APPENDIX C

Presentation of Thrust Area Working Group Reports

The following presentation contains seven Thrust Area Working Group Reports which were presented to the Manitoba Aerospace Research and Technology Committee, which is responsible for producing the Manitoba Aerospace Technology Road Map.

Appendix C – Thrust Area Working Group Reports

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ADVANCED MANUFACTURING

Thrust Area Working Group 1 (TAWG1)

Introduction

TAWG1 was assembled to consider revising their previous work under the Manitoba Aerospace Technology Road Map, which was published in 2014.

This team was to review the assigned key technology thrust areas, validate these, and provide updates as appropriate. To some extent, it was necessary to rebuild this team. Group members who had a grasp of this technical area and who may be able to ultimately benefit from the recommendations of this report were selected from Manitoba Aerospace Inc. membership. SME representation was also deemed to be important to achieve.

TAWG1 met and reviewed the previous work and recommendations. As a first order of business, the group chose to rename itself as "**Advanced Manufacturing"**. While this has overlap with other areas of the Technology Road Map, it was clear that most of the work effort, both previously and going forward, had more to do with manufacturing than machining (the group was formerly known as "**Advanced Machining**").

Several amalgamations from the former report structure were made and some new topics representing interests of the group were identified. The group also reconsidered its approach to several areas in the TAWG1 report recommendations. A number of amalgamations were made and some new titles were selected to represent these new areas of interest (see Table 1).

Technologies Considered

A set of seven technologies of interest in the field of Advanced Manufacturing for Manitoba were identified for the 2016 TAWG-1 update. These topics were consolidated and reduced from the previous set of eight. Table 1 is presented to demonstrate the difference between the considerations of 2014 and 2016.

Table 1: Comparison of the Technologies considered in 2016 versus the Technologies selected for consideration in 2014

New Areas of Interest: (2016)	Formerly Areas of Interest: (2014)
Inspection	3D Scanning, Automated Scanning, Non-Destructive Evaluation
Adaptive Machining	No Change
Additive Manufacturing	No Change
Machining Strategies	High-Speed Machining, Machining Strategies
Nanotechnologies	No Change
Joining	New addition
Post Processing	New addition

From this table, it is seen that two new topics of interest were considered: Joining and Post Processing. Otherwise, consolidation of 3D Scanning, Automated Scanning and Non-Destructive Evaluation took place and were reformed under the topic of Inspection. The revisions reflect the Group's consensus that the area of 'inspection' needed an integrated view rather than being fragmented into sub-topics and that the areas of 'Joining' and 'Post Processing' are new opportunities for development in Manitoba.

Technology Review Matrix

The TAWG1 group prepared and evaluated an updated Technology Review Matrix. The result of the matrix assessment is found at the end of this report and is titled "**Appendix A: Technology Evaluation Matrix Result from TAWG1**". Scoring and Ranking of the technologies was based on several factors, which included: Current research capability in Manitoba, Current manufacturing capability in Manitoba, Current economic value of the technology to Manitoba, Potential for growth of the technology in Manitoba, Potential for growth of HQP/HSP in Manitoba, Cost to implement, and Timeline to implement.

These Technologies were then scored with a minimal to maximal consideration between 1 to 10. Factored in afterwards was a Weight Classification which rebalanced the matrix to effectively demonstrate the value of each consideration to the group. In the end a score was achieved and following that, the highest scores were ranked.

Rankings which came from this process are identified in the following Table 2.

Table 2: TAWG1 Technology Rankings – Matrix Evaluation Output

Technology	Rank
Additive Manufacturing	**1**
Adaptive Machining	**2**
Inspection (NDT)	**3**
Machining Strategies	**4**
Joining	**5**
Post-Processing	**6**
Nano Technologies	**7**

Projects Approved and Activity since TRM 2014

Since the last TRM review, one key project from this technology grouping was approved for Manitoba. An investment in the order of $10M was made towards Additive Manufacturing (AM), and a new firm (Precision ADM) was created to support the development of this technology. At this time, the AM technology is being installed and commissioned. Support for this project was received from both the federal government (Western Diversification) and the province (Research Manitoba).

Additionally, the TAWG1 group met twice a year since the release of the TRM in 2014 to review their individual progress respecting the Technology Roadmap. It is anticipated that the TRM process going forward will require all TAWG teams to meet during the year to build a dialogue in the areas of interest and to formulate projects. TAWG members are in a very good position to address upcoming programs and to champion or evaluate opportunities for cross-company collaboration in their domains of technology interest.

Engagement of SME's

With respect to how SME's were engaged in this technology review process, two firms participated in this exercise as part of TAWG1. This represents a significant gain for SME inclusion and support. These SME priorities are embedded throughout the entire TRM-2016 process. The SME participants are identified in “Table 3: TAWG1 Participants,” which is listed at the end of this report.

TAWG1 Technology Priorities

1. Inspection

This area of interest combines the former (TRM 2014) areas of 3D Scanning, Automated Scanning, and Non-Destructive Evaluation. These technologies are considered to be necessary for the final inspection part of the manufacturing process. Most importantly these technologies need to be integrated into a combined solution in order to be effective. This presented a key problem to further development for TAWG1, in that while one company could manage or see its way to pursuing one of the technologies, the integration of all of the technologies was a skill found more in the digital domain rather than the manufacturing domain. This technology area of interest was ranked as having the third highest interest, but with no clear path to comprehensive solution from TAWG1. Individual technology elements are discussed below in more detail.

NDT, NDE and NDI are interchangeable terms use to identify as suite of inspection technologies such as ultrasonics, eddy current, x-ray and others used to characterize the condition of a part. The challenge of handling “hard to inspect” items is of interest to TAWG1 participants.

Automated scanning is an advancement on manual scanning techniques. The intent here is to integrate inspection with manufacturing so that decisions based on part condition and metrology can be made during the manufacturing process. The current view is that automated scanning needs to be able to work quickly.

Ultrasonic scanning was mentioned in this TAWG’s earlier report. We note now that Boeing is committed to this technology. The use of water to support this technique continues to be a distraction and improved coupling methods need to be developed.

Shape Grabber technology was discussed in this TAWG. This technology offers 1-micron resolution. It has a limitation of being able to support objects which fit into an 8” x 24” cylinder. To be effective this technology needs to interface with CAD systems. Precision ADM has the capability to do this for smaller objects. This size limitation needs to be addressed.

Our team notes that blue light is now in vogue for digital scanning. Blue light supports very fast scan routines. White light has been passed over, as it reflects excessively.

Lastly, Spin Testing was also raised as an opportunity within this area but it is a very expensive process. Spin Testing is often necessary at the end of the production process. Currently this test regime is not being performed in Winnipeg. The absence of this technology results in extra costs and turnaround times that need to be managed.

2. Adaptive Machining

Adaptive machining is typically used when individual components in a batch have slight geometric differences. Advanced Adaptive Machining technology integrates inspection and scanning systems, special software and an attendant computer integrated with a CNC machine's control to take executive control of the process, automatically modifying programmed tool paths to cope with subtle part-to-part variations. This technology was highly ranked as an opportunity for investment for TAWG1. Industry support is also indicated.

Adaptive Machining is important to the MRO industry, and had the support of both StandardAero and Boeing Canada. This technology was noted to have applicability in both the metals and composites area, where a product rebuilding process starts to take place. CAD is an important element to this rebuilding activity. A view was put forth, that this technology will need the support of an OEM for it to take hold. As such there are now several aerospace OEM's which have operations in Manitoba. Given that Adaptive Machining has applications in metal and composites, both of these materials can be supported through their respective OEM's.

Furthermore, it was suggested that Adaptive Machining has a learning and development process which could make it a candidate for the upcoming National Research Council's - Factories of the Future project. It was noted that the CATT Centre model would be particularly helpful for supporting this type of technology. The CATT model allows for research programs to be shrouded with a set of structured rules for usage.

An example was posed here was to use Adaptive Machining to enable Additive Manufacturing to be part of a repair of manufacturing process. In this case, 'Additive' steps would lay down a near net shape, with follow on machining, controlled adaptively to account for part variations.

