Appendix E

Presentation of Thrust Area Working Group Reports

The following presentation contains twenty-four Thrust Reports which were prepared by the Working Groups which were tasked by the Steering Committee responsible for producing a Manitoba Aerospace Technology Road Map.

Appendix E – Thrust Area Working Group Reports

THRUST AREA WORKING GROUP 1: Advanced Machining

THRUST AREA WORKING GROUP 2: Robotics and Automation

THRUST AREA WORKING GROUP 3: Composites

THRUST AREA WORKING GROUP 4: Simulation, Modelling and Analysis

THRUST AREA WORKING GROUP 5: Simulation, Modelling and Analysis

THRUST AREA WORKING GROUP 6: Space and Rockets

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*CT 3D X-Ray*

---

1. Description:

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.

This technology combines a series of 2-dimensional scans (i.e. flat scans) which have been generated via an x-ray source. These scans are then "computed" and converted into a 3D image which is now available for inspection on a video screen. The resultant technology is called CT 3D X-Ray, which now combines all the technological terms into a new term. By using X-rays as a non-destructive inspection technology, information about the 3D internal features of an object is provided. Generally this information is not available through any other means, especially in complex structures.

Radiography scans can be used to inspect almost any material for defects, and can also be used to locate internal features, confirm the location of hidden parts in an assembly and to measure thickness of materials. This technology has relatively few limitations or negative considerations. Orientation of the sample to be inspected is key to successful inspection. Radiography is however not as effective at detecting flaws that are oriented in a planar direction with respect to the radiation source, and is not effective at detecting delamination (i.e. a 2D void on a 2D scan plane)

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.

The evolution of this technology into more standard forms is compounded by constantly evolving design and manufacturing processes for composite components. This constant change will continue to pose considerable challenges to standardizing NDT procedures.

On the supply side, 3D non-contact measurements have varied challenges with respect to software tools and there is a need for the industrial community to focus on this aspect of technology development. Scanning speed has dramatically increased the amount of data that is needs to be computed, by exponential orders. This data now must be visualized on the computer, processed and the results analysed. This requires optimization of both the algorithms and data management capabilities.

One of the significant innovations in the field of the laser scanners is ToF (time of flight) technology. It is an emerging technology but it is not yet well developed for high resolution scans. The resolution achieved with this technology is in the range of few hundred points. With this increase in resolution, there is scope for diversification of applications.

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*CT 3D X-Ray*

NASA has begun research into X-ray and Terahertz methods to aerospace structures such as the inspection of external tank foam, shuttle underbelly tiles, ceramic materials and certain composite materials. In the proposed work, NASA intends to fully characterize the capabilities of first-generation terahertz computed tomography

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

- Failure Analysis, NDT of new composites.
- Provide orthogonal scans to planar composite components
- Simulations & Reverse Engineering of GT parts.
- 3D Dimensional Metrology of MRO parts being evaluated for return to service
- Review technology at each iteration of larger scanning volumes

4. Importance and Breadth of Application:

This technology is important to all three LE's in Manitoba (Magellan, StandardAero and Boeing) as it has metals-MRO and composite implications. Having access to this technology will allow industry participants to evaluate new opportunities and grow their enterprise.

This technology goes hand in hand with adaptive machining. Having a full feedback loop to the CNC machine control so as to alter the cutter path/geometry to suit internal cavities/features or the actual warping or movement of the machined component through the release of stresses could be very important to the aerospace sector to reduce scrap and other losses.

5. Alternatives:

1. Continue with the status quo. Users can 3D scan external features then section parts of internal features with limited current technologies.

2. Continue with scrapping out parts that are within OEM requirements.

3. Continue to do R&D trials to induce twist or warpage into parts during fixturing in order to have the part come out correct on final machine.

4. Reverse Geometry X-ray® (RGX®) from **Digiray Corporation**. Its features include post-acquisition digital image enhancement, 3-D imaging, and Motionless CT™ (laminography), a cost-effective alternative to computerized tomography (CT) that is capable of viewing samples one layer at a time. RGX® technology is production-proven for composite parts on the F-117. NASA has been using RGX® since 1993.

5. 4D X-ray Computed Tomography from **North Star Imaging, Inc.** allows users to reconstruct a complete 3D CT model that includes time and motion, creating a truly dynamic volumetric dataset. Because this is an X-ray Computed Tomography process, both the internal and external structures of an object are obtained. This new technology makes it possible to study form, structure, and function. This inspection technology is revolutionary for in situ testing applications such as compression, traction and similar processes. Studies in hydrodynamics, process and quality, reverse engineering, failure analysis and mechanical motion can benefit from the use of this technology.

6. Availability, Maturity and Risk:

Availability:

- **3DX-RAY Ltd**, Leicestershire, UK. http://www.3dx-ray.com/contact-us
- **Digiray Corporation**, CA, USA. Call: (925) 838-1510; info@digiray.com. http://www.digiray.com
- **North Star Imaging, Inc.** MN, USA. http://xviewct.com/about-industrial-xray/contact-us
- **GE Measurements & Control.** http://www.ge-mcs.com/en/radiography-x-ray/ct-computed-tomography.html

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. Users can develop functionality readily enough to perform adequately in their enterprises and the required developmental costs are modest. The risks here are in matching and developing the required Human Resources to the technology as these skill sets would be viewed as not-commonly available nor a recognized specialty.

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*CT 3D X-Ray*

7. Costs:

The cost of 3D non-contact measurement technologies is continuously decreasing. In the case of advanced systems the cost is still a prohibitive factor. For instance, the cost of these systems is currently more than $300k. This contrasts with the cost of the average competing hand scanner at about $30k. At this rate the capital cost is a hindering factor to implementation. Typically customers are interested in implementation when the ROI occurs relatively quickly or if the added value is significant. The challenge of inspection systems is that their ROI is often difficult to measure.

The cost of a CT 3D X-ray system for developmental purposes would be about $300k with and annual operating support cost of $200k. A small program such as this could be implemented well within a year and could have a 5-year life, for a net developmental cost of <$1.5 million over the 5 year period.

8. Collaborators and Development / Implementation Strategy:

This technology has great opportunities for applied research and development in Manitoba. Early stage development can be supported by the Industrial Technology Centre while applied projects can be supported by Red River College. Manitoba's three large Enterprises can consider projects to bring to such a centre and can collaborate with partners identified.

Offshore support may be possible from Boeing and GE which both have ties to Manitoba.

A strategy for the development of this technology would be to 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.

9. References:

1. Ruola Ning, Xiangyang Tang, and David Conover. 2004. *X-ray scatter correction algorithm for cone beam CT imaging*, Med. Phys. 31, 1195, DOI:10.1118/1.1711475

2. Reza Ghaffarian, 2012. *3D X - ray CT for BGA/CGA Workmanship Defect Detection,* Jet Propulsion Laboratory Pasadena, California, NASA Electronic Parts and Packaging (NEPP) Program, Office of Safety and Mission Assurance, found at: https://nepp.nasa.gov/files/24026/12_139_JPL%20Ghaffarian_%203D%20Xray%20CT%20for%20BGA%20CGA%20Workmanship%20Defect%20Detection%20Pub%2012%2011%2012_12%20rec%202%2012%2013%20version%20b.pdf Aug 6, 2013.

3. D. J. Roth, S. Reyes-Rodriguez, D. A. Zimdars, R. W. Rauser, and W. W. Ussery *Terahertz computed tomography of NASA thermal protection system materials*, AIP Conf. Proc. 1430, 566 (2012), DOI:10.1063/1.4716278

4. Mario Pacheco and Deepak Goyal, 2008. *New Developments in High-Resolution X-ray Computed Tomography for Non-Destructive Defect Detection in Next Generation Package Technologies,* ISTFA 2008: Proceedings from the 34th International

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*CT 3D X-Ray*

Symposium for Testing and Failure Analysis November 2-6, 2008, Portland, Oregon USA, found at: http://www.sector-technologies.com/publications/doc_download/12-new-developments-in-high-resolution-x-ray-computed-tomography.html?lang=en Aug 6, 2013

10. Contacts:

Dale Kellington,
Business Development/Project Manager
Industrial Technology Centre,
Phone: (204) 480-0340
Email: dkellington@itc.mb.ca

Bill Noakes,
Acting Chair MMC,
Red River College
Phone: (204) 632-2169
Email: bnoakes@rrc.ca

Kim B Olson,
Senior Vice President,
StandardAero
Phone: (204) 318-7820
Email: Kim.Olson@StandardAero.com

Loren Henrickson,
Engineering Manager
Boeing Winnipeg Operations
Phone: (204) 831-2856
Email: loren.hendrickson@boeing.com,

Elliott Foster
Team Leader Quality Control
Magellan Aerospace, Winnipeg
(204) 775-8331 x3023
elliott.foster@magellan.aero

Martin J. Petrak, M.Sc., P.Eng., President, Orthopaedic Innovation Centre
Director of Research Operations, Concordia Joint Replacement Group
Concordia Hip and Knee Institute, Suite 310 - 1155 Concordia Ave,
Winnipeg, MB R2K 2M9
Phone: (204) 926-1290,
Email: mpetrak@orthoinno.com

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Adaptive Machining*

---

1. Description:

Adaptive machining, (as perceived by the Aerospace MRO community), 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.

There are 3 things required to enable accurate machining in normal operations:

1. The location of the part
2. The initial shape of the stock
3. The final shape of the part

If any one of these is not accurately known, then an adaptive approach is required. In place of the traditional linear approach to machining from CAD to CAM, Adaptive Machining uses in-process inspection to make real time decisions about the machining process, and will make changes on the fly to ensure a quality part every time. This technology reduces -setup times, -scrap, and -manual rework while delivering higher accuracy, process stability, and profitability.

The traditional relationship between machining and inspection is that machining is completed first and the component is then transferred to a dedicated piece of inspection equipment to be approved or rejected. However, as machining techniques become more sophisticated, and as components become larger and more complex, there are a growing number of cases where closer integration is required to give higher productivity and reduced wastage. Instead of a simple linear progression from CAD to CAM to machining to inspection, a more complicated series of steps is needed, with extra data needed to fill any gaps in the information available at the various stages. These new processes are be grouped under the heading of "adaptive machining."

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.

A manufacturing process may dictate that the form of a finished component is dependent on the form of the input material for that process. This may occur where distortion of the part during machining varies from part to part (for example, owing to fixturing effects), or where the actual workpiece is a unique item and depends on uncontrollable effects (for example, in a remanufacture task where the lifetime history of the component has affected its form). In these circumstances, it is necessary to measure the form of the input component and use the measurement to produce a customised cutting program which is unique to that component.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Adaptive Machining*

Adaptive machining employs in-process inspection to determine the shape of the part to be machined, then adapts the CNC tool paths to machine the actual part with extremely high accuracies. Inspection data is collected in-process from the actual part to be machined. This data is then used to reshape a nominal CAD model so that it represents the real world part. This new model is then used to automatically generate a unique set of tool paths to machine the part to the highest accuracy possible. All while - eliminating blending issues and hand finishing operations that would otherwise be required.

As a last point, adaptive machining relates to the ability to create a 3D cutting geometry to machine a surface, using inspection data from the mating part, without requiring the use of a CAD system. This technique replaces the need for shims that are ordinarily required during assembly. There is a cross-over point here in that with composite manufacturing when a part requires repair after machining, that part will sometimes require holes to be re-drilled or edges to be re-trimmed in the repaired area. This repair preparation currently requires a programmer to create a repair program, which takes time and uses up resources. An ideal situation would be firstly machine-scanning the part, then detecting the area requiring repair and finally automatically creating a repair program.

2. Impact on Economic Development for Manitoba:

Adaptive machining has uses beyond the needs of Aerospace MRO such as the custom manufacture of orthopaedic implants and repairs to worn casting moulds and dies. Unfortunately at this time no one in Manitoba currently uses this technology.

Many, very expensive aero-engine parts are damaged in service by what’s loosely termed as ‘FOD’, (Foreign Object Damage). Other damage comes from exposure to service; the surfaces of these parts simply erode during use. When either of these conditions exist, 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 such parts 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.

Opportunity for Short Term Implementation

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 as part of the implementation. Despite this cost, however, 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.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Adaptive Machining*

3. Technology Performance Goals:

- Use technology in MRO for tooling manufacture, custom orthopaedic implants, and other metal components.
- Utilize and repair the large inventory of damaged/worn “repairable” parts held by a number of customers such as OEM’s and military.
- Use Adaptive Machining technology to become a ‘Center of Excellence’ for repairs to Aerospace parts in Manitoba.

4. Importance and Breadth of Application:

Benefits of developing this technology include opening up the ability to extend the useful life of extremely expensive components. It will also create the opportunity to develop new repairs that are currently unavailable.

Adaptive machining is only one of a number of technologies required to bring such repairs to reality. Other enabling technologies for the development of the repairs described above include 3D scanning, laser cladding/welding (for build-up), Digital X ray, spin testing, and FEA (stress analysis).

Adaptive Machining technology could well be deployed and operational within a 4 year period. Its application is specific to the MRO community - GTE repair area. A plan for the development of this technology is proposed and budgeted out in Section 7 (Costs).

If this technology is not pursued in Manitoba, other MRO companies will invest and profit from this technology.

5. Alternatives:

Alternatives to conventional techniques are necessary as OEM’s are requiring tighter tolerances on all products, which increase manufacturing costs.

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.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Adaptive Machining*

---

6. Availability, Maturity and Risk:

Availability

- **Delcam Professional Services.** Its technology expertise includes:
  1) Adaptive fixturing to simplify setups and remove human error.
  2) Robotics for machining, grinding, polishing, and deburring operations.
  3) Automation of complex manufacturing processes.
  4) Advanced Manufacturing Facilities.
  5) Software customization of repetitive tasks.

- **Third Wave Systems** provides validated software solution for:
  1) optimization of metal cutting; thereby enabling users to analyze machining processes in 2D and 3D environments,
  2) NC program optimization software integrating physics-based material models,
  3) CAD/CAM inputs, tooling and work piece geometries, and machine dynamics.

By predicting and displaying performance indicators not easily attained from trial-and-error tests, this technology empowers users to make better informed decisions on tooling and tool path strategies, thereby creating processes that machine dramatically faster while improving tool life and part quality.

- **Starrag Group** is a global technology leader in manufacturing high-precision machine tools for milling, turning, boring, and grinding of small, medium-sized, and larger workpieces of metallic and composite materials.

- **TTL** are part owned by the Starrag Group and are specialists in complex multi-axis CAM applications and automated CNC machining systems. Established in 1987, TTL has spent over two decades at the forefront of CAD/CAM & CNC machining technology. TTl has gained a global reputation for supplying innovative machining solutions to a wide range of demanding industries – including Aerospace, Power Generation, Pharmaceutical, Medical and Motor Sport. TTL's Adaptive Machining technology is used by many of the major OEM & MRO organisations around the world in both the Aviation and Power Generation market sectors.

- **BCT GmbH**, a system supplier founded in 1986, specializes in solutions for in-process scanning and adaptive machining.

Maturity:

Early adoption of this technology was driven by necessity but today the capabilities of this technology extend much further than ever before. Adaptive Machining is no longer used just in the repair of Gas Turbine Engine components; it is now commonly used to generate leading edge geometry on new blades, dress imperfections from castings to eliminate manual grinding operations, and in robotic grinding and polishing applications;

to name few applications. In all cases the goal is to eliminate manual operations, stabilize the process, maximize accuracy, and increase profitability of the manufacturing operation.

Adaptive Machining 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, the AI software necessary to function effectively is proprietary. Overall, the technology can be considered as early-stage.

Risk:

An Advanced Intelligent Machine Adaptive Control System was funded as part of the Seventh Framework Programme (European Common Union) at a cost of €3M (~$4.2M). This would indicate that applied research projects are underway and that this technology is in its early stage.

7. 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. The project payback period can be expected to start after 2.5 years. The following table illustrates the estimated investment scenario: (courtesy: Standard Aero). Note: This estimate does not take into account costs associated with housing this technology (buildings and facilities) nor does it include operational costs.

Table 1: Set up Estimate for a Dedicated Facility in Adaptive Machining

Item	Base equipment	Software	Support	Inspection	Fixtures (per Blisk)	
3D Digitizing	$390,000.00					
Adaptive Software		$650,000.00				
Machining-5 axis VMC	$1,144,000.00					
Welding and Cladding	$1,950,000.00					
Resonance Test Equipment			$650,000.00			
Spin Pit Testing (per Blisk)			$260,000.00			
Met Lab			$260,000.00			
Cleaning	$78,000.00					
Peening	$1,300,000.00					
CMM				$260,000.00		
Cold Forming	$65,000.00					
CBF Surface Finish	$39,000.00					
Plasma HVOF	$780,000.00					
Balance	$130,000.00					
FEA System		$78,000.00				
FPI				$78,000.00		
Digital X-ray				$520,000.00		
Eddy Current				$390,000.00		
Vac furnace	$975,000.00					
Fixture costs (per Blisk)					$260,000.00	
	$6,851,000.00	$728,000.00	$1,170,000.00	$1,248,000.00	$260,000.00	**$10,257,000.00**

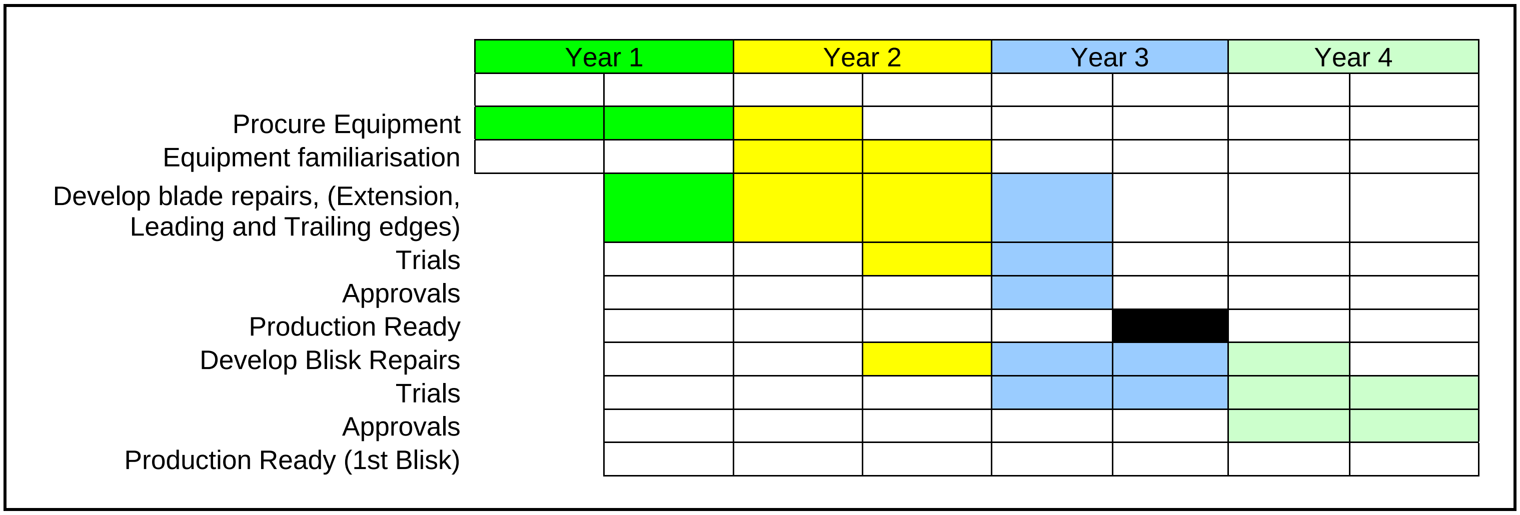
**Table 2:
Proposed Dedicated Facility in Adaptive Machining
CAPITAL SPEND - Years 1 - 4**

Year 1	$7,215,000.00
Year 2	$2,782,000.00
Year 3	$260,000.00
Year 4	$400,000.00

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Adaptive Machining*

Table 3: Suggested Implementation Plan for Dedicated Facility in Adaptive Machining



	Year 1		Year 2		Year 3		Year 4	
Procure Equipment	🟩	🟩	🟨					
Equipment familiarisation			🟨	🟨				
Develop blade repairs, (Extension, Leading and Trailing edges)		🟩	🟨	🟨	🟦			
Trials				🟨	🟦			
Approvals					🟦			
Production Ready						⬛		
Develop Blisk Repairs				🟨	🟦	🟦	🟩	
Trials					🟦	🟦	🟩	🟩
Approvals							🟩	🟩
Production Ready (1st Blisk)								

8. Collaboration and Development:

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 to us. (i.e. RRC and U of M)

The steps required to develop this technology would be as follows:

1) Gather 2 academic partners + 2 industrial partners.

2) Select machining opportunities to proceed.

3) Select site for trials and development (i.e. non-production site).

4) Select first-components to be produced.

5) Develop long term plan, for parts production and skill development

6) Exit products to industry and graduate trainees when satisfied with results

---

9. Literature References:

Textbook:

- Machining Impossible Shapes, IFIP TC5 WG5.3 International Conference on Sculptured Surface Machining (SSM98) November 9–11, 1998 Chrysler Technology Center, Michigan, USA, Series: IFIP Advances in Information and Communication Technology, Vol. 18, Olling, Gustav J.; Choi, Byoung K.; Jerard, Robert B. (Eds.)

Patents:

3 patents by Honeywell: (2009) Adaptive machining and weld repair process
Patent No:US 7472478 B2

Abstract:

An apparatus and method are provided for an adaptive machining and weld repair process for repairing airfoils, damage to an airfoil leading edge and tip. First, damaged material is machined away from a damaged airfoil edge so as to expose a weld surface. New material is laser deposited on the weld surface so as to create a weld-repaired airfoil having actual dimensions. The actual dimensions of the weld-repaired airfoil are automatically measured using a CMM system so as to generate an actual geometry. The actual geometry is deformed so as to develop deformation geometry. The component is then machined according to the deformation geometry

ADAPTIVE MACHINING AND WELD REPAIR 6,676,344 B1 1/2004 Amatt
PROCESS 6,701,615 B2 3/2004 Harding et a1.
Patent NO: 6,912,446 B2 * 6/2005 Wang et a1. .... 700/193

(75) Inventors: James H_ Graham, Sun City, AZ (Us);
Patent NO: 7,239,990 B2 * 7/2007 Struijs 703/2
Jeffrey Reinwand, Collinsville, OK 2002/0128790 A1 9/2002
Woodmansee 2004/0083024 A1 4/2004 Wang

Other Materials:

- Adaptive Robotics for Flexible Manufacturing (Frost & Sullivan, 2012)
- Advanced Manufacturing Technology Alert. Sustainable Printed Circuit Boards; Next Generation Feeding System for Small Parts; Numerical Tools Support Adaptive Machining (Frost & Sullivan, 2011)
- Aerospace automation: interview with Eric Beauregard of AV&R Vision & Robotics, Robotics Tomorrow, nd.

(http://www.roboticstomorrow.com/emagazine/2013/04/aerospace-automation/1846)

- Dhupia, Jaspreet S . and Ulsoy, A . Galip. Control of Machine Tools and Machining Processes in The Control Handbook, Second Edition, CRC Press, 2010.

- Dickin, Peter. The Adaptive Approach, Control Engineering Asia, 2008. (ftp://tawe.delcam.com/pub/pdf/ext_news/CEA-NOV-DEC08.pdf)Haftl, Larry. Adaptive controls save tools and time, American Machinist, 2007.

- (http://americanmachinist.com/machining-cutting/adaptive-controls-save-tools-and-time)Hewit, Philip.

- Using measurement and software to optimize part setup for machining, Quality Digest, 2012. (http://www.qualitydigest.com/inside/cmsc-article/using-measurement-and-software-optimize-part-setup-machining.html

10. Subject Matter References:

Dr. Mahmoud H Attia, Manager, National Research Council Canada
Material Removal, 5145 Decelles Avenue, Université de Montréal Campus
Montréal, Quebec H3T 2B2, Telephone: 514-283-9002,
Email: mahmoud.attia@nrc-cnrc.gc.ca

11. Contacts:

Kim B Olson
Senior Vice President
StandardAero
(204) 318-7820
Kim.Olson@StandardAero.com

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Additive Manufacturing*

---

1. Description:

Additive manufacturing (AM) technologies (a.k.a. 3D printing, fuse deposition modelling (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.

The ASTM F42 Technical Committee defines Additive Manufacturing (AM) as “the process of joining materials to make objects from three-dimensional (3D) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.”

Although the ASTM International Committee F42 on Additive Manufacturing Technologies was formed in 2009 in an effort to build support for AM, progress has been slow to date.

AM systems that produce metal parts can be divided into 2 broad groups.

Powder Bed Systems:

This group includes systems that use a laser or electric beams to heat powder to melt and form parts. This system produces parts in a powder bed, and the parts being fabricated are entirely inside the powder when the build process is complete. Approximately 552 units were installed in 2012 worldwide. This system can handle Stainless steel, tool steel, Aluminum, Inconel, Gold alloys, Cobalt-chrome, titanium and alloys including Ti-6Al-4V.fine feature detail can be achieved in products with surface finish as good as sand-cast finish. With shot-peening or bead-blasting, the surface quality is impressive, although not as good as a machined part. Mating surfaces and features that require high dimensional accuracy may require post-processing such as CNC machining.

Powder and Wire Deposition Systems:

This group of metal-based AM systems combines a laser heat source with a powder deposition head to deposit the metal powder. A 4- or 5-axis motion system is used to position the head, likely employing a robot to deliver this motion. Unlike the powder-bed systems, these machines can be used for the repair of existing parts (i.e. MRO) and tooling. However, these systems are generally more expensive, more complex to program, and require an operator skilled in CNC machining. The acceptance of this technology into industry has been limited, with a relatively high percentage of the systems sold going into academic and research facilities.

One version of this technology is referred to as Selective Laser Sintering (SLS) which uses a laser beam to selectively fuse and sinter polymer particles by scanning cross-sections on the surface of a powder bed layer-by-layer into an object that has a desired 3-dimensional shape based on a CAD model. Major commercial manufacturers of SLS equipment include 3D Systems and EOS. Several other firms are also involved with deploying variants of this technology.

The trend currently is towards applying AM to actual part production to displace traditional removal manufacturing methods. AM is set to revolutionize the manufacturing industry and will displace many existing methods and technologies in large scale.

