opportunities of interest.

Such a centre could undertake some of the smaller projects in Non-Destructive Evaluation, Machining Strategies, 3D Scanning and Automated Scanning. Midterm stages of such a program could consider the larger recommendations made under Adaptive Machining and High Speed Machining, once the experience base has been built and program management stabilized.

Lastly, the role of Nano needs to be engendered and supported by industry in Manitoba. A unique implementation is recommended here to establish an Industrial Research Chair at the University of Manitoba, to work in conjunction with the Nano-Systems Fabrication Laboratory and the Manitoba Institute for Materials. As technologies are advanced through those programs they could be further pursued (advanced through the TRL levels) in either the Advanced Machining Development Centre or the Composites Innovation Centre.

Technology Area: Additive Manufacturing	**Alternatives, Availability, Maturity and Risk**
• Additive manufacturing (AM) technologies (a.k.a. 3D printing, fuse deposition modeling (FDM), stereo lithography, etc.) have been in development and use for over 20 years. Starting from laser cured resins, laser sintered powders, and polymer curing powders, recent advancements and trends are towards achieving near net or net shape metallic parts with good material characteristics. This technology is accelerating in its implementation in the aerospace industry. • Key barrier to development and implementation is the less than full density of metallic AM parts which effects fatigue and fracture properties.	**Alternative**: CNC machining methods can be used but likely more costly and less attractive to clients. Hand lay-up, re-fabrication and shimming also offer some alternatives to AM. **Availability**: Commercially off the shelf systems available, particularly for non-metallics. What is not available are qualified process specifications to meet aerospace requirements. OEM's have internal developmental programs. **Maturity**: Some examples of OEM adoption for non-flight critical parts. Economic and rapid post-processing an issue in the production process. AM advancing rapidly and is set to revolutionize the manufacturing industry and displace existing methods. **Risk**: Some production processes and mechanical properties are the main areas of technology risk.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
• Transformational technology growing in the aerospace industry. Limited capability currently in Manitoba. • Aerospace OEM's adopting and developing technology. 5 year anticipated cycle before established with viable product lines. • Opportunity for Manitoba MRO's and manufacturers to establish themselves in this technology area to capitalize on its introduction to service. • Risk of no action is that Manitoba not ready to compete for business. Risk of action is that the technology does not mature at anticipated rate.	**Costs:** Capital costs for metal AM machine in order of \$1M. Material powders in range of \$100-800/KG. Notional budget for basic implementation of a capability in Manitoba, including some technology acquisition in order of \$2M. Polymer AM system costs approximately the same. **Schedule:** A 2-3 year developmental period required after acquisition of basic systems. **Way Forward:** Collaboration key to success. Steps include: 1) build Manitoba research consortium, 2) identify key stakeholders/external collaborators, 3) build program of support and sustainment 4) establish program of development 5) produce technologies as devised.

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Technology Area: Automated Scanning

- Two automated scanning technologies are of interest to this report -Optical and Ultrasonic scanner technologies.
- **Automated Optical** scanners combine 3D scanning systems using laser technology with robotics and an image recognition system. These systems can be used for automated inspection of parts and can be incorporated into the QC process.
- **Ultrasonic Testing** (UT) is a versatile non-destructive evaluation method using high frequency sound beams to help detect internal discontinuities in a wide range of materials, including metals, plastics, and composites.

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Alternatives, Availability, Maturity and Risk

Alternative:
For the optical suites the competing technologies are hand held probes and digital camera systems.
Competing technologies for the UT suite are manual systems and the relevant technologies that are available within those suites – ultrasonic pulse, eddy current, ultrasonic resonance etc.
Availability:
Five firms were identified which had some versions of these technologies.
Maturity:
3D laser scanning is considered a mature technology in most instances and is especially useful in replication projects because it saves time and money.
The development of new, large area UT /AUSS technology is still underway and these events are being led by OEM's. As such these technology elements are considered very early stage.
Risk:
Automated scanning presents a low risk technology adoption process in view of its current state of development and cost of implementation. AUSS systems conversely would be viewed as high risk systems as they are still being developed at the OEM's.

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Impact on Economic Development for Manitoba

This is an enabling or supporting technology for Manitoba, from which many other events and opportunities can flow. This is a mature technology and comes in some instances, with a low cost of entry. Other larger systems – for composites for instance, are still in development and it will be sometime before these systems will appear.

As such, investments are encouraged in this area at the earliest opportunity for purposes of gaining a position on scanning and visualization technologies, as they apply directly to the future of Manitoba's aerospace industry.

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Costs, Schedule, Way Forward

Costs:
The key ingredient to the take up of this technology is the application development and personnel training across a spectrum of capabilities which will need to be preceded with a local stakeholder who will take responsibility for sustainment and continuity of the integration process. At this rate the total investment will be <$500,000 including application development and personnel training.
Schedule:
At this rate the development of this technology is a short four part process – specification and procurement of the technology, development of the application, training of company personnel, and integration at the company level.
Way Forward:
The collaborators on this technology would most likely be the ITC and RRC through one of their four advanced tech development centres.

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Technology Area: High Speed Machining	**Alternatives, Availability, Maturity and Risk**
• Machining with high speeds (HSM) is one of the modern machining technologies, which in comparison to conventional cutting increases efficiency, accuracy, and quality of work in output pieces, while at the same time to decreases costs and machining time. • Practically, it can be noted that HSM is not simply high cutting speeds. It should be regarded as a process where the operations are performed with very specific methods and production equipment. Many HSM applications are performed with moderate spindle speeds and large sized cutters. In other cases HSM is performed in the finishing stages using hardened steel with high speeds and high feeds. HSM is often found using 4-6 times the conventional cutting speeds.	**Alternative**: The alternatives to this technology are conventional CNC and part assembly processes. **Availability**: Three sources of high speed machining centres were found: FANUC, Mitsubishi and Hurco. **Maturity**: Studies have indicated that high-speed machining can be economical for certain applications, and consequently, it is now implemented for machining aircraft turbine components with five to ten times the productivity of traditional machining. These indicators would suggest that this technology is in the leading edge stage, with early adopters investing it its deployment. **Risk**: The risks of this technology are related to the capital investment for this technology and securing appropriate contracts to support the investment in a sustaining business. Notional costs of this technology are in the order of less than $500k for a complete 5-axis centre.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
• This technology has been in Manitoba for sometime. However it is a stand-alone system in one SME. • The progress of this technology in the machining of blisks and related Gas Turbine Engine parts creates the opportunity for further exploration and investment in this technology. Part of the reasoning for this is that the engine sizes are ever increasing creating opportunities for large part machining via HSM. If Manitoba does not take this technology further, others will. • Our Working Group indicated that there were Human Resources challenges related to the training of advanced machining, therefor a technology development solution needs to be matched with a HR development plan.	**Costs:** Costs to purchase and implement a high speed machining center would be in the order of $1 million. A further $1 million would need to be spent on the development of this technology's opportunities and capabilities. **Schedule:** A 2-3 year development period would be necessary here. **Way Forward:** Collaboration is possible with the UBC NSERC-P&W Industrial Research Chair. A further partner here could be RRC which has a CNC system and interests in aerospace and manufacturing technology roadmaps. The NRC and U of M also have researchers who are capable of responding to industry needs in this area.

<u>Technology Area:</u> 3D Scanning	**<u>Alternatives, Availability, Maturity and Risk</u>**
• X-Ray Computed Tomography is a non-destructive technique for visualizing interior features within a solid object and for obtaining digital information on the object's 3D geometries and properties. Images produced from this technology are used to assess variations in thickness or density that represents cracks or other internal imperfections. • Challenges presented through this technology are that thick inspection samples are problematic for radiography as the (computational) analysis can be extremely time consuming. Most available CT 3D X-Ray technologies can only work with parts up to 12" in size which provides an upper limit to the service application. Magellan has deployed one of these systems.	**Alternative**: Continue with scrapping out parts that are within OEM requirements. Reverse Geometry X-ray 4D X-ray Computed Tomography **Availability**: Four sources of this technology and its variants are available. **Maturity**: This technology is in the early-adoption stream of uptake. Companies interested in using this technology will have to adopt it to their unique processes which will require development time and cost. **Risk**: This technology is considered to be of limited risk.
<u>Impact on Economic Development for Manitoba</u>	**<u>Costs, Schedule, Way Forward</u>**
• CT 3D X-ray technologies are important to Manitoba from both the composite and metals-MRO side. Composites, as indicated, are evolving and repairs that are made need rigorous examination of the fix. In the MRO side the case of assessing one rebuilt article at a time requires a tool that can perform the inspection of a complex part and provide a quality evaluation that the part is fit to be returned to service. • Other examples of applications for 3D X-Ray are related to 3D Metrology in the biomedical field, which has a growing profile.	**Costs:** Costs of these systems is still prohibitive ~$300k, however costs are decreasing. **Schedule:** establish a development team, collocate project within another facility, recruit a subject matter expert, build a 2 year and a 5 year plan, negotiate developmental projects, and operate the centre. **Way Forward:** This technology has great opportunities for applied research and development in Manitoba. Early stage development can be supported in Manitoba and our aerospace Large Enterprises. Offshore support may be possible from Boeing and GE which both have ties to Manitoba.