3. Additive Manufacturing

Noted earlier, a considerable investment in metals based Additive Manufacturing was made since the TRM 2014 report. This technology is currently being commissioned for the health, transportation and aerospace sectors.

Plastic based AM is not being advanced at this time in aerospace and no related production capability is yet found in Manitoba.

As a general comment, AM – Metals offers high precision and high strength products. These parts can be deployed into unique aerospace and medical applications. It was noted in our group that 7 types of AM technologies are now available. Additive Manufacturing is more expensive than traditional casting machining operations and as such it has unique applications. The choice of material substrate only partly influences the total process costs and the entire system needs to be evaluated before starting down one path to create an end product. AM is complemented with either traditional machining or adaptive machining for purposes of finishing the product.

Another challenge to Additive Manufacturing is to keep the heat levels down to avoid materials distortion. An interest in cold metal transfer for certain parts was also indicated, so as to minimize materials distortion.

As a result of growing interest in AM in Manitoba, it is noted that Manitoba now participates on certain international standards creating bodies. ASTM Committee F42 on Additive Manufacturing Technologies was formed in 2009 and meets twice a year. This Committee has now also representation from Manitoba. The benefits from joining this Committee are building an appropriate network and building an appropriate knowledge base to support product development.

Heat treating is an important requirement in working with metals-AM. Heat treatment changes the internal metallic structure of the component and this change needs to be explicitly considered during the design process. Unlike traditional manufacturing where many parts are produced and heat treatment produces a known result based on previous experience, AM does not have this history, nor does the operator likely have the depth of experience. To this end a general heat treating capability was noted as being needed in our region.

Challenges presented with AM are that this technology requires an Intellectual Property management regime. As well, OEM support is needed to advance the technology.

Other considerations are that developing a user base is of interest to the new local participant in this field. As well, partnership opportunities could also support the development of this technology in the region. Collaborative investment can also be considered to extend the technology.

4. Machining Strategies

Both Cormer Industries and Magellan Aerospace have interests in High Speed Machining. Magellan's interest is for reasons of providing components for the F35 program, and Cormer for reasons of supporting their international customers.

Other areas of interest in this section are cooling approaches, high performance cutting of titanium and nickel alloys, surface enhancement of metallic materials, and toolpath optimization. Some of these areas of interest - particularly high performance cutting and toolpath optimization, would fit into the Factories of the Future technology set.

5. Nanotechnologies

The Nano-Systems Fabrication Laboratory (NSFL) continues to support the nanotechnology efforts of University of Manitoba researchers and others. While certain elements of the aerospace sector are interested in supporting this technology, our local industry is currently not in a position to do so. Our researchers advise that Nano films present opportunities which have applications for aerospace, such as dispersion of electrostatic charges and shedding ice buildup. The TAWG1 group notes that the Factories of the Future has a high interest in supporting Nanotechnology.

6. Joining

This topic was added to our report as certain work has become more complex, which, along with light-weighting projects for aerospace parts has resulted in the creation of some components which are very thin and need to be joined.

Joining considers the view that materials have 'skins' which need to be managed in the joining process. This is particularly important in complex parts. The application of heat in many joining processes, creates distortions in the end products which then need to be managed or at least corrected in the post operations cycle. Cold Metal Transfer was indicated to be of interest for further development.

The CATT center, which is a partnership between Red River College and StandardAero is one location where this development work is currently being conducted. Our working group notes that this technology is in need of a refresh.

7. Post Processing

This technology area is a new addition to the discussion in TAWG1.

Grouped into this topic were heat treating, isostatic pressing, hipping and chemical treatments. Members of TAWG1 noted that these technologies were not available in Manitoba and were needed to sustain certain projects in the industrial base. Consideration for the introduction of these technologies is suggested.

Another Post Processing procedure identified was peening, which is typically used to correct distortions in thick pieces. This technology is in itself an art form. It is noted that in certain applications the materials are too light to support such an application so other approaches are needed.

Other post-processing alternatives such as using spray on metals and heat treatment itself to improve heat management are posed as opportunities for development.

A post processing view of joining is envisaged. This too has a potential application in the upcoming Factories of the Future where the effects of heat treatment and shot peening could be examined in more detail.

Projects of Interest to TAWG1

1. Additive Manufacturing for Aerospace applications, $5 million
2. Adaptive Machining; $5 million
3. Joining and Post Processing – retooling of CATT Centre. $20 million
4. Heat Treating - $2 million

Participants in the TAWG1

The following table which identified the TAWG1 participants and their supporting organizations:

Table 3: TAWG1 Participants

Martin Petrak, Chairperson	Precision ADM (SME)
Alfonz Koncan, Deputy Chair	EnviroTREC
Keith Jephcote	StandardAero
Richard Scarle	StandardAero
Chris Godin	Boeing Canada
Dale Kellington	Precision ADM (SME)
Leo Sousa	Cormer Industries (SME)
Bill Knoakes	Red River College
Elliot Foster	Magellan
Subramaniam Balakrishnan	University of Manitoba - Engineering
Raghavan Jayaraman	University of Manitoba - Engineering
Hong Yu	National Research Council - IRAP

* SME – denotes Small and Medium Enterprise Participant

Appendix A: Technology Evaluation Matrix Result from TAWG1

Manitoba's Aerospace Technology Roadmap - Advanced Manufacturing TAWG- Ranking Sheet

Technology	Current Research Capability in Manitoba	Current Manufacturing Capability in Manitoba	Current Economic Value of the Technology to Manitoba	Potential for Growth of the Technology in Manitoba	Potential for Growth of HQP / HSP in Manitoba	Cost To Implement	Timeline To Implement	Scoring	Rank
Additive Manufacturing	5	5	2	7	5	5	10	**126**	**1**
Adaptive Machining	1	1	1	10	5	5	10	**114**	**2**
Inspection (NDT)	6	5	5	5	3	1	10	**111**	**3**
Machining Strategies	3	7	7	5	1	5	10	**107**	**4**
Joining (Advanced)	9	4	1	3	2	1	10	**94**	**5**
Post-Processing (Heat treating, hipping, surface finish)	1	1	1	5	3	1	5	**61**	**6**
Nano Technologies	5	1	1	1	1	1	3	**43**	**7**
Weight of Classification	4	2	3	5	5	2	2		

Scoring Methodology:

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

ROBOTICS AND AUTOMATION

Thrust Area Working Group 2 (TAWG2)

Introduction

TAWG2 was assembled to consider updating their previous work under the Manitoba Aerospace Technology Road Map, which was published in 2014.

This team was to review the assigned key technology thrust areas, validate these, and provide updates as appropriate. In large part this was a continuation of the previous group. Group members who have a technical background in this emerging area and who may be able to ultimately benefit from the recommendations of this report were selected from Manitoba Aerospace Inc. An SME representation was also deemed to be important to achieve.

TAWG2 reviewed the previous work. Several amalgamations from the former report structure were made and some new topics representing interests of the group were identified. The group also reconsidered its approach to several areas in the TAWG2 report. Table 1 summarizes the amalgamations made and new areas of interest.

Technologies Considered

Five priority technologies in Robotics and Automation for Manitoba were identified in 2016. These topics are refined and expanded from the previous set of three. Table 4 is presented to demonstrate the difference between the considerations of 2014 and 2016.

Table 4: Comparison of the Technologies considered in 2016 versus the Technologies selected for consideration in 2014

Areas of Interest: (2016)	Areas of Interest: (2014)
Robotic Applications	Previously was Robotic Assembly and Robotic Finishing
Robot Integrated Sensing	Previously was Vision Systems
Robot Communications	New
Robot Software Systems	New
Robot Safety Systems	New

From this table, it is seen that three new topics of interest were identified: Robot Communications, Robot Software Systems and Robot Safety Systems. In addition, Robotic

Applications is an expansion to include Robotic Assembly and Finishing as well as capturing other applications. Similarly, Robotic Integrated Sensing is an expansion to include vision systems and also to capture Force Feedback, Feature identification and spatial awareness.

Technology Review Matrix

Given the integrated nature of the suite of Robotic and Automation technologies, the TAWG2 group did not prepare and rank a Technology Review Matrix.