As two last points to this section, the Advanced Machining TAWG sees the possibility of using Additive Manufacturing to provide repairs in Adaptive Machining situations, thereby inferring a cross-over of technologies which were discussed by this group. The second point is that 3D Printing is a rapidly changing technology these days. A 20 year plan is not appropriate, rather a 5 year horizon is more to the point here.

2. Impact on Economic Development for Manitoba:

AM is in its early days in Manitoba. Several aerospace entities are interested in this technology; however it will take a 5 year cycle before it will have established itself with a viable set of product lines. Enroute to this end will be a requirement to certify processes and parts produced through AM systems. As a result the OEM community will need to engage with our MRO providers to achieve the desired business and technological outcomes. In 2010, Canada was estimated to have less than 100 AM systems, while the global total was approximately 6000 systems, increasing at a rate of 15% per year (Wohlers Report 2010). Manitoba currently has at least 3 AM systems, located in government, academic and research organizations (ITC, RRC and Concordia Hip and Knee Institute). These three systems work solely with polymers.

The overall economic impact of AM technology is believed to be in the billions of dollars worldwide throughout the manufacturing sector. There are an estimated 5,000 users and customers of AM technology in the world. At that rate the aerospace sector can be surmised to be in the hundreds of millions while Manitoba can visualize an impact in the millions. CAGR rates of 13% have been claimed for AM technology within the aerospace industry; however this includes polymer systems, which are much further developed than metal deposition systems.

Of key interest at this time (and the core of this Thrust Report) are metal-AM technologies. Composite and polymer AM systems are likely not far behind in terms of local interest in uptake for manufacturing deployment.

The production trade-off that AM presents is low set up time, minimal WIP charges vs. high capital cost and longer production times. The best application of the AM technology is likely in small lots.

AM technologies on their own have the potential to reduce the carbon footprint of manufacturing by using less raw material to start with, creating less waste material (10 – 20% scrap of subtractive machining), eliminating hard tooling, producing lighter-weight components with optimized designs, and fabricating parts on demand. Transportation costs can be reduced by placing the manufacture of the products much closer to the MRO system, rather than inventory parts procured from global sources. In the long run AM technologies will speak well to manufacturing sustainability through the benefits identified here.

Sustainability of the business model with this technology will come through reinvestments in R&D, by selecting more complex and challenging parts and by altering the metal/alloy selections.

3. Technology Performance Goals:

AM technology in Manitoba is directed at the MRO group. Their concerns and opportunities in brief are:

- High accuracy, high strength, large parts
- Suitable for use in rotating components of aircraft engines
- Reduced (compared to current) costs of manufacturing
- Enabling one-off production

The key barrier to full take up of AM technology in the metals processing area is that the less-than-full density in metal AM parts compromises fracture toughness and fatigue properties. This area requires more research.

4. Importance and Breadth of Application:

AM technology will enable the creation of high value aerospace parts, done on a one-off basis and will be directed in Manitoba to the MRO community.

The laser-sintered parts also weigh less than the assemblies they replace, so this contributes to the savings in fuel costs over the lifetime of the aircraft.

Blueprints may not necessarily be available so a match-fit is required.

Engine MROs may eventually also be able to use this technology in combination with other technologies to analyze an existing part and rebuild it.

Companies such as Boeing are already working on the development of AM technology for their body structure applications, however this is Composite related. Boeing also currently manufactures many of its air ducts for the 787 in one piece using AM. This practice has eliminated part numbers and related overhead, tooling, inventory, labour, entire assembly lines, and maintenance.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Additive Manufacturing*

Although many barriers currently exist, engine OEMs may eventually be able to utilize this technology for rotating part production.

General Electric is currently running a contest, titled ‘GE's 3D Printing Production Quest: High Precision and Advanced Materials’ to try to define the level of capability existing today. The Phase 1 criteria are such that the successful respondents should be able to create parts that:

- Are made from high density, high atomic number metals, such as refractory metals and/or their alloys
- Have wall thicknesses down to 150 microns, with tolerances ±15 microns
- Precisely position walls 1mm apart, with tolerances ±25 microns
- Exhibit consistent, parallel walls, with little or no warpage across entire part
- Have a high density factor – as close as possible to the density of the bulk material
- Are able to withstand conditions that exert up to 80g’s of acceleration

5. Alternatives:

Continue with existing CNC machining methods and risk losing market share.
Hand lay-up, refabrication, and shimming also play a role in this area as an alternative to AM.

6. Availability, Maturity and Risk:

Availability:

Rolls-Royce has developed 4 technologies under this process:
1) Near-Net processes such as, Powder Hot Isostatic Pressing (HIP) which is used to make large complex parts
2) Blown Powder which is suited for the repair of engine components,
3) Powder bed – to make small complex parts that require high precision of deposition and
4) Metal Injection Moulding – used to make large quantities of small parts.

Optomec Inc. provides 3 – D printing solutions with metal handling capabilities using LENS (Laser Engineered Net Shaping) technology to prototype or repair small parts.

RMB Products Inc provides AM technology with plastic handling capabilities using Laser Sintering and Rotational Molding technology for ECD, HVAC, APU, AHU ducts, wire conduits, and fluid containment tanks.

Arcam AB, Sweden provides AM solution to use metals to make low pressure turbine blades using EBM technology.

Stratasys has been mentioned around Manitoba of late. They are interested in Manitoba as a market but however only work in polymers at this time.

Maturity:

Boeing uses Direct Digital Manufacturing employing Stereo lithography principle to make aerospace parts such as Environmental Control Ducting (ECD) for military and commercial jets. (polymer construction supporting growth phase of product lines)

Northrop Grumman Corp. produced laser-sintered ducting in two pieces as compared to the old design that contained nine aluminum pieces that were welded together. (moving AM into production systems)

The surface finish of metal parts produced in AM systems is often relatively poor compared to plastic parts from AM systems. As a result, a considerable amount of time and money can be required to post-process parts using a fixture and CNC machining. Parts with any freeform surfaces can be difficult to fixture during machining setup. And parts with internal surfaces can be very difficult or impossible to finish. “At the moment there is a gap between the AM technologies and the finishing technologies,” said Dr. Harrysson, North Carolina State University. He believes the total production process, including post-processing, needs to be perfected to fabricate metal components at an economical level and at a truly rapid rate.

Best in Class (Switzerland) has developed a finishing technology for metal AM parts. Their proprietary Micro Machining Process produces impressive, high-quality surface finishes for metal parts.

Risk:

On Demand Manufacturing (ODM), a Boeing spin-off company has produced an impressive number of ECD parts for military aircraft. By mid-2010, the company had used Laser Sintering to manufacture more than 20,000 flying parts, mostly air ducts—and all without a single failure!

Industry standards have been lacking for years in the additive manufacturing industry. In 2009, the STM International Committee F42 on Additive Manufacturing Technologies was formed. The purpose of this committee was to develop industry standards for terminology, testing, materials, processes, and design, which includes file formats. The first industry standard from this group—a terminology standard—was finally published in Q4 2009.

7. Costs:

Capital costs for metal-AM manufacturing will be upwards to $1 million and may well be depreciated over as little as a 5 – 7 year period. To acquire these assets would necessitate reallocation of Capital budgets towards the purchase of this technology with additional funds to support the development costs of a phase-in for a working production system to provide a stream of parts.

Metal powders, depending on alloy requirements range from $100/kg to over $800/kg requiring a very precise view of the application and inherent trade-offs being made with traditional manufacturing, before proceeding down this road.

A notional budget to implement this technology in Manitoba would be then $2 million - $1M for technology acquisition and $1M for technology development. A 2 - 3 year development period would be necessary. A polymer AM developmental system would cost roughly the same amount but would likely find more applications in Manitoba.

8. Collaborators and Development/Implementation Strategy:

Collaboration may be possible with Boeing on the polymer side and with Standard Aero on the metal side. Other collaborations with international organizations, identified earlier may be possible.

International collaborations with Rolls Royce may be possible, given that they already have a large role in Manitoba.

Domestic collaboration with the Concordia Hip and Knee Institute is of interest as they are interested in developing new knee and hip joints using metal-AM technology. Additionally the U of Manitoba - The Manitoba Institute for Materials has considerable laboratory and human resources which are capable of supporting development work. The ITC is also interested in building and supporting this technology in Manitoba and as such see themselves as early state development partners.

A strategy for development of metal-AM would follow along the lines of 1) build research consortium, 2) identify key stakeholders, 3) build program of support and sustainment 4) establish program of development 5) produce technologies as devised.

---

9. Literature References:

Australian TRM-Additive Manufacturing:
http://3dprintingexpo.org/wp-content/uploads/Additive-Manufacturing-Technology-Roadmap-CSIRO-2011.pdf last consulted 2013.06.25

Wohlers Report (2013), Additive Manufacturing Going Mainstream
http://www.sme.org/uploadedFiles/Publications/ME_Magazine/2013/June_2013/June%202013%20f1%20Additive.pdf last consulted 2013.06.25

Wohler Blog (2013)
http://wohlersassociates.com/blog/2013/05/losing-another-industry/ last consulted 2013.06.18

Plastics & Rubber Weekly (quoted by CISTI)
http://www.prw.com/subscriber/headlines2.html?cat=1&id=3056&q=china last accessed 2013.07.02

Allen, J. (2006) An Investigation into the Comparative Costs of Additive Manufacture vs. Machine from Solid for Aero Engine Parts. In C*ost Effective Manufacture via Net-Shape Processing* (pp. 17-1 – 17-10). Meeting Proceedings RTO-MP-AVT-139, Paper 17. Neuilly-sur-Seine, France: RTO. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA521730 [Last consulted: 2012.06.17]

Anderson, E. Additive Manufacturing in China: Aviation and Aerospace Applications (Part 2). SITC *Bulletin Analysis*, May 2013. http://igcc.ucsd.edu/assets/001/504640.pdf

Freedman, D.H. Layer by Layer : With 3-D printing, manufacturers can make existing products more efficiently—and create ones that weren't possible before*. MIT Technology Review*, December 19, 2011.
http://www.technologyreview.com/featuredstory/426391/layer-by-layer/ [Last consulted: 2013.06.17]

Gu, D. D. et al. Laser additive manufacturing of metallic components: materials, processes and mechanisms. *International Materials Reviews*, v. 57, no. 3, May 2012, p. 133-164.

Maxey, K. U.S. Losing its Edge in Additive Manufacturing? Posted on May 15, 2013
http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/5716/US-Losing-its-Edge-in-Additive-Manufacturing.aspx [Last consulted: 2013.06.18]

Vayre, B. et al. Metallic additive manufacturing: state-of-the-art review and prospects. *Mechanics & Industry*, v. 13, no. 2, p. 89-96.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Additive Manufacturing*

---

10. Subject Matter Contacts:

Dr. Olanrewaju Ojo: Professor, P.Eng, University of Manitoba,
Email: ojo@cc.umanitoba.ca

Dr Mahmoud H Attia, Manager, National Research Council Canada
Material Removal, 5145 Decelles Avenue,
Université de Montréal Campus Montréal, Quebec H3T 2B2,
Telephone: 514-283-9002,
Email: mahmoud.attia@nrc-cnrc.gc.ca

11. Contacts

Dale Kellington,
Business Development/Project Manager
Industrial Technology Centre,
Phone: (204) 480-0340
Email: dkellington@itc.mb.ca

Bill Noakes,
Acting Chair MMC,
Red River College
Phone: (204) 632-2169
Email: bnoakes@rrc.ca

Kim B Olson,
Senior Vice President,
StandardAero
Phone: (204) 318-7820
Email: Kim.Olson@StandardAero.com

Loren Henrickson,
Engineering Manager
Boeing Winnipeg Operations
Phone: (204) 831-2856
Email: loren.hendrickson@boeing.com,

Martin J. Petrak, M.Sc., P.Eng., President, Orthopaedic Innovation Centre
Director of Research Operations, Concordia Joint Replacement Group
Concordia Hip and Knee Institute, Suite 310 - 1155 Concordia Ave,
Winnipeg, MB R2K 2M9
Phone: (204) 926-1290,
Email: mpetrak@orthoinno.com

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Automated Scanning*

---

1. Description:

Two automated scanning technologies are of interest to this report -Optical and Ultrasonic scanner technologies. The automated scanning technology industry seems largely oriented to composite manufacture, however MRO's in Gas Turbine Engine facilities would also interested in match-fit solutions for parts replacement.

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. Challenges here are that parts inspection process is limited to parts ranging from 0.5 to 3 meters in size, however parts throughput is satisfactory with inspection in mass production systems of up to a few hundreds parts/day.

The 3D inspection process uses scan data that has been set to a point cloud. The part's reference data file (normally in CAD format) is then selected and the part's tolerance envelope specified. Then the point cloud data is imported from the scan, allowing the user to compare the reference data to the scanned information.

With the increase in the use of composite materials in the aerospace industry a need for new NDT techniques that can rapidly scan large structures and provide quantitative data on the material integrity has arisen. **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.

The problem often with UT is that the most common automated ultrasound testing machines employ immersion tanks filled with water as the medium through which the sound waves travel. As parts requiring this level of inspection have become more complex, the immersion tanks have become impractical. Technicians are often required to scan complex parts by hand; this is a slow and labour-intensive process that results in overlapping scans, which can lead to inaccurate or inconsistent test results.

The basic UT technique has been upgraded to Automated Ultrasonic Scanning Systems (AUSS) which offers value for high performance composite inspection in fabrication facilities that require rapid throughput and sophisticated motion control, data acquisition and analysis capabilities. The Boeing Company has filed several related patents which use these principles and also sells this technology in versions up to 13 axis robots. Its current Mobile Automated Scanner System is capable of has scan speeds of 400 sq. ft./hour and incorporates ultrasonic pulse echo, ultrasonic resonance and eddy current scanning capabilities within this one system. Boeing's interests in this technology is in finding inclusions in their composite products.

The challenge in Automated Scanning seems to be found with large part systems.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Automated Scanning*

---

2. Impact on Economic Development for Manitoba:

This is an enabling or supporting technology for Manitoba, from which many other events and opportunities can flow. As seen later in this presentation, this is a mature technology (in some instances) with a low cost of entry. Other larger systems – for composites for instance, are still in development and it will be some time before these 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 to the future of Manitoba's aerospace industry.

3. Technology Performance Goals:

Modelling for Aerodynamics and Stress Analysis (FEA, CFD)

- 3D scanning of mock-ups/models is used in preliminary air flow analysis for aerospace components, to bring into CFD models for further processing and evaluation
- Use for iterations, modifications and scale-ups (1:1) of 3D data files through CAD applications
- 3D scanning of original models for finite element analysis (FEA), to significantly streamline the aircraft manufacturing development cycle
- Introduce these elements in to Manitoba's aerospace capabilities within 2 years

OEM and Legacy Part Reengineering

- 3D scanning of old, broken or damaged parts
- Transfer of 3D files into CAD applications for redesign, simulation or remanufacturing
- Introduce these elements in to Manitoba's aerospace capabilities, in as short a timeline as possible (<1 year)

Reverse Engineering

- Reverse engineering of gas turbines, engine bays, and cockpits
- Of most use to older aerospace designs without 3D models
- Used for installation purposes and training: instead of using unreliable 2D models

---

- A cost reduction measure: supporting new suppliers with their bid preparation by providing a background data set; planning for the fitting of new controls systems; assists in redesigns of current technologies
- Used in training and planning for re-motoring - installation of new GT engines into an existing jet aircraft
- Used in cockpit scanning for redesign, simulation, ergonomic analysis and avionics retrofit
- Introduce these elements in to Manitoba's aerospace capabilities within 2 years

Tooling Adjustment

- 3D scanning is used to collect and track modifications made to prototypes, tools, and molds
- Introduce these elements in to Manitoba's aerospace capabilities, in as short a timeline as possible (<1 year)

Design & engineering of aircraft components

- Styling and design of interior aircraft components
- Design of tooling and jigs for blades, tube bending and assemblies
- Mechanism designs and kinematics analyses
- Design of pneumatic and hydraulic systems
- Data transfer : 2D drawings converted to 3D models
- Geometric dimensioning and tolerancing (GD&T)
- Introduce these elements in to Manitoba's aerospace capabilities, in as short a timeline as possible (<1 year)

A general limitation of automated scanning is that it can only scan stationary objects.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Automated Scanning*

---

4. Importance and Breadth of Application:

A mapping of this technology indicates that within 1 to 2 years modest progress can be accomplished in this area.

This technology is critical to the OEM, MRO community, and other aerospace SME's in Manitoba. There are various versions of this technology which are appropriate to each firm so the same suites are not needed in each installation.

The key likely outcome from not implementing this technology is a lagging aerospace technology suite and lost opportunities. These losses and declines are difficult to measure but benchmarking exercises would perhaps highlight these issues in a better way.

5. Alternatives:

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.

The differences in both scanning technologies are that manual systems are the only alternatives at this time. This results in slow, error prone scans which are costly to complete.

6. Availability, Maturity and Risk:

Availability:

3 D Digital Corp, USA http://www.3ddigitalcorp.com/applications/aerospace

ShapeGrabber, Ottawa. http://www.shapegrabber.com

3D3 Solutions, Burnaby, Canada http://www.3d3solutions.com/products/3d-scanner/

Creaform, Quebec: http://www.creaform3d.com/en/metrology-solutions/robot-mounted-optical-cmm-scanners-metrascan-r

Hexagon Metrology, USA: http://www.cognitens.com/Cognitens-WLS400M_628.htm

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Automated Scanning*

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. A 3D scanner saves hours or days of inspection/measurement tasks and results in better performing replacement parts that reduce manufacturing errors and their associated costs.

Scanning can handle complex shapes and laser scanners easily scan the complex surface dimensions of parts and tools that would otherwise be too time-consuming, costly or simply impossible to measure by hand. Curves and multiple features are not a problem!

The development of new, large area UT /AUSS technology is still underway and are 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.

7. Costs:

Creaform Metrascan 70-R Robot-mounted optical CMM 3D scanner ($250k) scans 36000 measures/sec with a part size up to 3 meters.

This would indicate that automated dimensional optical scanning technologies are well within the grasp of Manitoba's aerospace firms to invest, within a very short timeframe. 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.

8. Collaborators and Development / Implementation Strategy:

The collaborators on this technology would most likely be the Industrial Technology Centre (technology application development and service) and Red River College (through one of their four advanced aerospace technology development centres: such as Stevenson Aviation, Centre for Non-Destructive Inspection (CNDI), the Centre for Aerospace Technology and Training (CATT) or the Aerospace and Manufacturing Technology Access Centre).

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.

The role of the ITC as a collaborator and early-stage development partner should also be considered, in view of their ability for rapid response and flexibility.

9. Literature and other References:

- GOM manufactures ATOS ScanBox, a plug-and-play measuring cell for fully automated 3D digitizing and inspection. (http://www.gom.com/metrology-systems/system-overview/atos-scanbox.html)
- Adam Marciniec, Grzegorz Budzik, Tomasz Dziubek, 2011, Automated Measurement Of Bevel Gears Of The Aircraft Gearbox Using GOM, Journal of KONES Powertrain and Transport, Vol. 18, No. 4, (http://ilot.edu.pl/kones/2011/4_2011/2011_marciniec_budzik_dziubek_automated_measurement.pdf)
- Boeing Patent: Crawling automated scanner for non-destructive inspection of aerospace structural elements, US 8347746 B2
- Son, S., Park, H., & Lee, K. H. (2002). Automated laser scanning system for reverse engineering and inspection. International Journal of Machine Tools and Manufacture, 42(8), 889-897.
- Freemantle, R. J., Hankinson, N., & Brotherhood, C. J. (2005). Rapid phased array ultrasonic imaging of large area composite aerospace structures. Insight-Non-Destructive Testing and Condition Monitoring, 47(3), 129-132.
- Maurer, A., Deodorico, W., Huber, R., & Laffont, T. (2012) Latest Aerospace Composite Testing Solutions using Industrial Robots, 18th World Conference on Nondestructive Testing, Journal of Nondestructive Evaluation 31(1)
- Sicard, R. (2011) Inspection of Complex Composite Aerospace Structures Using Automated 3D Ultrasonic Scanning, Smart Materials, Structures & NDT in Aerospace, NDT In Canada 2011 Conference, Montreal, Canada

10. Contacts:

Dale Kellington: Industrial Technology Centre, Business Development/Project Manager,dkellington@itc.mb.ca, (204) 480-0340

Fred Doern: Red River College, Senior Research Chair, fdoern@rrc.ca, (204) 632-3770

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*High Speed Machining*

1. Description:

High speed machining typically refers to making light milling passes at high spindle speeds and feed rates to achieve an overall high metal removal rate. This practice can be effective for machining intricate core and cavity geometries in mold machining, and for quickly machining large, complex aircraft structural components out of solid blocks of aluminum.

Instead of creating large, thin-walled aircraft structures through assembly processes, high speed machining makes it practical to mill comparable structures in one piece from solid aluminum. This eliminates the need for assembly thereby reducing costs and lead times. In addition, replacing an assembly with a solid structure can improve the aircraft performance and maintenance systems, making it more fuel efficient and easier to service.

Some HSM workpieces require five-axis machining capability in order to be produced at all. These include more complex contoured parts such as mold cavities, blisks (bladed-disk parts), impellers, and other turbine-type parts. In these cases the tool orientation must be controlled in order to reach the surface to be machined.

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.

The definition of high-speed machining (HSM) means using cutting speeds that are significantly higher than those used in conventional machining operations. The term high speed is therefore relative. As a general guide, an approximate range of cutting speeds may be defined as follows:

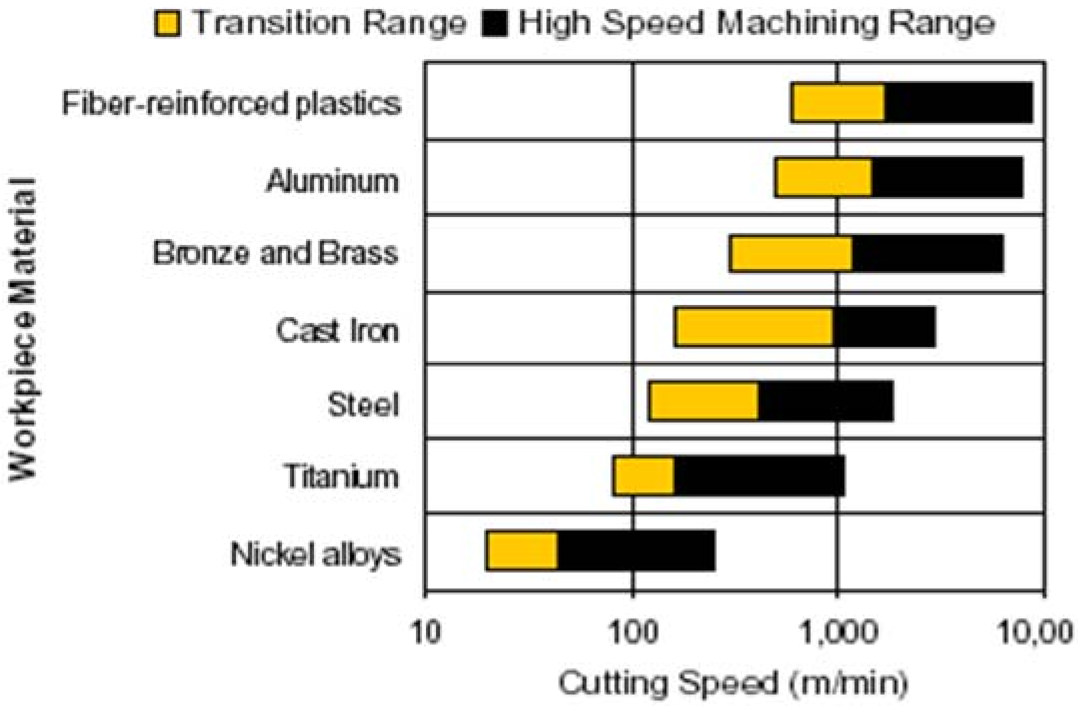
High speed: 600-1,800 m/min,

Very high speed: 1,800-18,000 m/min,

Ultra high speed: >18,000 m/min.

One popular HSM definition is by the DN ratio. Here the bearing bore diameter (mm) is multiplied by the maximum spindle speed (rev/min). For high-speed machining, the typical DN ratio is between 500,000 and 1,000,000. Other HSM definitions emphasize higher production rates and shorter lead times. In these cases, important noncutting factors come into play, such as high rapid traverse speeds and quick automatic tool changes ("chip-to-chip" times of 7 seconds or less).

Figure 1 shows the range of operation for HSM for various materials.



Another HSM definition is based on the ratio of horsepower to maximum spindle speed, or hp/rpm ratio. Conventional machine tools usually have a higher hp/rpm ratio than machines equipped for high-speed machining. By this metric, the dividing line between conventional machining and HSM is around 0.005 hp/rpm. Thus, high-speed machining includes 50 hp spindles capable of 10,000 rpm (0.005 hp/rpm) and 15 hp spindles that can relate at 30,000 rpm (0.0005 hp/rpm).

High-speed machining often means dry machining. The mechanics of the high-speed cut can convey some heat away, thereby supporting this idea. A consistent high temperature may be better for tool management and maintenance purposes than the widely varying temperature that coolant can bring about. While coolant does have a role at times, it is useful where lubrication is necessary to protect either the surface finish or the tool. As a consequence HSM is likely to be touted as a “Green” system by virtue of performing the cutting operations “dry”.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*High Speed Machining*

---

2. Impact on Economic Development for Manitoba

This technology has been in Manitoba for some time. 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.

3. Technology Performance Goals:

The key qualitative performance objectives for this technology are:

- Consistency of operations
- Evaluate and manage the resonant frequency of the machine.
- Establish true cutting speeds
- Maximize material removal rates
- Produce a high quality and consistent surface finish
- Manage tool and machining costs
- Selection of appropriate cutting tools under varying conditions,
- Manage the power of the machine vs. stiffness of tools, tool holders and the work-holding devices
- Use of probes to determine frequency of part (chatter) and latent resonant frequency of the HS Machine system, thereby allowing compensation for these events in the machine program
- High thermal stability and rigidity of the spindle
- Air blast/coolant provided through spindle, significantly reducing liquid coolants (i.e. flood cooling)
- Advanced look ahead function in the CNC

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*High Speed Machining*

The quantitative performance objectives for this technology are:

- Spindle speed range <=40000 rpm
- Spindle power >22 KW
- Programmable feed rate 40-60 m/min
- Rapid travels <90 m/min
- Block processing speed 1-20 ms

4. Importance and Breadth of Application:

This technology needs to be implemented in Manitoba in a more robust way within the next 5 years. Therefore LE's would be required to take this technology on, or at least subcontract on a committed basis with Manitoba's sole SME with this technology.

