CANADIAN AEROSPACE AND DEFENCE TECHNOLOGY FRAMEWORK

Acknowledgements

The Technology Framework is a joint initiative between Technology Partnerships Canada and Industry Canada in order to encourage and support the development and applications of technologies essential to the future well-being of the aerospace and defence sector.

In fulfilling the philosophy, goals and objectives of both these organizations of strengthening the industry through collaboration, this document was developed in consultation with industry and other aerospace and defence stakeholders. For their participation in developing the document, the appreciation of both Technology Partnerships Canada and Industry Canada is expressed.

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1. Introduction

1.1. Objective

The objective of the Technology Framework is to provide guidance to all Technology Partnerships Canada (TPC) stakeholders on the factors to be considered in the development, submission and evaluation of TPC cases. Necessary to this process is the definition of technology phases and technologies that are considered key to the continuing contribution of the aerospace and defence sector to the achievement of Canada's national strategic objectives.

1.2. Document Overview

This document is organized in the following manner:

- The technology development cycle is identified and terminology for each of the phases is defined. The definition of the technology development cycle is necessary to provide clarification on those phases where TPC emphasis is to be placed. These technology phases draw on established and accepted principles and concepts derived from Canadian sources and from those of our principle trading partners.
- Technologies considered to be of strategic importance to the success of Canada's aerospace industry are next identified and summarized. Eleven separate critical technology areas are identified with strategic technologies identified and characterized within each critical technology area. Critical technology areas and technologies are based on the existing TPC defined technology areas and augmented by data from The Aircraft Design, Manufacturing and Repair & Overhaul Technology Roadmap (Ontario Pilot Project), referred to within this document as "The DMR&O Road Map".
- Annex A to this document provides the definition of each strategic technology accompanied where relevant, by notes that characterize typical TPC cases of interest.

2. Technology Framework Guiding Principles

In the development of this Technology Framework the following three guiding principles have been followed:

- The technology framework and definitions must be comprehensive and correlate with existing Canadian and US equivalent classification schemes.
- The technology framework must address the specific needs and characteristics of the Canadian aerospace and defence sector.
- The technology framework will take advantage of, and be consistent with, both existing TPC technology definitions and The DMR&O Road Map.

Table 1A. - TPC Technology Framework – Technology Development Phases and Definitions

Technology Phase	Sub-Phase	Definition	Characteristics/Examples	Eligibility/Comments
Fundamental Research	Sponsored by University or other not-for-profit organization	Is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.	Fundamental research formulates and tests hypotheses, theories or laws, thereby providing the basis for future applied research. The results of basic research are generally not marketable. May employ a laboratory model which is used only to demonstrate a concept or process, and will usually bear no resemblance to a functional piece of equipment.	Typically not eligible.
	Sponsored by a for-profit Canadian corporation.			Typically Eligible.
Horizontal Technology Development	Applied Research	Is original investigation undertaken to acquire new knowledge that is directed primarily towards a specific practical aim or objective.	Applied research is undertaken to determine new methods or ways of achieving some specific and pre-determined objectives. Applied research typically develops and demonstrates that scientific knowledge or principles can be applied in a specific manner. May employ an experimental development model to demonstrate a concept or process.	Applied research is typically not product specific and will characteristically be medium to high risk. This is where government funding can provide perhaps the greatest stimulation to industry
	Component Technology Research	Is applied research that is directed towards a design element that may have wide applicability but which could be associated with a specific product or process.	An example of CTR could be combustor computational fluid dynamics which will require specificity to the combustor of a gas turbine, but the development of this design capability would be applicable to all gas turbines.	Eligible provided that it can be demonstrated that the technology development is not product specific.
	Core Competency Development	Is the development of technological capability which while not necessarily globally unique, is required in Canada to establish a strategic competency.	An example to demonstrate this concept is provided in the Suppliers Base Study and concerns systems integration. While not of a fundamental scientific nature, systems integration on a second tier level, has been identified as being of strategic importance for Canada. The funding of competencies necessary to the development of a systems integration capability would be considered.	Eligible if tied to Canadian strategic technology development requirements.

Table 1B - TPC Technology Framework - Technology Development Phases and Definitions

Technology Phase	Sub-Phase	Definition	Characteristics/Examples	Eligibility/Comments
Vertical Technology Development	Advanced Technology Demonstration/ Demonstrator	Is the evaluation and demonstration of technologies in a realistic operating environment to assess the performance potential or technical feasibility of advanced technology.	This is a mechanism for the cost effective evaluation and demonstration of emerging technologies. ATDs typically use an advanced development model device to explore design alternatives, establish the performance or durability of a component or to demonstrate the maturity or feasibility of a technological concept. May employ an advanced development model to demonstrate both concept or process, and technical feasibility. The advanced development model will often require sufficient practicality of design to allow the demonstration of the concept or process in a realistic or relevant environment.	Eligibility will vary dependent on the ability to differentiate between technology demonstration objectives and product specific development.
	Product Specific Technology Development	Is the evaluation of technologies developed for, and demonstrated in a specific product or component.	Technology development in the latter stages of the engineering design cycle and clearly associated with a specific product or service offering. Often involves a number of pre-production models or prototypes that are tested in near actual operating environments for extended test periods or for other specific regulatory agency imposed testing.	Typically not eligible.
Engineering Development	Advanced Manufacturing Technology	Are all efforts for the introduction, or refinement of design or manufacturing processes and techniques that are directed to reducing design, manufacturing, or product life cycle costs or otherwise improving the efficiency of those processes.	This topic covers a wide area of technology application from process development through a range of reliability and maintainability improvement processes	Eligibility will depend on the link between the objectives of the proposal and Canadian strategic technology development priorities.
	Product Production Development	Are all efforts specific to the production of a particular component or product and which employ established industrial practices.	Product specific technology development	Typically not eligible.