Technology Area: Adaptive Machining	**Alternatives, Availability, Maturity and Risk**
• Adaptive machining describes the ability to generate complex 3D surfaces that blends almost seamlessly with the surrounding, likely worn or eroded surfaces. It often replaces the use of 'hand-labour' that is performed by technicians skilled in the practice. • Entry level into this technology typically involves repairs to airfoil sections on Gas Turbine Engine components such as High Pressure Compressor (HPC) blades and High or Low Pressure Turbine (HPT/LPT) blades. More advanced machining strategies are required for other more complex parts such as Impellers, IBR's/Blisks (Integrally Bladed Rotors /Bladed Disks), and Fan Blades.	**Alternative**: The only alternative to further developing Adaptive Machining technology and the associated repairs to GTE components is to continue to manufacture these parts from materials that are becoming increasingly rare and expensive, and using CNC technologies. **Availability**: 5 sources of this technology were identified by our Working Group. **Maturity**: This technology is in its early stages but has been driven by the cost of computing and the cost/depth of Artificial Intelligence (AI) systems. While the technology has been in machining parlance for 25 years, only today's generation of computers has the memory and speed to work effectively with this concept. As such, while the idea has sufficient maturity. **Risk**: Applied research projects are underway in Europe and that this technology is in its early stage, but mid to later TRL levels.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
• Many, very expensive aero-engine parts are damaged in service. Current inspection criteria requires they be removed from service. As these components typically rotate at very high speeds many OEM's and MRO facilities are reluctant to repair them and simply replace with newly manufactured pieces. This then lends itself to the challenge of producing parts for older technologies, where the blueprints may no longer be available, or are in a non-CAD form. • Companies wanting to use adaptive machining processes must understand most adaptive machining projects will require some specific consultancy and customization work by a highly skilled engineering staff. Despite these costs, these projects often have some of the quickest payback periods of any improvement project undertaken – making this an early adoption project for Manitoba's TRM.	**Costs:** Implementation of this technology in Manitoba would require an off-site development program. The investment required for to undertake this project can be around $10 M over 4 to 5 years. **Schedule: a four year schedule has been identified and prepared by a regional stakeholder** **Way Forward:** This technology is an excellent candidate for a multi-partner collaboration, which can take place at the local level, using the academic support systems available in Manitoba.

Technology Area: Machining Strategies	**Alternatives, Availability, Maturity and Risk**
The four principal topics were covered in this section: • Cooling Strategies in Machining • High performance cutting of difficult-to-cut metals • Surface enhancement of metallic materials • CAM Toolpath Strategies	**Alternative**: Competing technologies for those mentioned in this report are those which are already used in the baseline business practices in Manitoba. **Availability**: The techniques and technologies required for cooling strategies, high performance cutting and surface enhancement are generally available. The challenge in many of these cases is fitting these new technologies into the current suite of technologies found at a manufacturing enterprise. **Maturity**: The techniques and technologies required for cooling strategies, high performance cutting and surface enhancement are new technologies, and are in their early stages of development. However, for the most part many of these technologies have been demonstrated somewhere as a stand-alone project, in a production or pre-production environment. **Risk**: The technologies presented are generally low risk, excepting that they require a work-in period and a complement of activity in order to mitigate the financial risks of acquisition.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
• A recommendation is made to enable this technology via the development of a Machining Development Centre (MDC). The best opportunity to pursue machining initiatives in a specific area that would support either individual or multiple industry partners in a consistent way, in Manitoba's aerospace industry, would be such an institution which would be dedicated to the challenge at hand. • A Machining Development Centre would be able to consistently forge forwards while being engaged with industry along the way, thereby ensuring that technology transfer is being achieved and that the skill sets being supported are current and leading edge. So in this way the MDC would have both technology and human resources development responsibilities.	**Costs:** A Machining Development Centre could cost $1 million to support on an annual basis, along with an equipment capitalization of up to $3 million. At this rate the first five year cost would be about $8 million. **Schedule:** A five year program should be developed here **Way Forward:** The steps to accomplish these developments would be to establish a Machining Development Centre in Manitoba, and from there assemble the teams that would select the projects of note to pursue. As a result the Machining Development Centre would be multi-faceted and have a variety of skills related to machining for aerospace purposes. Provincial engagement will be necessary as this Thrust Report suggests the creation of a new occupational skill category along the lines of a Software Enabled Tool and Die Maker.

Technology Area: Non-Destructive Evaluation	Alternatives, Availability, Maturity and Risk
• Electromagnetic non-destructive tests are important and widely used within the field of non-destructive evaluation (NDE). The recent advances have been made in sensing technology and hardware and software development dedicated to imaging and image processing. Material sciences have greatly expanded the application fields, leading to sophisticated systems design and have thereby made the potential of electromagnetic NDE imaging seemingly unlimited. • In general, NDE methods are employed at the manufacturing stage to assure the desired quality of a part and, during the lifetime of the part (i.e. MRO operations), to ensure that after certain usage the design parameters are still supporting the standardized safety limits.	**Alternative**: Four alternatives were identified for this technology; all provided some comparable measures. **Availability**: Several related NDE technologies are currently available in the marketplace. One of these technologies is located with GE, a partner in the Manitoba aerospace sector. **Maturity**: Pulsed and remote-field eddy-current NDE techniques for inspecting thick, multi-layered aircraft structures without the removal of paint or fasteners - are immature at present. However, there are some companies trying to commercialize the technology (so far, without success). Meanwhile, university and government laboratories are performing research on the technologies. **Risk**: Risks associated with developing this technology are considered small. The challenge here is to establish the potential for this technology to make significant inroads in Manitoba, to establish a base of operations and enough operational demand to produce economic returns.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
• NDE has the potential of reducing costs, thereby improving the competitive capability of Manitoba's Aerospace Industry. Use of NDE allows for deep inspection without disassembly as typically found in MRO operations.	**Costs:** Seven steps are identified, each with a development cost of $75K – $250K **Schedule:** A three year development schedule should be considered. **Way Forward:** If these technologies are to be developed it will most likely involve a partnership between Magellan Aerospace and RRC. The role of U of M Engineering is also probable in such a research project, given their materials research activities, such as at the Manitoba Institute for Materials.

Technology Area: Nanotechnology

- This report is focused on nanomaterials for aerospace purposes along two lines: composites and metallics. The most important aerospace applications currently are high strength, low weight composites.
- Investigation of metal and ceramic matrix composites with CNTs (Carbon Nanotubes) as constituent materials is in its infancy.

Alternatives, Availability, Maturity and Risk

Alternative:
There are no foreseen alternatives for this technology other than the status quo. The availability of nanotechnology will drive new opportunities; the absence of nanotechnology will present competitive challenges in building the aerospace industry.
Availability:
Two sources have been identified as having aerospace capable nano-materials.
Maturity:
Nanotechnology is viewed as a very early stage technology which is still under development. Technology Readiness Levels for this application are between 1 and 3. (i.e. 1. Basic principles observed and reported; 2.Technology concept and/or application formulated; and 3. Analytical and experimental critical function and/or characteristic proof of concept).
Risk:
The developments proposed in this Thrust Report are of low financial risk and from an adoption point of view it is low risk as well. The risks found with this technology lie in others making significant discoveries which are transformational to some part of the aerospace industry. At that point our industry would be in catch up mode particularly if it is necessary to arrange licensing of the required products.

Impact on Economic Development for Manitoba

- The future of nanotechnology is somewhat distant which is appropriate to a Thrust Report such as this.
- Technology transfer here will take place through two routes which will create the business opportunities. Firstly, OEM's will call for MRO's or their local organizations to use nano particles in certain applications and processes. Secondly local organizations will propose to use nano materials in various applications. While the first route is a top-down route, the second route is a bottom-up. Both approaches are necessary for continued success.

Costs, Schedule, Way Forward

Costs:
The most appropriate way to proceed in this area of development is to support the establishment of an Industrial Research Chair in Aerospace Nano Technology.
Schedule:
IRC require an industrial investment of $150,000 per year over 5 years. With perhaps 3 industry leaders supporting such a project the individual cost is minimal.
Way Forward:
Seeding particular experiments across the various nano facilities in Western Canada would be the next step following from the setting of a strategic research plan. These research projects would be presented as a project plan and would have a further cost of conducting research, which could be established by a research committee or otherwise. Between the IRC Chair and a research program, the costs of such a program over 5 years would be about $2 million over 5 years, with NSERC support provided for about half of that amount.

Thrust Area 2 – Robotics and Automation

The Robotics and Automation thrust group reviewed the role of robotics in manufacturing processes. This group identified three systems of interest:

- Robotic Assembly
- Robotic Finishing
- Vision Systems

Robotic Assembly is being practised in certain OEM aerospace firms. A push approach is considered to support Manitoba's entry into this field which offers productivity and quality gains. Challenges with this technology lie in the lack of precision which may be augmented with sensing systems.

Robotic Finishing includes painting, cladding and spray welding with the robot serving as the pointing device which is connected to a delivery system. This technology adds productivity by moving away from labour intensive jobs. The upcoming generation of robots will now be able to take on tasks that were previously thought to be too complex to automate.

Vision Systems allow the robot to adjust its position based on an analysis algorithm which compares the current positional information to a programmed position. Robots are now programmed to complete certain tasks which integrate the vision system into robotic applications. Vision technology offers the opportunity to reduce scrap while improving quality.

Technology Area: Robotic Assembly	Alternatives, Availability, Maturity and Risk
• **Automation** in aerospace is the use of machines, control systems and information technologies to optimize productivity in the production of goods. • **Robotics is** the branch of technology that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing. • Assembly is the means by which product components are combined to become one. The assembly process is performed by the assimilation of information, design, materials, etc., and translated into a methodology applied by human or machine systems.	**Alternatives** Robotics and Automation technology is an alternative and possible substitute for highly skilled human resources. **Availability** Robotic assembly technology is currently available and under continuous aggressive development in the global manufacturing sector and is currently being used in just about every OEM and supplier. **Maturity** At this time, the current technology capabilities are not fulfilling the needs of the aerospace industry. **Risk** The technological risk is low-medium due to the current industry gap and that the knowledge is readably available in order to catch up.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
Manitoba manufacturers are continually challenged with global pressures to remain competitive. The implementation and adoption of robotic assembly and automation will help Manitoba Aerospace companies remain competitive in the global market and gain the higher level of technical competencies that would help them adjust to the future market challenges more easily and rapidly.	**Costs:** Capital costs for the initial setup and development of a Robotic Assembly R&D environment would be upwards of $ 3 million. **Schedule:** A five to ten year development period would be necessary to meet the industry needs as competitiveness remains top of mind for most Manitoba Aerospace companies. **Way Forward** A strategy for the development of a Robotic Aerospace Assembly R&D environment would require the following: Industry consortium development, Industry – Academia consortium development (similar to CRIAQ model in Quebec), Other stakeholder identification [e.g. Ontario Aerospace Council (OAC)], Program definition and development, Program execution.

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<u>Technology Area:</u> Robotic Finishing

• A robotic system focussing on finishing work could imply many types of finishing, such as painting, cladding, spray welding, or others. The finishing process basically propels a material towards another in order to bind with the receiving surface thus producing a finish.