HSM lends itself as an MRO technology and as such it will support several aerospace OEM requirements, were the work to be available in Manitoba.

5. Alternatives:

The alternatives to this technology are conventional CNC and part assembly processes, currently being practised in the aerospace industry.

6. Availability, Maturity and Risk:

Availability:

Three sources of high speed machining centres were found:

- **FANUC Corporation**, Japan. http://www.fanuc.co.jp/en/product/cnc/index.html
- **Mitsubishi Electric Corporation**, Japan. http://wwwf8.mitsubishielectric.co.jp/cnc/english/product/cnc_m70v/index.html
- **Hurco**, USA. http://www.hurco.com/en-us/machine-tools/machining-centers/vertical/Pages/High-Speed.aspx

Maturity:

Much research and development work has been carried out on high-speed machining (turning, as well as milling, boring, and drilling) of aluminum alloys, titanium alloys, steels, and super alloys.

Considerable data have been collected regarding the effect of high speeds on the type of chips produced, cutting forces, temperatures generated, tool wear, surface finish, and the economics of the HSM process.

These studies have indicated that high-speed machining can be economical for certain applications, and consequently, it is now implemented for machining aircraft turbine components and automotive engines 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:

Even though HSM has been known for a long time, research is still being conducted for further improvement of quality and the minimization of costs.

Limitations here are the need for expensive and special machine tools with advanced spindle and controllers, excessive tool wear, good work and process planning are necessary for successful operation of an HSM centre.

Indicated earlier, it can be difficult to find and recruit advanced machinists to support these systems.

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.

7. 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 over 2 – 3 years on the development of this technology’s opportunities and capabilities.

8. Collaborators and Development / Implementation Strategy:

Collaboration is possible with the University of BC which has an NSERC-P&W Industrial Research Chair with interests in modeling and analysis of machining processes. That researcher is highly aware of and capable of working in HSM.

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.

A short term strategy here would be to engage Dr. Altinas and to have Manitoba Aerospace members join in on the annual CIRP - International Conference on High Performance Cutting. Other alliances are possible here through P&WC which is a partner in the GLACIER Facility in Thompson. The role of NRC (see Contacts, below) should also be given some thought as the aerospace industry has a very high opinion of this resource.

9. Literature References:

- Altintas, Yusuf, 2007. High Performance Cutting. “The International Journal of Advanced Manufacturing Technology,” Vol 33, No 3-4, Springer-Verlag, p 367-367, doi=10.1007/s00170-006-0822-x.

- Steve Krar & Arthur Gill, (eds), 2003. “Exploring Advanced Manufacturing Technologies,” ISBN 0-8311-3150-0, Industrial Press Incorporated. Chapter 2 (available at the Industrial Technology Centre Library, Wpg.)

10. Subject Matter References:

Dr. Mahmoud H Attia, Manager, National Research Council Canada
Material Removal, 5145 Decelles Avenue, Université de Montréal Campus
Montréal, Quebec H3T 2B2, Telephone: 514-283-9002,
Email: mahmoud.attia@nrc-cnrc.gc.ca

Dr. Olanrewaju Ojo: Professor, P.Eng, University of Manitoba,
Room E2-327 Engineering Information and Technology Complex,
75A Chancellors Circle
Phone: (204) 474 7972
Email: ojo@cc.umanitoba.ca

Dr. Yusuf Altintas, Professor,
NSERC –P&WC Industrial Research Chair
Coordinator of Mechatronics Option at UBC
Phone: (604) 822-5622
Email: altintas@mech.ubc.ca

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*High Speed Machining*

---

10. Contacts:

Chris Godin
Equipment Engineering
Boeing Canada Operations
(204) 230-0591
Christian.Godin@boeing.com

Elliott Foster
Team Leader Quality Control
Magellan Aerospace, Winnipeg
(204) 775-8331 x3023
elliott.foster@magellan.aero

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Machining Strategies*

1. Description:

This Thrust Report captures several of the machining related topics which were raised in TAWG#1 meetings, and which are not particularly complete as stand-alone Thrust Reports. However, there was enough information and interest developed here such that these ideas were combined into one topic under the general topic of “Machining Strategies.” This Thrust Report for the most part will avoid discussion on High Speed Machining, as that topic is covered under its own cover. The organization of this section will be to identify four topics, followed by a general discussion of each topic. Green machining is also indirectly referenced in this section. Some of the techniques presented in the following sections reduce waste and resources and as a result have been considered as “Green Machining” methods.

The four principal topics covered in this section are:

Cooling Strategies in Machining
High performance cutting of difficult-to-cut metals
Surface enhancement of metallic materials
CAM Toolpath Strategies

1.1 COOLING STRATEGIES IN MACHINING:

Thermal and mechanical loading demands create fundamental challenges when difficult-to-cut materials are machined. Machining difficult-to-cut materials produces excessive tool wear in the secondary deformation zone. Recent research by various institutes and researchers has determined the following cooling strategies or techniques as viable strategies to reduce tool wear.. The strategy and technique used in each particular case depends on the material and parameters surrounding the machining process:

• Flood cooling
Flood cooling is best described as an uninterrupted flow of an abundant quantity of coolant which also removes chips via a flushing action. With flood cooling, thermal shock on milling tools are minimized and the ignition of chips is eliminated. This method is often a benchmark for experiments due to its extensive use in standard machining application. Challenges arising here deal with the volatility of coolants and related operator safety.

• Forced air cooling (dry cutting)
Dry cutting involves reliance on the natural environment for cooling such as radiation and air convection. Specifically there is no use of cooling fluids or lubrication directly onto the cutting zone in this case. Included in this category of cooling is the consideration for vaporization of cryogenic coolants, as well as inclusion of thermo-electric cooling systems. Dry cutting is often supplemented by an external supply of compressed air as a common practice. The main reason for using dry machining is the benefit to the environment and to the operator’s workplace environment.

- **Minimal quantity lubrication (MQL)**

Minimum quantity lubrication refers to the use of cutting fluids of only a minute amount – typically of a flow rate of 50 to 500 ml/hour, which is about three to four orders-of-magnitude lower than the amount of lubricant commonly used in flood cooling conditions. Sometimes this is referred to as “near dry lubrication” or “micro lubrication,” This approach has been suggested for over a decade ago as a means of addressing the issues of environmental intrusiveness and occupational hazards associated with the airborne cutting fluid particles on factory shop floors. The minimization of cutting fluid also leads to economic benefits by way of saving lubricant costs and workpiece/tool/machine cleaning cycle time.

- **High pressure through spindle cooling (HPTSC)**

High pressure cooling demonstrates the possibility of improvements in tool life when machining Ti-6Al-4V metals with cemented carbide (coated and uncoated) tools at higher cutting speeds.

In general, techniques which avoid flood cooling are considered to be “green” techniques.

1.1.1 SPECIALISED COOLING TECHNIQUES IN INDUSTRY:

Two specialized cooling techniques are discussed which have application in the aerospace industry

- **Cryogenic Through Spindle, Through Tool Cooling (MQL)**

FIVES machine tool and systems use an internally developed through-spindle liquid nitrogen cooling system in their machine systems. FIVES technology combines liquid nitrogen cooling with through-spindle cooling for the machining of difficult-to-machine materials. One such liquid-nitrogen system provides a 60% speed increase in the milling of compacted graphite iron with carbide and a four times speed increase using Polycrystalline Diamond tooling. Full commercialization of this technology is forthcoming.

The benefits of cryogenic machining are not only economic or operational. In terms of environmental friendliness, there is no mist collection, filtration, wet chips, contaminated workpieces or disposal cost and energy consumption is reduced for a system which does not require pumps, fans and drives for handling coolant.

The production of titanium alloy components for the F-35 Lightning II fighter jet, was accomplished by using through-spindle cooling with liquid nitrogen. A 10-times improvement in cutting tool life was observed in this project by Lockheed Martin.

- **Through-Spindle Cooling with Split Tool Inserts**

Kennametal’s split tool technology also uses through-tool cooling, with the exception being the coolant type. With this method a high pressure coolant flows through the cutter body and ejects from the split tool inserts. This technology is also available for milling and turning operations. A cost reduction over conventional high pressure cooling methods is claimed, due to the insert that directs the coolant precisely where it is needed.

The Kennametal Company pioneered through-spindle cooling with split tools inserts in 2010. This technology came as a result of Boeing’s pre 2010 market research that indicated that there would not be enough titanium alloy machining capacity in the world during the peak requirement period for the new 787’s. Many aerospace parts in this segment have about 80 to 90 percent of the materials machined away.

1.2 HIGH PERFORMANCE CUTTING OF DIFFICULT TO CUT METALS (i.e. TITANIUM & NICKLE ALLOYS)

Future engine components present a more complex geometry, and components such as “Blisks” which are made of advanced materials. Super alloys, such as nickel-based alloys, are frequently employed in aerospace industry for components which are subjected to high dynamic stresses at high working temperatures, (e.g. blades, discs, and housing components of jet engines). Super alloys usually have high temperature strength and high toughness - properties which also make them difficult to machine at room temperature resulting in excessive tool wear and a poor surface finish. Consequently, the material removal rates here are low and machining costs are high. Under these conditions the future for the supporting production technologies for these materials will need to deal with the demand for increasing productivity and for the machining of highly heat-resistant-nickel-based- and titanium-based alloys, which also have elevated mechanical strength.

Emerging high performance machining processes such as laser assisted machining (LAM), microstructure evolution, and vibration-assisted machining (VAM) will need to be modeled and simulated before directing these materials to a machining centre. Supporting these machining processes are certain new developments in Finite Element Method (FEM) techniques.

- **Laser-Assisted Machining (LAM)**

LAM offers an opportunity to machine certain difficult-to-cut materials more efficiently and economically. In the LAM process, the workpiece material is locally heated by an intense laser beam, prior to material removal. As the temperature exceeds a certain critical level, the yield strength of the material is reduced. Experimental work has showed that the cutting force decreases by nearly 49% in the LAM of Inconel 718 and by 30% for Ti-6Al-4V, compared to conventional machining. In addition, when using the LAM technology, the tool wear was reduced and the surface quality was improved. Although the feasibility of the LAM process has only been demonstrated experimentally, modeling of the LAM process is necessary to understand properly the physical mechanisms in the process.

• Vibration-Assisted Machining (VAM)
VAM, especially ultrasonic vibration cutting (UVC), is an advanced method developed for machining tough and brittle materials, such as super alloys, metal matrix composites - MMC's, ceramics, and glass. VAM combines a machining process with a small-amplitude/high-frequency tool vibration to improve the machining process. The tool tip is driven in either a small linear motion (1D-VAM) or an elliptical motion (2D-AM). This technique has been applied to a number of machining processes, such as turning, drilling, and grinding. Vibration assisted drilling (VAD) is an example of the 1D-VAM process. Proper combinations of cutting velocity, tool vibration amplitude, and frequency can reduce machining forces up to several times, improve surface finishes up to 50%, as well as prolong tool life and suppress burr formation, when compared to conventional machining. Although VAM has been used in industry for many years, the understanding of the VAM process is still limited. Considerable work still needs to be carried out to develop predictive models in order to optimize the VAM process.

• Micro Structure Evolution
In the metals processing industry typically a metal is continuously cast and then subsequently hot rolled. Many different microstructure transformations come into action in this complex materials processing line. The influence of processes such as solidification, diffusion, phase transformation, deformation, recrystallization and grain growth need to be modeled for high-performance nickel and titanium alloys.

• "**Greening" of Aerospace Materials**
The replacement of chrome in aerospace is a continuing process. This material performs very well but is both expensive and an environmental/workplace challenge to manage. Typical replacements for chrome are alloys which are a challenge to machine due to their hardness.

Surface treatments such as High Velocity Oxy-Fuel coating sprays (HVOF) often also replace chrome. These materials, due to their hardness, present unique cutting and grinding challenges in aerospace.

1.3 SURFACE ENHANCEMENT OF METALLIC MATERIALS:

A layer of residual compression which is developed at the surface through local plastic deformation helps to improve fatigue life for many components. Peening is a well-known conditioning process that induces subsurface compressive residual stress in metals while improving fatigue and stress corrosion resistance.

• Shot Peening
Shot peening is a process in which small steel, glass, or ceramic spheres are repeatedly impinged onto a metal surface. This is an inexpensive and popular technology, but the plastic deformation of 20 to 40% imparted by the impacts can be harmful. This plastic deformation can cause damage to the microstructure, severely limiting the ductility and durability of the material near the surface.

Excessive plastic deformation has also been shown to promote excessive relaxation of the advantageous compressive residual stresses at elevated temperatures. Lower plastic deformation produced by gravity peening, laser shock peening, and low-plasticity burnishing provides more stable compression features.

- **Gravity Peening**

This approach utilizes the same mechanism as shot peening, but fewer impacts by larger shot produce less cold work and an improved surface finish. Compressive residual stresses comparable to shot peening are achieved with only 5 to 10% of the cold work.

- **Laser Peening**

Peening with laser pulses imparts a deeper layer of compressive residual stress with more precise control over processing parameters.

Laser peening is seen to improve performance while reducing costs for aircraft in both propulsion and structures thereby saving airlines hundreds of millions of dollars in maintenance and replacement costs. Laser peening has proven viable for blades for electric-generation steam turbines, for critical parts and systems on military and civilian aircraft, and for gears and engine components of high performance racing cars. This technology is also supports the manufacture of higher-lift wings for very large commercial aircraft, thereby providing greater fuel efficiency.

The surface profile of the base material and the laser peened specimens do not differ significantly. This is in contrast to shot peening which results in significant surface roughness.

Rolls-Royce has introduced a new method called Laser Shock Peening (LSP). In LSP, a high-power laser pulse irradiates the surface of the material, producing plasma that generates shock waves. These shock waves induce compressive stresses on and beneath the surface of the metal. This method has the advantage of improving the depth of compressive residual stress fields (up to several millimeters) in the material while maintaining a smooth surface finish.

- **Low Plasticity Burnishing**

LPB has been developed as an improved method for surface enhancement. It is a variation of roller burnishing, which has been successful in refining surface finishing. This concept was adopted and then optimized as a means of producing a layer of compressive stress of high magnitude and depth, with minimal plastic deformation. In LPB, a single pass of a smooth, free rolling spherical ball under a normal force deforms the surface of the material in tension, creating a compressive layer of residual stress. The ball is supported in a fluid with sufficient pressure to keep the ball from touching the surface of the retaining spherical socket. The ball is in mechanical contact only with the surface of the material being burnished, and is free to roll on the surface. This apparatus is designed to be mounted in conventional CNC lathes and vertical mills.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Machining Strategies*

1.4 TOOLPATH OPTIMIZATION:

Toolpath optimization (part of the CAM process) provides both green machining management and in general a machining strategy for complex parts. This topic is for the most part software enabled and can employ many cutting and other strategies. Adaptive machining plays in well with this theme, so in this way the two ideas are related. A key understanding here is that the suite of technologies used here are high skill areas which cross over between tool and die makers and software technicians.

Toolpath optimization requires modest human intervention as generally complex parts will not present an obvious cutting program. CNC and CAM systems still need someone with experience with the relevant technology and knowledge of the projects at hand to deploy the system properly. Toolpath optimization is important because the machining process will relieve stress in the material as metal is removed, but this results in placing new stresses and creating distortions in the remaining stock, if the cutting plan is not carefully thought through.

2. Impact on Economic Development for Manitoba

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.

A recommendation is also made at this point to support the development of a new machinist related occupational category, that of a Software Capable - Tool and Die Maker, perhaps following the Red Seal –Tool and Die Maker exam.

Manitoba's aerospace industry through the MDC would be able to support developments in industry relating to forthcoming environmental regulations, changing requirements from customers and addressing competitiveness issues.

3. Technology Performance Goals

Cooling Strategies

- Conduct forced air cooling trials within 1 year
- Conduct advanced cooling techniques within 2 years.

High Performance Cutting of advanced materials and alloys

- Establish a working set of materials used in Manitoba within 1 year
- Produce first-articles within 18 months

- Produce an Advanced Material Strategic Technology Plan for Manitoba, within 24 months
    - Consider 3 cases at the most

Surface Enhancement of Metallic Materials

- Identify a working set of materials which require surface enhancement, in Manitoba within 1 year
- Procure appropriate technologies and produce first-articles within 18 months
- Produce a Surface Enhancement Strategic Technology Plan for Manitoba, within 24 months.

4. Importance and Breadth of Application:

A Machining Development Centre is recommended to be implemented within 2 years and this centre will support the aerospace sector going forward.

The technologies considered in this Thrust Report are of critical concern to the MRO communities and SME’s alike.

Likely outcomes if these technologies are not available to, or are not implemented by the Manitoba aerospace industry are that the industry will lag, will not grow and will be less competitive globally.

5. Alternatives:

Competing technologies for those mentioned in this report are those which are already used in the baseline business practises in Manitoba.

There are no alternatives to the approach suggested here, other than the null set.

6. Availability, Maturity and Risk:

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.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Machining Strategies*

7. 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.

8. Collaborators and Development / Implementation Strategy:

This is an excellent project for collaboration and in fact will require this facet in order to proceed at any rate.

Collaborators here would be RRC and U of M, along with StandardAero, Magellan and others from industry.

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.

9. References:

Machining Titanium/ High Performance Machining:

1. Krämer, A; Lung, D; Klocke, F. “High performance cutting of aircraft and turbine components.” AIP Conference Proceedings. 4/30/2012, Vol. 1431 Issue 1, p425-432.
2. Lapovok, R; Molotnikov, A; Levin, Y; Bandaranayake, A; Estrin, Y. “Machining of coarse grained and ultra-fine grained titanium.” Journal of Materials Science. Jun2012, Vol. 47 Issue 11, p4589-4594.
3. Sun, J et al. “Effects of coolant supply methods and cutting conditions on tool life in end milling titanium alloy.” Machining Science & Technology. Jul-Sep2006, Vol. 10 Issue 3, p355-370.
4. Huang, Panling et al. “Milling force vibration analysis in high-speed-milling titanium alloy using variable pitch angle milling.” International Journal of Advanced Manufacturing Technology. Jan2012, Vol. 58 Issue 1-4, p153-160.
5. Zhang, S et al. “Investigation on diffusion wear during high-speed machining Ti-6Al-4V alloy with straight tungsten carbide tools.” International Journal of Advanced Manufacturing Technology. Dec2009, Vol. 44 Issue 1/2, p17-25.
6. Yang, S et al. “Finite element modeling of machining of hydrogenated Ti-6Al-4V alloy.” International Journal of Advanced Manufacturing Technology. Mar2012, Vol. 59 Issue 1-4, p253-261.
7. Li, Anhai et al. “Progressive tool failure in high-speed dry milling of Ti-6Al-4V alloy with coated carbide tools.” International Journal of Advanced Manufacturing Technology. Jan2012, Vol. 58 Issue 5-8, p465-478.

8. Fernández-Abia, A et al. “Effect of very high cutting speeds on shearing, cutting forces and roughness in dry turning of austenitic stainless steels.” International Journal of Advanced Manufacturing Technology. Nov2011, Vol. 57 Issue 1-4, p61-71.
9. Oosthuizen, Gert et al. “The performance of PCD tools in high-speed milling of Ti6Al4V.” International Journal of Advanced Manufacturing Technology. Feb2011, Vol. 52 Issue 9-12, p929-935.
10. Zhang, S. et al. “Tool wear and cutting forces variation in high-speed end-milling Ti-6Al-4V alloy.” International Journal of Advanced Manufacturing Technology. Apr2010, Vol. 46 Issue 1-4, p69-78.
11. Novakova, Jana et al. “Influence of High Speed Parameters on the Quality of Machined Surface.” World Academy of Science, Engineering & Technology. Aug2009, Vol. 56, p274-277.
12. Kadirgama, K. et al. “Effect of Dry Cutting on Force and Tool Life When Machining Aerospace Material.” World Academy of Science, Engineering & Technology. Dec2010, Vol. 71, p452-456.
13. Shi, Bin; Attia, Helmi. “Current status and future direction in the numerical modeling and simulation of machining processes: a critical literature review.” Machining Science & Technology. Apr-Jun2010, Vol. 14 Issue 2, p149-188.
14. Zain, Azlan Mohd et al. “Simulated annealing to estimate the optimal cutting conditions for minimizing surface roughness in end milling Ti-6Al-4V.” Machining Science & Technology. Jan-Mar2010, Vol. 14 Issue 1, p43-62.

Cooling Strategies:

1. Paul, S. et al. “Environmentally conscious machining and grinding with cryogenic cooling.” Machining Science & Technology. Jan-Mar2006, Vol. 10 Issue 1, p87-131.
2. Zeilmann, Rodrigo et al. “Implications of the reduction of cutting fluid in drilling AISI P20 steel with carbide tools.” International Journal of Advanced Manufacturing Technology. Jan2012, Vol. 58 Issue 5-8, p431-441.
3. 2013 Materials Supplement. http://www.kemblerude.com/pdfs/AMD-Supp002.pdf
4. C. Prins; N.F. Treurnicht; “An overview of advanced cooling techniques for titanium alloy machining in aerospace.” Department of Industrial Engineering, University of Stellenbosch, South Africa http://conferences.sun.ac.za/index.php/saiie/SAIIE25/paper/viewFile/657/247

Surface Enhancement Processes (Peening):

1. Mall, S; Jain, V. K; Fadag, H. A. “Effects of Shot-Peening on Fretting Fatigue Crack Growth Behavior in Ti-6Al-4V.” Strain. Jun2011 Supplement, Vol. 47, pe305-e318.
2. Edwards, Kenneth R; Edwardson, Stuart P; Carey, Chris; Dearden, Geoff; Watkins, Ken G. “Laser micro peen forming without a tamping layer.” International Journal of Advanced Manufacturing Technology. May2010, Vol. 47 Issue 1-4, p191-200.
3. Ding, K; Ye, L. “FEM Simulation of Two Sided Laser Shock Peening of Thin Sections of Ti-6Al-4V Alloy.” Surface Engineering. Apr2003, Vol. 19 Issue 2, p127.

4. Sabelkin, V; Martinez, S.A; Mall, S; Sathish, S; Blodgett, M.P. “Effects of shot-peening intensity on fretting fatigue crack-initiation behaviour of Ti–6Al–4V.” Fatigue & Fracture of Engineering Materials & Structures. Mar2005, Vol. 28 Issue 3, p321-332.
5. Gao, Y.K. “Influence of shot peening on tension–tension fatigue property of two high strength Ti alloys.” Surface Engineering. Aug2006, Vol. 22 Issue 4, p299-303.
6. Gabb, Timothy P; Telesman, J; Kantzos, P; Prevey, Paul S. “Surface Enhancement of metallic materials.” Advanced Materials & Processes. Jan2002, Vol. 160 Issue 1, p69.
7. Hatamleh, Omar; Lyons, Jed; Forman, Royce. “Laser peening and shot peening effects on fatigue life and surface roughness of friction stir welded 7075-T7351 aluminum.” Fatigue & Fracture of Engineering Materials & Structures. Feb2007, Vol. 30 Issue 2, p115-130.
8. Baragetti Guagliano. “Influence of low-intensity shot peening on the fatigue strength of an al/al.” Fatigue & Fracture of Engineering Materials & Structures. Jun98, Vol. 21 Issue 6, p717-726.
9. Hill, Michael R; DeWald, Adrian T; Demma, Anne G; Hackel, Lloyd A; Hao-Lin Chen; Dane, C. Brent; Specht, Robert C; Harris, Fritz B. “Laser peening technology.” Advanced Materials & Processes. Aug2003, Vol. 161 Issue 8, p65.
10. Teresko, John. “Peening With Light: New Laser, New Benefits.” Industry Week/IW. Mar2004, Vol. 253 Issue 3, p20-20.
11. Yu, F; Nagy, P. B. “The Role of Cold Work in Eddy Current Residual Stress Measurements in Shot-Peened Nickel-Base Superalloys.” AIP Conference Proceedings. 2006, Vol. 820 Issue 1, p1402-1409.
12. Lawrence Livermore National Laboratory; University of California, Davis. “Laser shot Peening of Landing Gear Components.” Advanced Materials & Processes. Feb2008, Vol. 166 Issue 2, p55-55.
13. Engineering laboratories,Newcastle University (Newcastle, England). “Sharpening up shot-peening.” Professional Engineering. 1/15/2003, Vol. 16 Issue 1, p53.
14. USF Abrasive Developments. “Peening tackles blade fatigue.” Professional Engineering. 5/21/2003, Vol. 16 Issue 9, p48.
15. Afazov, S. M; Becker, A. A; Hyde, T. H. “Effects of micro-stresses from machining and shot-peening processes on fatigue life.” International Journal of Advanced Manufacturing Technology. Nov2010, Vol. 51 Issue 5-8, p711-722.
16. Greving, Dan; Gorelik, Mike; Kington, Harry. “Manufacturing Related Residual Stresses and Turbine Disk Life Prediction.” AIP Conference Proceedings. 2005, Vol. 760 Issue 1, p1339-1346.
17. Berglund, Johan; Liljengren, Magnus; Rosén, Bengt-Göran. “On finishing of pressing die surfaces using machine hammer peening.” International Journal of Advanced Manufacturing Technology. Jan2011, Vol. 52 Issue 1-4, p115-121.
18. Jianming, Wang; Feihong, Liu; Feng, Yu; Gang, Zhang. “Shot peening simulation based on SPH method.” International Journal of Advanced Manufacturing Technology. Sep2011, Vol. 56 Issue 5-8, p571-578.
19. Chang, S.H; Tang, T. P; Tai, F. C. “Enhancement of thermal cracking and mechanical properties of H13 tool steel by shot peening treatment.” Surface Engineering. Sep2011, Vol. 27 Issue 8, p581-586.