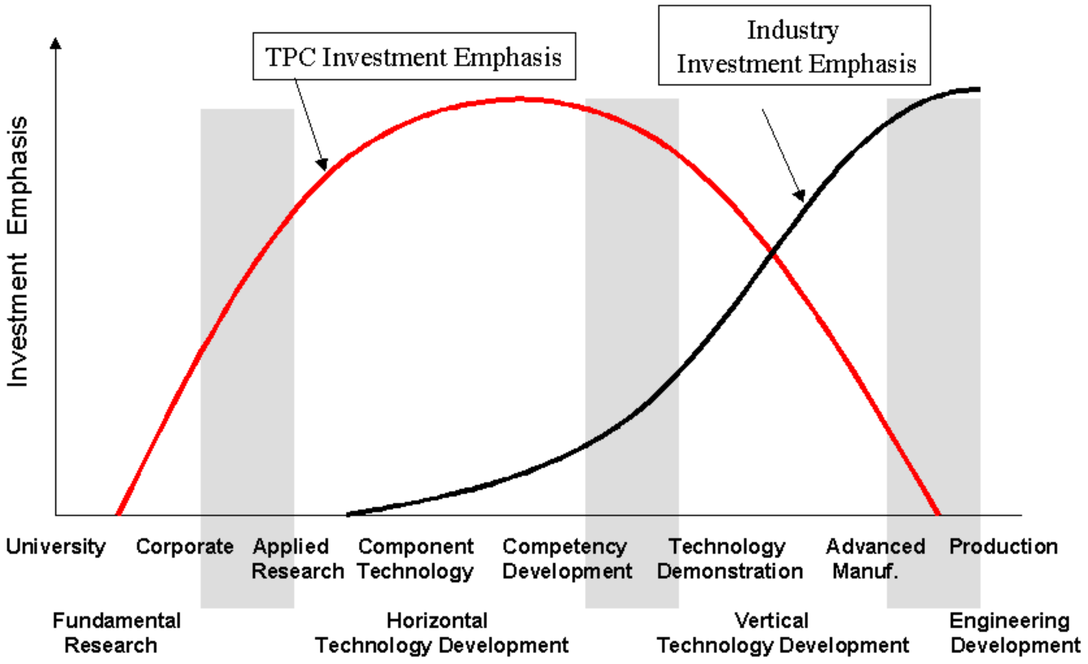

Figure 1. TPC and Industry Investment Emphasis

3. Technology Investment Emphasis

3.1. TPC Investment Emphasis

Figure 1 depicts the general TPC investment emphasis by technology phase. Also included in Figure 1 is the perceived industrial emphasis in technologies by phase. The TPC investment emphasis recognizes that at early evolutionary stages, well in advance of commercialization, there is less industrial interest, hence investment. Here TPC investment in technologies is of a more strategic nature and can be used to encourage a longer-term industrial collaborative technology development interest. Investment at this stage in technology development is typically not product specific but rather of a strategic nature.

3.2. The Technology Development Spiral

While Figure 1 portrays a uni-dimensional technology evolution, it is recognized that other factors require consideration in the development of a technology base. The same technology development phase may be revisited during a company's product line or product specific growth or as a result of technology evolution. Figure 2 below, attempts to depict this continually evolving environment.