The following rankings determined by the TAWG2 group are identified in Table 5.

Table 5: TAWG2 Technology Rankings

Technology	Rank
Robotic Applications	**1**
Robot Integrated Sensing	**2**
Robot Communications	**3**
Robot Software Systems	**4**
Robot Safety Systems	**5**

Projects Approved and Activity since TRM 2014

No projects were approved or begun in this time period.

Potential projects under discussion:

1. Fixtureless Assembly
2. High Precision Adaptive Assembly
3. Automated Paint and Coatings
4. ROS Industrial

Since 2014, significant gains with regards to adoption have been made within a few Manitoba aerospace companies. Those that have embraced the technology, continue to explore and implement it as resources and budgets allow. However, it is important to note that the adoption or robotics has enabled innovative thinking to take place. This in turn has allowed companies to pursue work that has previously been a challenge to get.

Furthermore, Manitoba has seen the installation of robotics within support organizations; namely the Industrial Technology Centre and Red River College’s Technology Access Centre.

Companies now benefit from having access to such technology allowing them the opportunity to pilot, explore and validate processes without disrupting ongoing plant operations. Expertise and capability continue to grow as interest increasing in robotics and associated technologies.

Engagement of SME's

With respect to how SME's were engaged in this process, two firms participated in this exercise. This represents a significant gain for SME inclusion and support. These results were found throughout the TRM process. The SME participants are identified in Table 3: TAWG2 Participants, which is listed at the end of this report.

TAWG2 Technology Priorities

1. Robotic Applications

The use of robotic machines, control systems, and information technologies to optimize productivity and quality in aerospace component manufacturing. This includes Robotic Assembly and Robotic Finishing that were identified previously. There are endless possibilities for applications; similar to that of a human.

2. Robot Integrated Sensing

The use of various sensing technology to improve task performance. This includes Vision, Force Feedback, Sonar, and Lasers, anything that assists with feature identification, location and validation. In addition, this includes End Effector use and effectivity and Spatial positioning and awareness areas.

3. Robot Communications

The effective use of information to support robot associated activities. This includes the Industrial Internet of Things, Machine to Machine Protocols and Analytics. Additional technologies relate to Interconnectivity (wireless, cloud based, Bluetooth, etc.), high speed, high volume data communication and performance measurement and management.

4. Robot Software Systems

The development and use of systems and tools to manage resources required to support robotic activity. This includes Environmental Awareness, Real-time/Live Simulation, Machine Learning (AI), Algorithms, OS. Additional technologies of interest include proximity awareness, real-time interconnected systems, data collection towards AI and Controller Operating Systems.

5. Robot Safety Systems

The development and use of systems (regulatory or other) to protect collaborative humans from harm, as well as product and environment from damage.

Projects of Interest to TAWG2

While there are no specific collaborative projects ongoing or planned, there is a significant amount of interest in Robotics and Automation in the Manitoba Aerospace community, with large automation projects ongoing at Magellan Aerospace and Boeing Winnipeg. Automation in Aerospace is seeing a tremendous growth and one side effect in the increase in internal projects is a diminishing capacity to take on new automation projects. TAWG 2 will continue to meet and evaluate collaborative projects and as the current wave of internal projects are completed and the technical bandwidth increases, the likelihood of identifying a project will increase also.

Participants in the TAWG2

The following table which identifies the TAWG2 participants and their supporting organizations

Table 6: TAWG2 Participants

Serge Boulet, Chairperson	Magellan
Myron Semegen, Deputy Chair	Industrial Technology Centre
Fred Doern	Red River College
Iraj Mantegh	National Research Council
David Boonstra	Boeing Winnipeg
Subramaniam Balakrishnan	University of Manitoba - Engineering
Brendan Guyot*	Phantom Motion
Shawn Schaerer*	Schaerer Innovation

* SME – denotes Small and Medium Enterprise Participant

COMPOSITES

MAI Thrust Area Working Group 3 (TAWG3)

Revision 20 September 2016

Introduction

TAWG3 was assembled to consider updating their previous work under the Manitoba Aerospace Technology Road Map, which was published in 2014.

This team was to review the assigned key technology thrust areas, validate these, and provide updates as appropriate. In large part this was a continuation of the previous group. Group members who had a grasp of this area of work and who may be able to ultimately benefit from the recommendations of this report were re-selected from Manitoba Aerospace Inc. An SME representation was also deemed to be important to achieve.

TAWG3 reviewed their previous work. Several amalgamations from the former report structure were made and some new topics representing interests of the group were identified. The group also reconsidered its approach to several areas in the TAWG3 report. A number of amalgamations were made and some new titles were identified to represent these new areas of interest (see Table 1).

Technologies Considered

Seven priority Composite technologies for Manitoba were identified in 2016. These topics are refined and expanded from the previous set of five. Table 7 is presented to demonstrate the difference between the Key Thrusts of 2014 and 2016.

Table 7: Comparison of the Key Thrust Technologies in 2016 versus 2014

Key Thrust Areas of Interest: (2016)	Key Thrust Areas of Interest: (2014)
Out of Autoclave*	Out of Autoclave
Mid Temp Resin Systems	Previously was High Temp Resins
Resin Infusion*	Resin Infusion
Pre-forms*	Pre-forms
Hybrid Processing	new
Automated Fab – Right sized equipment	Previously was Automated Lamination
Automated Inspection	new

* N/C – no change

From this table, it is seen that two new topics of interest were considered: Hybrid Processing and Automated inspection. In addition, Mid Temp Resin Systems is a refinement from High Temp Resin systems (focusing on the lower 350F to 600F, Bismaleimide (BMI) and new resins classes PI and CE). Automated Lamination was refined to Automated Composites Fabrication with Right Sized Equipment (tailored to product, pre-cure operations) including preforming, lamination, reticulation, drape forming, and consolidation.

In addition, three technologies were identified as being of secondary interest, suitable for partnering opportunities, primarily because of inherent capital cost and risk and not being key drivers in the current Manitoba Product strategy. These include Thermoplastics (Infusion, forming, joining and bonding), Additive manufacturing of composites using long fiber reinforcement) and Hi Temp Composites (2500F+ Ceramic Matrix Composites (CMC) braided preforms, pyrolysis fabrication, feature machining, joining and MRO).

Technology Review Matrix

The TAWG3 group prepared and evaluated a Technology Review Matrix. This full matrix follows at the end of this report. Scoring and Ranking of the technologies was based on the long-term customer and industry needs as defined in the TRM.

These projects were then scored with a minimum to maximum value from 1 to 5. The technologies to consider for follow-on actions were aligned into two groups.

1) Key Thrusts - Technology investment and leadership
2) Partner Technologies - Thrust contributors and participants in a larger Tech Demo

The groupings which came from this process are identified in Table 8.

Table 8: TAWG3 Technology Groupings

Technology Thrust	**Technology Group**
Preforms	Key Thrust
Auto Fab - Composites	Key Thrust
Hybrid Processing	Key Thrust
Resin Infusion	Key Thrust
Auto Fab - Inspection	Key Thrust
Out of Autoclave	Key Thrust
Mid Temp Composites	Key Thrust
Thermoplastics	Partner Technology
Additive Manufacturing – long fibre composites	Partner Technology
High Temperature composites – 2500F+	Partner Technology

Projects Approved and Activity since TRM 2014

Since the last TRM review, one key project was approved as part of the Canadian Composite Manufacturing R&D Inc Consortium (CCMRD), with support from the Consortium for Aerospace Research in Canada (CARIC). Project CCM10/COMP-709 evaluates the design, development and manufacture of contoured knife edge 3D structures, suitable for trailing edges on winglets, wings and fairings. The total value for the project is approx. $2.5M and began in November 2015 with completion scheduled in March 2019. This project demonstrates three of the key technologies of interest including preforms, resin infusion, and out-of-autoclave. In addition, it includes thermoplastics as development technology. Manitoba CCMRD Members participating are Boeing Winnipeg, Magellan Aerospace, the Composites Innovation Centre MB and Red River College.