20. Turnbull, A; Pitts, J. J; Lord, J. D. “Residual stress relaxation in shot peened high strength low alloy steel.” Materials Science & Technology. Mar2008, Vol. 24 Issue 3, p327-334.
21. Takahashi, F; Tange, A; Ando, K. “Effect of shot peening on fatigue limit of surface flawed samples.” Fatigue & Fracture of Engineering Materials & Structures. Mar/Apr2008, Vol. 31 Issue 3/4, p242-250.
22. Singh, Lakhwinder; Khan, R. A; Aggarwal, M. L. “Relationship between Damping Factor and Compressive Residual Stress for Shot-Peened Austenitic Stainless Steel.” ISRN Mechanical Engineering. 2011, Special section p1-7.
23. Bloch, Heinz P. “Straightening carbon steel shafts.” Hydrocarbon Processing. Dec2004, Vol. 83 Issue 12, p9-10.
24. Harada, Yasunori; Fukaura, Kenzo. “Influence of shot peening on surface characteristics of high-speed steels.” International Journal of Modern Physics B: Condensed Matter Physics; Statistical Physics; Applied Physics. 12/30/2008, Vol. 22 Issue 31/32, p6094-6099.
25. Gao, Y. K. “Influence of shot peening on fatigue property of Ti-60 high temperature titanium alloy.” Surface Engineering. Dec2007, Vol. 23 Issue 6, p431-433.
26. Jifeng Xu; Koch, William J. “Finite-Element Analysis of the Influence of Edge Geometry on Shot Peening Process.” Journal of Aerospace Engineering. Apr2009, Vol. 22 Issue 2, p153-159.
27. Afazov, S; Nikov, S; Becker, A; Hyde, T. “Manufacturing chain simulation of an aero-engine disc and sensitivity analyses of micro-scale residual stresses.” International Journal of Advanced Manufacturing Technology. Jan2011, Vol. 52 Issue 1-4, p279-290.
28. Valentini, E; Beghini, M; Bertini, L; Santus, C; Benedetti, M. “Procedure to Perform a Validated Incremental Hole Drilling Measurement: Application to Shot Peening Residual Stresses.” Strain. Jun2011 Supplement, Vol. 47, pe605-e618.
29. Sangid, Michael; Stori, James; Ferriera, Placid. “Process characterization of vibrostrengthening and application to fatigue enhancement of aluminum aerospace components-part I. Experimental study of process parameters.” International Journal of Advanced Manufacturing Technology. Mar2011, Vol. 53 Issue 5-8, p545-560.
30. Sangid, Michael; Stori, James; Ferriera, Placid. “Process characterization of vibrostrengthening and application to fatigue enhancement of aluminum aerospace components-part II: Process visualization and modeling.” International Journal of Advanced Manufacturing Technology. Mar2011, Vol. 53 Issue 5-8, p561-575.
31. Camargo, A; Voorwald, H. “Influence of anodization on the fatigue strength of 7050-T7451 aluminium alloy.” Fatigue & Fracture of Engineering Materials & Structures. Nov2007, Vol. 30 Issue 11, p993-1007.
32. Zhang Jian-Bin; Fan Ding; Yu Shu-Rong; Wang Jing-Yi. “Influence of mechanical surface treatments on fatigue strength of commercial purity titanium.” Journal of Materials Science. Aug2003, Vol. 38 Issue 16, p3455-3459.
33. Garcia, D. B; Forman, R; Shindo, D. “Experimental evaluation of fatigue crack initiation from corroded hemispherical notches in aerospace structural materials.” Fatigue & Fracture of Engineering Materials & Structures. Feb2012, Vol. 35 Issue 2, p122-140.

34. Sghaier, R. Ben; Bouraoui, Ch; Fathallah, R; Degallaix, G. “Probabilistic prediction of high cycle fatigue reliability of high strength steel butt-welded joints.” Fatigue & Fracture of Engineering Materials & Structures. Sep2010, Vol. 33 Issue 9, p575-594.
35. Lee, Hyukjae; Sathish, S; Mall, S. “Evolution of residual stress under fretting fatigue.” Journal of Materials Science. Dec2004, Vol. 39 Issue 23, p7089-7092.
36. COLUMBIA Marking Tools Inc. “Part making machine.” Automotive Design & Production. Apr2004, Vol. 116 Issue 4, p21-21.

Conferences:

1. Specialised Cooling Techniques In Industry: http://conferences.sun.ac.za/index.php/saiie/SAIIE25/paper/viewFile/657/247

2. International Conference on Virtual Machining Process Technology

CAM Software References:
http://www.cnccookbook.com/CCCAMToolpaths.htm

The reports referenced here have been provided by the Industrial Technology Centre’s Senior Librarian and are secured by Alfonz Koncan (TAWG#1 – Deputy Chair). These technical reports are available for examination to interested parties.

10. Subject Matter References:

Dr. Mahmoud H Attia, Manager,
National Research Council Canada, Material Removal,
5145 Decelles Avenue, Université de Montréal Campus
Montréal, Quebec H3T 2B2, Telephone: 514-283-9002,
Email: mahmoud.attia@nrc-cnrc.gc.ca

Dr. Yusuf Altintas, Professor,
NSERC –P&WC Industrial Research Chair
Coordinator of Mechatronics Option at UBC
Phone: (604) 822-5622
Email: altintas@mech.ubc.ca

Dr. Olanrewaju Ojo: Professor, P.Eng, University of Manitoba,
Room E2-327 Engineering Information and Technology Complex,
75A Chancellors Circle
Phone: (204) 474 7972
Email: ojo@cc.umanitoba.ca

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Machining Strategies*

---

11. Contacts:

Kim B Olson, Senior Vice President, StandardAero
(204) 318-7820; Kim.Olson@StandardAero.com

Bill Noakes, Acting Chair MMC, Red River College
(204) 632-2169; bnoakes@rrc.ca

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*Nanotechnology*

1. Description:

According to National Nanotechnology Initiative – US, “Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers (i.e. 10^{-9} m), where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.”

At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

This report will focus 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.

Nano-metallics

Nano coatings are generally desirable due to their potential to exhibit lower thermal conductivity and are generally used to provide corrosion resistance, wear damage resistance, thermal barriers, and gas permeation resistance. Several preparation methods for nano-particles are currently used and these include plasma processing, chemical vapour deposition, electro deposition, sol-gel processing and the well tried and true ball mill or grinding approach. Inherent in the processing problem is the resultant management of the human health and safety matters. Considerable focus is found on these matters in certain domains.

Current developments in aerospace nano application areas are physical sensors, actuators, and nanoelectromechanical systems. The aerospace industry can expect to gain much from the field of nanotechnology.

In the electrical field the complementary metal–oxide–semiconductors (CMOS) technology for constructing integrated circuits is considered a valid opportunity for nanotechnology development. However the current approaches with CMOS downscaling (such as lithography, heat dissipation, etc.), does not show an order of magnitude performance improvement as would be expected. The critical issue now is to develop alternative architectures in addition to deploying these novel materials. In contrast, the opportunities for CNTs in sensors – both physical and chemical sensors – are better and near-term.

Nano-sensors can perform at high temperatures as well as providing other physical and chemical sensing capabilities. Such nano-sensors can also be used to perform safety inspections cost effectively, quickly, and more efficiently than the present procedures. Sensitivity of nanosensors is in the ppb range with selectivity accomplished through doping, coating CNTs with polymers, and using multiplexing in post signal processing.

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*Nanotechnology*

Nano-composites
Nanotechnology provides new opportunities for radical changes in composite functionality. Functionalities can be added to the substrate when the orientation of the nanoscale reinforcement is controlled.

Novel ideas for composites include ‘self-healing’ as a way of repairing cracks in the material without human intervention. Plastic components break over time because of mechanical or thermal fatigue. In these cases small cracks become large cracks which lead to catastrophic failure. Self-healing plastics can be embedded in these composites which would contain small capsules that would release a healing agent when a crack first forms. The agent travels to the crack through capillaries similar to blood flow to a wound. Also worth pointing out here is that repairing a crack that has just formed takes less resources than once the crack has progressed for some time.

Nano reinforced composites are seen as an opportunity which would replace existing materials where resultant properties can be superior. Applications of this approach would be where traditionally composites were not a candidate.

CNTs (carbon nano tubes) have been shown to provide desirable electrical properties for polymer matrix composites. In many cases, the current problem is the inability to disperse the nanotubes homogeneously across the host matrix.

Nano technologies are largely in their early stage development having Technology Readiness Levels between 1 and 3.

2. Impact on Economic Development for Manitoba

The future of nanotechnology is somewhat distant which is appropriate to a Thrust Report such as this.

The University of Manitoba established its Nano-Systems Fabrication Laboratory (NSFL) about a decade ago. This open access facility has been used by over 200 users (professors, students, and industry) since its inception. These projects have produced numerous research articles and innovative technologies. User projects have included the U of M T-Sat nano-satellite, micro-sensors (magnetic, gas, food analysis and electric field), nano-solar materials, adaptive antenna technologies, nano-magnetics, nano-electronics, micro-fluidic systems (biological, high performance thermal), spectroscopy technology (electric, optical), detectors for high energy physics, medical devices, and many more. At this rate the NSFL has had a good start working through TRL levels of 1 to 3. The road ahead will focus on the mid-TRL levels of technology development and demonstration.

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.

3. Technology Performance Goals:

- Achieving Complementary metal–oxide–semiconductor (CMOS) cooling and lithography for electrical circuits (i.e. metallics).
- create self-healing/self-evaluation composites
- create nanosensors for structural health monitoring of aircraft
- achieve “special purpose-on the fly” nanotechnologies

4. Importance and Breadth of Application:

There is no particular deadline for these technologies, as best as can be determined at this time. The availability of this technology will lead to new products and processes, which will represent new opportunities in Manitoba.

This technology will be critical to both the Manitoba OEM and MRO community.

Opportunities presented through the acquisition and development of this technology represents a competitive management issue. The use of nanotechnologies will enhance the aerospace sector in Manitoba; the absence of it will disadvantage the sector.

5. Alternatives:

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.

6. Availability, Maturity and Risk:

Availability:

Two sources have been identified as having aerospace capable nano-materials

- **Applied NanoStructured Solutions, LLC** (ANS), a wholly-owned subsidiary of Lockheed Martin Corporation offers Carbon Nanostructures (CNS) which are added to common composite materials and thereby provide a light-weight, low-cost alternative to cumbersome metal mesh lightning strike systems while at the same time enhancing lightning strike protection.
- **Nanotec-USA** offers a paint barrier which offers ice and snow rejection, as well as dirt and water deflecting, thereby reducing maintenance, and increasing operational efficiencies.

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 nanotechnology field is interdisciplinary but at its core are material sciences. Challenges include:

- Novel synthesis techniques
- Characterization of nanoscale properties
- Large scale production of materials
- Application development
- Health 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.

7. 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. These research chairs 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, after consideration of the SRED tax credits.

Due to the gravitas of this position, a worldwide search could be undertaken to secure an appropriate appointment. Key requirements of the person secured would be to mobilize nanotechnology within the aerospace sector in Manitoba and to lead the public/business dialogue in this area. A strategic research plan would also be initiated at this time.

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.

8. Collaborators and Development / Implementation Strategy:

The nanotechnology field is interdisciplinary but everything starts with material sciences. Challenges include: novel synthesis techniques, characterization of nanoscale properties, large scale production of materials and lastly application development

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*Nanotechnology*

Several collaborators are available for nanotechnology applications in aerospace. Examples of available collaborations are:

- Composites Research Network (BC)
- Composites Innovation Centre (MB)
- Canadian Light Source (composites, SK)
- Nano-Systems Fabrication Laboratory (U of Manitoba)
- Others, such as NINT, etc.

These partners present the access to unique research facilities which are necessary to develop nano technologies. Each partner identified above also represents a unique scale and depth of requirements. Manitoba industry can well negotiate access to all of these research institutions identified above.

Red River College provides a Nanotechnology Fundamentals course through its Continuing Education Division.

In the short term, nanotechnology products which focus on composite enhancement should be pursued. In the mid-term, composite doping and nanosensors would be pursued and in the long term light and super strong materials as well as new electronics suites would be of interest.

It will be necessary to support long-term nanoscience research so that it will lead to the fundamental understanding of the design, synthesis, characterisation, modelling, and fabrication of nano-materials for aerospace purposes. Enroute to this will be a necessity to remain aware and engaged on a global scale of developments in this sector, so as to identify technologies of particular interest. The selection of research elements at the local level would need to be consistent with industry interests.

Technology adoption activities will also be necessary, which would be early stage in order to promote this technology through Manitoba’s aerospace industry.

To support the development of a Nano Industry, an annual “nano tech” day should be hosted where all practitioners in the Region with interesting projects would present their findings and state of research to the Manitoba industrial community.

A recommendation is made here for the development of a nano composite industry. This area is possible to develop given both Manitoba’s commitment to composites and its research background in nano technology.

Specific areas to consider here are:

1. Given that Flight Hardware development and qualification processes are both lengthy and costly, an industry development approach should be considered. A material supplier should be engaged for a research partnership opportunity as the supplier would have a focus on what the future market needs (performance goals and technical gaps), and have the ability to become qualified to a standard (i.e. AGATE or NCAMP) or a Tier 1 or OEM specification. Such a technology

development approach would require being a sub-set of a larger R&D project, and with a supplier outside of Manitoba. As an example, two companies: Applied NanoStructured Solutions, LLC and Nanotec-USA could be reviewed in terms of what are they developing for their next set of products and what research capabilities and technical solutions are of interest to them.

2. Another alternative would be to engage with a material supplier that could be targeting materials for un-manned vehicles. Here the qualification path is shorter. (Three Points Composites: https://www.asme.org/engineering-topics/nanotechnology/manufacturing-nanocomposite-materials)

In both of these first two cases, the supplier would be in a better position to focus the technical research thrust and draw on local capabilities. Whether this would lead to the supplier setting up a facility in Manitoba remains to be seen.

3. A third approach would be to consider nano applications to tooling or even consumables as non-flight materials are less onerous to qualify. A strategy here would be to collaborate with an existing supplier and identify nano applications that would solve manufacturing problems or enable new product fabrication methods.

9. References:

Bauer, M. et al., 2008, Advanced Materials Research, 32, 149

Karmani, M.; Ka Lok Man; Khedhiri, C.; Hamdi, B., "Design for testability in nano-CMOS analog integrated circuits using a new design analog checker," *SoC Design Conference (ISOCC), 2011 International* , vol., no., pp.317,320, 17-18 Nov. 2011
doi: 10.1109/ISOCC.2011.6138774

Schultz, K.; Tatzel, A.; Worapattrakul, N.; Woidt, C.; Jakel, A.; Viereck, V.; Hillmer, H., "Micro- and nano-scaled sensors and actuators for aerospace applications," *Networked Sensing Systems (INSS), 2012 Ninth International Conference on* , vol., no., pp.1,4, 11-14 June 2012. doi: 10.1109/INSS.2012.6240546

Udupa, G.; Shrikantha Rao, S.; Gangadharan, K. V., "Future applications of carbon nanotube reinforced functionally graded composite materials," *Advances in Engineering, Science and Management (ICAESM), 2012 International Conference on* , vol., no., pp.399,404, 30-31 March 2012

Ziaei, A.; Demoustier, S., "NANOPACK - Nano packaging technology for interconnect and heat dissipation," *Thermal Inveatigation of ICs and Systems, 2008. THERMINIC 2008. 14th International Workshop on* , vol., no., pp.153,155, 24-26 Sept. 2008
doi: 10.1109/THERMINIC.2008.4669899

THRUST AREA WORKING GROUP:	*Advanced Machining*

CRITICAL TECHNOLOGY:	*Nanotechnology*

10. Contacts:

Dr. Olanrewaju Ojo: Professor, P.Eng, University of Manitoba
Phone: +1 (204) (204) 474-7972
Email: ojo@cc.umanitoba.ca

Dr. Raghavan Jayaraman, , P.Eng, University of Manitoba
Phone: +1 (204) 474-7430,
E-mail: rags@cc.umanitoba.ca

Gene Manchur, Aerospace Manager, Composites Innovation Centre
Phone: +1 (204) 262-3400 ext. 203
Email: gmanchur@compositesinnovation.ca

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Non-Destructive Evaluation*

---

1. Description:

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.

A very stringent inspection situation in the aerospace industry is NDE investigation for cracks and corrosion in multi-layer structures and under installed fasteners. A multitude of variables influence the electromagnetic signal in a non-distinctive way: fastener geometry and conductivity, protruding fastener, surface deformation, variable thickness, lift-off, and possible flaws, as schematically shown in Figure 1.

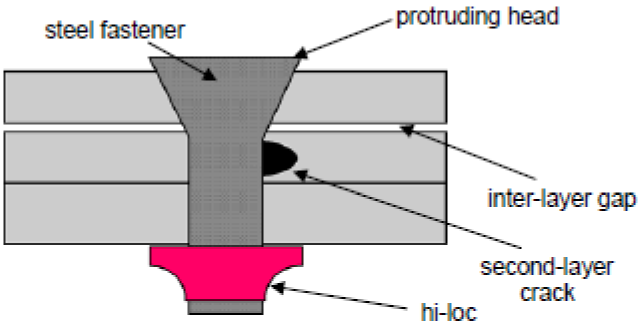


Figure 1: Representative NDE inspection challenges, solvable through electromagnetic NDE

The greatest advantage is made using solid-state sensors with a pulsed eddy-current method, which operates a high-power, broadband excitation frequency waveform. This, in combination with the low-frequency sensitivity of the solid-state sensors, could allow the inspection of thick specimens and ferromagnetic materials. A generic pulsed eddy current system and its components are shown in Figure 2.

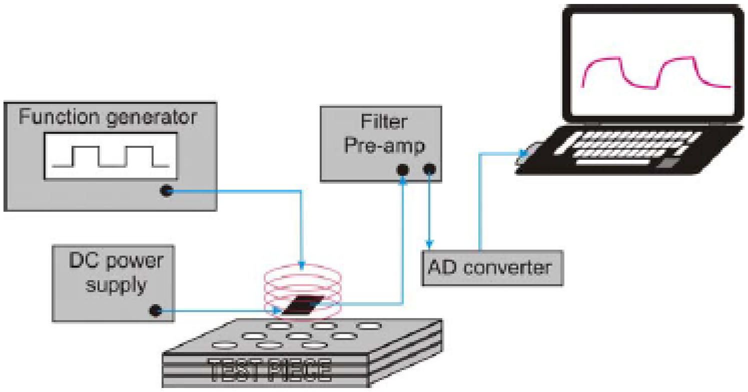


Figure 2: Typical pulsed eddy-current inspection setup

Canadian Aerospace Environmental Technology Road Map
September 2011, Version 2.0

NDE enables deeper inspection capabilities and compensates for the probe-part coupling (i.e. lift-off variation) introduced by protruding fasteners or uneven paint coatings.

2. Impact on Economic Development for Manitoba:

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.

3. Technology Performance Goals:

Some of the advantages of eddy current inspection include:

- Sensitivity to small cracks and other defects,
- Detects surface and near-surface defects,
- Inspection can give immediate results,
- Recent equipment is portable,
- Minimum part preparation is required,
- Test probe does not need to contact the part,
- “Hot” products can be tested,
- Inspects complex shapes and sizes of conductive materials.

Some limitations of eddy current and this technology include:

- Only conductive materials can be inspected,
- Surface must be accessible to the probe,
- Skills and training required are more extensive than other techniques,
- Reference standards are needed for setup,
- Depth of penetration is limited,
- Flaws that lie parallel to the probe coil windings and probe scan direction are undetectable.

To deploy this technology in Manitoba it will be necessary to:

- Apply this technology to several players in the Aerospace Industry
- Produce sufficient turnaround and capability to reduce the costs of inspection
- Reduce the number of steps and work requirements for parts inspection at MRO's
- Add these capabilities to Manitoba's tool kits; incorporate NDE to the CNDI program
- Reduce time off-line by 1 day for each structure.

4. Importance and Breadth of Application:

The potential benefits of implementing these technologies will reduce raw material consumption and the amount of effort required to make an inspection, and increase the availability of aircraft fleets.

NRC's Institute for Aerospace research (NRC-IAR) has a long tradition of developing electromagnetic inspection methods. It has been one of the promoters and key players working to bridge pulsed eddy-current technology from the laboratory to the field.

This technology is important to the MRO group and may have applications in the first-build area as well.

This is an early-stage project opportunity as it can be developed at the CNDI site (RRC and Magellan partnership)

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Non-Destructive Evaluation*

---

5. Alternatives:

- Electromagnetic Imaging Methods for Nondestructive Evaluation
- Lock-in Thermography for Nondestructive Evaluation of Aerospace Structures
- Infra-red thermography
- SQUID magnetometry (superconducting quantum interference device)

6. Availability, Maturity and Risk:

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.

GE Measurements & Control http://www.ge-mcs.com/en/eddy-current-testing.html

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. The technology is currently at TRL 5 to 6. (i.e. System/subsystem/component validation in relevant environment → System/subsystem model or prototyping demonstration in a relevant end-to-end environment such as ground or space).

Risk:

This technology could complete the trial stages in Manitoba; the suggestion out there is that this technology is stranded due to budgetary concerns elsewhere.

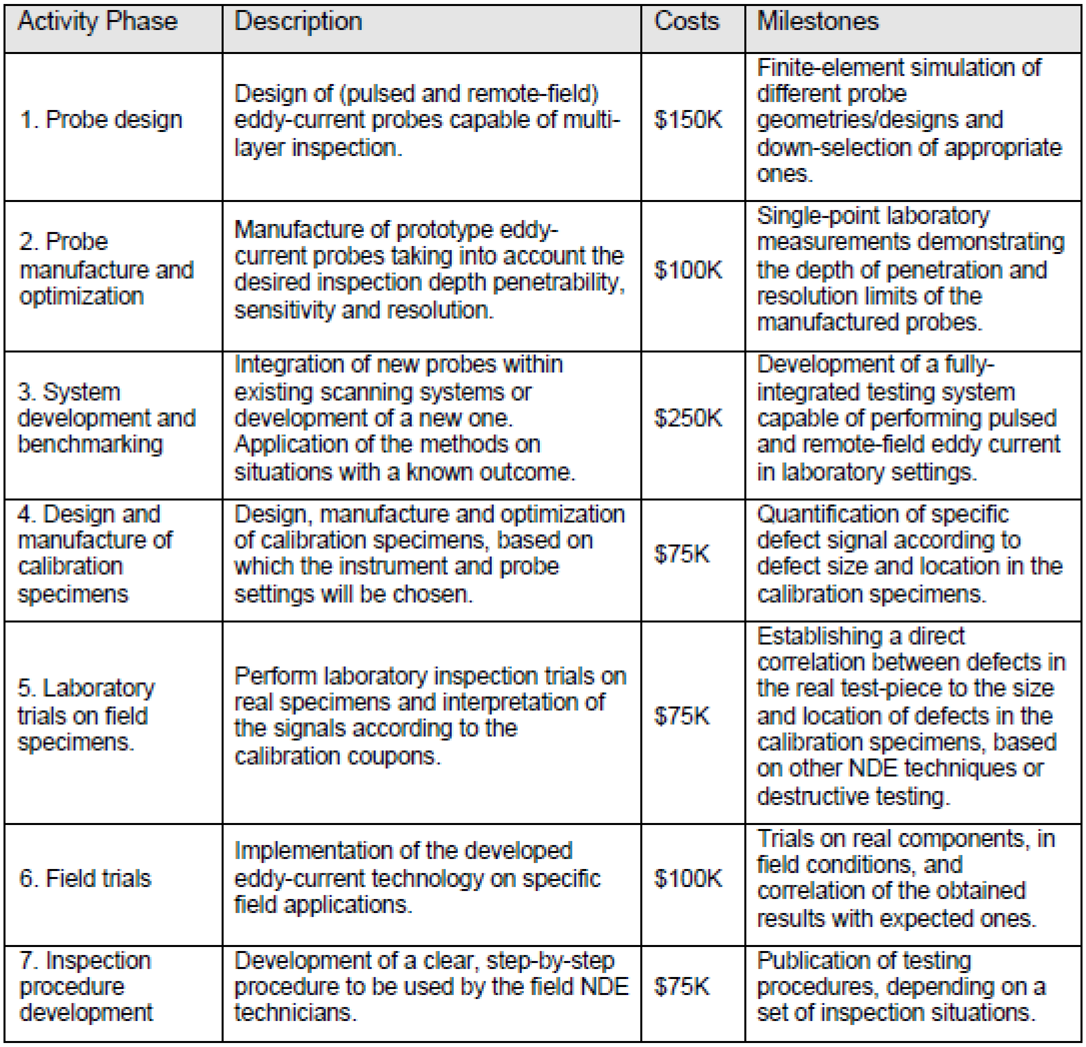
Risks associated with developing this technology are considered small. The challenge here is to establish the potential for this technology to make significant inroads in Manitoba, to establish a base of operations and enough operational demand to produce economic returns.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Non-Destructive Evaluation*

---

7. Costs:



Activity Phase	Description	Costs	Milestones
1. Probe design	Design of (pulsed and remote-field) eddy-current probes capable of multi-layer inspection.	$150K	Finite-element simulation of different probe geometries/designs and down-selection of appropriate ones.
2. Probe manufacture and optimization	Manufacture of prototype eddy-current probes taking into account the desired inspection depth penetrability, sensitivity and resolution.	$100K	Single-point laboratory measurements demonstrating the depth of penetration and resolution limits of the manufactured probes.
3. System development and benchmarking	Integration of new probes within existing scanning systems or development of a new one. Application of the methods on situations with a known outcome.	$250K	Development of a fully-integrated testing system capable of performing pulsed and remote-field eddy current in laboratory settings.
4. Design and manufacture of calibration specimens	Design, manufacture and optimization of calibration specimens, based on which the instrument and probe settings will be chosen.	$75K	Quantification of specific defect signal according to defect size and location in the calibration specimens.
5. Laboratory trials on field specimens.	Perform laboratory inspection trials on real specimens and interpretation of the signals according to the calibration coupons.	$75K	Establishing a direct correlation between defects in the real test-piece to the size and location of defects in the calibration specimens, based on other NDE techniques or destructive testing.
6. Field trials	Implementation of the developed eddy-current technology on specific field applications.	$100K	Trials on real components, in field conditions, and correlation of the obtained results with expected ones.
7. Inspection procedure development	Development of a clear, step-by-step procedure to be used by the field NDE technicians.	$75K	Publication of testing procedures, depending on a set of inspection situations.