• The robot is only a pointing device to allow the delivery system to discharge in the appropriate location. The coating management system, the containment booth, the air makeup unit, prep chambers, the robot program, and other systems are all part of an automation strategy. All of these systems must work together seamlessly in order to provide a true automated robotic finishing system.
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<u>Alternatives, Availability, Maturity and Risk</u>

Alternatives:
Robotics finishing technology is an alternative and possible substitute for skilled human resources. There are no other known substitute/alternate technologies in this area.
Availability:
Some Robotic Finishing technology is currently available and under continuous and aggressive development in the world-wide automotive industry. This technology is currently also being used to some degree within most OEM's and suppliers.
Maturity:
At this time, the technology capabilities are not completely fulfilling the needs of the aerospace industry. The available robots and systems are still not as intelligent as the industry requires.
Risk:
The technological risk is low-medium due to the current industry gap and the knowledge is readily available in order to catch up.
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<u>Impact on Economic Development for Manitoba</u>

Manitoba manufacturers are continually challenged with global pressures to remain competitive. The implementation and adoption of robotic finishing will help Manitoba Aerospace companies remain competitive by:

• Moving away from labour intensive jobs and replacing them with highly complex and technically challenging jobs.

• Producing more products per square foot of factory floor space.
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<u>Costs, Schedule, Way Forward</u>

Costs:
Capital costs for the initial setup and development of a Robotic Finishing R&D environment would be upwards of $2.8 million.
Schedule:
A five to ten year development period would be necessary to meet the industry needs as competitiveness remains top of mind for most Manitoba Aerospace companies.
Way Forward:
A strategy for the development of a Robotic Aerospace Finishing R&D environment would require the following: Industry consortium development, Industry – Academia consortium development, Other stakeholder identification, Program definition and development, and Program execution.
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Technology Area: Vision Systems	**Alternatives, Availability, Maturity and Risk**
The vision system determines the position of a product or feature through embedded software which provides the robot with exact coordinates for that item. Before the robot performs a task, such as picking up or placing a part, the vision system identifies the location and orientation of the part. By integrating vision system technology into robot applications, the robots become increasingly more efficient and intelligent. These capabilities allow the robot to adapt appropriately based on different situations.	**Alternatives:** The alternative and possible substitute to the use of vision based robotic systems is the acquisition and training of highly skilled human resources. Additional training, skill development and process improvements could continue to yield an increase in productivity and quality. **Availability:** 2D and 3D vision systems are currently available and under continuous aggressive development in the world-wide robotics and automation industry and are currently being used to some degree within most OEM's and suppliers. **Maturity:** At this time, the technology capabilities are not completely fulfilling the needs of the aerospace industry. The available robots and systems are still not as intelligent or autonomous as industry requires. Although this may be a limitation, vision system technologies are being coupled with robotics to augment and increase the real-time interaction of the overall system. The development, existence and maturity of computer programs/algorithms will get this technology to where aerospace wants and needs it to be. **Risk:** The technological risk is low-medium due to the current industry gap and that the knowledge is readily available in order to catch up.
Impact on Economic Development for Manitoba Manitoba manufacturers are continually challenged with global pressures to remain competitive. The implementation and adoption of vision system technology as it relates to robotics will help Manitoba Aerospace companies remain competitive by performing tasks more accurately. The use of vision technology will help reduce scrap, whilst increasing quality.	**Costs, Schedule, Way Forward** **Costs:** Capital costs for the initial setup and development of a Vision System for Robotics R&D environment would be upwards of $1.5 million. **Schedule:** A five to ten year development period would be necessary to meet the industry needs as competitiveness remains top of mind for most Manitoba Aerospace companies. **Way Forward:** A strategy for the development of an Aerospace Robotics Vision System R&D environment would require the following: Industry consortium development, Industry – Academia consortium development (similar to CRIAQ model in Quebec), Other stakeholder identification [e.g. Ontario Aerospace Council (OAC)], Program definition and development, and Program execution.

Thrust Area 3 - Composites

Workgroup #3 evaluated emerging composite technologies and recommended five key composite thrust areas deemed to be strategic, with Manitoba stakeholders being either lead or a significant partner in their development:

- Out-Of-Autoclave processing (OOA);
- High Temperature Composites;
- Resin Infusion (RI);
- Fiber Pre-Forms; and,
- Automated Lamination processing.

For three of these areas, the workgroup recommends that the Manitoba stakeholders take a leadership role and two technology development centres be created. A high-temp composite technology development centre and a combined OOA/Automated lamination technology centre are proposed. The mandate of these centres would be to conduct pre-production technology demonstrator projects and subsequent improvement evaluations. The technologies developed would be transitioned into industry as it achieves higher TRLs.

These centres would also provide for development of subject matter experts, links to academic and research organizations, and provide a platform for advanced training and education. These centres could be modeled after other successful centres in aerospace such as GETRDC, CNDI and CATT (General Electric-Aviation Engine Testing, Research and Development Centre, Centre for Non-Destructive Inspection and Centre for Aerospace Training and Technology).

For the Resin Infusion and Fibre Pre-Form areas, it is recommended that collaborative technology development and commercialization partnerships be created with existing technology leaders in these specialized areas. This could be driven in support of an OEM or Tier 1 planning on a new product introduction. A long term commitment could then be entered into whereby the next generation of product designs, requiring a new RI technology, would be used as the driver for the establishment of this capability.

Workgroup #3 recommends engagement as a participant or contributor (not as lead or a key role) in two other emerging composite fields, Fibre Reinforced Composite Additive Manufacturing (a potential disruptor technology) and Automated Inspection technologies.

Technology Area: Out-of-Autoclave (OOA) processing	**Alternatives, Availability, Maturity and Risk**
Conventional aerospace manufacturing practice relies on the use of an autoclave to provide the high temperatures and pressures required to produce parts that satisfy demanding quality and performance specifications. OOA technology enables a fundamental shift in the manufacturing approach by allowing aerospace grade parts to be fabricated at reduced pressures, eliminating the need for an autoclave.	**Alternatives:** The non-recurring costs to redesign current products into OOA will slow down the uptake into current models as the cost/weight trade advantage will not provide an ROI that drives mass changes. Other composite technologies such as Resin Infusion (et al) and thermoplastics will compete with some OOA, but each will be best suited to a specific application and will not wholesale encompass another's area. **Availability:** A number of prepreg raw material suppliers and composite manufacturers are currently introducing the OOA generation of materials for Commercial Airplanes. **Maturity:** In aggregate the TRL for the basic applications range from about TRL5 to TRL7. The TRL range for larger and more complex parts is about TRL3 to TRL5. **Risk:** The capabilities that will need to be developed by Manitoba's aerospace industry are: 1. Processing knowledge - complex geometry and integrated designs, and large sized structures; high risk. 2. Optimized tooling concepts – tooling non-recurring cost reduction and cure process optimization; medium risk. 3. Structural Design and Analysis – Allowables generation and design Guidelines; medium risk as OEMs and Tier 1's will lead 4. Cure equipment – ovens or integrally heated tooling systems; low risk
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
OOA expands the envelope of possible manufacturing methods to include options such as vacuum-bag-only oven processing. This reduces the need for large capital autoclave equipment and provides a potential competitive advantage. Eliminating the need for an autoclave also lowers the entry level barrier and opens up fabrication to a wider global supply base of potential competitors. Manitoba industries must maintain a technical advantage through IP knowledge to remain competitive and win higher value added work statement.	**Costs:** A very ROM (Rough Order-of-Magnitude) estimate to develop the OOA technologies in Manitoba is $4M. **Schedule:** these technologies could be developed over a 4 year period. **Way Forward:** The following elements will need to be assembled: • Technology Development Team • Pre-production fabrication materials, tooling, equipment and facilities • Material mechanical and physical properties testing

Technology Area: High Temp Composites	**Alternatives, Availability, Maturity and Risk**
High temperature capable composites are grouped into three material classes depending on the sustained and peak service temperatures required. • In the very high temperature region, 2500F+, Ceramic Matrix Composites (CMC) are utilized. These are created from carbon fibre braided preforms and a pyrolysis fabrication method in a high temperature oven. • In the middle temperature region, 600F+, Polyimide (PI) matrices are used with carbon fibre reinforcements. • In the elevated temperature region, 350F+, Bismaleimide (BMI) matrices are used with either carbon fibre or fibreglass reinforcements.	**Alternatives:** The competing technologies are a next generation of improved super-alloys or other novel material systems (currently undefined). **Availability:** The gas turbine engine OEMs are currently developing CMC technologies for initial applications and the first commercial products will be on the GE LEAP engine 1st Stage Shroud with an EIS of 2016. The use of CMC's will expand into other engine applications such as combustors and 2nd Stage airfoils in the 2020 timeframe. **Maturity:** BMI's are currently used in selected areas on both Commercial and Military platforms. PI's are currently used in niche areas, primarily Military platforms. For both BMI's and PI's, new generations of resins are being developed to improve performance and reduce manufacturing costs. **Risk:** The development of these new processes is medium risk.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
Currently, super-alloys, titanium and steel are being used in the manufacture, maintenance, repair and overhaul of these types of products. As high temperature materials are adopted, the fabrication and MRO industry in Manitoba will be affected. The work statement for these industries will gradually shift from the metallic components to more CMC, PI and BMI's and therefore revenues could be negatively impacted if not adopted.	**Costs:** A very rough order of magnitude estimate of the total funding required to develop high temperature composite technologies in Manitoba would be $12M. **Schedule:** Such technology could be developed over 5 years **Way Forward:** The development of high temperature composites is a good candidate for a multi-partner collaborative project that could build on existing activities at research organizations such as the CIC, CCMRD, NRC and UBC. The recommendation is to engage GE Aviation and The Boeing Company as OEMs, Magellan Aerospace and Standard Aerospace as industry, the U of M, RRC and the CIC as academic and research partners from Manitoba.