It is anticipated that the TRM process going forward will require all TAWG teams to meet during the year to build a dialogue in the areas of interest and to consider proposing projects at such times as appropriate. It stands to reason that the TAWG members are in a very good position to address upcoming programs and to champion or evaluate opportunities for cross-company collaboration in their domains of technology interest.

Engagement of SME's

With respect to how SME's were engaged in this process, unfortunately the two firms who participated in this exercise in 2014 were unable to participate in 2016. Partly this underlines the historical challenges in composites with respect to the investments in capital and technical support. Of significant interest, then is the increased focus on two of the Technology areas: Automated Composites Fabrication with Right Sized Equipment and Out of Autoclave. Both of these technologies promise significant reductions in capital cost and should ease the investment threshold required for SMEs in the near future.

TAWG3 Group 1 - Key Technology Thrusts

1. Preforms

This area of interest includes the design, analysis and fabrication of 3D fibre pre-forms, in braided, woven and stitched configurations. Preforms include the fibre only and work in conjunction with two other technologies identified: Resin Infusion and Hybrid processing. These enable more cost efficient closed mould processing with it's advantages in part geometry (elimination of "bag side" surfaces) and high volume production. Additional structural advantages are inherent in the stitched configuration, increasing the "through-the-thickness" strength, a typical weakness of laminated structures.

2. Automated Composites Fabrication with Right Sized Equipment

This technology is related to pre-cure operations preforming, lamination, reticulation, drape forming, for composites fabrication. Typically, these are specialized processes without off the shelf solutions and lend themselves to right sized solutions. One exception is lamination where large gantry type machines are commonly available. However, the size and capital expense of those solutions, combined with the process flow advantages of smaller dedicated equipment provides significant impetus for right sized lamination also. The increasing usage and reduced cost of industrial robots is a significant enabler in this area, lending more commonality to the programming and facilitation of an application with a right sized end effector.

3. Hybrid Processing

This entails SQRTM (Same Qualified Resin Transfer Molding) and its variants where traditional prepregs are processed at the same time as preforms and resin transfer molding. This combines the effectiveness of prepreg for large acreage (minimizing issues with long path resin flows in RTM) with advantages in consolidation and part geometry inherent with cavity molding. The use of the same resin system simplifies both the processing environment and the material allowables utilized in the structural analysis thus significantly enabling the certification process.

4. Resin Infusion

This technology moves away from traditional pre-impregnated materials (prepregs) to the introduction of the resin separate from the reinforcement. This can be via injection into a preform in a closed cavity mold, in adhesive films interleafed with dry fibers or various combinations (e.g. Hybrid Processing entailed above). In addition to the dimensional advantages discussed previously, the separation of fibers and resins provides a cost reduction, particularly at higher production volumes. Additional benefits are available at the other end of the scale with the elimination of out-time restrictions on prepregs on very large structures that inherently take significant layup time.

5. Automated Composites Fabrication - Inspection

This technology area covers both the pre-cure and post-cure environments for composites fabrication. Inspections prior to cure during lamination (confirming ply number and orientation) and the detection of FOD (primarily backing not removed from the plies prior to lamination) in a timely fashion allowing errors to be corrected have a significant cost avoidance potential as detection after cure usually results in part scrappage. Additionally, post cure inspections (typically NDI and dimensional) are often bottle necks in the production process so alternate technologies that increase flow (e.g. laser NDI, Blue light scans) are of significant benefit.

6. Out of Autoclave

Traditionally aerospace prepreg composites are cured in an autoclave, where the autoclave pressure minimizes voids between plies from air entrapped during the lamination process and from resin off-gassing. Newer prepreg systems that enable equivalent consolidation at lower pressures allow cure without an autoclave. Typically, these are processed with Vacuum Bag Only (VBO) allowing an oven cure only. In addition to eliminating a significant capital expense, there are also processing advantages to reduced pressure cures in terms of avoidance of typically defects such as core crush for sandwich constructions. This also enables production synergies by allowing discrete part flows as part of a dedicated production line vs dedicated or batch processing in a fixed autoclave.

For reference, an autoclave for large composites processing is not only expensive (notionally $10 - $20M for a 15 – 20 ft diameter x 30 – 50 ft long) but is a complex custom installation, built on site to pressure vessel codes and certifications (typically 1 – 2 years) and must be ordered in advance. The combination of this capital cost and lead time act as a significant barrier to both new entrants and growth for existing manufacturing.

7. Mid Temp Composites

This technology area is a refinement from High Temp Resin systems (focusing on the lower 350F to 600F, Bismaleimide (BMI) and new resins classes PI and CE). This separates it from the very high temperature (2500F+) for Ceramic Matrix Composites, allowing conventional epoxy based composites processing but providing higher temperature capability for new applications with reduced cost.

TAWG3 Group 2 – Partner Technologies

In addition, three technologies were identified as being of secondary interest primarily because of inherent capital cost and risk and not being key drivers in the current Manitoba Product strategy. It is felt that these technologies would be appropriate to participate at a national level as part of a larger Technology Demonstrator.

8. Thermoplastics Composites

This includes several thermoplastic composite processing technologies including Infusion, forming, joining and bonding.

9. Additive Manufacturing of Composites

This includes additive manufacturing of composites using long fiber reinforcement.

10. Hi Temp Composites

This includes 2500F+ Ceramic Matrix Composites (CMC) braided preforms, pyrolysis fabrication, feature machining, joining and MRO.

Projects of Interest to TAWG3

Other than the previously mentioned ongoing composites collaboration through CCMRD, there has been no significant progress on the other future projects at this point. However, two project areas do stand out. Firstly, given the overlap with the Robotics and Automation (TAWG 2), a collaborative project in either the Composites Fabrication using Right Sized Equipment or the Composites Fabrication – Inspection would bring a wider interest for participation. The automated detection of backing would be a likely area of industry wide benefit and collaboration without any proprietary materials and processing concerns. Secondly, the Hybrid Processing provides a significant amount of overlap in the preforms and resin infusion technology areas making it a likely candidate to find common ground for a collaborative effort.

Participants in the TAWG3

The following table identifies the TAWG3 participants and their supporting organizations:

Table 9: TAWG3 Participants

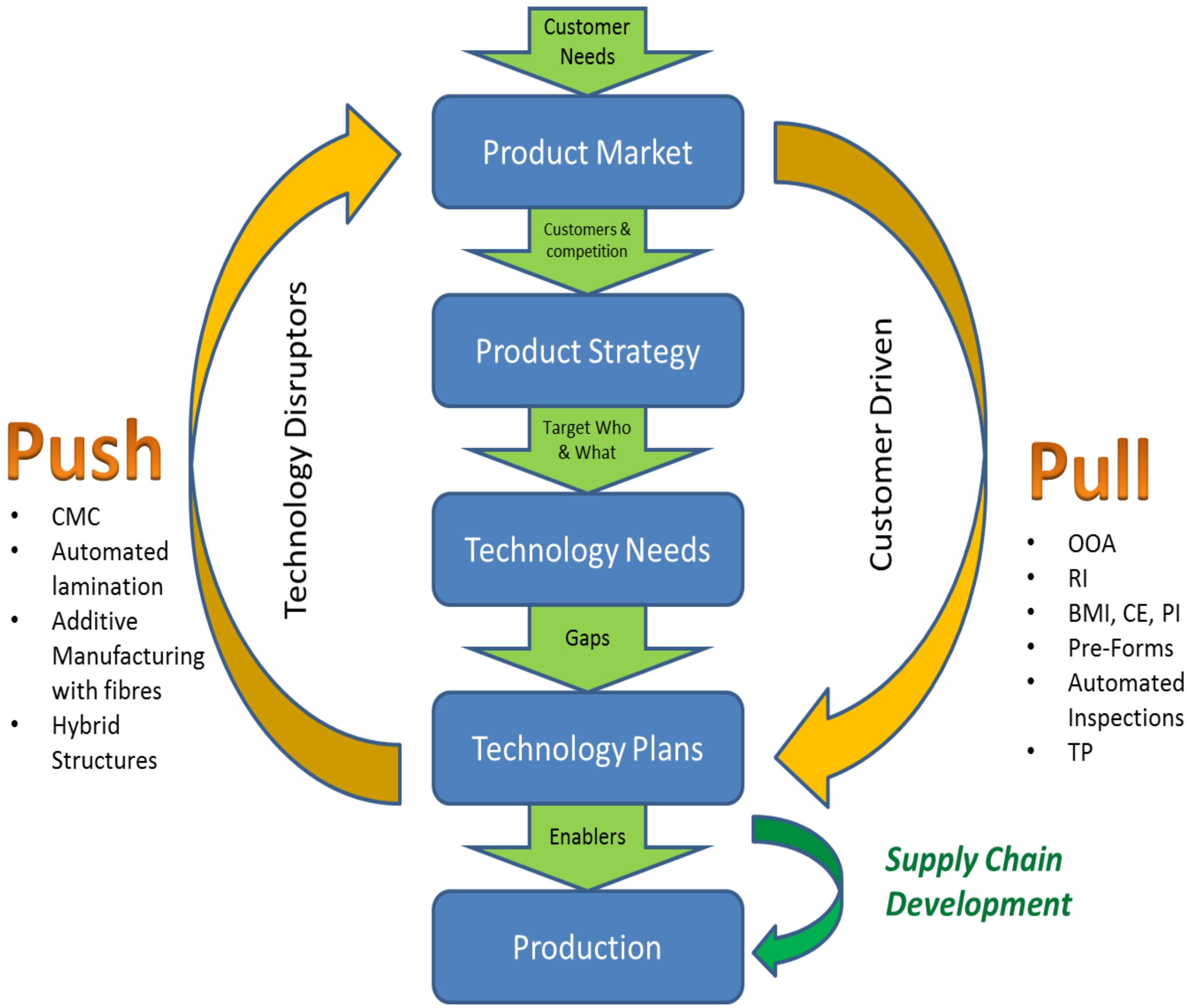
Kevin Robbins, Chairperson	Boeing Winnipeg
Gene Manchur, Deputy Chair	Composites Innovation Centre
John Bagan	Magellan
Chris Marek	Red River College
Raghavan Jayaraman	University of Manitoba - Engineering
Andrew Johnston	National Research Council

* SME – denotes Small and Medium Enterprise Participant

Appendix B – Technology Evaluation

MB Composite TRM Technical Opportunity Rating Matrix													
Apr 19/16	Key Thrusts - invest and lead												
Composite Workgroup #3	Partner Technologies - contribute and participate in a larger Tech Demo												
	Technology thrust												
Criteria: rating 1=low and 5=hi	**OOA**	**Mid Temp Composites**	**Hi Temp Composites**	**RI**	**TP**	**Drape Forming**	**Auto Fab - composites**	**Auto Fab - machining**	**Auto Fab - inspection**	**Bio Composites**	**Additive Mfg - composites**	**Pre-forms**	**Hybrid Structures**
Total score	51	48	47	54	50	45	56	50	52	44	49	58	54
Ranking 1 = first	5	8	9	3	6	10	2	5	4	11	7	1	3
Efficient Manufacturing enabler													
• Lower total product cost	3	2	1	4	4	4	4	3	3	4	4	4	4
• Integrated structures	3	3	3	5	4	3	5	5	5	2	5	5	5
• Higher complexity	3	4	4	5	4	4	4	4	4	3	5	5	5
• Larger sized structures (monolithic, sections)	5	3	2	4	4	3	5	5	5	3	2	4	4
• High rate production	2	2	2	4	4	3	5	5	5	3	2	5	4
Increased product performance													
• Mid temperatures 650F	2	5	1	2	3	2	2	2	2	1	2	3	3
• Higher temperatures 2000F+	1	1	5	1	1	1	1	1	1	1	1	5	1
• Lighter weight	3	4	5	4	3	3	4	3	3	3	4	4	4
Breadth of Application													
• Platform applications, niche=1, widespread=5	4	2	1	3	3	4	5	3	4	2	2	3	4
• Adaptable to New or Current Airplane configuration	5	4	4	3	3	3	3	3	3	3	3	3	3
• Multiple Platform capabilities (GA, MIL, COM, UAS)	5	3	1	4	3	3	3	3	3	4	3	3	3
Provides competitive advantage													
• Economic growth to Industry	4	3	4	4	3	3	4	3	3	4	3	4	4
Direct links to market needs	4	4	5	3	4	3	4	4	4	4	3	3	3
TRL advancement potential (from now to reach TRL9)	4	3	4	4	4	3	4	3	4	4	5	4	3
Disruptor technology (push, replaces current workstatemen	3	5	5	4	3	3	3	3	3	3	5	3	4

Appendix C – TRM page 1



Appendix C – TRM page 2

MB Aero Composite Product and Technology Roadmap

Rev: 26Apr16

MB Product Strategy

Structures:

- Nacelles: Pylon Fairings, Cowls,
- Inner barrel, Thrust Reversers
- Acoustic treated structures
- Wing-to-Body Fairings
- Landing Gear Doors
- Winglets
- Movable control surfaces, LE and TE
- UAV and UAS
- Space components
- Extended 350F+ components
- Tailcones
- Empennage
- Fuselage Frames, Beams, PAX Doors and other structures

Engines:

- High temp combustion sections
- Exhaust Nozzle

Propulsion: non-metallic structures, Heat Shields

Interiors:

- Panels
- Seats
- Assemblies

Product Market

- OEM
- Tier I
- Commercial
- Military
- Space

- Primary structure
- Secondary structures
- Interiors

Global Customer Needs 2028-2033

Efficient Manufacturing

- Lower cost
- Integrated structures
- Higher complexity
- Larger sized structures
- High rate production

Increased product performance

- Higher temperatures
- Lighter weight
- Intelligent structures
- Integrated systems
- Passenger comfort and connectivity
- Safety

Environmental Improvements

- Lower noise levels
- Reduced operating and maintenance costs

Tier I capabilities

- Design
- Certification
- Rapid design and development cycles

New Airplane configurations

- Faster cruise
- Higher altitude
- Blending Wing Body
- Higher efficiency
- Autonomous vehicles

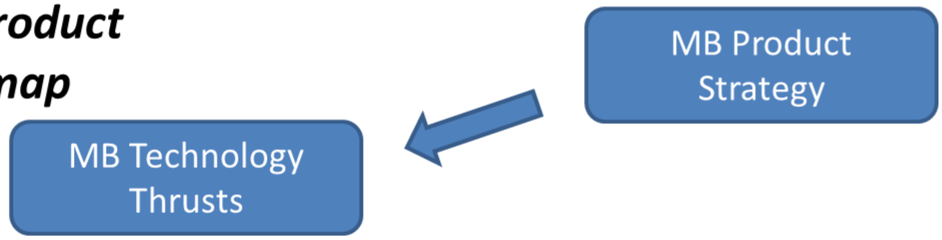
Legislative and Regulatory

- Security
- Environmental

Appendix C – TRM page 3

MB Aero Composite Product and Technology Roadmap

Rev: 26Apr16



Key Thrusts - Technology investment and leadership

- Out-Of-Autoclave (OOA): prepreg, Vacuum Bag Only (VBO)
- Mid Temp 350F to 600F Bismaleimide (BMI) and new resins classes PI and CE, prepregs, infusion
- Resin Infusion (RI): braided preforms, RTM and its variants
- Hybrid Structures, SQRTM and variants
- Automated Fabrication with Right Sized Equipment (tailored to product) - composites: (pre-cure operations) preforming, lamination, reticulation, drape forming, consolidation
- Automated Fabrication - inspection of composites, lamination, NDI, dimensional
- Pre-Forms: Design, analysis and fabrication of 3D fibre pre-forms, braided, woven, stitched

Partner Technologies - Thrust contributors and participants in a larger Tech Demo

- Hi Temp Composites: 2500F+ Ceramic Matrix Composites (CMC) braided preforms, pyrolysis fabrication, feature machining, joining, MRO
- Additive Manufacturing - Composites: Additive Manufacturing for reinforced composites through incorporation of reinforcing fibres into a polymer AM system
- Thermoplastics: infusion, sheet forming, joining, bonding

SIMULATION MODELING & ANALYSIS

Thrust Area Working Group 4 (TAWG4)

TAWG 4 considered three technologies in their 2013 deliberations which are presented as follows:

1. Enhanced Technical Instructions and VR Training

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 increasing be used to help speed the development and effectiveness of product instructions and training through the following methods:

- **Interactive Electronic Technical Manuals (IETMs)** utilizing the latest hardware and software to enhance delivery of instructions through guided troubleshooting, relational content, and enhanced graphical content (3D models and simulations).
- **Virtual Reality (VR) training** offers an immersive environment that more closely simulates aerospace maintenance scenarios.