8. Collaborators and Development / Implementation Strategy:

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.

THRUST AREA WORKING GROUP:	*ADVANCED MACHINING*

CRITICAL TECHNOLOGY:	*Non-Destructive Evaluation*

---

9. Literature References:

- Satish S. Udpa, Patricl O. Moore (eds.), 2004, Nondestructive Testing Handbook, Vol. 5, Electromagnetic Testing, 3rd Edition, American Society of Nondestructive Testing, Inc.

- Mandache C., and Lefebvre J.H.V., 2006, Transient and Harmonic Eddy Currents: Liftoff Point of Intersection, NDT & E International, Vol. 39, No. 1, p. 57–60.

- Mandache C., 2008, "New trends in eddy current testing," Canadian Institute for Non-Destructive Evaluation Journal, Vol. 29, No. 6, pp. 7–14.

10. Subject Matter References

Dr. Catalin Mandache
National Research Council Canada
Institute for Aerospace Research
1200 Montreal Road
Ottawa, ON K1J 6S5
(613) 991-2132
catalin.mandache@nrc-cnrc.gc.ca

Dr. Abbas Fahr
National Research Council Canada
Institute for Aerospace Research
1200 Montreal Road
Ottawa, ON K1J 6S5
(613) 993-5258
abbas.fahr@nrc-cnrc.gc.ca

Dr. Olanrewaju Ojo
Associate Professor, P.Eng
University of Manitoba,
Winnipeg, MB
(204) 474 7972
Office: E1-446
ojo@cc.umanitoba.ca

11. Contacts:

Fred Doern
Senior Research Chair
Red River College,
(204) 632-3770
fdoern@rrc.ca

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Robotic Assembly*

1. Description:

Automation in aerospace is the use of machines, control systems and information technologies to optimize productivity in the production of goods. The correct incentive for applying automation is to increase productivity, and/or quality, equal to, or beyond that possible with current human labor levels, so as to realize economies of scale and/or realize predictable quality levels. Automation is playing an increasingly important role within the Canadian aerospace industry in order to remain globally competitive.

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. These technologies deal with automated machines that can take the place of humans or work with human operators cooperatively in difficult and complex manufacturing processes, or resemble human behavior, and/or cognition.

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. This is done by using various unique techniques/tools such as: drilling, welding, riveting, bonding, fastening, to mention a few.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

The following are key qualitative and quantitative performance objectives for the pre-competitive enabling technology as related to the application of the technology in Manitoba.

- 100% product conformance.
- Increased product quality / repeatability.
- Decreased product cost.
- Decreased product lead time.
- Decreased employee Safety and Health incidents.
- Exceed compliance to Local Environmental Standards.

Robotic Assembly in aerospace will depend on the development and deployment of increasingly more capable robots. This will include enhanced tools, sensing and perceptions, dexterity and intelligence. This upcoming generation of robots will take on tasks that were previously thought to be too delicate or complex to automate. These tasks must be able to be seamlessly coordinated between robot systems, as well as allow human interaction and intervention whenever necessary. The robot system must be intelligent enough to understand and process task-level commands and in many cases pick up where the human has left off, without the need for reprogramming.

4. Importance and Breadth of Application:

Robotic Automation technology is required now. The aerospace industry has an immediate need to decrease costs and increase product quality. However, the technologies associated with enhancing the overall automation abilities will be developed over the next decade.

Robotic assembly is either already being explored, or implemented within OEM's and major suppliers. Companies such as Lockheed Martin, Northrop Grumman, Bombardier, BAES, AirBus, Boeing and StandardAero are taking serious steps towards the inherent use of this technology.

A significant push is required in Manitoba within the next few years, in order to catch up to other global players already active within this technology area.

Robotic assembly has an impact on other areas throughout the product development lifecycle. Whether at the product design stage, where specific product features or elements can be affected by the way components and assemblies are manufactured, or within the MR&O environment where efficiencies, turn-around-time (TAT), safety and quality are of high importance robotic assembly has an effect on the end product.The design and manufacturing philosophies must conjointly be considered. From this consideration, specific to robotic assembly and automation, a significant positive effect could be had on an end product.

Any reluctance to engage in this technology will result in negative impact on the Canadian aerospace sector. As other aerospace companies in other jurisdictions including 3rd world nations are moving ahead with robotic assembly, Manitoba aerospace companies will slip into an inefficient, costly and un-competitive mode, resulting in loss of business. This is not a case of whether Manitoba aerospace companies should pursue this, but rather, a case of how quickly and aggressively they can do so.

Robotics and Automation technology is critical to all levels of aerospace manufacturing; OEMs, suppliers and MR&O'rs.

If this technology is not available to Manitoba aerospace manufacturers, especially given the current demographics of the skilled workforce in the aerospace industry, we can expect to see a decrease in work being awarded to our companies.

OEM's are constantly looking to their suppliers to reduce the cost and increase quality of delivered goods. Automation is a significant way of achieving positive results in these areas.

5. Alternatives:

Robotics and Automation technology is an alternative and possible substitute for highly skilled human resources. It can also be a complement to the existing skilled human resources by mitigating health and safety risks, or adding agility and physical strength; hence raising productivity. Additional training, skill development and process improvements could continue to yield slight increases in productivity and quality; however, the sum of all of the abovementioned efforts would still not yield the scale of positive results that robotic assembly and automation implementation would.

There are no known substitute/alternate technologies in this area.

6. Availability, Maturity and Risk:

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. The available robots and systems are still not as precise in some applications as the industry requires. Although this may be a limitation in the robot systems, other technologies are being coupled with robotics to augment and increase the accuracy of the overall system. The development, existence and maturity of the following will provide support to robotic assembly:

- Intelligent sensing
    - Vision and tactile systems
    - Sensor integration
    - Data processing
    - Object recognition
- Multi use end of arm tooling
- Self reconfiguring and learning systems
- Human machine interaction
    - Voice
    - Gesture
    - Haptic and wearable
    - Neural

In relation to other aerospace industry jurisdictions, Manitoba is about 5 years behind and has just recently started to catch up. Manitoba must realize the gap is continuously widening and that a strong push must be made in order to engage this technology. The Manitoba Aerospace sector must work quickly to reduce the 5 year gap in order to participate equally with our peers within the industry and possibly become a pioneer instead of a settler.

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.

7. Costs:

Capital costs for the initial setup and development of a Robotic Assembly R&D environment would be upwards of $ 3 million.

Additional cost estimates are as follow:

- $ 500 K per year during the initial catch up period of 5 years.
- $ 800 K per year after that.

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.

8. Collaborators and Development / Implementation Strategy:

Robotic assembly technology is a very good candidate for multi-partner, multi-disciplinary collaboration.

Regional Collaborators

- Boeing of Canada – Boeing of Canada produces complex composite aircraft structures. Robotic technologies activities include the participation in a vision based robotic systems consortium/collaboration with another aerospace company and government technology based agency, as well as some self directed robotics R&D.
- Magellan Aerospace Winnipeg – Magellan develops and produces complex and integrated products and services for the civil aerospace and defence market. Robotic technologies include a collaboration team of government and other aerospace companies to research and demonstrate vision enhanced robotic assembly of an aero-structure.
- StandardAero Ltd. – MRO service provider. Robotic technologies include: Robotic laser welding (fiber, CO2, and diode lasers), robotic cold metal transfer (CMT), robotic laser cutting, laser additive manufacturing or cladding, robotic hybrid laser/TIG welding.
- Phantom Motion Inc. – Advanced Robotic Systems Integrators. Industrial partner, facilitating the commercial development and implementation of next generation robotic systems.
- University of Manitoba – Robotics lab. Supports the development of student skills in the area of robotics and automation.
- Red River College – Robotics lab and Centre for Aerospace Technology and Training in partnership with StandardAero. Supports the development of student skills and workforce skills upgrading in the area of robotics and automation. Included in the existing robotic training and demonstration units are a series of Yaskawa Motoman (single-arm 6-axis) training robots, Motoman welding robots, Motoman dual-arm robot, FANUC training robot with integrated vision system and automated end-of-arm tool changer, and a Rethink Robotics “Baxter” research robot (dual arm with integrated vision system). On the training side, there are also small autonomous robots with integrated vision and voice-control interfaces. For automated assembly there is a 10-station training center that is focused around the use of PLC, sensors and actuators for the integrated design and trouble-shooting of product assembly operations.

- Industrial Technology Centre – Advanced Technologies. Technology based economic development agency. Supports industry awareness and adoption of robotic technology through demonstration projects.
- Manitoba Aerospace Association – Currently supporting a consortium based pilot project on Vision based Robotic Systems. Consortium comprises of Boeing, Magellan and Industrial Technology Centre. Project demonstrates non-composite advanced manufacturing technology R&D collaboration.

National Collaborators

- National Research Council of Canada – Structures, Materials and Manufacturing Lab (formerly, Aerospace Manufacturing Technology Centre (AMTC)). Supports industry implementation of advanced, cost-effective, manufacturing methods for aerospace. A major focus is to facilitate the transition to next-generation manufacturing, particularly among small and medium-sized enterprises (SMEs).
- Polytechnique Montreal – Robotics Lab.
- McGill University
- Concordia University
- Ryerson University
- York University
- Centre technologique en aérospatiale (CTA), St. Hubert, PQ – focus on robotics and machining

International Collaborators

None identified at this time.

Strategy

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 (eg. Ontario Aerospace Council (OAC))
- Program definition and development
- Program execution

9. References:

List of pertinent documents.

NRC-CISTI, STI Assessment
Human Machine Interaction in Robotics, STI 17174, July 29, 2013.

NRC-CISTI, STI Assessment
Intelligent Sensing Robots, STI 17174, July 26, 2013.

NRC-CISTI, STI Assessment
Multi-use End of Arm Tooling, STI 17174, July 26, 2013.

NRC-CISTI, STI Assessment
Self-reconfiguring Robotic Systems, STI 17174, July 26, 2013.

10. Contacts:

The following organizations and persons are referenced as contacts.

Boeing of Canada
David Boonstra, 204-831-2843, david.boonstra@boeing.com

Industrial Technology Centre
Myron Semegen, 204-480-0355, msemegen@itc.mb.ca

Magellan Aerospace
Serge Boulet, 204-788-2850 x3068, serge.boulet@magellan.aero

National Research Council of Canada
Iraj Mantegh, 514-283-9240, iraj.mantegh@nrc-cnrc.gc.ca

Phantom Motion Inc.
Shawn Schaerer, 204-293-0150, shawn@phantom-motion.com

Red River College
Fred Doern, fdoern@rrc.ca or Tracey Dyer, tdyer@rrc.ca

StandardAero Ltd.
Brendan Guyot, 204-318-7746, brendan.guyot@standardaero.com

University of Manitoba
Subramaniam Balakrishnam, 204-474-9688, balakri@cc.umanitoba.ca

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Robotic Finishing*

---

1. Description:

A robotic system focussing on finishing work could imply many types of finishing. The first that usually comes to mind is painting, but it could also include cladding, spray welding, to mention a few. The process basically propels a material towards another in order to bind with the receiving surface thus producing a finish.

Regardless of the type of finishing, 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. Most of these systems are commercially available today but one technology is on the horizon. This technology would encompass scan, paint and inspect without a CAD file or a dedicated part program.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

The following are key qualitative and quantitative performance objectives for the pre-competitive enabling technology as related to the application of the technology in Manitoba.

- 100% product conformance.
- Increased product quality / repeatability.
- Decreased product cost.
- Decreased product lead time.
- Decreased employee Safety and Health incidents.
- Exceed compliance to Local Environmental Standards.

Robotic Finishing in aerospace will depend on the development and deployment of increasingly more capable robots using sensors and intelligence. This upcoming generation of robots will take on tasks that were previously thought to be too complex to automate.

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Robotic Finishing*

4. Importance and Breadth of Application:

Robotic Finishing technology is required now. The aerospace industry has an immediate need to decrease costs and increase product quality without compromising safety and the environment.

The most important aspect of successfully depositing coatings is the path programming of the robot system, usually done manually, and making sure that all other systems are co-operating and functioning as part of a complete system. The automation system must be “Intelligent” enough to allow auto path programming without the use of a CAD program. It is understood that it would still be necessary to instruct the robot system some fundamentals, such as the desired result but not necessarily the methodology. Having this technology would allow skilled resources to finish the first articles or rework only certain spots. With regards to Repair and Overhaul (R&O) of material, the automated finishing technology would calculate the appropriate amount of material required to execute a repair at the self-identified place/location.

This robotic finishing technology would be useful to the aerospace sector within the next five years and will become a critical feature to suppliers by providing a quick and programmer free environment in order to attain a repeatable, quality finish on parts.

It is not a question of if it can be done, but a matter of when it can be perfected to meet the needs of the aerospace sector. The fundamentals of this technology already exist. This has been demonstrated in a number of service robots that redirect and reprogram new paths in order to achieve or avoid dangerous tasks and/or situations. Examples of these technologies are found in the Google car and the house-hold robot vacuum cleaner.

The shortcomings of not adopting or planning for this technology will have a significant impact on the future competitiveness of Manitoba aerospace companies.

If this technology is not available to Manitoba aerospace manufacturers, we can expect to see a decrease in work being awarded to our companies.

OEM’s are constantly looking at their suppliers to reduce costs and increase product quality. Intelligent automation is a significant way of achieving positive results in this area.

5. Alternatives:

Robotics finishing technology is an alternative and possible substitute for skilled human resources. Additional training, skill development and process improvements could continue to yield an increase in productivity and quality.

However, it is believed that the sum of all of the abovementioned efforts would still not yield the positive results that robotic finishing implementation would.

It may be possible to implement a partial solution. Pre-programming paths using CAD geometry will yield some positive results. Although this may be an introductory solution, it is believed to fall significantly short of the end goal.

There are no other known substitute/alternate technologies in this area.

6. Availability, Maturity and Risk:

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. Although this may be a limitation, sensor 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.

In relation to other aerospace industry jurisdictions, Manitoba is about 5 years behind in the overall use of robotics and just recently started to do things in this area. Manitoba must realize the gap is continuously widening and that a strong push must be made in order to engage this technology. The Manitoba Aerospace sector must work quickly to reduce the 5 year gap in order to participate equally with our peers within the global industry and possibly become a pioneer in this area.

Risk

The technological risk is low-medium due to the current industry gap and the knowledge is readily available in order to catch up.

7. Costs:

Capital costs for the initial setup and development of a Robotic Finishing R&D environment would be upwards of $ 2.8 million.

Additional cost estimates are as follow:

- $ 400 K per year during the initial catch up period.
- $ 600 K per year after that.

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.

Depending on specific interests, Manitoba may be in a position to develop an R&D environment which would allow for various/multiple interests to be pursued, without duplicating infrastructure.

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Robotic Finishing*

8. Collaborators and Development / Implementation Strategy:

The technology being sought is focused on the development of an algorithm to allow different types of coating automation systems to self-program a solution, but will also require hardware to test solutions. This development would have to be a multi-disciplinary collaboration due to the nature of the many different types of machinery in the workplace and not all utilize the same logic programming.

Robotic finishing technology is a very good candidate for multi-partner, multi-disciplinary collaboration.

Regional Collaborators

- Boeing of Canada – Boeing of Canada produces complex composite aircraft structures. Robotic technologies activities include the participation in a vision based robotic systems consortium/collaboration with another aerospace company and government technology based agency, as well as some self directed robotics R&D.
- Magellan Aerospace Winnipeg – Magellan develops and produces complex and integrated products and services for the civil aerospace and defence market. Robotic technologies include a collaboration team of government and other aerospace companies to research and demonstrate vision enhanced robotic assembly of an aero-structure.
- StandardAero Ltd. – MRO service provider. Robotic technologies include: Robotic laser welding (fiber, CO2, and diode lasers), robotic cold metal transfer (CMT), robotic laser cutting, laser additive manufacturing or cladding, robotic hybrid laser/TIG welding.
- Phantom Motion Inc. – Advanced Robotic Systems Integrators. Industrial partner, facilitating the commercial development and implementation of next generation robotic systems.
- University of Manitoba – Robotics lab. Supports the development of student skills in the area of robotics and automation.
- Red River College – Robotics lab and Centre for Aerospace Technology and Training in partnership with StandardAero. Supports the development of student skills and workforce skills upgrading in the area of robotics and automation. Included in the existing robotic training and demonstration units are a series of Yaskawa Motoman (single-arm 6-axis) training robots, Motoman welding robots, Motoman dual-arm robot, FANUC training robot with integrated vision system and automated end-of-arm tool changer, and a Rethink Robotics “Baxter” research robot (dual arm with integrated vision system). On the training side, there are also small autonomous robots with integrated vision and voice-control interfaces. For automated assembly there is a 10-station training center that is focused around the use of PLC sensors and actuators for the integrated design and trouble-shooting of product assembly operations.

- Industrial Technology Centre – Advanced Technologies. Technology based economic development agency. Supports industry awareness and adoption of robotic technology through demonstration projects.
- Manitoba Aerospace Association – Currently supporting a consortium based pilot project on Vision based Robotic Systems. Consortium comprises of Boeing, Magellan and Industrial Technology Centre. Project demonstrates non-composite advanced manufacturing technology R&D collaboration.

National Collaborators

- National Research Council of Canada – Structures, Materials and Manufacturing Lab (formerly, Aerospace Manufacturing Technology Centre (AMTC)). Supports industry implementation of advanced, cost-effective, manufacturing methods for aerospace. A major focus is to facilitate the transition to next-generation manufacturing, particularly among small and medium-sized enterprises (SMEs).
- Polytechnique Montreal – Robotics Lab.
- McGill University
- Concordia University
- Ryerson University
- York University
- Centre technologique en aérospatiale (CTA), St. Hubert, PQ – focus on robotics and machining

International Collaborators

None identified at this time.

Strategy

A strategy for the development of a Robotic Aerospace Finishing R&D environment would require the following:

- Industry consortium development
- Industry – Academia consortium development (similar to CRIAQ model in Quebec)
- Other stakeholder identification (eg. Ontario Aerospace Council (OAC))
- Program definition and development
- Program execution

9. References:

List of pertinent document.

NRC-CISTI, STI Assessment
Human Machine Interaction in Robotics, STI 17174, July 29, 2013.

NRC-CISTI, STI Assessment
Intelligent Sensing Robots, STI 17174, July 26, 2013.

NRC-CISTI, STI Assessment
Multi-use End of Arm Tooling, STI 17174, July 26, 2013.

NRC-CISTI, STI Assessment
Self-reconfiguring Robotic Systems, STI 17174, July 26, 2013.

10. Contacts:

The following organizations and persons are referenced as contacts.

Boeing of Canada
David Boonstra, 204-831-2843, david.boonstra@boeing.com

Industrial Technology Centre
Myron Semegen, 204-480-0355, msemegen@itc.mb.ca

Magellan Aerospace
Serge Boulet, 204-788-2850 x3068, serge.boulet@magellan.aero

National Research Council of Canada
Iraj Mantegh, 514-283-9240, iraj.mantegh@nrc-cnrc.gc.ca

Phantom Motion Inc.
Shawn Schaerer, 204-293-0150, shawn@phantom-motion.com

Red River College
Fred Doern, fdoern@rrc.ca or Tracey Dyer, tdyer@rrc.ca

StandardAero Ltd.
Brendan Guyot, 204-318-7746, brendan.guyot@standardaero.com

University of Manitoba
Subramaniam Balakrishnam, 204-474-9688, balakri@cc.umanitoba.ca

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Vision Systems (as they relate to robotics)*

1. Description: Vision System

A vision guided robot control system gives the robot the ability to adjust its position based on the analysis and comparison of positional information relayed to the robot control system by a camera against a preprogrammed position.

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.

2. 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.

Additionally, there is an opportunity to participate in the development and/or integration of vision system and robots. Manitoba has the potential to spawn and grow companies, as well as R&D communities around vision technology.

3. Technology Performance Goals:

The following are key qualitative and quantitative performance objectives for the pre-competitive enabling technology as related to the application of the technology in Manitoba.

- 100% product conformance.
- Increased product quality / repeatability.
- Decreased product cost.
- Decreased product lead time.
- Decreased employee Safety and Health incidents.
- Exceed compliance to Local Environmental Standards.

Robotics and automation in aerospace will depend greatly on the development and deployment of increasingly more capable robots using intelligence, which in many cases will be based on sensors and vision technology. This upcoming generation of robots will take on tasks that were previously thought to be too complex to automate.

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Vision Systems (as they relate to robotics)*

---

4. Importance and Breadth of Application:

Robotic based vision technology is required now. The aerospace industry has an immediate need to decrease costs and increase product quality without compromising safety and the environment.

Vision systems are available to suit a range of application complexities. They can be simple 2D systems, or much more complex 3D stereo systems.

2D vision systems use area or line scan cameras to measure visible characteristics of an object; position, surfaces and edges.

2.5D or 3D vision systems are high speed cameras coupled with a laser to measure variation; shape and volumes.

Autonomous robots are the future of manufacturing. These robots will require sophisticated vision system capabilities. Whether to adjust the execution of tasks in real-time, or for obstacle avoidance, 3D vision systems will be embedded within the processing of such tasks.

The future of human-robot collaboration depends on such systems. This will allow humans to work side-by-side with robots in a safe and efficient manner. Such future robotic based vision systems will need to be able to handle the processing of huge datasets, but also compute the complex algorithms required to keep robot decision making as quick as possible to accommodate a safe and efficient work environment.

Other complicating factors affecting the use of vision systems within robotic environments are; lighting conditions and product material.

Highly reflective surfaces coupled with less than ideally lit spaces will require these vision systems to be effective within all conditions.

The shortcomings of not participating in the development, understanding, application and adoption of this technology will have a significant impact on the future competitiveness of Manitoba aerospace companies.

If this technology is not available to Manitoba aerospace manufacturers, we can expect to see a decrease in work being awarded to our companies.

OEM’s are constantly looking at their suppliers to reduce costs and increase product quality. Intelligent autonomous robots supported by vision system technology will be a sure fired way of achieving positive results.

Two of the main reasons for the slow adoption of robotics and automation in aerospace is due to the complexity of products and assemblies, added to this is the inaccuracy of the robotic technology. Vision systems can now be used to supplement robot accuracy through compensation and can now deliver robots that can achieve the accuracies needed to support aerospace applications. If Manitoba aerospace companies want to remain competitive and increase efficiencies, they must be prepared to invest in this technology.

THRUST AREA WORKING GROUP:	*Robotics and Automation*

CRITICAL TECHNOLOGIES:	*Vision Systems (as they relate to robotics)*

5. Alternatives:

The absence of vision system technology coupled with robotics will significantly decrease the opportunity to automate complex tasks such as; adaptation to system variations, non-system interruption of human collaboration, augmentation of system accuracy, part analysis and measurements, to mention a few.

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.

However, it is believed that the sum of all of the abovementioned efforts would still not yield the positive results that vision based robotic system implementation would provide. This is especially true when a vision system capable of viewing beyond the visible spectrum is considered.

There are no other known substitute/alternate technologies in this area.

6. Availability, Maturity and Risk:

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.

In relation to other aerospace industry jurisdictions, Manitoba is about 5 years behind in the overall use of robotics and just recently started to do things in this area. Manitoba must realize the gap is continually widening and that a strong push must be made in order to engage this technology. The Manitoba Aerospace sector must work quickly to reduce the 5 year gap in order to participate equally with our peers within the global industry and possibly become a pioneer instead of a settler.

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.

7. 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.

Additional cost estimates are as follow:

- $ 300 K per year during the initial catch up period.
- $ 450 K per year after that.

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.

Depending on specific interests, Manitoba may be in a position to develop an R&D environment which would allow for various/multiple interests to be pursued, without duplicating infrastructure.

8. Collaborators and Development / Implementation Strategy:

The technology being sought is hardware, software and computer algorithm development. This development would be very well suited for multi-disciplinary collaboration due to the various areas of development and application.

Vision system technology is a very good candidate for multi-partner, multi-disciplinary collaboration.

Regional Collaborators

- Boeing of Canada – Boeing of Canada produces complex composite aircraft structures. Robotic technologies activities include the participation in a vision based robotic systems consortium/collaboration with another aerospace company and government technology based agency, as well as some self directed robotics R&D.
- Magellan Aerospace Winnipeg – Magellan develops and produces complex and integrated products and services for the civil aerospace and defence market. Robotic technologies include a collaboration team of government and other aerospace companies to research and demonstrate vision enhanced robotic assembly of an aero-structure.
- StandardAero Ltd. – MRO service provider. Robotic technologies include: Robotic laser welding (fiber, CO2, and diode lasers), robotic cold metal transfer (CMT), robotic laser cutting, laser additive manufacturing or cladding, robotic hybrid laser/TIG welding.
- Phantom Motion Inc. – Advanced Robotic Systems Integrators. Industrial partner, facilitating the commercial development and implementation of next generation robotic systems.
- University of Manitoba – Robotics lab. Supports the development of student skills in the area of robotics and automation.

- Red River College – Robotics lab and Centre for Aerospace Technology and Training in partnership with StandardAero. Supports the development of student skills and workforce skills upgrading in the area of robotics and automation. Included in the existing robotic training and demonstration units are a series of Yaskawa Motoman (single-arm 6-axis) training robots, Motoman welding robots, Motoman dual-arm robot, FANUC training robot with integrated vision system and automated end-of-arm tool changer, and a Rethink Robotics “Baxter” research robot (dual arm with integrated vision system). On the training side, there are also small autonomous robots with integrated vision and voice-control interfaces. For automated assembly there is a 10-station training center that is focused around the use of PLC sensors and actuators for the integrated design and trouble-shooting of product assembly operations.
- Industrial Technology Centre – Advanced Technologies. Technology based economic development agency. Supports industry awareness and adoption of robotic technology through demonstration projects.
- Manitoba Aerospace Association – Currently supporting a consortium based pilot project on Vision based Robotic Systems. Consortium comprises of Boeing, Magellan and Industrial Technology Centre. Project demonstrates non-composite advanced manufacturing technology R&D collaboration.