Technology Area: Resin Infusion	**Alternatives, Availability, Maturity and Risk**
Resin Infusion (RI) is a broad-based term covering a number of technologies whereby dry fibres are impregnated with a liquid resin in-situ, resulting in near net shape composite products.	**Alternatives:** A non-technological alternative to developing this technology in Manitoba would be to purchase the Resin Infused products from existing or new suppliers. **Availability:** A number of composite manufacturers are currently using Resin Infusion processes and materials for Commercial Airplanes. OEMs and Tier 1's currently have specific sets of Design Allowables, Design Guides, material and process specifications and qualified materials. **Maturity:** Typically complex structures will be certified using point design methods rather than using general design methods. The TRL for the current applications range from about TRL5 to TRL10. **Risk:** The capabilities that will need to be developed by Manitoba's aerospace industry are: • Processing knowledge -high risk • Optimized tooling concepts – medium risk • Structural Design and Analysis – medium risk as OEMs and Tier 1's will lead • Processing equipment – low to medium risk depending upon advancement desired
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
Global competitiveness will require lower manufacturing costs, including labour reductions. In addition, larger more highly integrated and complex structures will be required by OEMs. One of the means to accomplish this is to use resin infusion technologies.	**Costs:** A rough cost estimate for developing the knowledge and capability for Resin Infusion technology would be $3M. **Schedule:** Up to 4 years for a basic process. **Way Forward:** Needed for RI implementation are the following: • Technology Development Team • Pre-production fabrication materials, tooling, equipment and facilities • Inspection technologies, equipment, standards • Repair technologies, equipment, standards • Material mechanical and physical properties testing

Technology Area: 3D Fibre Pre-Forms	**Alternatives, Availability, Maturity and Risk**
Pre-forming is a broad-based term covering a number of technologies whereby dry fibres are woven, stitched or braided into a reinforcement charge that is subsequently impregnated with a polymer matrix to form a highly controlled composite structure.	**Alternatives:** A non-technological alternative to developing this technology in Manitoba would be to purchase the pre-forms from existing suppliers. **Availability:** A number of fibre raw material suppliers and composite manufacturers are currently using pre-forms for Commercial, Military and General Aviation aircraft. OEMs and Tier 1's currently have a limited set of Design Allowables, Design Guides, material and process specifications and qualified materials approved. Most preforms are still in the development stage for the Airplane market. **Risk:** Processing knowledge - complex geometry and integrated designs, and large sized structures are considered as high risk. Structural Design and Analysis – Allowables generation and design Guidelines are considered medium risk as OEMs and Tier 1's will lead these developments. Braiding, weaving or stitching equipment are high risk.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
The pre-forms feed into Resin Infusion manufacturing processes such as RTM, VaRTM, and are precursors for CMC manufacturing. The design, analysis and fabrication of pre-forms have high value added content. As the aerospace industry drives for cost and weight improvements, the use of composites in general and those that use 3D pre-forms will increase. The potential for revenue generation is high.	**Costs:** Entry into the 3D pre-forming industry will be capital extensive and require specialized knowledge. Estimates for development: $5M. **Schedule:** A 4 year development period is needed. **Way Forward:** A three step process is recommended 1. Define product opportunity with OEM or Tier 1 2. Individual industry either collaborate with a capable partner or purchase capability to perform basic pre-forming 3. Develop the next generation of capability with new materials and processes for the next line of products in a collaborative effort with an OEM/Tier 1 and research organizations

Technology Area: Automated Lamination	**Alternatives, Availability, Maturity and Risk**
Automated lamination a broad-based term covering a number of technologies whereby prepreg materials are laminated, reticulated, drape formed and/or consolidated in the pre-cured state using specialized manufacturing equipment.	**Alternatives:** Alternatives are to purchase existing systems or continue with hand layup fabrication. This may not address unique requirements necessary to create a competitive advantage. **Availability:** A number of equipment suppliers and composite manufacturers are currently using Fibre Placement, Tape Layers and Filament Winding machines for Commercial and Military products. **Maturity:** In aggregate the TRL for the basic applications range from about TRL5 to TRL10. A number of large scale applications of fibre placement and tape laying equipment to specific applications such as fuselage barrel sections and wing skins are in production at TRL10. **Risk:** What is seen thus far are very specific and complex applications with capital intensive tooling and equipment tailored to a singular product, representing high risk.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
The drive for both cost and manufacturing flow time reduction necessitates innovative solutions to reduce labour input and optimize process flows. The potential for increased profitability is high.	**Costs:** Entry into the automated lamination processes will be capital extensive and require specialized knowledge. ROM (Rough Order of Magnitude) Estimate of costs: $8M. **Schedule:** Over 4 years will be needed to develop this technology. **Way Forward:** A recommended approach would be to establish an innovative composite fabrication technology development centre to conduct pre-production technology demonstrator projects and subsequent improvement evaluations. It is recommended that this centre focuses on developing novel and innovative manufacturing techniques that do not require capital intensive equipment and facilities in production.

Thrust Area 4 – Simulation Modeling & Analysis

This group evaluated the role of simulation, modelling and analysis in regards to Manitoba's technology roadmap.
The group identified three technologies of interest:

- Enhanced Technical Instructions and VR Training
- Simulation Platform for Complex Interconnected Systems
- Modelling of New and Emerging Composite Materials

Enhanced Technical Instructions and VR Training call for the utilization of the latest hardware and software to enhance delivery of instructions through guided troubleshooting, and enhanced graphical content using 3D models and simulations. A second component - Virtual Reality training offers an immersive environment that more closely simulates aerospace maintenance scenarios.

A Simulation Platform for Complex Interconnected Systems recognizes that product complexity comes from the introduction of a higher number of integrated systems. Some systems are currently too complex to effectively analyze with non-interfacing traditional simulation tools, and require multi-discipline system level tools in order to be well understood.

Modelling of New and Emerging Composite Materials refers to the next generation of aerospace designs which will call for the deployment of more and different composite materials. The modelling of these new materials would be performed using software and simulation tools. Of particular and early interest is the development and verification of process modelling software for 3D preforms.

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<u>Technology Area:</u> Enhanced Technical Instructions & Analysis

• As advances in computer hardware and software are applied to the design and analysis of aeronautical products, new approaches in developing manufacturing and maintenance instructions and training are available.
• Design data can be used in an increasing extent to help speed the development and effectiveness of product instructions and training.
• Interactive Electronic Technical Manuals (IETMs) Utilize the latest hardware and software to enhance delivery of instructions through guided troubleshooting, relational content, and enhanced graphical content (3D models and simulations).
• Virtual Reality (VR) training offers an immersive environment that more closely simulates aerospace maintenance scenarios.
• This technology includes the software, hardware, and know-how to provide the service of translating design data and maintenance requirements into IETM and training products at various levels of product use. The technology lends itself well to the use of mobile delivery platforms such as tablets and VR glasses, etc.
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<u>Alternatives, Availability, Maturity and Risk</u>

Alternatives:
There are no technologies or non-technological solutions that could be applied as a potential substitute for this technology.
Availability:
Aerospace and automotive OEMs such as
Boeing, EADS, Rockwell Collins and Sikorsky are working with this technology. Some nine software firms are working with this technology.
Maturity:
This technology is in the early stages.
Risk:
Risk is believed to be low for the take up and implementation of this technology.
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<u>Impact on Economic Development for Manitoba</u>

This technology is critical for the economic development of the Manitoba aerospace industry for reasons of:
• Reduced engineering/development time involved in producing the necessary manufacturing, operation and maintenance instructions and training required to support an aeronautical product design.
• OEM and other customer demands will expect instruction and documentation format matching the best in the industry.
• It is not out of the question that new standards and approaches regarding IETMs and training will emerge relating the manufacturing and maintenance of aeronautical products.
• This technology could generate business for publications, 3D animation, and VR businesses in Manitoba in support of the needs of local aerospace companies.
• Manitoba Aerospace companies require an increasing amount of trained technicians to support our businesses. This technology provides enhanced training that can reduce the cost and time needed to train technicians to a competency level where they can work on products.
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<u>Costs, Schedule, Way Forward</u>

Costs:
One possibility is to utilize the existing ITC VR equipment. Costs associated are estimated to be below $200K.
For comparison purposes the development of aerospace specific training programs along with turnkey hardware for the VR system could be expected to cost up to $10m depending on fidelity.
Schedule: could be quite mid-term at 5 years since capable VR systems are currently available.
Way Forward:
Strategy 1: VR training
Partner with NGRAIN (Canadian)/ Panametric Corp – Creo/ Silkan to enhance existing or develop new training elements in existing Gas Turbine R&O (GTRO) training in Manitoba.
Strategy 2: Purpose Made Engine Test Simulator. Partner with a 3d Software provider (NGrain, Bluedrop, Silkan), StandardAero – Test Cell group and an OEM to develop an engine test cell simulator app.
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<u>Technology Area:</u> Simulation Platform for Complex and Interconnected Systems
Demands for ‘smarter’ and ‘greener’ aerospace products and processes have resulted in additional product and process complexity. Increasing numbers of interdependent systems integrated into products has led to complex control schemes and modes of operation.
Complex systems may be broken down into various subsystems which perform a specialized role within the system such as propulsion subsystems and communications subsystems on aircraft. While each subsystem must be able to be analyzed and simulated on its own, the simulation must be capable of modeling the entire platform as a single integrated unit.
The proposed technology is a simulation platform that enables high-fidelity representation of numerous systems. It may be a multi-disciplinary tool, or a common interface that provides a mechanism for linking individual detailed models and allowing them to exchange data.
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<u>Alternatives, Availability, Maturity and Risk</u>
Alternative: Graphical system design tools provide the closest approximation to the proposed design, but are limited. Agent based modeling techniques may be appropriate for some applications today, but are less intuitive and do not have the ability to be reused. In the absence of reliable modelling tools manufacturers must rely on expensive testing campaigns.
Availability: A range of commercial simulation and modeling tools exists but can be difficult to apply and integrate.
Maturity: Graphical and agent based modeling techniques are available but are typically very simplified or idealized representations of a type of component. Components of single system simulators are difficult to integrate with each other and custom models are difficult to re-use or repurpose.
Risk: Development is too specific and not broadly applicable. Given the unsuccessful projects and competition from commercial or propriety systems, the risk overall here is moderate.
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<u>Impact on Economic Development for Manitoba</u>

The use of better simulation and modeling tools can improve competitiveness through reducing non-recurring costs and improving understanding of products and processes at a system level, revealing opportunities for improvement.
Robust modeling can reduce the requirement for lengthy and expensive testing programs.
Risk of no action - system level simulation will continue as it is now. Some systems are currently too complex to effectively analyze without multi-discipline system level tools, so there is reliance on lengthy and expensive testing campaigns.