Benefits from these technologies 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 from 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.

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 (e.g. 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.

Importance and Breadth of Application:

These technologies are required by OEMs which 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’s, suppliers, MRO, training organizations, operators and regulators.

Costs:
This section considers a rough order of magnitude estimate of the total funding required to develop this technology area in Manitoba to an appropriate level of maturity and a near term timeframe.

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 such as in:

- Specific training applications needed for developing technicians in areas of critical skills gaps or shortages.
- Engine test cell simulator training

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.

Three Strategies are proposed for Enhanced Technical Instructions and VR Training
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 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. 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.

2. Simulation Modeling & Analysis

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.

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

- 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).

Importance and Breadth of Application:
This technology is required - ASAP for greatest benefit. No firm deadline.

This technology critical to - OEM, suppliers and 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.

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.

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.

3. Modelling of New and Emerging Composite Materials

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 several 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.

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.

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 and suppliers. It is potentially critical to 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 are:

- 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.

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.

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.

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.

The 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.

TEST AND CERTIFICATION

Thrust Area Working Group 5 (TAWG5)

Introduction

The Manitoba Aerospace Research and Technology Committee (MARTC) of Manitoba Aerospace Inc (MAI) decided that the Manitoba Aerospace Technology RoadMap (TRM), published in 2014, should be revisited by the Thrust Area Working Groups with the following objectives:

- Review the key technology thrust areas developed during the TRM to validate and update these as appropriate, and
- Continue the TRM activities as appropriate, focusing on the definition of specific projects that would stimulate collaboration amongst Manitoba Aerospace stakeholders.

A collateral objective of this process would be to prepare for Manitoba's participation in a National Technology Roadmap.

Key Technologies – Revised Key Technology List

The Test and Certification Thrust Area Working Group (TAWG5) evaluated aero-propulsion technology requirements for development, production, and certification testing for gas turbines that could be furthered through collaboration. The primary motivation for TAWG5 is sourced in the two large aero-engine test and certification facilities located in Manitoba. The Thompson/GLACIER facility serves the needs of Pratt & Whitney and Rolls-Royce, while the Test Research and Development Centre at Winnipeg International Airport delivers engineering development as well as test and certification requirements of GE Aviation. These facilities are driven by the three largest aircraft engine manufacturers and together, they result in approximately 85% of the world's new commercial aircraft engine fleet passing through Manitoba as part of their airworthiness certification. This engages Manitoba firms in early phases of technology development and thus offers insight into emerging technologies and systems.

The subparagraphs below identify the critical technologies originally identified by TAWG5 as well as evaluating which critical technologies offer potential for further investigation and opportunities for collaborative projects.

Emerging Tests

The original technology objectives were the development of new engine test capabilities at Winnipeg and Thompson test facilities to perform water, hail, ice crystal, and volcanic ash ingestion tests.

Ice Crystal Testing is OEM agnostic and still presents a sizable challenge, although regulatory agencies have accepted that ice crystal certification may be performed either experimentally or analytically. The necessity for allowing an analytical certification process is based on the fact that there are currently no facilities capable of generating a representative ice cloud.

A discussion was held regarding the development of an ice cloud generator which could be used in both Thompson and Winnipeg Sites (GLACIER and TRDC facilities). However, it is felt that sea-level-static ice crystal ingestion testing would not represent altitude effects of ice crystal ingestion and that there is little potential for collaborative project engagement.

It was determined that Emerging Tests is a key technology that requires continuing assessment and offers numerous collaborative project opportunities for Manitoba Aerospace companies as well as the potential for research and development aimed at development of human capital.

Specialized Instrumentation

The original objectives were the custom design of specialized gas turbine engine instrumentation to support enhanced test capabilities at Manitoba's certification and production test facilities.

Wireless sensors were targeted in the earlier deliberations of TAWG5 and a project with GE Aviation was initiated. That project was cancelled after a Phase1 Feasibility study, however, as the developmental targets were felt to be insufficient to warrant the required funding. A summary of the Phase I activities is provided later in this document.

Specialized instrumentation and sensors are an area where there is significant potential for collaboration and opportunities for commercialization. Specialized Instrumentation warrants further analysis with collaborative project opportunities being feasible.

Efficiency of Test Sites

The original objectives were the development of advanced data capture and communication technologies for Manitoba's test facilities, such as wireless sensors and instrumentation, high-speed imaging, and high-volume data acquisition and communication.

This Key Technology was identified when both the GLACIER and TRDC test sites were in their early stages of deployment. There were a number of areas where there was thought to be collaborative potential. However, the significant design differences between sites, as well as, the differences in OEM processes, made collaborative project evolution difficult for this technology area. At this point in time, both test sites are at a mature stage of operation and there is felt to be little need to continue with this Key Technology.

Engine Test Cell Training Simulator (ETTS)

The goal of the ETTS project was to develop (and build upon) a common training or gaming simulation capability that would facilitate training in an economical fashion for both industrial partners, StandardAero and GE Aviation.

In 2014, a team including General Electric Aviation (GE), StandardAero, WestCaRD, Industrial Technology Centre, University of Manitoba, and Red River College, was bought together to develop a project plan for an Engine Test Cell Training Simulator, based on that TRM project idea. Phase 1 of the ETTS project was completed in early 2016.

While ETTS Phase II did not proceed, primarily due to funding issues, it was decided that a simulation topic warrants further analysis and that there was good potential for other projects in the modelling and simulation domain. Although this technology area may be re-focused, it will persist into the next phase of the TRM.

Technology Review Matrix

During initial Phase activities, the technology matrix which follows was developed and utilized for assessing critical technologies within the Test and Certification technology area. All technologies originally considered by TAWG5 have now been revisited with discussion summaries provided in subsequent sections of this report.

Table 10: TAWG5 Technology Review Matrix

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

2016 Technology Review

As there were a number of new TAWG5 participants, the technologies that were originally identified by this group were reviewed to determine if additional analysis was warranted. The results of that review are summarized below:

- Ice Crystal Testing Methodology: Discussion on how the wind tunnel could support this methodology resulted in a recommendation to not consider ice crystal activities other than for the purposes of academic pursuit/human capital development.
- Use of Analytical Evaluation to Demonstrate Equivalency to Regulatory Requirements: It was felt that this technology area would be too restricted by commercial sensitivity issues to enable effective collaboration.
- Engine Testing Simulator: this is a large and target-rich domain for collaborative endeavours. The TAWG will examine the lessons learned from earlier TRM activities and will continue to pursue modelling and simulation collaboration opportunities.

- Ingestion Testing Modelling: This technology was again considered to be restricted by commercial sensitivity issues and was extremely expensive to pursue. As such, no further effort is envisaged for this technology area.
- Fuel Testing and Evaluation (Ice, Biofuels): Fuel icing is currently not an issue for aviation fuels employing icing inhibitors. Biofuels certification testing is currently being pursued by numerous organizations. There are opportunities for collaborative ice crystal research particularly for seed based biodiesels and high content ethanol fuels intended for aviation use. There is also opportunity for collaboration on localized icing conditions, for instance, in the oil-fuel exchangers of where fuels are used as a heat sink.
- Development of Emerging Ingestion Tests (Volcanic Ash, Sand Ingestion): Although there are no pressing issues related to ingestion testing, it was decided to maintain a watching brief on this technology area.
- Health Monitoring of Test Sites (Infrastructure): Due to design variations between test sites, there was considered to be little collaborative potential in this technology area. No further work is planned.
- Improvement of Efficiency of Test Sites (Wireless Communication, Robust Instrumentation, Robust High Speed Video): This technology area will not be pursued for the same reasons as the previous technology area - Health Monitoring of Test Sites.
- Health Monitoring of Engines to Develop Engine Maintenance Scheduling: This topic addresses a vast area of research, development, test and evaluation which has been under study for several decades. While some specific projects may arise, there are insufficient resources for the TAWG to pursue this technology area.
- Custom Design of Specialized Instrumentation: There are a number of sensor/instrumentation collaborative activities underway, such as the Manitoba Aerospace Sensor Centre of Excellence (MASCoE). Advanced sensors and instrumentation will continue to offer significant collaborative potential; however, this technology area will be re-focused in downstream TAWG5 deliberations.