National Collaborators

- National Research Council of Canada – Structures, Materials and Manufacturing Lab (formerly, Aerospace Manufacturing Technology Centre (AMTC)). Supports industry implementation of advanced, cost-effective, manufacturing methods for aerospace. A major focus is to facilitate the transition to next-generation manufacturing, particularly among small and medium-sized enterprises (SMEs).
- Polytechnique Montreal – Robotics Lab.
- McGill University
- Concordia University
- Ryerson University
- York University
- Centre technologique en aérospatiale (CTA), St. Hubert, PQ – focus on robotics and machining

International Collaborators

None identified at this time.

Strategy

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 (eg. Ontario Aerospace Council (OAC))
- Program definition and development
- Program execution

9. References:

List of pertinent documents.

NRC-CISTI, STI Assessment
Human Machine Interaction in Robotics, STI 17174, July 29, 2013.

NRC-CISTI, STI Assessment
Intelligent Sensing Robots, STI 17174, July 26, 2013.

NRC-CISTI, STI Assessment
Multi-use End of Arm Tooling, STI 17174, July 26, 2013.

NRC-CISTI, STI Assessment
Self-reconfiguring Robotic Systems, STI 17174, July 26, 2013.

10. Contacts:

The following organizations and persons are referenced as contacts.

Boeing of Canada
David Boonstra, 204-831-2843, david.boonstra@boeing.com

Industrial Technology Centre
Myron Semegen, 204-480-0355, msemegen@itc.mb.ca

Magellan Aerospace
Serge Boulet, 204-788-2850 x3068, serge.boulet@magellan.aero

National Research Council of Canada
Iraj Mantegh, 514-283-9240, iraj.mantegh@nrc-cnrc.gc.ca

Phantom Motion Inc.
Shawn Schaerer, 204-293-0150, shawn@phantom-motion.com

Red River College
Fred Doern, fdoern@rrc.ca or Tracey Dyer, tdyer@rrc.ca

StandardAero Ltd.
Brendan Guyot, 204-318-7746, brendan.guyot@standardaero.com

University of Manitoba
Subramaniam Balakrishnam, 204-474-9688, balakri@cc.umanitoba.ca

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT
SUMMARY

Workgroup #3 Composites

---

1. Executive Summary:

The Manitoba Aerospace Association, EnviroTREC and WestCaRD partnered to sponsor the development of an industry led Manitoba Technology Strategy Document through a Technology Roadmapping process. Workgroup #3 was tasked with evaluating the composite technologies that form a sub-set of this Technology Strategy Document. The purpose of this document is to provide recommendations on the creation of a strategic direction for Manitoba's aerospace stakeholders.

Workgroup #3 recommends that five key composite thrust areas be deemed strategic and Manitoba stakeholders should either lead or be a significant partner in their development. The five areas are: Out-Of-Autoclave processing (OOA); High Temperature Composites (CMC, PI, BMI); Resin Infusion (RI); Fibre 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 Temperature Composite CMC/PI/BMI 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 they achieve higher TRLs. These centres would also provide for development of subject matter experts, link 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.

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.

Workgroup #3 also evaluated two other areas and recommends engagement as a participant or contributor (not as lead or a key role). These are Fibre Reinforced Composite Additive Manufacturing and Automated Inspection technologies.

It is also recommended that the Composite Technology Roadmap be treated as a live document that is refreshed periodically.

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT
SUMMARY

Workgroup #3 Composites

Process:

The Workgroup met between April and August 2013 and collaboratively created a Product and Technology Roadmap to guide the group in its identification, evaluation and selection of strategic composite technology areas. See attached document MAA Composite WG #3 TRM 20June13. The steps the group followed were:

- Envisioned the long term future global customer needs, YE2028 to YE2033
- Projected future aerospace product markets for Manitoba
- Identified Manitoba product strategies defining specific structures of interest to industry. Envisioned what the families of future products would be in Manitoba factories and production facilities.
- Defined an all up listing of technology thrusts required to support these future products.
- Gathered information on each technology thrust and reviewed CISTI surveys.
- Evaluated and ranked the technology thrusts against a set of criteria that included the future customer needs, economic potential, TRL advancement potential and whether the technology is considered as disruptor or incremental.
- Down-select the five key thrust areas to led or partner in a significant role, and the two areas to be participants or contributors, see MAA Composite WG #3 TRM selection matrix 29Oct13.
- Defined strategies for each of the five thrust areas and compiled the information into individual Reports.

2. Reports:

The workgroup generated Reports for each of the five key thrusts, see attachments.

- Out of Autoclave (OOA) processing.
- High Temperature Composites (CMC - Ceramic Matix Composites, PI - Polyimides, BMI - Bismaleimide) manufacture and MRO.
- Automated Lamination fabrication technologies.
- Resin Infusion (RI).
- 3D Fibre Pre-Forms.

3. Recommendations:

To maintain and grow the Manitoba aerospace composite sector, and enhance economic viability and competitiveness, stakeholders will need to invest in the key technologies identified in this Summary and the individual Thrust Reports. It is recommended that collaborative partnerships and strategic alliances be built as a means to create the proposed technology development centres and collaborative technology demonstrator projects.

In addition, the workgroup identified two important technologies where it is recommended that Manitoba stakeholders consider participation or contribution, but not at a leadership level. These are Fibre Reinforced Composite Additive Manufacture and Automated Inspection technologies. The rationale for this recommendation is that Manitoba stakeholders will likely be end-users of the technology, but not directly involved with lower TRL research and its requisite subject matter expertise.

As the workgroup completed its Technology Roadmap and thrust area evaluation it became evident that potential disruptor technologies exist. Ceramic Matrix Composites have the potential as a disruptor in high temperature metallic alloy product manufacture and MRO. Also considered as a disruptor is Fibre Reinforced Composite Additive Manufacturing. Globally, Additive Manufacturing is making strong advancements in both metallic and polymeric structures. The potential exists to extrapolate this technology into fibre reinforced polymers and this could be a disruptor technology. The recommended Automated Lamination technology development centre could create both competitive new fabrication technologies, and potentially a disruptor in pre-cured processing.

To build on collaborative partnerships and maintain visibility on technology advancements, it is recommended that the Composite Technology Roadmap be treated as a living document that is refreshed periodically.

4. Workgroup #3 members:

The composite Workgroup consisted of the following individuals representing industry, academia and research organizations.

Individual	**Organization**
Loren Hendrickson – Workgroup Chair	Boeing Canada Technology Ltd, Winnipeg loren.hendrickson@boeing.com
Gene Manchur – Deputy Chair	Composites Innovation Centre MB gmanchur@compositesinnovation.ca
John Bagan	Magellan Aerospace Ltd john.bagan@magellan.aero
Jordan Bisharat	Cormer Aerospace Ltd jbisharat@cormeraerospace.com
Neil Dobson	Red River College ndobson@rrc.ca
Raghavan Jayaraman	University of Manitoba rags@cc.umanitoba.ca
Andrew Johnston	National Research Council Andrew.Johnston@nrc-cnrc.gc.ca
Dave Vanderzwaag	EMTEQ Canada dvanderzwaag@emteq.com

Attachments:

- MAA Composite WG #3 TRM 29June13
- MAA Composite WG #3 TRM selection matrix 29Oct13
- Composite WG#3 Thrust Area Report High Temperature Composites 29Oct13
- Report Composite WG#3 Thrust Area Report CMC 30Aug13
- Report Composite WG#3 Thrust Area Report Automated Lamination 30Aug13
- Report Composite WG#3 Thrust Area Report Fibre Pre-Form 30Aug13
- Report Composite WG#3 Thrust Area Report RI draft 26Aug13
- CISTI Shortlist Questions WG#3 Composites 12June13
- 2014-IRAP-17174-SEARCHRESULTS-3D PREFORMS-20130724
- 2014-IRAP-17174-SEARCHRESULTS-CMCs-20130717

MB Composite TRM Technical Opportunity Rating Matrix

May 31/13 R1
Composite Workgroup #3

Technology Thrust	Description	Disposition
OOA	Out-Of-Autoclave: prepreg, Vacuum Bag Only (VBO)	keep and evaluate
CMC	Ceramic Matrix Composites: braided preforms, pyrolysis fabrication, feature machining, joining	keep and evaluate
RI	Resin Infusion: preforms, RTM and its variants, tooling	keep and evaluate
TP	Thermoplastics: infusion, sheet forming, joining, bonding	keep and evaluate
Drape Forming	Drape Forming of prepreg materials, laminate and sandwich panels	keep and evaluate - fits into Auto Fab composites
Auto Fab - composites	Automated fabrication of composites, preforming, lamination, reticulation (pre-cure operations)	keep and evaluate
Auto Fab - machining	Automated processing of composites, drill and trim, finishing (post-cure operations)	keep and evaluate
Auto Fab - inspection	Automated inspection of composites, lamination, NDI, dimensional	add and evaluate
~~Novel Mfg~~	~~Novel Manufacturing: innovative competitive advantages~~	remove unless pre-competitive element defined
Bio Composites	Bio-Fibres, bio-resins	keep and evaluate
Additive Mfg - composites	Additive Manufacturing for reinforced composites through incorporation of reinforcing fibres into a polymeric AM system	keep and evaluate
~~Tooling~~	~~Tooling:~~	remove as each application is specific, to be investigated within each technology thrust
~~Material Eqiv~~	~~Material Equivalency: low Cert cost and short timeline approval methodology~~	remove as each material is specific and FAA and TC constraints limiting
Pre-forms	Design, analysis and fabrication of 3D fibre pre-forms, braided, woven, stitched	keep and evaluate
~~Multi-function materials~~	~~intelligent, nano, multi-purpose materials and coatings~~	remove as each application is specific, to be investigated within each technology thrust

MB Composite TRM Technical Opportunity Rating Matrix

May 31/13 R1

Composite Workgroup #3

Key Thrusts - invest and lead

Partner Technologies - contribute and participate in a larger Tech Demo

	Technology thrust										
Criteria: rating 1=low and 5=hi	**OOA**	**CMC**	**RI**	**TP**	**Drape Forming**	**Auto Fab - composites**	**Auto Fab - machining**	**Auto Fab - inspection**	**Bio Composites**	**Additive Mfg - composites**	**Pre-forms**
Total score	**54**	**52**	**49**	47	45	**54**	48	50	44	50	**59**
Ranking 1 = first	**2**	**4**	**7**	9	10	**2**	7	5	11	5	**1**
Efficient Manufacturing enabler											
• Lower total product cost	**4**	**1**	**3**	3	4	**4**	3	3	4	4	**3**
• Integrated structures	**3**	**4**	**5**	3	3	**5**	5	5	2	5	**5**
• Higher complexity	**3**	**4**	**5**	4	4	**4**	4	4	3	5	**5**
• Larger sized structures (monolithic, sections)	**5**	**3**	**4**	4	3	**5**	5	5	3	2	**4**
Increased product performance											
• Higher temperatures 650F	**2**	**4**	**2**	2	2	**2**	2	2	1	2	**5**
• Higher temperatures 2000F+	**1**	**5**	**1**	1	1	**1**	1	1	1	1	**5**
• Lighter weight	**4**	**5**	**4**	3	3	**4**	3	3	3	4	**4**
• Intelligent structures	**3**	**3**	**3**	3	3	**3**	3	3	3	3	**4**
Breadth of Application											
• Platform applications, niche=1, widespread=5	**5**	**1**	**3**	3	4	**5**	3	4	2	2	**4**
• Adaptable to New or Current Airplane configurations	**5**	**4**	**3**	3	3	**3**	3	3	3	3	**3**
• Multiple Platform capabilities (GA, MIL, COM, UAS)	**5**	**1**	**4**	3	3	**3**	3	3	4	3	**3**
Provides competitive advantage											
• Economic growth to Industry	**4**	**3**	**3**	4	3	**4**	3	3	4	3	**4**
Direct links to market needs	**4**	**4**	**3**	4	3	**4**	4	4	4	3	**3**
TRL advancement potential (from now to reach TRL9)	**3**	**5**	**3**	4	3	**4**	3	4	4	5	**4**
Disruptor technology (push, replaces current workstatement)	**3**	**5**	**3**	3	3	**3**	3	3	3	5	**3**

MB Composite TRM Technical Opportunity Rating Matrix

May 31/13 R1

Composite Workgroup #3

Y - applicable or high potential

P - possibility of application

	Technology thrust									
Product and applicability - Indicates breadth of technology thrust application potential	**OOA**	**CMC**	**RI**	**TP**	**Drape Forming**	**Auto Fab - composites**	**Auto Fab - machining**	**Auto Fab - inspection**	**Bio Composites**	**Additive Mfg - composites**	**Pre-forms**
Structures											
• Nacelles											
• Pylon Heat Shields		y				p	y	y			y
• Cowls	y		p	p	y	y	y	p		p	y
• Inner barrels	p		p	p	y	y	y	p		p	y
• Acoustic treated structures	p		p	p	p	y	y	p		p	
• Thrust Reversers	p		p	p	p	y	y	p		p	
• Winglets	y		y	y	y	y	y	p		p	y
• Movable LE and TE	y		y	y	y	y	y	p		p	y
• UAS	y		y	y	y	y	y	p	p	p	y
• Space components	p	y	y	p	p	p	p	p		p	y
• Wing to Body Fairings (WBF)	y		p	p	p	y	y	p	p	p	
• Landing Gear Doors	y		p	p	p	y	y	p		p	
Engines											
• High temp core		y				p	p	p			y
• Exhaust Nozzle		y				p	p	p			y
Interiors											
• Panels	y		y	p	y	y	p	p	p	p	p
• Seats	y		y	y	y	p	y	p	p	p	y
• Assemblies			y				y	p		p	

Composite Technology Workgroup #3

THRUST AREA WORKING GROUP:	*Composites*

CRITICAL TECHNOLOGY:	*Automated Lamination Processes for composite products*

1. Description:

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.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

The key performance objectives for the Automated Lamination technologies are:

- Reduced labour content
- Higher throughput with optimized process flows
- Optimized tooling and equipment integration
- Enabling of complex geometries and structures

4. Importance and Breadth of Application:

Fibre Placement, Tape Layers, Filament Winders and other composite processing machines are currently available commercially, however with a substantial capital investment and laydown/processing rates not where they always need to be, the business case cannot always be closed and a favorable ROI realized for many products. As the aerospace demands for lower cost increases globally, reductions in part production labour will be pursued. Automated Lamination technologies reduce labour content and could provide solutions unique to an application such that a new design concept could be enabled. Carbon fibre and glass fiber materials are of primary interest.

5. 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.

6. Availability, Maturity and Risk:

A number of equipment suppliers and composite manufacturers are currently using Fibre Placement, Tape Layers and Filament Winding machines for Commercial and Military products. OEMs and Tier 1's currently have a limited set of Design Allowables, Design Guides, material and process specifications and qualified materials. 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. These are very specific and complex applications with capital intensive tooling and equipment tailored to the singular product.

The capabilities that will need to be developed by Manitoba's aerospace industry are:

- Processing knowledge - complex geometry and integrated designs, and large sized structures, high risk
- Structural Design and Analysis – Allowables generation and design Guidelines, medium risk as OEMs and Tier 1's will lead
- Application specific tooling and equipment – hi risk
- Key Intellectual Property to develop is the knowledge of what currently exists and what specific applications can benefit from the automation processes
- Automated lamination of composites includes complex manufacturing equipment and specialized knowledge of material processing and handling techniques
- Development of right sized equipment for the application and to meet the business case requirements

7. Costs:

Entry into the automated lamination processes will be capital extensive and require specialized knowledge.

ROM (Rough Order of Magnitude) Estimate: $8M over 4 years.

- Technology Development Team
- Pre-production fabrication materials, tooling, equipment and facilities
- Inspection technologies, equipment, standards
- Material mechanical and physical properties testing

8. Collaborators and Development / Implementation Strategy:

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. The focus should be on creating right-sized tooling and equipment that supports specific industry needs in the pre-cured lamination stage. The goal should be to enable the development of innovative means to accomplish lamination, reticulation, drape forming, consolidation and/or other specialized processing in a highly competitive manner. This technology development centre could be a joint effort by the interested stakeholders and modeled after other successful centres in aerospace such as GETRDC, CNDI and CATT. The innovative composite fabrication technology development centre could include the OOA technology development needs (as outlined in the OOA Processing TRM Report) within its mandate as well. The technology developed via this centre would then be transitioned into industry as it achieves the higher TRLs. This centre would also provide for development of subject matter experts, link to academic and research organizations, and provide a platform for advanced technology training and education.

9. References:

- MAA Composite WG#3 Roadmap 12June13
- MAA Composite WG #3 TRM selection matrix 31May13 r1

10. Contacts:

- Loren Hendrickson, Engineering Manager, Boeing Canada Technology
- Gene Manchur, Aero Sector Manager, Composites Innovation Centre

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

Composite Technology Workgroup #3

THRUST AREA WORKING GROUP:	*Composites*

CRITICAL TECHNOLOGY:	*High Temperature Composites (CMC, PI, BMI)*

1. Description:

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.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

The key performance objectives for the high temperature composite technologies are:

- High temperature capabilities, CMC 2500F+, PI 600F+, BMI 350F+
- Lighter weight structures
- Integrated structural designs

4. Importance and Breadth of Application:

CMC applications exist within the next generation of jet engines, including the high temperature core and exhaust regions. Potential for other CMC applications such as airplane pylon heatshields, exhaust ducts and spacecraft components will emerge. PI's and BMI's are currently used in niche airframe applications where the temperature exceeds the commonly used epoxy system's capability. Weight reduction and increased temperature capabilities are essential to meet the aggressive fuel efficiency and performance targets for both airframes and engines, and this will drive additional PI and BMI applications forward.

5. Alternatives:

The competing technologies are a next generation of improved super-alloys or other novel material systems (currently undefined).

6. Availability, Maturity and Risk:

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.

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.

To introduce and obtain high temperature composite products, Manitoba industry must gain the following capabilities:

- Manufacturing knowledge and expertise in the CMC and PI fabrication processes
- Increased subject matter expertise and depth in BMI fabrication
- High temperature oven, potentially a high temperature and pressure autoclave, and supporting equipment purchase, installation, qualification and operation
- Production tooling knowledge
- Ability to manufacture CMC and PI components
- Ability to inspect and repair in-service CMC and PI components

7. Costs:

A very rough order of magnitude estimate of the total funding required to develop high temperature composite technologies in Manitoba would be $12M over 5 years:

- Technology Development Team
- Pre-production fabrication materials, tooling, equipment and facilities
- Inspection technologies, equipment, standards
- Repair technologies, equipment, standards

8. Collaborators and Development / Implementation Strategy:

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. Additional interest from other industrial and research partners from other regions of Canada (i.e. UBC, CRN, NRC, AMTC) should be determined. A recommended approach would be to establish a fabrication, inspection and repair technology development centre to conduct pre-production technology demonstrator projects and subsequent improvement evaluations. This centre could be a joint effort by the interested stakeholders and modeled after other successful centres in aerospace such as GETRDC, CNDI and CATT. The technology developed via this centre would then be transitioned into industry as it achieves the higher TRLs. This centre would also provide for development of subject matter experts, link to academic and research organizations, and provide a platform for advanced technology training and education.

9. References:

- MAA Composite WG#3 Roadmap 29Oct13
- MAA Composite WG #3 TRM selection matrix 29Oct13
- “GE Aviation: Perspectives on Clean Efficient Engines”, Dr. Dale Carlson, May 7, 2013 as presented at the Western Aerospace Expo.

  http://www.manitoba-aerospace.mb.ca/pdfs2/dale_carlson_geaviation.pdf
- CISTI Report 2014-IRAP-17174-SEARCHRESULTS-CMCs-20130717

10. Contacts:

- Loren Hendrickson, Engineering Manager, Boeing Canada Technology
- Gene Manchur, Aero Sector Manager, Composites Innovation Centre
- John Bagan, Senior Manager, Business Development, Magellan Aerospace

Composite Technology Workgroup #3

THRUST AREA WORKING GROUP:	*Composites*

CRITICAL TECHNOLOGY:	*3D Fibre Pre-Forms for composite products*

1. Description:

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.

2. Impact on Economic Development for Manitoba

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 has a 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.

3. Technology Performance Goals:

The key performance objectives for the 3D pre-form technologies are:

- Highly tailored fibre orientation
- Complex fibre patterns
- Through thickness reinforcement
- Lighter weight structures
- Integrated structural designs

4. Importance and Breadth of Application:

2D pre-forms are currently available commercially and 3D pre-forms to a lesser degree. As the aerospace industry demands lower cost, the reduction in part production labour will be pursued. Pre-form technologies reduce labour content as these are fabricated with automated equipment. Carbon fibre and glass fiber materials are of primary interest.

5. Alternatives:

A non-technological alternative to developing this technology in Manitoba would be to purchase the pre-forms from existing suppliers.

6. Availability, Maturity and Risk:

- Key Intellectual Property which is still necessary to develop is the knowledge and capability to perform structural engineering design and analysis for products using the 3D pre-forms
- Fabrication of 3D preforms includes complex manufacturing equipment and specialized knowledge of fibre processing and handling techniques

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. This limits the applications currently available for Commercial aerospace. In aggregate the TRL for the basic applications range from about TRL5 to TRL10. The TRL range for larger and more complex parts is about TRL3 to TRL5.

The capabilities that will need to be developed by Manitoba's aerospace industry are:

- Processing knowledge - complex geometry and integrated designs, and large sized structures, high risk
- Structural Design and Analysis – Allowables generation and design Guidelines, medium risk as OEMs and Tier 1's will lead
- Braiding, weaving or stitching equipment – hi risk

7. Costs:

Entry into the 3D pre-forming industry will be capital extensive and require specialized knowledge.

Estimates for development: $5M over 4 years.

- Technology Development Team
- Pre-production fabrication materials, tooling, equipment and facilities
- Material mechanical and physical properties testing

8. Collaborators and Development / Implementation Strategy:

The recommended strategy is to partner with an existing braiding or weaving supplier looking to expand their capabilities or increase their production capacity. 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 pre-forming technology, would be used as the driver for the establishment of this capability.

- Define product opportunity with OEM or Tier 1
- Individual industry either collaborate with a capable partner or purchase capability to perform basic pre-forming
- 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

9. References:

- MAA Composite WG#3 Roadmap 12June13
- MAA Composite WG #3 TRM selection matrix 31May13 r1
- 2014-IRAP-17174-SEARCHRESULTS-3D PREFORMS-20130724

10. Contacts:

- Loren Hendrickson, Engineering Manager, Boeing Canada Technology
- Gene Manchur, Aero Sector Manager, Composites Innovation Centre

Composite Technology Workgroup #3

THRUST AREA WORKING GROUP:	*Composites*

CRITICAL TECHNOLOGY:	*Out-of-Autoclave processing (OOA)*

1. Description:

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.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

The key performance objectives for the OOA technologies are:

- Lower capital equipment purchase, installation, and maintenance costs
- Ability to manufacture larger structures that are not limited by autoclave dimensions, including highly integrated structures allowing for designs with lower part count and reduced weight
- Greener manufacturing practices through reduced energy consumption during part processing and a smaller factory footprint
- Extended cure tool life and an ability to use lower cost tooling concepts due to reduced requirements for tooling integrity based on lower processing pressures; reduced tool weights allowing for easier handling

4. Importance and Breadth of Application:

The baseline technology will be required in 2015 to capture potential OEM markets for airplane derivatives already in post-launch development. This technology targets both primary and secondary airframe structures. Advanced knowledge in processing, scale-up and complexity must be gained to enable application in new designs as the next generation of derivatives and new airplane launches occur, approximately 2018-2023.

This technology is critical to all the OEMs as they move forward with performance improvements and cost reductions for their platforms. This will directly affect their composite supply chain, from Tier 1 integrators, to fabricators and raw material suppliers.

A wider global supply base of potential competitors will emerge as this technology is implemented by the OEMs and Tier 1s. Manitoba's composite aerospace industry will only compete and maintain market share for these structures in 2018 if the engineering design and advanced processing knowledge remains superior to the emerging competition.

5. Alternatives:

Current autoclave composite processing will continue for the current products for the foreseeable future. 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.

6. Availability, Maturity and Risk:

A number of prepreg raw material suppliers and composite manufacturers are currently introducing the OOA generation of materials for Commercial Airplanes. OEMs and Tier 1's currently have a limited set of Design Allowables, Design Guides, material and process specifications and qualified materials approved, most are still in the development stage for the large Commercial Airplane market. This limits the applications currently available for Commercial aerospace, 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.

In the General Aviation market the use of OOA prepreg materials is more mature and the TRL range is about TRL7 to TRL10.

The next iteration of OOA, No Oven No Autoclave (NONA) is currently at a lower TRL3 to TRL5 range. The goal with NONA is to provide matrix systems that will cure at a lower temperature, have low resin contents and sufficiently high Tg (glass transition temperature) so that commercial airplane products are within scope.

The capabilities that will need to be developed by Manitoba's aerospace industry are:

- Processing knowledge - complex geometry and integrated designs, and large sized structures, high risk
- Optimized tooling concepts – tooling non-recurring cost reduction and cure process optimization, medium risk
- Structural Design and Analysis – Allowables generation and design Guidelines, medium risk as OEMs and Tier 1's will lead
- Cure equipment – ovens or integrally heated tooling systems, low risk

7. Costs:

A very ROM (Rough Order-of-Magnitude) estimate to develop the OOA technologies in Manitoba is $4M over a 4 year period. 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

8. Collaborators and Development / Implementation Strategy:

The OOA technology development is a good candidate for collaborative development as it covers a wide spectrum of needs. There is currently a CCMRD OOA Project that includes Boeing Winnipeg, Magellan, Cormer, Emteq and the CIC from Manitoba, plus other Canadian organizations which includes Convergent Manufacturing Technologies (CMT), PCM Innovation, NRC, and Barrday. The proposed strategy is to build on this collaborative effort. Additional interest from other industrial and research partners from other regions of Canada should be determined. A recommended approach would be to establish an OOA composite fabrication technology development centre to conduct pre-production technology demonstrator projects and subsequent improvement evaluations. The OOA composite fabrication technology development centre could also include within its mandate the innovative composite fabrication technology development centre as outlined in the Automated Lamination TRM Report. This technology development centre could be a joint effort by the interested stakeholders and modeled after other successful centres in aerospace such as GETRDC, CNDI and CATT. The technology developed and demonstrated via this centre would then be transitioned into industry as it achieves the higher TRLs. This centre would also provide for development of subject matter experts, link to academic and research organizations, and provide a platform for advanced technology training and education.