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<u>Costs, Schedule, Way Forward</u>
Costs and Schedule:
The estimated costs of developing a high fidelity multi-discipline system simulation platform (leveraging existing tools) and developing a proficient local user base is $5 million over 5 years.
Way Forward: Possible collaboration with Maplesoft (developers of MapleSim) and multi-physics/FEA software company of choice (SIEMENS, Dassault, MSC, etc.)
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Technology Area: Modeling of New and Emerging Composite Materials	**Alternatives, Availability, Maturity and Risk**
Next generation aircraft and engine designs are utilizing more composite materials. In addition to higher content of composite materials, more specific applications of new material forms and material systems are being looked at. The Manitoba aerospace industry has identified composites produced using 3D preforms and ceramic matrix composites (CMC) as areas of high importance to the future local aerospace industry. While simulation tools are widely used in the design and manufacture of more traditional composite systems, simulation tools for 3D preforms and CMCs are not as mature and are not utilized within Manitoba aerospace companies. In order to support organizations in design and manufacture of 3D preform and CMC components, simulation tools to support engineering analysis as well as process modeling are required. Simulation of these material systems can be broken into systems to support engineering analysis, and systems to support process modeling.	**Alternatives**: No alternative modeling tools available. But others could develop. New technologies could be developed without simulation tools but with higher risk. **Availability**: Analysis tools for conventional composite materials are widely available and considered to be a mature technology. CMC structural and process modeling and 3D Preform tools that can produce reliable results are not commercially available. **Maturity**: With wider utilization of CMCs, expertise in the area will increase and speed up development on the simulation side but at this point in time there is limited expertise in the area when compared with more conventional composite materials. For the analysis of 3D preforms, individual software solutions can predict many of the individual inputs required for full structural and process models of components but no solution is known that connects the systems together. **Risk**: The development of reliable modeling techniques for CMCs is viewed to be a medium risk item due to the potential for development to take longer than anticipated. The overall risk of developing software solutions for analyzing 3D preform composite materials is low and focused primarily around integration and communication between different software solutions.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
• The use of 3D preforms and CMCs are expected to continue to increase with next generation engine and structure designs. • The adoption of new processes and technologies carries high risk and development costs. • Companies or regions with supporting simulation tools to reduce risk and development time will have a large advantage in capturing new work scopes. They can bring more added value to a risk sharing partnership with OEMs. • Opportunity for MB companies to engage in next generation work packages as use of composites continues to increase. • Risk of no action - without simulation technologies ability to utilize these new material systems will be diminished. • Risk of action – others also develop capabilities/tools, development time too long.	**Costs:** Development requires verification through testing and the ability to access facilities with capable manufacturing systems to validate process models. Estimated cost for CMCs is $2M-$3M with a timeframe of 2-3 years. Estimate for 3D preform is $1M over a 2 year timeframe. Estimates dependent on the ability to access facilities with manufacturing capabilities and expertise in the processes. **Schedule:** 2-3 years **Way Forward:** The development of simulation tools are best approached by including a simulation component in a larger development program. As part of a larger program, simulation tool development can make use of initial manufacturing trial and test results to develop and validate the software and may be used in later stages to support the design and manufacture of demonstrator articles.

Thrust Area 5 – Test and Certification

Workgroup #5 evaluated aero-propulsion system needs for development, production and certification testing for gas turbines, including turboshaft engines. The group ranked a series of Technology Streams and selected four priority test and certification technologies to report on:

- Emerging Tests
- Specialized Instrumentation
- Efficiency of Test Sites
- Gas Turbine Testing Simulator

The (Gas Turbine Testing Simulator report) describes the requirement for a gas turbine testing capability including a training simulator to support efforts in Manitoba to train engine test technicians and engineers which are needed to support both of Manitoba's certification and production test facilities. A gas turbine test simulator, including turboshaft training capabilities, would create a virtual test cell that would enable operators to practice engine test procedures under normal and emergency situations. Such a simulator would be a training facility for understanding the critical reaction timing requirements of certain certification tests including icing, ingestion and blade-out procedures. Creation of a turboshaft test facility would also greatly enhance the potential to attract engine MRO work to Manitoba. This report considered the placement of engine test cells in Manitoba to support gas turbine development, including turboshaft development and MRO opportunities. The following tables summarize the TAWG reports in Appendix D.

Technology Area: Emerging Tests	**Alternatives, Availability, Maturity and Risk**
New aero engine test capabilities are needed at the Winnipeg (GE TRDC) and Thompson (GLACIER {PW and RR} Test Facilities). Systems to perform current Certification tests for water and hail ingestion are required – water and hail at Glacier facility, and ice crystal and ash at both Glacier and GE facilities. Turboshaft MRO opportunities also support a turboshaft production and development testing facility.	**Alternatives:** Alternatives do not exist since the requirements to perform Certification Tests are mandated by aviation's Regulatory Bodies. Analytical methods may be partially acceptable for ice crystal ingestion certification depending on the in-use GTE history and international GTE deployment experiences. Acceptability of these alternatives is at the discretion of the Regulatory Bodies. **Availability and Maturity:** OEMs already have designs for water and hail ingestion. The NRC is conducting research into methods of creating ice crystal clouds suitable for ingestion. Volcanic Ash Ingestion technology is in the early stages of development. Turboshaft test cell designs are readily available. **Risk:** Water and Hail Ingestion - Technological risk is low Ice Crystal Ingestion - Technological risk is moderate Volcanic Ash Ingestion - Technological risk is moderate. Turboshaft test cell designs are readily available.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
The world's largest three manufacturers of civil aero engines have made significant investments in cold weather test facilities in Manitoba. The addition of the new test capabilities described in this report, will more firmly establish these as 'year-round' facilities. Performing additional Certification tests at these Manitoba facilities will further raise the profile of the Province as a key location for aero engine test capability, as well as other important aerospace technologies. A turboshaft test facility will support MRO opportunities which have potential to create significant jobs.	**Costs and Schedule:** are estimated as: • $6M in the first 2 years - water and hail ingestion • $10M in years 3 to 4 - ice crystal ingestion • $10M in years 4 to 7 - volcanic ash ingestion • $9M in years 1 to 3 – turboshaft test facility **Way Forward:** Water Ingestion (Glacier): • Collaborative: Rolls-Royce, Pratt & Whitney, MDS Aero Support (Ottawa), NRC (Ottawa) Hail Ingestion (TRDC and Glacier): • Collaborative: Rolls-Royce, Pratt & Whitney, MDS Aero Support, NRC • Collaborative: GE, Standard Aero, WestCaRD Ice Crystal Ingestion: • Collaborative: GE, Rolls-Royce, Pratt & Whitney, MDS Aero Support , NRC Volcanic Ash Ingestion: • Collaborative: GE, Rolls-Royce, Pratt & Whitney, MDS Aero Support , NRC, U of M, Red River College Turboshaft (StandardAero) • Collaborative: StandardAero, RRC, others as appropriate As a means of maximising collaborative effort and minimising costs, the design and creation of portable test systems that could be shared by the TRDC and GLACIER test facilities should be considered.

Technology Area: Specialized Instrumentation	Alternatives, Availability, Maturity and Risk
This report describes the requirement for the custom design of specialized gas turbine engine test instrumentation to support both Manitoba's certification and production test facilities. Specialized instrumentation is a broad thrust area and could include many specific areas of technology development such as: • High temperature dynamic strain and pressure measurement • Blade tip deflection, clearance and timing measurement • Gas, particulate, and acoustic emissions measurement • Wireless • Others	**Alternatives:** Since this thrust area is broadly stated as 'custom design of specialized instrumentation', there could be a number of competing technologies being developed in any number of specific testing areas. **Availability:** There are two main organizations that are currently investigating new technologies related to gas turbine engine test instrumentation – the Propulsion Instrumentation Working Group (PIWG) and the European Virtual Institute for Gas Turbine Instrumentation (EVI-GTI). OEMs are conducting their own technology development instrumentation. **Maturity and Risk:** Due to the level of expertise in the area of gas turbine testing and instrumentation development in Manitoba, the level of technological risk is assessed as Medium. However, there could be higher risk involved in the development of instrumentation that is exposed to the gas path of an engine, as these technologies could be exposed to high temperatures and will require additional testing and OEM approval.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
The world's largest three manufacturers of civil aero engines have made significant investments in GE's TRDC and Glacier certification test facilities in Manitoba. In addition, StandardAero, a world leader in gas turbine maintenance, repair and overhaul (MRO) services currently supports the operation of over 20 internal test cells through its Central Engineering department located in Winnipeg. Design and development of specialized instrumentation to support both - certification and production test cells will provide Manitoba with the opportunity to locally support these facilities with state-of-the-art equipment while commercializing these technologies throughout the globe. Further to this, instrumentation technologies developed for gas turbine engine applications could also be migrated to other industries that require accurate measurements in high temperature environments.	**Costs and Schedule:** • $1-2 million per instrumentation technology over a 3 year period **Way Forward:** The custom design of specialized instrumentation to support the gas turbine test and certification industry is an ideal candidate for multi-partner, multi-disciplinary collaboration. Collaborative partners could include: • Existing Organizations: PIWG, EVI-GTI • OEMs: GE, Pratt & Whitney, Rolls-Royce • Service Providers: StandardAero, MDS Aero Support • Research Organizations: NRC, ITC, NASA • NPOs: WestCaRD, EnviroTREC • Academia: University of Manitoba, Red River College