First Phase Projects

Engine Test-Cell Training Simulator Phase I – Proof-of-Concept

This project was intended to develop a proof of concept demonstrator that could be developed in subsequent phases for training engine test cell operators. The intent was to train operators both for normal operations and to respond to emergency conditions in a developmental engine test cell. This type of training is extremely expensive and carries risk when training is being performed on developmental engines.

The Simulator Phase 1 project drew requirements from GE Aviation and StandardAero with developmental contributions by the University of Manitoba (engine physics model and integration), Red River College (user interface and gaming approach), as well as participation by the Industrial Technology Centre and WestCaRD.

Phase I of the project was modestly funded for a project that requires significant investment. A summary of funding and sources is provided below:

- WestCaRD contribution - $7500 + in-kind
- MITACS federal funding contribution - $7500 cash
- University of Manitoba - $7500 in-kind
- Red River College Technology Access Centre (TAC) contribution - $7500 in-kind
- GE contribution - $3750 + in-kind
- StandardAero contribution - $3750 + in-kind

Phase 1 of the ETTS project was completed in early 2016. Nearing the end of phase 1 development, EnviroTREC was approached regarding their (and their OEM's – Pratt and Whitney and Rolls-Royce) interest in supporting Phase 2 development of the ETTS. EnviroTREC was attracted to the project as it represented a collaboration of a number of different aero-engine testing partners. However, due to conflicting project priorities within GE and a lack of perceived alignment of the project objectives with StandardAero goals, these latter two partners withdrew support for Phase 2 development in March 2016. Although there was funding in place on the EnviroTREC side, without the other partners, they were unable to continue the project on their own.

Wireless Sensor Project- Phase I – Proof-of-Concept

The overall objective of this project was to develop a wireless solution for temperature surveying within the cowl of an aircraft engine. Phase I was to develop a technology demonstrator that would be developed into a production sensing system in Phase II.

Technology demonstration requirements were to develop a wireless temperature sensor capable of operating at temperatures of up to 125˚C, with sampling at modest rates (>4 times/s), accuracy of +-1˚C and capable of sensing temperatures of up to 375 ˚C.

This project was funded through an NSERC Engage grant of $25,000 with significant in-kind contributions by IDERS Incorporated. GE Aviation defined the project's technology objectives and provided in-kind support.

Projects Under Consideration

Three potential collaborative projects have been discussed, however there is a lack of detail to quantify either the resources required, or the collaborative partners. The project titles are listed below:

- Ice Crystal Cloud Generator at U of M
- Turboshaft Engine Test Facility
- Advanced Sensor Research Network

Small and Medium Business Participation

At present, there are two Small and Medium Businesses participating on TAWG5. They are identified below as well as in the listing of TAWG 5 participants which follows:

- IDERS Incorporated, and
- MDS AeroTest

Table 11: TAWG5 Participants

Bob Hastings, Chairperson	WestCaRD, Pointman (SME)
Alfonz Koncan, Deputy Chair	EnviroTREC
Doug Thomson	University of Manitoba, Engineering
Kathryn Atamanchuk	University of Manitoba, Engineering
Jim McLeod – via WebEx	National Research Council
Trevor Cornell	Industrial Technology Centre
Brent Osterman	StandardAero
Kevin Luellman	IDERS Incorporated (SME)
Troy Ramnath	MDS AeroTest (SME)
Fred Doern	Red River College

SPACE AND ROCKETS

Thrust Area Working Group 6 (TAWG6)

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 operation 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, 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.

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.

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.

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.

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.

ULTRA-LIGHT AERIAL VEHICLES

Thrust Area Working Group 7 (TAWG7)

Introduction

TAWG7 was created following a decision by certain industry members with an interest and capability to respond and support MARTC in their efforts. The group decided that it should consider creating a new working group, called Thrust Area Working Group 7 or TAWG7. In the former TAWG6, some related concerns to this group were addressed.

Permission to proceed was obtained from the MARTC Chairman. A Chair and Deputy Chair were then selected to support the development of this new TAWG report. Industry members from within Manitoba were selected from those whom were known to have an interest and capability to respond to this area of interest. A professor from the University of Manitoba Faculty of Engineering was also approached, and indicated a willingness to participate. An additional member was selected from the local IRAP contingent, based on their willingness and interest in this area of technology development.

The reasons for assembling this team was so that participants were aware that this is a quickly growing aerospace segment, and that the previous social, political, etc. constraints are changing while the underlying technology opportunities are escalating.

The area of concern to the TAWG7 group, was UAV's, or Unmanned Aerial Vehicles. A key distinction is that this group is not interested in the now commonplace hobbyist elements but rather the professional and business sector. More so, the interest here was in considering the advancement of this technology to support those latter interests. TAWG7 is interestingly also only comprised of SME business interests.

Technologies Considered

Autonomy

The TAWG7 group is of the view that Autonomy is the key discipline of interest to UAV's. Our work proceeds with how this discipline can be applied and be of value to such an application for industry opportunities in Manitoba.

Autonomy has a connotation that is separate and distinct from previous work in this area (i.e. TAWG6 report, satellites). Autonomy for UAV's refers to the fact that this technology is increasingly capable of operating independently and is evermore able to interface with other UAV's without the support of an operator. Key technology differentiators such as technology development cycles are also found in this area which are distinct from satellites.

Autonomy as a general precept is non-deterministic. That means that all the possible circumstances that the UAV will encounter, will not be anticipated in its design and development process, but nevertheless the craft will need to overcome those matters and remain on mission for the duration.

As a general specification, UAV's can be assigned for relatively short periods of time, in the order of minutes to days, depending on the design of the payload. The difference here is that if a "fix" is needed it can be accomplished during the downtime, if it cannot be accomplished while it is aloft. So, UAV's can readily be adapted and adjusted as the client prefers without serious consequences. Additionally, as new technology is developed, those elements of interest can be incorporated into an upcoming rebuild.

A key differentiator for UAV's is that they have significantly more commercial potential compared to satellites. Satellites are highly government supported for a variety of broadly societal and governmental reasons. UAV's on the other hand can be singly purposed for a commercial entity, such as spectrum scanning in an area, for anomalies of one sort or another.

Autonomy is important to the UAV segment being considered. The human operator may be quite remote in certain applications and, given the likelihood that the UAV is in higher altitudes, it now falls into air traffic control requirements which call for software certification standards. In such cases the UAV may need to read and recognize environmental factors, and act appropriately.

TAWG7 notes that the regulatory industry in the USA has recently lifted. Until recently, Canada had an open sky environment for UAV development, and the USA had a very restrictive view of where these craft could operate. That restrictive approach in the USA is changing. We note that a considerable UAV proving ground was available near Grand Forks, ND. Likewise, another UAV proving ground is available near Stonewall, Manitoba.

UAV's are believed to have considerable opportunities in the future, while the Satellite industry is highly constrained by government funding limits.