9. References:

- MAA Composite WG#3 Roadmap 12June13
- MAA Composite WG #3 TRM selection matrix 31May13 r1

10. Contacts:

- Loren Hendrickson, Engineering Manager, Boeing Canada Technology
- Gene Manchur, Aero Sector Manager, Composites Innovation Centre

Composite Technology Workgroup #3

THRUST AREA WORKING GROUP:	*Composites*

CRITICAL TECHNOLOGY:	*Resin Infusion (RI)*

1. Description:

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.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

The key performance objectives for the Resin Infusion technologies are:

- Complex geometries with integrated structures can be formed in one operation
- New generations of resin systems are in development to enable shorter cure cycles
- New generations of resin systems are in development for higher temperature applications up to 650F
- Out of autoclave processing options
- High fibre contents are possible

4. Importance and Breadth of Application:

Resin Infusion is a higher valued added manufacturing process where the applications are specific to each technology sub-area. These range from the basic one tooled surface vacuum pull system up to the high pressure injected multi-surfaced closed mold RTM process. Each has unique advantages and disadvantages within each niche.

The next generation of RI materials and processes will enable products with economic revenue generating potential. It would be beneficial for Manitoba industry to be a supplier to these next generation products as they will likely have high value on the next airplanes.

5. Alternatives:

A non-technological alternative to developing this technology in Manitoba would be to purchase the Resin Infused products from existing or new suppliers.

6. Availability, Maturity and Risk:

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. 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.

The capabilities that will need to be developed by Manitoba's aerospace industry are:

- Processing knowledge - complex geometry and integrated designs, and large sized structures, high risk
- Optimized tooling concepts – tooling non-recurring cost reduction and cure process optimization, medium risk
- Structural Design and Analysis – Point design methodology, or general Allowables generation and design Guidelines, medium risk as OEMs and Tier 1's will lead
- Processing equipment – depends upon which RI process is selected, low to medium risk depending upon advancement desired

7. Costs:

A rough cost estimate for developing the knowledge and capability for Resin Infusion technology would be $3M over 4 years for a basic process. This would set the infrastructure and knowledge to extend into the next generation of materials and processes which would be an additional $3M over 3 years. 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

8. Collaborators and Development / Implementation Strategy:

The recommended strategy is to partner with either an existing RI fabricator looking to expand their capabilities or increase their production capacity, or partner with a RI tooling/material supplier that could provide the expertise required to establish capability with an existing Manitoba stakeholder. 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.

- Define product opportunity with OEM or Tier 1
- Individual industry either collaborate with a capable partner or purchase capability to perform basic RI fabrication
- 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

9. References:

- MAA Composite WG#3 Roadmap 12June13
- MAA Composite WG #3 TRM selection matrix 31May13 r1

10. Contacts:

- Loren Hendrickson, Engineering Manager, Boeing Canada Technology
- Gene Manchur, Aero Sector Manager, Composites Innovation Centre

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP: *Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY: *Enhanced Technical Instructions and VR Training*

---

1. Description:

- 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.

  \- <u>Interactive Electronic Technical Manuals (IETMs)</u> Utilize the latest hardware and software to enhance delivery of instructions through guided troubleshooting, relational content, and enhanced graphical content (3D models and simulations).

  \- <u>Virtual Reality (VR) training</u> offers an immersive environment that more closely simulates aerospace maintenance scenarios.

  Benefits include :
    - reduced time, costs and risks of training
    - improved features to deliver complex contents to trainees
    - more learning by doing
    - more attractive training
    - the possibility to learn by mistakes
    - improved means to provide a more general understanding of the technical system as well as relationships and interdependencies
    - provision of means not only to raise the awareness of HF (Human Factors) issues but by experiencing them personally

- 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.

2. Impact on Economic Development for Manitoba

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. Future training and instructional information will take advantage of 3D design data technologies to improve delivery (VR goggles, tablets, etc.) to reduce errors in manufacturing and operations and to enhance training. This technology is already being used in product design and manufacturing and maintenance instruction development at the OEM level.

- 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. Manitoba aerospace businesses that possess this technology would be in a key position to support OEM needs in this case. Eg. MIL-PRF-87268A (US Military), S1000D (International Committee), AITRAM (VR Training – Europe)

- 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.

3. Technology Performance Goals:

The key qualitative and quantitative performance objectives for the pre-competitive enabling technology as related to the application of the technology in Manitoba are:

- Reduction of cost and development time in training of aerospace product technicians along with associated improvements in training quality and performance. VR training studies performed on surgery teams found that VR trained teams were able to complete many procedures in 30% less time with a 6 - 9x reduction in the probability of errors.

- Potential to reduce the overall requirements for hands on training on engines / airframes with rich / interactive pc / tablet / virtual reality training. This opens up possibility of remote training.

- Ability to simulate real-time training scenarios on equipment that is expensive to operate and maintain and with limited availability (Eg. Engine test cell simulator). Value will vary by simulator application and cost and availability of the real world system it replaces.

- Reduction of cost and time in development of aerospace product design along with improvements in design quality and early identification of manufacturing challenges. This technology is becoming increasingly important and is necessary to maintain competitiveness in product / component design.

- Ability to take both design data and 3D component scan data (in the absence of design data) to reduce development time/cost and increase effectiveness of manufacturing, operation and maintenance instructions and training.

- Identification of training programs that this technology could be applied to. This may be an opportunity to develop a tech demonstrator that rolls directly into a training program.

- Versatility – capability to incorporate interactive software to work with tablet, VR goggles, and other emerging delivery systems.

4. Importance and Breadth of Application:

These technologies are required by:

- OEMs are beginning to utilize this technology now in the development of next generation aerospace products. The following key growth opportunities are available in the next 5-10 years in the event that Manitoba aerospace companies develop and grow this technology:

    - Support OEMs in ‘build to spec’ work as well as full design and certification of aircraft components and reduce cost and time in developing tech docs for maintenance, assembly, and operation.

    - Provide the service of developing VR/3D interactive tech docs for new and legacy aerospace products. OEM targeted.

    - Be a world leader in the unique technology of engine test cell simulator training.

    - Employ this technology in reducing cost and time in the development of skilled technicians needed in Manitoba aerospace today and in the future.

- This technology is critical to OEM, suppliers, MRO, Training organizations, operators, regulators.

The likely outcomes if this technology is not available to, or implemented by the Manitoba aerospace industry:

- Loss of competitiveness at the design house level.

- No incremental improvements in the training and development of MRO and manufacturing technicians.

- Loss of new incremental business (Test cell training sim, tech doc development service).

- Lack of skilled workers vs industry requirements. With this technology, it may be possible to quickly train and redeploy workers from other industry sectors (eg. Automotive).

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Enhanced Technical Instructions and VR Training*

---

5. Alternatives:

Technologies or non-technological solutions that could be applied as a potential substitute for this technology:

None. This is a clear progression based on emerging/developing computer technologies.

Competing technologies:

None. This is a clear progression based on emerging/developing computer technologies.

6. Availability, Maturity and Risk:

Availability:

- Aerospace and automotive OEMs. Ref. www.sae.org/events/arvr/
  Boeing, EADS, Rockwell Collins, Sikorsky..
- Software companies working on this technology.
    - NGrain (Canada) – 3D IETM Software
    - Bluedrop (Canada) – 3D visualization and training Software
    - CAE (Canada) – Some maintenance training programs utilizing in-house 3d Simulator technology.
    - Christie Digital – Display and projection technology. Hardware.
    - Barco (Projection and VR systems). - Hardware
    - Siemens (NX simulation suite) – Software
    - TWB Aerospace and Defense (develops tech docs for OEMs). (India, Israel, us). – IETMs.
    - I3M Aerospace Multimedia (France). IETMs.
    - Cortona3D – 3D software, geared to training. Also has software for the development of 3D IETM documentation.

7. Costs:

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:

- The necessary software, hardware, and techniques are being developed by a multitude of companies in a variety of industries today. The key goal would be to partner with a leader and use the technology to develop the unique or local business needs for the technology:

  - Specific training applications needed for developing technicians in areas of critical skills gaps or shortages.
  - Engine test cell simulator training
- One possibility is to utilize the existing ITC VR equipment to put together a tech demonstrator and provide some VR training to GTRO classes. Cost would be associated with the development of the training material. Estimate cost below $200K.
- 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. The US military is developing a state of the art system for infantry training that is expected to cost $57 million (upper end of the scale). Timeline could be quite short at 5 years since capable VR systems are currently available.
- The cost would not be associated with developing the core enabling technology (the VR delivery system itself), the level of existing competition and development here puts this beyond the scope of what member companies would be expected to support.

8. Collaborators and Development / Implementation Strategy:

The development of this technology is a good candidate for multi-partner / multi-disciplinary collaboration because:

- Development of many of the core software and hardware capabilities are beyond the scope and capability of member companies (Applies to IETM and VR training).
- The software and hardware needed (IETMs and VR training) has already been developed to some extent in other industry areas: medical, automotive, etc.
- Member companies bring the below applications and an understanding of OEM needs to the table.
- Project benefits are applicable to multiple Manitoba Aerospace companies.

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. Delivery methods could be pc based – geared to large classrooms or VR based with a simulation system being used. Cost would be largely dependent on delivery method and software package – VR or PC based (more like IETM). If ITC VR equipment could be utilized, the cost could be reduced to less than $20K. If a VR

system is purchased specifically for the training program, the cost would be in the hundreds of thousands.

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. The OEM participation element of this project would be critical in its funding (need a customer!). Cost is heavily dependent on delivery method, fidelity of the simulation and how closely engine characteristics would need to be modelled. Estimate cost between $50K for a PC only based simulator to over 0.5 million for a control cab based simulator with all controls.

Strategy 3: IETM based training.
Partner with an Engine OEM and software provider (NGrain, Cortona3D, Panametric Technology Corp - Arbortext) to develop an IETM based training module geared towards improving and accelerating training on a particular aerospace product. IETM obviously would not be the product manual, but the training material would be presented in an interactive way to have the students work through maintenance and troubleshooting operations. Cost could be significantly reduced if the partner OEM provides funding for the project as something they can incorporate into their own factory approved training program. Estimated cost between $100-$200k primarily in software and labor to document engine maintenance data.

9. References:

MTC UK – Manufacturing Technology Center - manufacturing simulation. Coventry UK.

News & Home website – Barco supplies VR system to Commercial Aircraft Corp of China. (http://www.barco.com/en/News/Press-releases/Barco-Installs-the-First-Simulation-and-Virtual-Reality-Training-System-for-Chinas-Commercial-Aviati.aspx)

Using Virtual Reality technology for aircraft visual inspection training: presence and comparison studies – Dept of Industrial Engineering – Clemson University. Ergon, November 2002; 33(6):559-70. (http://www.ncbi.nlm.nih.gov/pubmed/12507340)

AMRC UK – University of Sheffield Advanced Manufacturing Resource Center – Website. VR in support of iterative product design, assembly process design and training, maintenance simulation and remote support. (http://www.amrc.co.uk/research/support/vr/)

News and Home Website : NGRAIN (Vancouver, Canada). – *The Honourable Christian Paradis, Minister of Industry, today announced a repayable contribution of $9.5 million to NGRAIN (Canada) Corporation.* (http://news.gc.ca/web/article-eng.do?nid=753149)

MIL-PRF-87268A (US Military), S1000D (International Committee), AITRAM (VR Training – Europe) IETM Standards.

Virtual Reality Training Improves Operating Room Performance Results of a Randomized, Double-Blinded Study; Ann Surg. 2002 October; 236(4): 458–464. (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1422600/)

New Approaches for Navy Technical Training and Job Performance Aiding Using Expanded IETM Technology;
Eric L. Jorgensen and Joseph J. Fuller, NSWCCD Code 2052, October, 1996
(http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC0QFjAA&url=http%3A%2F%2Fwww.dtic.mil%2Fcgi-bin%2FGetTRDoc%3FAD%3DADA445758&ei=yQNgUuiyFeerjAK84oCICA&usg=AFQjCNHSzbEbuCQT-7Pkzxn5uLhgyv2rTw)

Proposed DoD Guidelines For Implementation Of A Web-Based Joint IETM Architecture (JIA) To Assure The Interoperability of DoD IETMs
Eric L. Jorgensen, Carderock Report NSWCCD-20-TR-1999-12+TR, August 1999

10. Contacts:

Michael Thomlinson –Industrial Technology Center.
Email: mthomlinson@itc.mb.ca, Phone: (204) 480-0351

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Simulation Platform for Complex Interconnected Systems*

1. Description:

Demands for ‘smarter’ and ‘greener’ aerospace products and processes have resulted in an increase of product and process complexity. Supporting this development requires better understanding of product designs and simulation methods.

These increases to product complexity come from the introduction of a higher number of integrated systems. In this context, a system is an interconnected and organized structure of ‘elements’ which work together for a common purpose and whose activities influence each other. 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). This advancement has led to complex control schemes and modes of operation, all of which need to be analysed in detail to ensure that the product will meet effectiveness and efficiency targets. However, some systems are currently too complex to effectively analyze with traditional simulation tools, and these require multi-discipline system level tools in order to be well understood.

The proposed technology is a simulation platform that enables high-fidelity representation of numerous systems simultaneously. It may be a multi-disciplinary tool, or a common interface that provides a mechanism for linking Bespoke detailed models and allowing them to exchange data.

Co-simulation of multiple systems by a single model may reduce the stack-up of conservatism at (sub)system interfaces, which can be a barrier to innovation, and this reduces the number of unnecessary concurrent simulations by different organizational groups. Ideally, co-simulation also eliminates the need to create reduced variants of an existing system (or component) models for incorporation into other systems’ simulations.

2. Impact on Economic Development for Manitoba

Development of system level simulation tools and analysis methodologies in Manitoba brings the following benefits:

- Competitiveness:
    - Better understanding of product and process functioning from a system level highlights areas for potential improvement.
    - Reduction in non-recurrent engineering (NRE) costs through:
        - Better understanding of product functioning from a system level can reduce the level required testing (more requirements validation by analysis) and/or aid in troubleshooting tests which return anomalous results
        - Reduction to the number of concurrent simulations

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Simulation Platform for Complex Interconnected Systems*

- Customer Concerns:
    - By applying the technology to MRO operations scheduling or to improve repair/overhaul processes there is opportunity to reduce time lost on the ground by aircraft requiring service.

3. Technology Performance Goals:

Key qualitative and quantitative performance objectives for the pre-competitive enabling technology as related to the application of the technology in Manitoba:

- Versatility – capability to represent a multitude of systems, physics based models (mechanical and electrical simulations), and production workflow models found throughout the aerospace industry
- Sensitivity studies – modification of variables and monitoring of system response
- Collaborative – Ability to create ‘design libraries’ is critical for multi-domain models. Allows for users of different disciplines to create the system/component models related to their area of expertise. A systems engineer/analyst can use the completed submodels to create the complete system model.
- Life-cycle simulation – predict how product performance changes throughout its design life due to wear and exposure to its operating environment
- Where control systems are included in the model, the ability to use the developed model real-time in the system software to provide greater autonomy is desirable (space segment in particular)

4. Importance and Breadth of Application:

This technology required:

- ASAP for greatest benefit. No firm deadline.

This technology critical to:

- OEM, suppliers, MRO

Without this technology, 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 a reliance on lengthy and expensive testing campaigns.

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Simulation Platform for Complex Interconnected Systems*

5. Alternatives:

No technologies are identified as competing or substitute technologies at this point.

6. Availability, Maturity and Risk:

Graphical system design tools currently in the market provide the closest approximation to the system simulation platform technology that is proposed. However, the available ‘modules’ within these types of software are typically a severely simplified or idealized representation of a type of component. Examples of this type of software include: Dymola, Imagine.Lab AMESim, LabVIEW, Simulink, Maplesim

- MapleSim is a Canadian product.
- Many tools of this type act as a front end to the modeling language Modelica

Currently it is difficult to integrate models developed with these software packages with external physics/multi-physics based solvers and finite element analysis (FEA) packages, particularly so for transient simulations. This interface would require development. But, with Dymola being owned by Dassault Systemes, and AMESim owned by SIEMENS, the expectation is that an interface between these tools and their parent companies’ multi-physics and FEA packages will be developed in the future

An alternative to the graphical system design tools listed above is agent based modeling techniques. This may be appropriate for some applications today, but are less intuitive and do not have the ability to be reused as easily as a graphical system design tool with a component library might be.

- Potential uses in spacecraft performance analysis (though graphical system design tools may be a better choice)
- MRO sector reliability and scheduling simulation is possible. Agent based models may be better than graphical system design tools for scheduling applications.

Overall risk of development here is moderate.

7. Costs:

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. It is possible that a company interested in developing the software would take it on as an internal development project in which case the external investment would be lessened.

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Simulation Platform for Complex Interconnected Systems*

---

8. Collaborators and Development / Implementation Strategy:

The staffing and business objectives of local aerospace companies preclude them from taking on the development of the simulation tools discussed in this report and making them commercially available. Collaboration with a simulation software company is needed.

Assembling a working group consisting of simulation specialists from local aerospace industry to define a set of requirements for the simulation platform, and discussing the feasibility of creating the tool with developers at Canadian simulation software companies (Maplesoft, Maya HTT Ltd, etc) is recommended.

As well, a close watch should be kept on the software offerings of companies such as Dassault Systemes and SIEMENS to see if interfaces between their multi-domain FEA tools and graphical system design tools are further developed.

Workshops and short courses providing hands-on exposure to current graphical system design tools are recommended to increase awareness and adoption of such tools in local industry.

9. References:

N/A

10. Contacts:

Doug Roberge, StandardAero, Phone: (204) 308-7322,
Email: doug.roberge@standardaero.com

Nick Bellinger, NRC, Phone: (613) 993-2410, Email: nick.bellinger@nrc-cnrc.gc.ca,

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Modelling of New and Emerging Composite Materials*

---

1. Description:

- Next generation aircraft and engine designs are utilizing more composite materials. In addition to higher content of composite materials for specific applications, new material forms and material systems are being investigated. The Manitoba aerospace industry has identified composites produced using 3D preforms, and ceramic matrix composites as areas of high importance to the future of the 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 ceramic matrix composites are not as mature and not utilized within Manitoba aerospace companies. In order to support organizations in design and manufacture of 3D preform and ceramic matrix composite (CMC) components, simulation tools to support engineering analysis as well as process modelling are required.

- Simulation of these material systems can be broken into systems to support engineering analysis, and systems to support process modelling.

    - Engineering analysis requires reliable materials models, modelling techniques, and understanding of failure mechanisms for the material forms/systems

    - Process modelling systems allow for reliable simulation of process parameters and their impact on the final product. In the case of 3D preforms, the modelling systems required are available individually (braiding simulation, permeability and flow modelling, cure modelling, shrinkage/warping models) but require separate systems that do not communicate with one another. A single system to simulate and provide reliable results is not currently known to be available.

    - Process modelling for ceramic matrix composite systems is an area that is currently being researched by a number of organizations but to this point has not resulted in commercial software that could be adopted by potential manufacturers of ceramic matrix composites. Some aspects of process modelling of ceramic matrix composites (braiding, permeability and flow modelling) may be similar to those required for process simulation of polymer matrix components using 3D preforms.

- The composite materials and processes of interest (3D preforms and CMCs) have been highlighted by the Composite Thrust Area Working Group as being high priority technologies. The simulation techniques are intended to be tools to support development of these composite technologies if they are pursued by local industry.

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Modelling of New and Emerging Composite Materials*

---

2. Impact on Economic Development for Manitoba

Key reasons why this technology is critical for the economic development of the Manitoba aerospace industry

- The areas of composite simulation identified correspond with high priority thrust areas determined from the composites working group. The ability to utilize the processes and materials will be limited without the ability to perform engineering analysis and design activities to incorporate them effectively.

- The adoption of new manufacturing processes such as the manufacture of CMCs carries with it high risk and development cost. Utilization of process simulation can greatly reduce the costs and risk in developing or adopting manufacturing for a new component. Process simulation tools give a competitive advantage to those who have them due to reduced cost and development cycles

- In development in this area, companies or regions with supporting simulation tools to reduce risk and development time will have a large advantage in being able to capture new work scopes. This also adds more value that they can bring to a risk sharing partnership with OEMs to develop and manufacture next generation components for high temperature applications. It allows them to bring something to the partnership that other competing organizations may not be able to bring.

- The use of 3D preforms and CMCs are expected to continue to increase with next generation engine and structure designs. For organizations looking to adopt these manufacturing processes, having reliable software tools to support the design and manufacture of components will be of great importance to help reduce risk and manufacturing development costs.

3. Technology Performance Goals:

Key qualitative and quantitative performance objectives for these pre-competitive enabling technologies as related to the application of the technology in Manitoba:

- Develop and verify process modelling software for CMCs. This will include prediction of the impact of process parameters on final part geometry and performance.

- Structural analysis techniques and failure prediction for CMCs

- Develop and verify process modelling software for 3D preforms. This includes production of the preform itself, as well as production of the composite components. Aspects to the process model will likely include braiding simulation, permeability prediction, injection/flow analysis, and cure process modelling. Individual software solutions can currently simulate many of the process steps individually but no system is known to exist which can simulate the entire process and link the structural analysis directly to the preform design and processing.

4. Importance and Breadth of Application:

- The composite simulation technologies address two areas identified by the Composite Thrust Area Working Group as high priority composite technologies. The importance of simulation technologies in these areas is contingent on members of the Manitoba aerospace sector actively pursuing the development of the composite technologies.

- The development timeline for the simulation technologies should be prior to full adoption of the composite technologies themselves by local industry. Development of the simulation solutions during the earlier stages of developing capabilities with the composite manufacturing technologies can reduce the risks and development times which are required for implementation of these technologies.

This technology is critical to:

- OEM, suppliers. Potentially MRO's on development/risk reduction in repair processes.

Likely outcomes if this technology is not available to, or implemented by the Manitoba aerospace industry:

- The competitiveness of Manitoba aerospace companies to support upcoming opportunities utilizing these material systems will be diminished. The trend has been for OEMs to look for risk-sharing partners in the development of next generations systems. Not having simulation tools to support this will reduce the attractiveness of involving Manitoba companies in these proposed partnerships.

5. Alternatives:

Technologies or non-technological solutions that could be applied as a potential substitute for this technology:

- There are no competing technologies.

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Modelling of New and Emerging Composite Materials*

6. Availability, Maturity and Risk:

Analysis platforms for conventional composite materials are widely available from a number of software providers and considered to be a mature technology. This includes both structural analysis tools as well as process simulations. Composite structural analysis solutions are integrated into most commercial FEA systems and stand-alone software for performing analysis and sizing of simplified structures. Such systems and software are commercially available. Process modelling of conventional composite materials is performed by organizations using in-house systems as well as commercially available software. In the case of both ceramic matrix composites and analysis of composites utilizing 3D preforms there are not widely utilized and trusted systems.

Ceramic matrix composites will see increased use in the next generation of engine programs. Simulation of the components and manufacturing processes are becoming an area of interest to a number of organizations. Research organizations in both Canada and the United States have been working in the area of ceramic matrix composite structural and process modelling in recent years. Development to this point has not produced known commercially available software that can produce reliable results. The development of reliable modelling techniques for CMCs is viewed to be a medium risk item due to the potential for development to take longer than anticipated. 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 that connects the systems together is known to exist. Approaches for simulating and analyzing 3D composite systems with varied material properties throughout the component have been developed for short-fiber reinforced injection molded thermoplastics. It is believed that simulation of systems utilizing 3D preforms may have some additional complexity but the overall flow of analysis and techniques in mapping data could be utilized in a similar manner. 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.

7. Costs:

The costs associated with developing simulation methodologies are highly dependent on the ability to combine the simulation development work with a larger demonstration program. Development of a reliable analysis system for a new material or process requires verification through testing for structural analysis aspects, and the ability to access facilities with capable manufacturing systems to develop and validate process models. As the benefits of development and adoption of the modelling techniques is related to utilization of the composite technologies by Manitoba companies for which development programs are required, the approach of completing the modeling development work as part of a large program is a suitable approach.

A ROM (Rough Order of Magnitude) estimate of the cost to develop simulation tools for CMCs is $2M-$3M with a timeframe of 2-3 years. The ROM cost for development of 3D preform analysis methodologies is estimated to be under $1M over a 2 year timeframe assuming the program includes testing and validation on top of software development. The cost for each is dependent on the ability to access facilities with manufacturing capabilities and expertise in the processes. If the simulation tools are developed as part of a larger collaborative development program utilizing the manufacturing technologies, the costs may be reduced as test and validation articles would be manufactured as part of the development program and could be used to support simulation development. This could significantly reduce the cost to produce components required to support only the simulation aspects.

8. Collaborators and Development / Implementation Strategy:

Identification of partners involved in collaborative development would depend on the type of materials for which the simulation is being developed. For ceramic matrix composites, the main partners would be engine OEMs, potentially universities and NRC, and software development companies. Companies with specific experience in modeling of CMCs through previous research contract awards (Altasim) would provide high value to a collaborative program. Additionally, larger software providers (Siemens, Dassault Systemes) would be valuable for integration of software solutions with commercial packages used by local industry.

For development of 3D preform modelling, additional collaborators are required in the areas of modelling textile braiding/weaving, flow modelling, and modeling of materials with complex 3D microstructures. Examples of organizations with experience in these areas are:

- ESI Group – modelling of braiding process and RTM process modelling
- E-Xstream Engineering –3D mapping of material properties based on injection molding simulation and analysis of materials with complex 3D microstructures

THRUST AREA WORKING GROUP:	*Simulation Modeling & Analysis*

CRITICAL TECHNOLOGY:	*Modelling of New and Emerging Composite Materials*

Development programs for analysis of 3D preforms are based mainly on integration of software solutions to meet requirements of industrial partners and would likely require the participation of larger software providers.

The development of simulation tools for new and emerging composite materials are best approached by including a simulation component in a larger development program based around the new composite technologies. 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.

Simulation technologies described were selected based on composite manufacturing technologies highlighted by the Composite Thrust Area Working Group. Any development on the simulation tools is intended to be in direct support of local industries developing capabilities with the highlighted composite manufacturing technologies and is not intended to be viewed as a stand-alone analysis development program.