Technology Area: Efficiency of Test Sites	**Alternatives, Availability, Maturity and Risk**
Advanced infrastructures for aircraft engine testing have been recently built at Thompson (GLACIER) and Winnipeg (TRDC). Now there is an opportunity to develop these facilities into the world's finest testing facilities to maximize utilization of these sites. Developing leading-edge technologies such as wireless sensors and instrumentation, high-speed imaging, and high-volume data acquisition and transmission would attract new opportunities for Manitoba. Such technologies would also potentially benefit other production test cells in Manitoba and elsewhere.	**Alternatives:** • Current equipment and methods could continue to be used in the near term; however, new data acquisition and communications technologies would constitute world leading 'differentiators" for Manitoba industry. • The existing 'wired' technology currently in use would continue to be deployed, but is largely old technology. A potential exists for limited replacement of wireless sensors as they are proven. This would result in a gradual evolution to wireless test communications where feasible. **Availability:** Wireless sensing and communication research is taking place at various government and commercial organizations around the world. Engine test cell owners are indicating a desire to embark on this technology, but it is not yet being fully exploited. **Maturity:** These technologies are early stage. **Risk:** Technological risk: medium
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
Improvements in Manitoba test facilities will attract more and additional types of OEM engine test programs in this province. In addition with state-of-the-art data capturing capabilities developed in Manitoba, there would be opportunities to use these technologies at test cells in Manitoba, plus the potential to commercialize those technologies in other test cells around the world. There may also be spin-off opportunities for the Manitoba IT industry.	**Costs and Schedule:** • To develop/install robust sensors including wireless in Manitoba engine test cells: $2M – 3 years • To develop/adapt/ adopt wireless transmission of data capability in Manitoba engine test cells: $1M – 2-3 years • To develop capability and expertise in analyzing high speed imaging and near real time transmission of high speed video: $1M – 2 years **Way Forward** This is a good candidate for multi-partner, multi-disciplinary collaboration. Potential organizations: • Industry: engine OEMs, RR, P&W, GE, StandardAero, MDS Aero, IT Companies • Research organizations: NRC, ITC, NASA • Educational institutions: U of M, Red River College, other universities • NPOs: WestCaRD, EnviroTREC, ICTAM, MAA, CRIAQ, • Government funders: Industry Canada, Prov. of MB

Technology Area: Gas Turbine Testing Simulator

This report describes the requirement for a gas turbine testing simulator to support training of engine test technicians and engineers, to support both Manitoba's certification and production test facilities. A gas turbine test simulator to include turboshaft engine training would enable operators to practice engine test procedures under normal and emergency situations at lower cost and less risk. It would be a training ground for understanding the critical timing involved in critical certification tests including icing, ingestion and blade out procedures.

A proposal is made to consider evaluate the industry support for building new gas turbine test facilities including turboshaft production and development testing cells and to develop plans to incorporate training simulator capabilities to meet current and such future test cell needs.

Alternatives, Availability, Maturity and Risk

Alternatives:
Without an engine testing simulator, training would continue to be performed on the job using actual engines. There are some risks associated with this approach. Damage to an engine caused by operator error during certification testing could be extremely costly to the OEMs and MRO operators. As a result, delay penalties would be exacted by airframe manufacturers and airlines. Training of technicians and engineers in a simulated environment would consume less fuel, which would result in fewer emissions supporting a greener environment.

Availability:
Some of this technology may exist in a few large training institutions.

Maturity:
This technology is in its early stages.

Risk:
Technological risk: Medium

Impact on Economic Development for Manitoba

This technology would enable Manitoba to train test technicians and engineers in a more environmentally acceptable way than current practise. This simulator would prepare and train our workforce in Manitoba to different types of engine testing situations. It would also develop expertise in Manitoba at a quicker rate so as to better support development, certification and production testing efforts currently underway in Manitoba. In addition, with the capability to provide a Manitoba solution for training its workforce for testing engines, this technology could be marketed for use at other test cells around the world support OEM's, MRO's, and Major Airlines.

Costs, Schedule, Way Forward

Costs and Schedule:
Development of software for engines tests for a variety of different engine models for use in certification and aftermarket situational testing.

- $2-3M over 2 years

Build a test simulator test cell for a technology demonstrator.

- $1M over 3 years

Way Forward:
This is a good candidate for multi-partner, multi-disciplinary collaboration.

Potential collaboration organizations:

- Industry: engine OEMs, RR, PW, GE, StandardAero, MDS Aero, IT Industry
- Research organizations: NRC, ITC, NASA
- Educational institutions: U of M, Red River College
- NPOs" WestCaRD, EnviroTREC
- Government funders: Industry Canada, WD, Prov. of MB

Summarized strategy for (single firm or collaborative) development and implementation of this technology in Canada (major steps required):

- Engage potential partners in all categories
- Define needs, timelines, resources
- Establish funding and timelines

Thrust Area 6 – Rockets and Space

This group evaluated the role of rockets and space for Manitoba's aerospace future.

The group identified two Space System Management technologies of interest:

- Space Autonomy
- Unmanned Aerial Vehicles

Autonomy of spacecraft is considered to be an important element which needs further development. Autonomy is principally comprised of algorithms which consider failure detection, isolation of failed elements and possibly recovery of craft to either a "safe-hold" state or a fully operational state.

The second key element identified by this group is UAV technology, which is increasingly being demanded by civilian and military customers.

Markets for both products are very large and have large CAGR's (compound annual growth rates) in the order of 7%. The market for satellites is about $190 billion while UAV's have a $90 billion market making opportunities in these areas very worthwhile to pursue.

<table>
<tr>
<td><u>Technology Area:</u> Space and Rockets

• Autonomy permits a spacecraft to operate in the absence of human control. Most autonomy is implemented in the form of pre-programmed responses to anticipated (desired or undesired) input conditions.
• A significant and somewhat unpredictable portion of the life cycle cost for the space mission can be attributed to the on-orbit operations. The unpredictable portion is associated with the real, vs. planned, on-orbit life of the spacecraft.
• Nominal condition autonomy includes concepts such as sensor fusion (combining the inputs from various sensors to determine the current “state” of the system), and prediction of future states.
• Off-nominal (or anomaly), autonomy includes failure detection, isolation and recovery to either a “safe-hold” state or a fully operational state.
• Most spacecraft being designed today have significantly higher levels of autonomy.</td>
<td><u>Alternatives, Availability, Maturity and Risk</u>

Alternatives:
Competition is more or less in the Satellite sector from other suppliers and last-gen products. If a new satellite is not available, then the last generation of technology will be deployed until a suitable replacement is found.
Availability:
Satellites are most often purpose-built projects and have a market size of $190B.
Maturity:
Satellites are experiencing high growth rates. This is due to the fact that new capabilities are being forthcoming and both technologies are quickly expanding in use. As such these technologies are generally early stage.
Risk:
Satellites are high risk projects as most often these technologies are being assembled into a saleable system for the first time. Accordingly there is considerable market risk in that the system may cost too much to develop, compared to what the contract provider may be able to afford or what competitors may be prepared to bid.</td>
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<tr>
<td><u>Impact on Economic Development for Manitoba</u>

Spacecraft development contracts that are of interest are significant for Manitoba. Sales of tens of millions on an annualized basis are of key interest.

Satellite contracts have a modest impact on Manitoba’s economy. This industry is very competitive and Magellan - Manitoba’s sole participant in that sector, has to compete on a global scale in order to succeed. The opportunity to develop better autonomous systems provides a competitive edge and will improve economic results for this province. Satellite systems are largely procured by both the Canadian and foreign governments.</td>
<td><u>Costs, Schedule, Way Forward</u>

Costs:
Annual development plans for satellites are in the range of $2 million per year. This is an escalating technology and support costs are still in the growth stage. Accordingly, these annual development costs continue for some time.
Schedule:
This competitive marketplace requires accelerated schedules and constant watch on available technologies for integration into space systems.
Way Forward:
Satellite collaboration can be conducted in partnership with firms such as MDA and others, wherein Magellan is responsible for key components which are integrated elsewhere. A key trend in satellite development at this time is satellite miniaturization with the purpose of developing smaller devices. Magellan has developmental experience in this design and development area. This is highly dependent on the scale of the satellite project. Smaller projects are completed on site, and larger ones may be partnered.

The role of the Canadian Space Agency (CSA) to support and collaborate with this industry is recognized and is an important stakeholder.</td>
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Technology Area: Unmanned Aerial Vehicles (UAV's)	**Alternatives, Availability, Maturity and Risk**
There are now hundreds of UAV projects around the world. Some have gone large scale and as a result the line has become blurred between small projects such as quadcopter-with-a-cameras and full-blown airliners. A UAV program can be tailor-made for the customer to accomplish specific goals such as: • Target and decoy • Reconnaissance - providing battlefield intelligence, border patrol service • Combat - providing attack capability for high-risk missions • Research and development - used to further develop UAV technologies • Civil and Commercial UAVs - UAVs specifically designed for civil and commercial applications (e.g. Pipeline oil spill monitoring, forest fire detection, etc.) Manitoba's contribution to this industry is comprised of MicroPilot which has been recognized as one of the world's leading manufacturers of small autopilots for UAV's and micro aerial vehicles (MAV). MicroPilot operates a UAV test facility situated on 40 acres adjacent to its facilities in Stonewall, MB. Autonomy technology and focus will be the overriding issues for UAV's now on the drawing board. Of particular opportunity are algorithms for multi-UAV systems.	**Alternatives:** Competition in the UAV area is from other suppliers and last-gen products. If a new technology is not available, then the last generation of technology will be deployed until a suitable replacement is found. **Availability:** UAV's are also generally available and have a market size of $89B. **Maturity:** UAV's are experiencing high growth rates. This is due to the fact that new capabilities are being forthcoming and the technology is quickly expanding in use. **Risk:** UAV's are high risk as most often this technology is being assembled into a saleable system for the first time. Accordingly there is considerable market risk in that the system may cost too much to develop, compared to what the contract price available.
Impact on Economic Development for Manitoba	**Costs, Schedule, Way Forward**
Manitoba presents a good opportunity for UAV development through its established firm, MicroPilot. A market niche has been created through the unique capabilities which have been developed over time and are well linked to our academe. A competitive UAV development system in Manitoba will lead to global opportunities for these technologies. Our interest is to grow high value jobs around this technology so that this industry will be doubled in sized by 2020.	**Costs and Schedule:** Annual development plans for UAV's are in the range of $1 million per year. As this is an escalating technology, these annual development costs continue. **Way Forward:** Collaboration is most necessary on the UAV side as only the image capture and transmission component is currently manufactured and developed in Manitoba. Potential collaborators here need to be aligned with Manitoba's interests and capabilities. Manitoba needs better and deeper partnerships in the UAV manufacturers and system developers.