Key considerations in the UAV space are the following topical areas:

1. Autonomy
    a. The need to be self-managed in a swarm environment
    b. Remoteness of some applications requires systems to operate autonomously
    c. Key challenges are processing power onboard and weight payload issues
    d. Opportunities exist for autonomous processing of data for governmental and industry applications
2. Robustness and Safety
    a. These concerns are parallel to those found in the general area of Robotics and IEC 61508 (International Electrotechnical Commission, Functional Safety)
    b. An interest was expressed on how to manage loss of power, etc. when autorotation is desirable for a reduced risk landing
3. Certification
    a. Certification is coming in to this sector. We note here that Manitobans are participating in Tech Committee: D0-178 (Software Considerations in Airborne Systems and Equipment Certification, FAA).
    b. There is an need to be aware of the necessity to participate in these types of technical committees to learn and to promote our understanding of UAV's, etc.
4. Sensors
    a. Unique sensors will need to be developed to support future UAV's as their mission expands.
    b. Sensors need to be developed which can operate without GPS.
    c. Further to sensors development is the need to continue light weighting of sensors
5. Data Collection
    a. Data collection and retention is possible when UAV's are transmitting back to the home station
    b. This data needs to be managed in post processing environment and reconciling multiple sources
6. Control and Optimization of Performance
    a. There is a need to create and innovate to improve light weighting
    b. There is a need to achieve weather proofing
    c. Complexity management is a concern
7. Innovative Design
    a. Designs need to be adaptive and innovative

Technology Review Matrix

No technology review matrix was considered given that the TAWG7 group was working with a relatively narrow technology span.

Projects and Activity since TRM 2013

No projects of note have been developed in Manitoba since 2013, however, it is the intent that this report will propose one.

Engagement of SME's

SME participants are identified in Table 12: TAWG7 Participants, which is listed at the end of this report.

Noted earlier, TAWG7's industry participation is entirely comprised of four SME's, along with support people from the Governmental, NPO and Academic areas.

TAWG7 Technology Opportunities

Development and Purposing of UAV's

Developmental opportunities for UAV's in Manitoba can serve several local and further afield interests. Several opportunities were raised in our group:

- Hydro lines can be inspected via UAV's. Work would remove humans from this dangerous environment, which is typically performed by helicopters. Manitoba Hydro has an extensive system of high voltage lines, which move power from the north to markets in the south. This application has opportunities in global markets.

- Hydro Line de-icing can be performed by special purpose UAV's. This type of work has global opportunities and is to a considerable degree pre-emptive as typically human crews are dispatched, after a hydro transmission line has broken due to the weight of ice on the cables.

- Pipeline fault detection could be performed using spectrographic anomaly detection and even gas detection in the ppb range. This is a very economical and elegant solution to the current method of waiting for the creation of a crisis first, and then responding to that crisis.

- Recharge-induction is considered as an approach to recharging a UAV, while in service. In this case the UAV would settle on a hydro transmission cable and recharge its cells through induction, before leaving to continue its possible long-distance assignment.

An autonomous application of UAV's utilizing the opportunities suggested here would be a case where a UAV would conduct daily patrols of pipelines using spectrographic and smell sensors to determine if a break has occurred. The UAV would hover and analyze detail further if a set of suspicious circumstances are found. When its cell packs are near depletion, the UAV would settle on a power line and would recharge its batteries before proceeding. The UAV could work from dawn till dusk, adjusting the light sensors for the ambient light spectrum at that time of the day, all the while providing a stream of data back to the server to demonstrate that the pipeline service provider is in compliance with safety protocols.

Collaboration Opportunities for TAWG7

Three collaboration opportunities are identified:

1. Autosensing and Data Collection: this opportunity deals with improving and managing the processing power on board.
2. Innovative Design and Optimization: this opportunity has a view of interpreting client needs to accomplish some end goal.
3. RF Shielding for UAV's: it was noted that as UAV's approach high power lines, their internal signals become scrambled and one of the results from this event was denied navigation through GPS failure.
4. GPS-Denied: this is a smaller subset of problems from the previous point and deals with UAV's working in areas where GPS is not available such as mines or moving from inside to outside of buildings.

Project of Interest to TAWG7

A consensus was reached in the group for the formation of a project proposal. TAWG7 group interests were to develop a project which works through a GPS - Denied Navigation environment.

The TAWG7 team will continue to work together post-TRM report submission to build a proposal. Our funding sources may be CARIC or IRAP.

References

1. Peters, J. R., Srivastava, V., Taylor, G. S., Surana, A., Eckstein, M. P., & Bullo, F. (2015). Human Supervisory Control of Robotic Teams: Integrating Cognitive Modeling with Engineering Design. *Control Systems, IEEE*, *35*(6), 57-80.

2. IEEE Control Systems Magazine 35(2), Special Issue on Distributed Control and Estimation of Robotic Vehicle networks

Participants in TAWG7

The following table identified the TAWG7 participants and their supporting organizations

Table 12: TAWG7 Participants

Martin Petrak, Chair	Precision ADM (SME)
Alfonz Koncan, Deputy Chair	EnviroTREC
Howard Loewen	Micropilot (SME)
Shawn Schaerer	Northstar Robotics (SME)
Leon Hanlan	Altus Group (SME)
Nariman Sepehri	University of Manitoba, Engineering
Hong Yu	NRC Industrial Research & Assistance Program

* SME – denotes Small and Medium Enterprise Participant

LIST OF ACRONYMS USED IN THIS REPORT

A list of acronyms is provided for the reader. Our working groups readily move in and out of jargon-filled conversations, understanding fully what they have referenced in their discussions. Similarly too, when one working group is presented with jargon of other working groups, the span of knowledge is needed to understand other discussions in this report is present.

Acronym	**Expansion of Acronyms**
3D	Three Dimensional
ADM	Advanced Digital Manufacturing
AI	Artificial Intelligence
AM	Additive Manufacturing
ASAP	As Soon As Possible
ASTM	American Society for Testing and Materials
B	Billions ($)
BMI	Bismaleimide
CAD	Computer-Aided Design
CARIC	Consortium for Aerospace Research in Canada
CATT	Centre for Aerospace Technology & Training
CCMRD	Canadian Composite Manufacturing R&D Inc Consortium
CE	Cyanate esters
CMC	Ceramic Matrix Composites
CNC	Computer-Numerical Control
CSA	Canadian Space Agency
ETTS	Engine Test Cell Training Simulator
F	Fahrenheit (temperature)
F35	Joint Strike Fighter
F42	An ASTM Committee on Additive Manufacturing Technologies
FAA	Federal Aviation Administration
FOD	Foreign Object Damage
GE	General Electric
GLACIER	Global Aerospace Centre for Icing and Environmental Research
GPS	Global Positioning System
GTRO	Gas Turbine Repair &Overhaul
HQP	Highly Qualified People
HSP	Highly Skilled People
IEC	International Electrotechnical Commission
IETM	Interactive Electronic Technical Manuals
IRAP	Industrial Research Assistance Program
k	Thousands ($)

km	Kilometers
LE	Liquid Epoxy
M	Millions ($)
MAI	Manitoba Aerospace Inc.
MARTC	Manitoba Aerospace Research and Technology Committee
MASCoE	Manitoba Aerospace Sensor Centre of Excellence
MB	Manitoba
MRO	Maintenance, Repair and Operations
N/C	No Change
ND	North Dakota
NDE	Non-Destructive Evaluation
NDI	Non-Destructive Inspection
NDT	Non Destructive Testing
NSERC	Natural Sciences and Engineering Research Council of Canada
NSFL	Nano-Systems Fabrication Laboratory
OEM	Original Equipment Manufacturer
OOA	Out Of Autoclave
OS	Operating System
PAX	Potassium Amyl Xanthate
PI	Polyimide
RF	Radio Frequency
RI	Resin Infusion
ROM	Rough Order of Magnitude
ROS	Robot Operating System
RTM	Resin Transfer Molding
SCISAT	Scientific Satellite
SME	Small and Medium Enterprises
SQRTM	Same Qualified Resin Transfer Molding
TAWG	Thrust Area Working Group
TE	Thixotropic Epoxy
telco	Telephone Company
TP	Terpene (resins)
TRDC	Test Research and Development Centre
TRM	Technology Road Map
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
US	United States
USA	United States of America
VBO	Vacuum Bag Only
VR	Virtual Reality

WHERE TO FIND THIS REPORT?

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

Manitoba Aerospace Inc	EnviroTREC	WestCaRD
www.mbaerospace.ca	www.envirotrec/projects.ca	www.westcard.ca