9. References:

N/A

10. Contacts:

Doug Roberge, StandardAero, Phone: (204) 308-7322,
Email: doug.roberge@standardaero.com

Nick Bellinger, NRC, Phone: (613) 993-2410, Email: nick.bellinger@nrc-cnrc.gc.ca,

Manitoba's Aerospace Technology Roadmap - Test and Certification Working Group - Technology Streams - Ranking

	Technology	Current Capability in Manitoba	Value of the Technology to Manitoba	Cost	Timeline	Scoring	Rank	
1	*Ice Crystal Testing Methodology*	4	5	1	10	20	4	
2	*Use of Analytical Evaluation to Demonstrate Equivalency to Regulatory Requirements*	1	8	1	1	11	9	
3	*Engine Testing Simulator - Development of Data Acquisition Systems for Engine Test Modelling*	7	8	3	5	23	3	
4	*Ingestion Testing Modelling*	5	2	7	10	24	2	
5	*Fuel Testing and Evaluation (Ice, Biofuels)*	2	7	3	5	17	6	
6	*Development of Emerging Ingestion Tests (Volcanic Ash, Sand Ingestion)*	4	5	1	5	15	7	
7	*Health Monitoring of Test Sites (Infrastructure)*	8	2	8	10	28	1	
8	*Improvement of Efficiency of Test Sites (Wireless Communication, Robust Instrumentation, Robust High Speed Video)*	6	8	5	5	24	2	
9	*Health Monitoring of Engines to Develop Engine Maintenance Scheduling*	5	1	5	1	12	8	
10	*Custom Design of Specialized Instrumentation*	7	2	5	5	19	5	
11	*Component Testing of Aerospace Materials*							* May be a consideration after environmental scan
12	*Icing in Fuels*							* May be a consideration after environmental scan

*** Rank each category from 1 to 10 per scale under each category*	1 = No capability 5 = Some capability, but further development required 10 = Current capability recognized in Manitoba	1 = Small markets, low economic impact 5 = Medium market requirement, med. economic impact 10 = Large market, high economic impact	1 = High Cost 5 = Medium Cost 10 = Low Cost	1 = Greater than 10 years 5 = Within 5 years 10 = 18-24 months

THRUST AREA WORKING GROUP:	*Test & Certification*

CRITICAL TECHNOLOGY:	• Gas Turbine Testing Simulator

1. Description:

This report describes the requirement for a gas turbine testing simulator to support effort's in Manitoba to train engine test technicians and engineers to support both Manitoba's certification and production test facilities. The gas turbine test simulator for turbofan and turboshaft engines would create a virtual test that would enable operators to practice engine test procedures under normal and emergency situations. It would also prove to be a training ground for the timing of critical certification tests including icing, ingestion, and blade out procedures.

2. Impact on Economic Development for Manitoba

This technology would enable Manitoba to train test technicians and engineers in a more environmentally accepted way than what is currently done. This simulator would prepare and train our workforce in Manitoba to different types of engine testing situations. It would also bring forth the expertise in Manitoba at a quicker rate to be able to better support production, development and certification testing efforts currently underway in Manitoba. In addition to growing jobs in Manitoba, with the capability to provide a Manitoba solution for training the workforces for testing production and development engines, this technology could be marketed for use at other test cells around the world support OEMs, MROs, and Major Airlines.

3. Technology Performance Goals:

Develop software for engines tests for a variety of different turbofan and turboshaft engine models for use in certification and aftermarket situational testing.

Acquire data from a variety of different engines from the major OEMs for use in the simulator.

Build a test simulator test cell as part of a technology demonstrator project or In stages to progressively meet the business and training needs of interested collaborators as funds become available.

4. Importance and Breadth of Application:

Timing - Certification: 2 years – This technology should be in place in time for emerging test requirements by the FAA and the engine OEM's

Timing – Aftermarket (MRO) – 3 years – Once proven for use in certification test training, this could be commercialized to MRO's and airlines.

This technology would be important to OEMs (RR, PW, GE), MRO organizations, and Airlines. Such capability in Manitoba would significantly assist the global competitiveness of StandardAero's MRO capabilities in turbofan and turboshaft product lines, and would have a very positive impact on jobs retention and growth.

If the development of training tools is not incorporated into Manitoba, some of the highly skilled jobs to be developed and filled by Manitoban's would go to others from outside of Manitoba.

Potentially, for certification testing the OEM's could utilize their own people resources. The knowledge base would never be developed in Manitoba.

5. Alternatives:

Without an engine testing simulator, training would continue to be performed on the job using actual engines. There is some risk associated with this. Damage to an engine caused by operator error during certification or production testing, could be extremely costly to the OEMs and MROs. , as a result of delay penalties exacted by airframe manufacturers and operators. Training of technicians and engineers in a simulated environment would consume less fuel, result in fewer emissions and be better and greener to the environment.

6. Availability, Maturity and Risk:

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

Aero Systems Engineering has worked with GE on an engine test simulator (ASE2000/SIM). This is a very costly system (>$2M per unit) and is specific to GE engines.

The incremental technologies that must be developed in Manitoba would be:

- Application of certification test simulation into software.
- Development of simulation capability to train for testing of all types of OEM engine models including production testing of turboshaft engines.

Technological risk: Medium

7. Costs:

Cost estimates:

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

Collaborators and Development / Implementation Strategy:

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 to evaluate options 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.

Define needs, timelines, resources

Establish funding and timelines

8. References:

List of pertinent documents. TBD

9. Contacts:

Resource persons for further information:

Brent Ostermann, StandardAero, 204-318-7524, brent.ostermann@standardaero.com

Vic Gerden, WestCaRD, 204-471-9979, vicgerden@mts.net

THRUST AREA WORKING GROUP:	*Test & Certification*

CRITICAL TECHNOLOGY:	• Improvement of Efficiency of Test Sites (Wireless Communication, Robust Instrumentation, Robust High Speed Video)

---

1. Description:

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.

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

Three Technology Performance Goals are identified for this Thrust Report

1. Develop/install robust sensors, including wireless in Manitoba engine test cells;
2. Develop/ adapt/ adopt wireless transmission of data capability in Manitoba engine test cells;
3. Develop expertise in analyzing high speed imaging and near real time transmission of high speed video.

4. Importance and Breadth of Application:

Timing: these technologies should be developed within two years to accommodate ingestion testing. These technologies could eventually also be used in multiple test cells - (100s) globally.

Relevance: OEMs (RR, PW, GE), MDS Aero, StandardAero, MRO organizations, Manitoba IT companies (Iders, Parker, etc.)

If this technology is not available to, or implemented by the Manitoba aerospace industry:

- some of the testing will go elsewhere instead of Manitoba;
- Manitoba industry would lose the opportunities to commercialize the associated technologies.

THRUST AREA WORKING GROUP:	*Test & Certification*

CRITICAL TECHNOLOGY:	• Improvement of Efficiency of Test Sites (Wireless Communication, Robust Instrumentation, Robust High Speed Video)

---

5. Alternatives:

Other technologies or non-technological solutions that could be applied as a potential substitute for this technology:

- 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. There is an opportunity to capitalize on the existence of multiple, costly engine test cells to grow the type and amount of testing taking place in Manitoba.

Competing technologies:

- 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.

6. Availability, Maturity and Risk:

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.

Risks include: high temperature environments, noise. EMI, line of sight limitations, etc.

Technological risk: medium

7. Costs:

Cost estimates:

To develop/install robust sensors including wireless in Manitoba engine test cells:

- $2M – 3years (would take about six months to determine objectives and develop the sensor specifications)

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

THRUST AREA WORKING GROUP:	*Test & Certification*

CRITICAL TECHNOLOGY:	• Improvement of Efficiency of Test Sites (Wireless Communication, Robust Instrumentation, Robust High Speed Video)

---

8. Collaborators and Development / Implementation Strategy:

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

Potential organizations:

- Industry: engine OEMs, RR, PW, GE, StandardAero, MDS Aero, IT Companies
- Research organizations: NRC, ITC, NASA
- Educational institutions: U of M, Red River College, other universities, CRIAQ,
- NPOs: WestCaRD, EnviroTREC, ICTAM, MAA
- Government funders: Industry Canada, (tech demo program?) Prov of MB,

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

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

9. References:

Navy SBIR N08-004, N68335-08-C-0267, "Thin-film High Temperature Sensors

Air Force, SBIR AF112-175, FA8650-11-M-5146, "Passive Wireless Sensors for Extreme Turbine Conditions

Dai, X.; Mitchell, J.E.; Yang, Y.; Glover, I.; Sasloglou, K.; Atkinson, R.; Panella, I.; Strong, J.; Schiffers, W.; Dutta, P., "Development and validation of a simulator for wireless data acquisition in gas turbine engine testing," *Wireless Sensor Systems, IET* , vol.3, no.3, pp.183,192, September 2013
doi: 10.1049/iet-wss.2012.0064

10. Contacts:

Brent Ostermann, StandardAero, 204-318-7524, brent.ostermann@standardaero.com

Vic Gerden, WestCaRD, 204-471-9979, vicgerden@mts.net

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Custom Design of Specialized Instrumentation*

---

1. Description:

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
- Others

2. Impact on Economic Development for Manitoba

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.

3. Technology Performance Goals:

Three Technology Performance Goals are identified as serving this Thrust Area.

1. Develop specialized instrumentation to meet changing/new test requirements.
2. Test specialized instrumentation in Manitoba test cells (GLACIER, GE TRDC, StandardAero, MDS Aero Support).
3. Market instrumentation globally.

4. Importance and Breadth of Application:

New and improved methods for measuring and monitoring engines undergoing test are required now and into the future depending on the specific testing parameter.

For example, turbine exhaust particulate matter is a test measurement requirement currently being considered by the FAA. Instrumentation to measure this particulate matter must be developed in conjunction with the FAA's consideration of this parameter.

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Custom Design of Specialized Instrumentation*

If and when an FAA regulation on particulate matter emissions testing is released, instrumentation to measure such conditions must be available to industry.

The timeline for development of specialized instrumentation could vary from 2-5 years.

These instrumentation technologies are critical to OEMs, MRO organizations, and Test Cell design firms to meet current and future Regulatory Requirements and to reduce both engine testing time and costs.

If these new instrumentation technologies are not available to, or implemented by the Manitoba aerospace industry to support both the certification and production test facilities, there is a risk that these facilities will not be able to operate in accordance with Regulatory Requirements and that costs and time required to perform testing will be higher due to a lack of state-of-the-art equipment.

5. 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.

6. Availability, Maturity and Risk:

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).

PIWG is US based; EVI-GTI is European. Both PIWG and EVI-GTI are collaborative organizations that include OEMs, Industry partners, Government, and Academia, and work together to further gas turbine instrumentation development.

Please see the following websites for information on the current capabilities and technology development areas of these organizations.

www.piwg.org

www.evi-gti.com

Incremental capabilities will be dependent on the specific test instrumentation technologies that are selected for development in Manitoba.

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 will require additional testing and OEM approval.

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Custom Design of Specialized Instrumentation*

---

7. Costs:

Costs are estimated to be:

- $1-2 million per instrumentation technology over a 3 year period

8. Collaborators and Development / Implementation Strategy:

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

The major steps required to support a collaborative effort include:

- Introduce Manitoba partners to both PIWG (completed in Feb. 2013) and EVI-GTI (TBD)
- Determine key area(s) of support that a Manitoba partnership could provide
- Establish membership with suitable organization (PIWG or EVI-GTI or both)

9. References:

www.piwg.org

www.evi-gti.com

10. Contacts:

Brent Ostermann, StandardAero, 204-318-7524, brent.ostermann@standardaero.com

Vic Gerden, WestCaRD, 204-471-9979, vicgerden@mts.net

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Emerging Aero Engine Tests*

---

1. Description:

This report describes new civil aero engine test capabilities that stake holders, most significantly engine OEMs, want to add to the outdoor development test beds in Winnipeg (GE's TRDC) and Thompson (GLACIER {PW and RR} Test Facility).

Systems to perform current Certification tests for water and hail ingestion are required – water at Glacier facility, and hail at both Glacier and GE facilities.

Systems to perform future Certification tests for ice crystal and volcanic ash are required at both Glacier and GE facilities.

Turboshaft test facilities are also needed to exploit opportunities for other new MRO product lines in Manitoba.

2. Impact on Economic Development for Manitoba

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.

Economic spin-offs in the areas of operations support, lodging and infrastructure support.

Substantial MRO is carried out in Manitoba on various gas turbine engines including turboshaft engines. Having appropriate test production test facilities and trained operators is critical to remaining competitive, maintaining and creating jobs in the MRO sector.

3. Technology Performance Goals:

Compliance to established Regulatory Standards for engine certification (water and hail ingestion)

- Install water ingestion system at Glacier facility
    - RR and PW have existing designs, but merging and scaling may be required
- Install hail ingestion system at Glacier and TRDC facilities
    - RR and PW have existing designs, but merging and scaling may be required
    - GE should have an off-the-shelf design

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Emerging Aero Engine Tests*

Compliance to future Regulatory Standards for engine certification (ice crystal and volcanic ash).

- Install ice crystal system at Glacier and TRDC facilities
    - Develop ice crystal ingestion technology
    - Design and build ice crystal systems
    - Install, commission and calibrate systems
    - Demonstrate systems to Regulatory Bodies
- Install volcanic ash ingestion system at Glacier and TRDC facilities
    - Participate with Regulatory Bodies in the development of the Standard for volcanic ash ingestion
    - Develop volcanic ash ingestion technology
    - Design and build volcanic ash ingestion systems
    - Install, commission and calibrate systems
    - Demonstrate systems to Regulatory Bodies
- Capability to test turbofan and turboshaft engines for production and potentially development projects.
    - Create turboshaft engine testing capability

4. Importance and Breadth of Application:

The approximate timelines for having these regulatory test technologies in place are as follows:

Water and hail ingestion – 1 to 2 years
Ice crystal ingestion – 3 to 4 years
Volcanic ash ingestion – 4 to 7 years

Water and hail ingestion technologies are established. Approximate cost of outfitting each test facilities is: water - $1M; hail $2.5M.

Ice crystal and volcanic ash ingestion technologies are new, and would require design ‘from the ground up.’ Approximate cost of outfitting each test facilities is: ice crystal - $5M; volcanic ash $5M.

New technology for ice crystal and volcanic ash should be developed with scalability in mind such that the same methodology could be employed at smaller test facilities, testing smaller engines, world-wide.

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Emerging Aero Engine Tests*

These test technologies are critical for OEMs both currently, and to meet future Regulatory Requirements.

If these technologies are not developed and delivered to these world-class test facilities, the OEMs will add these capabilities to test facilities outside Manitoba. As such engine test, and associated research, development and test support dollars will be spent outside of the Province. Opportunities to further showcase Manitoba as an aero engine test centre of excellence will be lost.

The timeline for creating a turboshaft engine test facility would be 1-2 years.

5. Alternatives:

Alternatives don't exist since the requirement to perform Certification Tests are mandated by aviation's Regulatory Bodies. Analytical methods may be acceptable for ice crystal ingestion; previous experience may also be applicable. Acceptability of these alternatives is at the discretion of the Regulatory Bodies.

6. Availability, Maturity and Risk:

Water and Hail Ingestion:

- OEMs already have designs for water and hail ingestion.
- Engineering effort would be required to generate designs specific to the Glacier and TRDC facilities.
- In the case of the Glacier facility RR and PW may work with a third party to combine their design knowledge to create a hybrid for Glacier.
- Knowledge base is being lost at OEMs due to retirements
- Technological risk is low

Ice Crystal Ingestion:

- The NRC is doing research into methods of creating an ice crystal cloud suitable for ingestion
    - A workable method that can be scaled up to meet the requirements of large turbofan engines must be identified
- OEMs are aware that Regulatory Bodies may soon mandate this as a Certification Requirement – therefore motivated to collaborate on solutions
- There is an opportunity for collaboration in Manitoba
- Technological risk is moderate

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Emerging Aero Engine Tests*

Volcanic Ash Ingestion:

- Technology is in the early stages of development
    - Technology previously used for sand ingestion could be adapted
- The April 2010 eruption of Eyjafjallajökull (E15) that shut down European airspace has prompted discussion of mandating volcanic ash ingestion tests
    - All civil aviation stakeholders, including engine OEMs are keenly aware of this threat, and motivated to collaborate towards workable solutions
- Technological risk is moderate, however Regulatory Bodies may not mandate this type of test

Turboshaft Testing Facility

- The technological risk would be low as the technology exists

7. Costs:

Costs 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 1-3 – gas turbine/turboshaft test facility

8. Collaborators and Development / Implementation Strategy:

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

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

As a means of maximising collaborative effort, and minimising costs, the design and supply of portable test systems that could be shared by the TRDC and Glacier test facilities should be considered.

THRUST AREA WORKING GROUP:	*Test and Certification*

CRITICAL TECHNOLOGY:	*Emerging Aero Engine Tests*

Turboshaft Test Facilities

- Collaborative: StandardAero, Red River College, University of Manitoba, NRC, potentially OEMs as customers

9. References:

FAR 33; EASA CS-E

10. Contacts:

Brent Ostermann, StandardAero, 204-318-7524, brent.ostermann@standardaero.com

Vic Gerden, WestCaRD, 204-471-9979, vicgerden@mts.net

Don Pereira, MDS AeroTest 204-778-6352 ext 2222, don.pereira@mdsaerotest.com

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Autonomy*

---

1. Description:

Autonomy permits a spacecraft (or other entity, with a control system, such as an aircraft, automobile, or machinery) 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. One of the challenges is to package the autonomy into very small and reliable computer processors that are tolerant of the demanding environment of space.

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. (For example - the SCISAT-1 spacecraft has completed 10 years on-orbit compared to a planned lifetime of only 2 years). The actual operations costs are typically outside of the control of the product supplier; however, additional autonomy allows for more efficient management of the anomalies onboard the satellite and undoubtedly reduces those costs.

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. From a spacecraft or aircraft perspective, this might include tolerance for sensor unavailability or variable sensor accuracy, as well as selection of less-costly/accurate sensors and using mathematical algorithms to improve the accuracy of the measurement.

Off-nominal (or anomaly), autonomy includes failure detection, isolation and recovery to either a “safe-hold” state or a fully operational state. This technology area includes both development of the autonomy methods themselves, as well as verification of the effectiveness, robustness, and safety of the autonomous responses.

Satellite technology is generally characterized by long dedicated mission cycles, in orbits ranging from 1,000 km to high orbits of 35,800 km (geostationary orbits). Technology purposed to these missions need to survive the hostile space environment consisting of in part, orbital debris and x-rays.

Most spacecraft being designed today have significantly higher levels of autonomy. In order to continue to compete in this market, Magellan Aerospace Winnipeg will have to catch up, keep up, and ideally lead, in this technology area.

2. Impact on Economic Development for Manitoba

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.

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Autonomy*

---

3. Technology Performance Goals:

Nominal Mission: (satellites)

- Algorithms (for use onboard): this software needs to be developed which will combine a variety of low cost sensors to provide attitude accuracy on a par with a commercial star tracker.
- Algorithms (for use onboard): this software needs to be developed which will combine a variety of low cost sensors to provide positional accuracy on a par with GPS.
- Algorithms (for use onboard): this software needs to be developed to maximize the output of the mission in the context of a number of competing observers with conflicting resource demands. An example of this would be when nine science experiments all want to look in a different direction at different times throughout the orbit. Priority would be defined in these cases as a response to the concurrent measurements.
- Algorithms for managing the anomalies onboard satellites. The outcome of such systems is the lifetime extension of the host satellites.
- Failure detection algorithms that can assess the state of the satellite and take appropriate actions. Algorithms need to be developed which monitor the health of the satellite and to correct for, or compensate for, orbital debris events.

4. Importance and Breadth of Application:

Satellite technologies are required within the next 2 years as the satellite industry is growing at a rate of 7% annually, with a current market size of $190B. Satellites are sold on a contractual basis to telco’s and governments as special purpose projects. There are few similarities between satellite contracts as technology has generally advanced between orders such that each configuration is unique.

5. 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.

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Autonomy*

6. Availability, Maturity and Risk:

Availability:

Satellites: are generally available and have a market size of $190 B.

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.

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.

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.

7. Collaborators and Development / Implementation Strategy:

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, which produce the same results. 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.

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Autonomy*

---

8. References:

So Young Kim; Castet, J.-F.; Saleh, J.H., "Satellite Electrical Power Subsystem: Statistical Analysis of On-Orbit Anomalies and Failures," *Aerospace Conference, 2011 IEEE* , vol., no., pp.1,12, 5-12 March 2011
doi: 10.1109/AERO.2011.5747465

Lambert, H.; Limouzin, G., "The Eads Astrium Astrosat Product Line A New Generation of High Resolution Small and Micro Satellites Embarking Innovative Technologies," *Recent Advances in Space Technologies, 2007. RAST '07. 3rd International Conference on* , vol., no., pp.9,13, 14-16 June 2007
doi: 10.1109/RAST.2007.4284105

Satellite Industry Report Shows Satellite industry Growth of 7% in 2012, http://spaceref.biz/2013/06/satellite-industry-report-shows-satellite-industry-growth-of-7-in-2012.html
Lin Lin; Sun Qibo; Wang Shangguang; Yang Fangchun, "Research on PSO based multiple UAVs real-time task assignment," *Control and Decision Conference (CCDC), 2013 25th Chinese* , vol., no., pp.1530,1536, 25-27 May 2013
doi: 10.1109/CCDC.2013.6561171

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Autonomy*

---

9. Contacts:

Diane Kotelko, Space Systems Engineer, Magellan Aerospace,
T: (204) 775-8331 Ext 3369, E: diane.kotelko@magellan.aero

Igor Telichev, Assistant Professor, University of Manitoba,
T: 204.474.9812, E: Igor.Telichev@ad.umanitoba.ca

David Bertin, Research Technologist, Red River College, T: (204) 632-3807
E: dbertin@rrc.ca,

Sylvie Beland, Director R&D Structures Materials and Manufacturing, National Research Council, T: (514) 283-9139, E: sylvie.beland@nrc-cnrc.gc.ca

MANITOBA AEROSPACE TECHNOLOGIES ROADMAP
CRITICAL TECHNOLOGY REPORT

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Unmanned Aerial Vehicles (UAV's)*

---

1. Description:

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 - providing ground and aerial gunnery a target that simulates an enemy aircraft or missile
- Reconnaissance - providing battlefield intelligence, border patrol service
- Combat - providing attack capability for high-risk missions (see Unmanned Combat Air Vehicle)
- Research and development - used to further develop UAV technologies to be integrated into field deployed UAV aircraft
- Civil and Commercial UAVs - UAVs specifically designed for civil and commercial applications (e.g. Pipeline oil spill monitoring, forest fire detection, etc.)

Some early UAVs are referred to as drones because they are no more sophisticated than a simple radio controlled aircraft being controlled by a human pilot or operator. More sophisticated UAV's will have built-in control and/or guidance systems to perform low level human pilot duties such as speed and flight path stabilization, and simple prescripted navigation functions such as waypoint following.

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). The company serves more than 750 clients in 65 countries worldwide and builds fixed and rotary wing UAVs for a variety of applications including the MP2028, which is the world standard for UAV autopilots. 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 which use autonomy and image processing to identify, decide, and then remain on-station irrespective of the mission cycle of one particular UAV.

2. Impact on Economic Development for Manitoba

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.

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Unmanned Aerial Vehicles (UAV's)*

---

3. Technology Performance Goals:

UAV's have technology performance challenges such as

- Managing the growing amounts of sensor data
- Leveraging technologies such as FPGAs and GPGPUs
- Handling streams of data from multiple sensors
- Finding the tools needed for effective image processing
- SWaP (Size, Weight and Power) and ruggedization
- Upgradability/scalability
- Meeting shortened design cycles
- Creating autonomous, networked UAV's to maintain a high level of presence in certain situations.
- Support survivability considerations such as stealth, impact assessment and drone recoverability,

Goals for these challenges are sequentially to:

a) Develop compact storage mediums
b) Complete beta testing of opportunities for field-programmable gate arrays and general-purpose graphics processing unit
c) Improve UAV on-board operating and autonomous systems
d) Consider COTS technologies, if downloading is possible, otherwise build more memory into hardware and add additional needed algorithms
e) Since size, weight and power (SWaP) trade-offs and ruggedization work against one another, new materials and miniaturization are common approaches to solve these challenges
f) Upgradability and scalability are solved as next generation processes. Once next gen technology is developed it is retrofitted and scalability of UAV's is done as payload requirements move up to a new category.
g) Shortened design cycles need to be solved as systems challenges, using common platforms, reducing iterations, and even using simulations.

4. Importance and Breadth of Application:

UAV's are an escalating and growing market. However most purchases here are for government and military use. New technologies are constantly being introduced here, such that the demand for new applications and innovations is immediate.

5. 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.

THRUST AREA WORKING GROUP:	*Space and Rockets*

CRITICAL TECHNOLOGY:	*Unmanned Aerial Vehicles (UAV's)*

---

6. Availability, Maturity and Risk:

Availability:

UAV's are also generally available and have a market size of $89 B.

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.

Costs:

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.

7. Collaborators and Development / Implementation Strategy:

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.

8. References:

Unmanned Aerial Vehicle (UAV) Market (2013 - 2018),
http://finance.yahoo.com/news/unmanned-aerial-vehicle-uav-market-201400403.html

Mapping Drone Proliferation: UAVs in 76 Countries
(http://www.globalresearch.ca/mapping-drone-proliferation-uavs-in-76-countries/5305191)

Technology Challenges in Small UAV Development, Michael Logan, NASA Langley Research Center; Thomas Vranas, NASA Langley Research Center; Mark Motter, NASA Langley Research Center; Qamar Shams, NASA Langley Research Center; Dion Pollock, U.S. Army, Chapter DOI: 10.2514/6.2005-7089, Publication Date: 26 September 2005 - 29 September 2005

Small UAV Payloads Wrestle with SWaP Challenges,
http://www.cotsjournalonline.com/articles/view/100869

---

9. Contacts:

Howard Loewen, President, Micropilot, T: (204) 344-5558, E: howard@micropilot.com

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

Manitoba Aerospace Association

EnviroTREC