DISCUSSION

The TRM process, which included 50 subject matter experts from across the Manitoba aerospace industry supported by technical leaders from the National Research Council, identified 25 critical technologies in six key areas (Appendix D).

The key areas are consistent with those identified by the national Technology and Innovation Working Group working under direction of the Aerospace Industries Association of Canada.

The cross sector working groups identified that the critical technologies are shared across the industry, and that development will benefit multiple companies and the sector as a whole. Many of the technologies were universally applicable in both manufacturing and MRO applications. Often the same technology required for the manufacture of an aerospace product is required for subsequent repair of the product at a later maintenance event. As a result, the key technologies provide a broad life-cycle portfolio of technologies. Moreover, a number of the technologies, e.g. composites, advanced manufacturing, simulation, etc. will also support non-aerospace companies in manufacturing, ground transportation, etc.

The efforts required to develop many of the technologies will require collaborative approaches, both to critical mass of knowledge and facilities and to share the risks and costs. The MAA has previously identified the value of collaborative R&D and has initiated a small pilot project which has the Industrial Technology Centre leading a joint Boeing/Magellan project.

Industry will need to develop a greater capacity to undertake collaborative research projects. Existing programs such as CRIAQ, GARDN, CRN and CCMRD may offer opportunities or models for collaboration. In addition, the new Technology Demonstration Program and the national applied research network being explored by Industry Canada may provide opportunities.

While these programs may provide opportunities, Manitoba will need to establish a strategy and a mechanism to pursue collaborative research and development. The current TRM Steering Committee or some variation of it may be a suitable leadership group. This would provide the added benefit of maintaining continuity and momentum for the TRM project. Funding strategies will also be required.

After the report is adopted by Manitoba aerospace leaders, a communication strategy should be implemented to create a dialogue within industry, to brief external stakeholders and policy makers and to engage key OEMs, academia, NPOs, government agencies and research organizations in the research thrust areas.

To mobilize the technologies identified in this TRM an implementation strategy needs to be developed. The following section outlines a potential strategy for Manitoba which seeks to accomplish a modest portfolio of projects by the end of the fifth year, and a renewal of the TRM.

IMPLEMENTATION STRATEGY

A two part implementation strategy is proposed related to the scale of the proposed technology development activity.

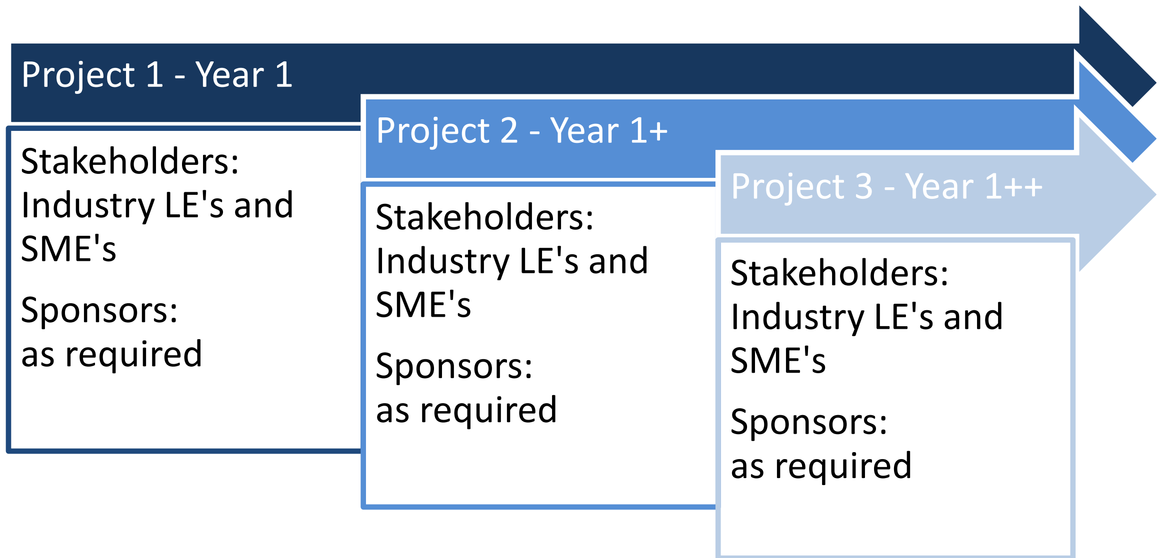
For smaller projects up to $250,000 (see Figure 2) external funding will be sought from appropriate government and private agencies who will be brought into partnership with industry and academia to pursue projects, on a project by project basis. SME's should be assisted in developing their capacity to work with these agencies and to participate in R&D initiatives.

For the longer term, a more established process is required to minimize time to project initiation, minimize overhead on industrial and academic partners and to ensure that the project preparation and submission processes are well managed and meet funding agency requirements.

The Emerson Report *'Beyond the Horizon: Canada's Interests and Future in AEROSPACE'* identified this same issue and made recommendations to implement a program of collaborative national applied research program based on adapting the processes used by the CRIAQ program in Quebec. While Manitoba plans to be a full participant in any national applied research initiative, it should also consider provincial initiatives to address provincial priorities. For example, one approach could be to develop a virtual program, linked to the national initiative, with the goal of bringing Manitoba based large enterprises (LE's), Small and Medium Enterprises (SME's) and academe in partnership with funding agencies.

The scale would be intentionally small by design to ensure that project flows are continuous rather than sporadic. Normal project funding rules and ratios would be used such as 40% industry, 40% academe and 20% SME's. A key benefit to a virtual program would be the absence of administrative overhead for its management. Partners would support their project development and project management costs throughout each project, which would be up to two years in duration.

Figure 2 –Process for Small Project Management



For larger projects, implementation would be led by the industrial partners who would best benefit from them.

Some Thrust Reports indicate that a broader partnership should be built to review and test certain technologies before committing to an industrial installation. Such partnerships could be comprised of two or more Large Enterprises (LE's), one or two Small and Medium Enterprises (SME's) and members of the academic community from Manitoba and beyond. Funding support for these larger projects may be available from through appropriate government and private agencies. Figure 3 has been developed to demonstrate this schema.

Accordingly, these project teams would be raised as needed by the project partners. These project teams would also be expected to manage the proposal through to the ultimate conclusion of the project, which would be likely several years down the road. Figure 3 provides a graphical representation of the composition and sponsorship of large projects.

Figure 3: Process for Large Projects

CONCLUSIONS

A technology road map is a pathway projection for decision makers to use in identifying the research and development priorities for Manitoba's aerospace industry.
Based on the analysis of the 50 subject matter experts from across the Manitoba aerospace sector and the National Research Council, it is concluded that:

1. Manitoba aerospace companies share many common technology areas of interest
2. Twenty-five critical technologies were identified in six key focus areas;
3. The key areas are consistent with those identified by the national Technology and Innovation Working Group working under direction of the Aerospace Industries Association of Canada;
4. Collaboration will be required to develop many of the technologies identified, including collaboration from beyond Manitoba's borders;
5. The Manitoba aerospace community will need to develop a greater capacity to undertake collaborative research projects;
6. There is a collaborative spirit and collective willingness to pursue the R&D activities and the business opportunities they will create to develop the key technologies;
7. The Manitoba aerospace community will need to establish a strategy and a mechanism to pursue collaborative research and development;
8. Both funding models and coordination/leadership models will be required;
9. Existing programs such as CRIAQ, GARDN, CRN, WINN and CCMRD may offer opportunities or models for collaboration; and
10. The industry-led current TRM Steering Committee may be a suitable leadership group.

RECOMMENDATIONS

The Manitoba aerospace industry strongly supports the Emerson Report, '*Beyond the Horizon: Canada's Interests and Future in AEROSPACE'* and the recommendation to identify key technologies with the greatest long term potential and where we can build on our competitive advantages to secure a global leadership position.

Based on a sector-wide, industry led strategic review of technology needs for Manitoba's aerospace industry using a Technology Road Map process, it is recommended that:

1. Strategies be developed to pursue the development of the critical technologies identified;
2. A communication strategy be developed to engage governments (public policy and programs), research organizations (R&D programs), academia (research and post-secondary education priorities), and the public (awareness) in supporting the development of the key technologies;
3. Funding strategies be pursued by leveraging local and national programs for both large and small scale technology research and development projects and by developing local strategies to fit regional resources and opportunities.
4. Systematic processes be developed to ensure the continuity and governance of this Technology Road Map, including periodic renewal and revision;

ACKNOWLEDGEMENTS

The Manitoba Aerospace Technology Road Map – Steering Committee wishes to thank the National Research Council of Canada Industrial Research Assistance Program (NRC-IRAP) for its support in preparing this Technology Road Map.

NRC (IRAP), provided advisory services, as well as funding, to EnviroTREC to support the activities required to plan and execute the January 2013 Economic Development Workshop. These funds were also used by EnviroTREC to support the Non Profit Organizations which provided coordination support to the TRM Steering Committee and to each of the TRM Thrust Groups.

In addition, the Information Specialists from the NRC Knowledge Management branch aided considerably with our work. They produced 16 environmental scans in support of the TRM Thrust Groups and met a challenging schedule. These reports made a considerable impact on the content of the Thrust Group Reports.

The Steering Committee would also like to acknowledge ***Betty Dearth***, Senior Librarian at the Industrial Technology Centre for her considerable contributions to Working Group 1 in providing the necessary research reports for their work.

APPENDIX A: Technology Road Map Steering Committee

Chair
Kim Olson, StandardAero, Senior Vice President

Deputy Chair
Ken Webb, MAA, Executive Director

Secretariat
Alfonz Koncan, EnviroTREC, Director of Business Development and Government Relations

Members:

Rick Jensen, Boeing Canada, Winnipeg; Director, Government and Community Relations

Dave O'Connor, Magellan Aerospace, Division Manager Defence and Space Products

Leo Sousa, Cormer Group Industries, President

Udaya Silva, EMTEQ, Business Unit Director

David Simpson, EnviroTREC, Executive Director

Sean McKay, CIC, Executive Director

Myron Semegen, ITC, Manager, Advanced Technologies

Wendell Wiebe, MAHRCC, Executive Director

Fred Doern, RRC, Research Chair, STAM

Jonathan Beddoes, U of M, Professor and Dean

Vic Gerden, WestCaRD, CEO

Greg Dandewich, Wpg-ED, Director, Economic Development

APPENDIX B: Thrust Area Working Groups and Membership

TAWG1: Advanced Machining

Deputy Chair

Alfonz Koncan, EnviroTREC, Director of Business Development and Government Relations Elliott Foster, Magellan Aerospace, Team Leader Quality Control
Bill Noakes, RRC, Chair: Mechanical, Manufacturing and Communication
Keith Jephcote, StandardAero, Manager, Process Engineering
Richard Scarle, StandardAero, Specialist, Process
Chris Godin, Boeing Canada, Operations Equipment Engineering
Dale Kellington, ITC, Manager, Engineering & Technical Services
Mahmoud Attia, NRC, Manager, Material Removal

TAWG 2: Robotics and Automation

Chair

Serge Boulet, Magellan Aerospace, Manufacturing Technology Engineering

Deputy Chair

Myron Semegen, ITC, Manager, Advanced Technologies
Subramaniam Balakrishnan, U of M, Professor
David, Boonstra, Boeing Canada
Fred Doern, RRC, Research Chair
Brendan Guyot, StandardAero, Manager, Engineering
Iraj Mantegh, NRC, Research Officer

TAWG3: Composites

Chair

Loren Henrickson, Boeing Canada, Engineering Manager

Deputy Chair

Gene Manchur, CIC, Aerospace Sector Manager
John Bagan, Magellan Aerospace, Senior Manager, Business Development
Jordan Bisharat, Cormer Group Industries
Neil Dobson, RRC, Research Technologist
Raghavan Jayaraman, U of M, Associate Professor
David Vanderzwaag, EMTEQ, Composites Product Manager
Andrew Johnston, NRC, Group Leader

TAWG 4: Simulation Modelling and Analysis

Chair
Doug Roberge, StandardAero, Senior Airworthiness Engineer
Deputy Chair
Ken Webb, MAA, Executive Director
Steve Crouch, CIC, Principal Engineer, Aerospace Sector EIT
Ray Woodason, StandardAero, Director, Performance Engineering
Brent Jones, Magellan Aerospace, Mechanical Engineering, Space Systems
Hartley Waldman, Boeing Canada
Michael Thomlinson, ITC, Engineering Manager
Franco De Luca, EMTEQ, Design and Stress Manager
Nick Bellinger, NRC, Group Leader

TAWG 5: Testing and Certification

Chair
Brent Ostermann, StandardAero, Director, Engineering
Deputy Chair
Vic Gerden, WestCaRD, CEO
Don Pereira, MDS Aerotest, Site Manager
Doug Thomson, U of M, Professor & Associate Dean, Computer Engineering
David Bertin, RRC, Research Technologist
Trevor Cornell, ITC, Chief Operating Officer
Kathryn Atamanchuk, U of M, EIR
Jim MacLeod, NRC, Group Leader

TAWG 6: Space and Rocket Systems

Chair
Diane Kotelko, Magellan Aerospace, Space Systems Engineer
Deputy Chair
Wendell Wiebe, MAHRC, Executive Director
Igor Telichev, U of M, Assistant Professor
Howard Loewen, Micropilot, President
David Bertin, RRC, Research Technologist
Sylvie Beland, NRC, Director R&D Structures Materials and Manufacturing

APPENDIX C: Critical Technologies Report Template

THRUST AREA WORKING GROUP:	*e.g. Composites*

CRITICAL TECHNOLOGY:	*e.g. High Temperature Applications*

- **Description:**

A brief technical description of this pre-competitive, enabling technology.

- **Impact on Economic Development for Manitoba**

Identify the key reasons why this technology is critical for the economic development of the Manitoba aerospace industry (e.g. future environmental regulations, customer concerns and demands, competitiveness issues).

- **Technology Performance Goals:**

In bullet form, list the key qualitative and quantitative performance objectives for the pre-competitive enabling technology as related to the application of the technology in Manitoba.

- **Importance and Breadth of Application:**

When is this technology required (approximate deadline (month, year) when this technology must be in place to meet regulatory and / or competitive requirements.

To whom is this technology critical (e.g. OEM, suppliers, MR&O community, operators, etc.)

What are the likely outcomes if this technology is not available to, or implemented by the Manitoba aerospace industry.

- **Alternatives:**

What other, if any, technologies or non-technological solutions could be applied as a potential substitute for this technology.

What are the competing technologies.

- **Availability, Maturity and Risk:**

Where is this technology currently available or under development (internationally, nationally, organizations), and what are the current capabilities of this technology (i.e. the current state-of-the-art). What incremental capabilities (preferably in bullet form) must be developed <u>in Manitoba</u> to reach the required level of maturity by the deadline identified in section 3. What is the level of <u>technological risk</u> (i.e. high, medium or low) in achieving this level of maturity by this deadline.

- **Costs:**

Provide a rough order of magnitude estimate of the total funding required to develop this technology in Canada to the level of maturity and within the timeframe identified above (e.g. $2 million over 3 years).

- **Collaborators and Development / Implementation Strategy:**

Indicate whether or not, and why, the development of this technology is a good candidate for multi-partner, multi-disciplinary collaboration. Identify the Canadian as well as offshore organizations which could collaborate in developing this technology for the Manitoba aerospace industry.

Summarize a strategy for (single firm or collaborative) development and implementation of this technology in Canada (what are the major steps required).

- **References:**

List of pertinent documents.

- **Contacts:**

Resource persons for further information (organization, name, phone, e-mail).

APPENDIX D: Environmental Scans in Support of TRM Thrust Reports

NRC Knowledge Management - Environmental Scan reports in support of the Manitoba Aerospace TRM Thrust Reports are available on line at:

http://www.mbaerospace.ca
http://www.envirotrec.ca/projects

APPENDIX E: Thrust Area Working Group - Critical Technology Reports

Thrust Reports produced by the Working Groups are available on line at:

http://www.mbaerospace.ca
http://www.envirotrec.ca/projects

The entirety of the Manitoba Aerospace Technology Road Map reports are available through the Manitoba Aerospace Association and EnviroTREC websites:

Manitoba Aerospace Association

EnviroTREC

APPENDIX F: Listing of Acronyms used in this Report

The following is a list of acronyms and their meanings that were used in this report.

3D – Three-dimensional space
4D – Four-dimensional space
$M – Millions of dollars
$B – Billions of dollars
AI – Artificial Intelligence
AIAC – Aerospace Industry Association of Canada
AUSS – Automated Ultrasonic Scanning Systems
AM – Additive Manufacturing
BMI – Bismaleimide
CAD – Computer Assisted Design
CAGR – Compound Annual Growth Rate
CAM – Computer Assisted Manufacturing
CATT – Centre for Aerospace Training and Technology
CEO – Chief Executive Officer
CCMRD – Canadian Composites Manufacturing R&D Inc.
CIC– Composite Innovation Centre
CMC – Ceramic Matrix Composite
CNC – Computer Numerical Control
CNDI – Centre for Non-Destructive Inspection
CNT – Carbon Nanotube
CRIA-M – Consortium for Research and Innovation in Aerospace - Manitoba
CRIAQ – Consortium for Research and Innovation in Aerospace in Québec
CRN – Composites Research Network
EADS – European Aeronautic Defence and Space Company N.V.
EIS – Environmental Impact Statement
EVI-GTI –European Virtual Institute for Gas Turbine Instrumentation
CT – Computed Tomography
EnviroTREC – Canadian Environmental Test Research & Education Centre
FDM – Fuse Deposition Modelling
FEA – Finite Element Analysis
GARDN – Green Aviation Research & Development Network
GE – General Electric
GETRDC – General Electric-Aviation Engine Testing Turbine Research and Development Centre
GLACIER – Global Aerospace Centre for Icing and Environmental Research
GTE – Gas Turbine Engines
HR – Human Resources
HPC – High Pressure Compressor
HPT – High Pressure Turbine
HSM – High Speed Machining
ICTAM – ICT Association of Manitoba
IETM – Interactive Electronic Technical Manuals
IT – Information Technology
ITA – Industrial Technology Advisor
ITC – Industrial Technology Centre

IRAP – Industrial Research Assistance Program
IRC – Industrial Research Chair
KG – kilograms
LE – Large Enterprise
LPT – Low Pressure Turbine
MAA – Manitoba Aerospace Association
MAHRC – Manitoba Aerospace Human Resources Council
MB – Manitoba
MDC – Machining Development Centre
MRO – Maintenance, Repair and Overhaul
Nano – Nanotechnology
NASA – National Aeronautics and Space Administration
NDE – Non-Destructive Evaluation
NPO – Not-For-Profit Organization
NRC – National Research Council
NSERC– Natural Sciences and Engineering Research Council
OAC – Ontario Aerospace Council
OEM – Original Equipment Manufacturers
OOA – Out-Of-Autoclave processing
P&W – Pratt & Whitney
PI – Polyimide
PIWG – Propulsion Instrumentation Working Group
QC – Quality Control
R&D – Research and Development
RI – Resin Infusion
ROI – Return on Investment
ROM – Rough Order-of-Magnitude
RR – Rolls-Royce
RRC – Red River College
RTM – Resin Transfer Molding
SME – Small and Medium Enterprise
STAM – School of Transportation, Aviation, and Manufacturing (RRC)
TAWG – Thrust Area Working Groups
TRL – Technology Readiness Level
TRM – Technology Road Map
UAV – Unmanned Aerial Vehicle
UT – Ultrasonic Testing
UBC – University of British Columbia
U of M – University of Manitoba
VaRTM – Vacuum Assisted Resin Transfer Molding
VR – Virtual Reality
WestCaRD –West Canitest R & D Inc.
WD – Western Economic Diversification Canada
Winnipeg-ED – Winnipeg Economic Development