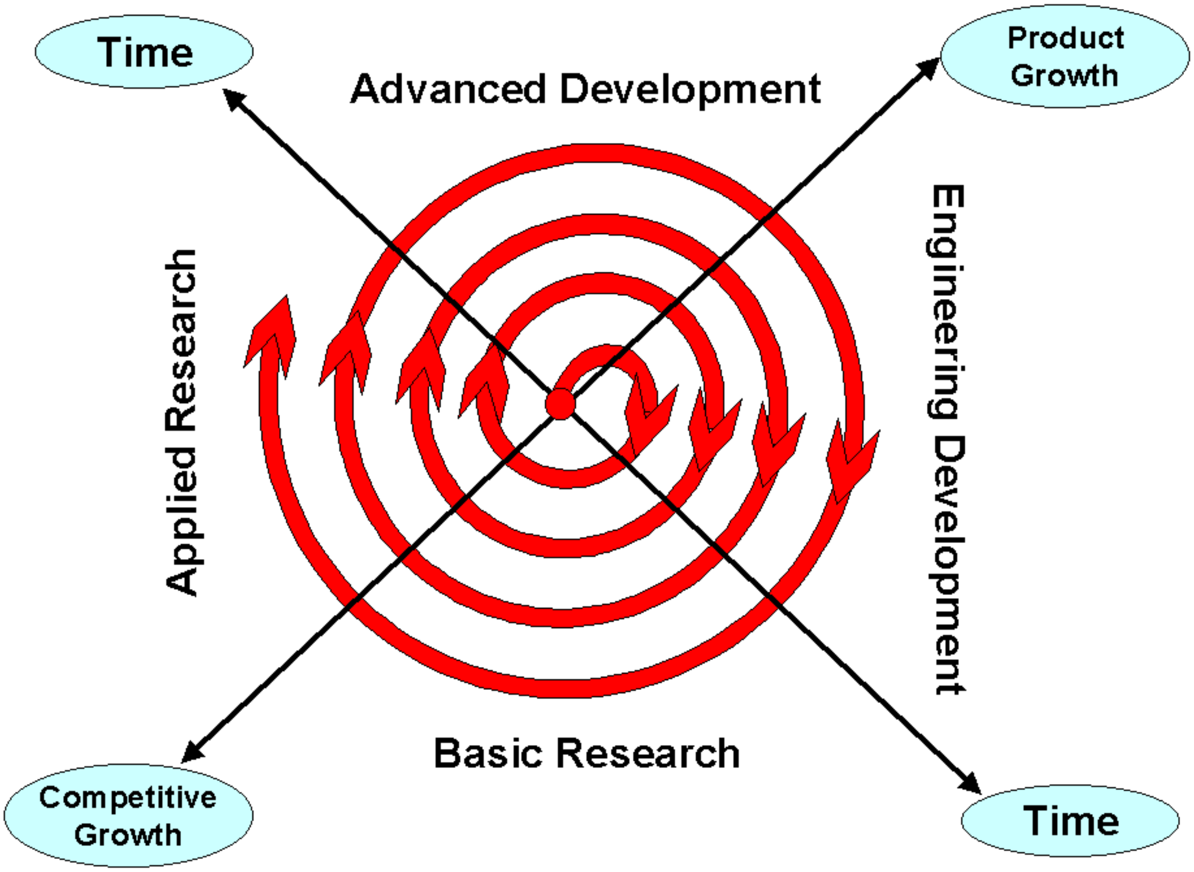

Figure 2. The Technology Development Spiral

4. Canadian Aerospace and Defence Critical Technology Areas

4.1. Critical Technology Areas

Eleven Critical Technology Areas have been identified for the Canadian aerospace and defence Sector. These technology areas consist of discipline, segment, and process related categories. The Critical Technology Areas for the Canadian aerospace and defence sector are listed below and are also listed in Figure 3 following:

- Advanced Industrial Methods and Practices;
- Design and Analysis Technologies;
- Advanced Avionics and Electronics;
- Aerodynamics and Flight Mechanics;
- Aeropropulsion and Gas Turbine technologies;
- Aircraft Structural Materials and Manufacturing Processes;
- Aircraft Systems;
- Simulation and Modeling;
- Advanced Manufacturing Technologies;
- Maintenance Repair and Overhaul Technologies; and
- Space Systems and Communications.

Table 2. below provides a correlation of the TPC Technology Framework Critical Technology Areas with those technical areas identified in the DMR&O Road Map:

Table 2. Critical Technology Areas/ DMR&O Road Map Correlation

TPC Technology Framework Critical Technology Areas	The Aircraft Design, Manufacturing and Repair & Overhaul Technology Roadmap (Ontario Pilot Project)
Advanced Industrial Methods and Practices	Design Technologies Management Technologies
Design and Analysis Technologies	
Advanced Avionics and Electronics	Systems Technologies
Aerodynamics and Flight Mechanics	Design Technologies
Aeropropulsion and Gas Turbine Technologies	Environment Technologies
Aircraft Structural Materials and Manufacturing Processes	Materials and Structures Technologies Environment Technologies
Aircraft Systems	Systems Technologies
Simulation and Modeling	Visualization Technologies
Advanced Manufacturing Technologies	Manufacturing Technologies
Maintenance, Repair and Overhaul Technologies	Maintenance, Repair and Overhaul Technologies
Space Systems including Communications	
	Environment Technologies

- 5.1. Advanced Industrial Methods and Practices
  - 5.1.1. Quality Standards and Practices
  - 5.1.2. Environmental Standards and Processes
- 5.2. Design and Analysis Technologies
  - 5.2.1. Multidisciplinary Design And Optimization (MDO)
  - 5.2.2. Structural Analysis, Design and Optimization - Aircraft Structures
  - 5.2.3. Product/Technical Data Interchange (PDI/TDI)
  - 5.2.4. Concurrent Engineering And Virtual Design
- 5.3. Advanced Avionics And Electronics
  - 5.3.1. Advanced Avionics Systems Development And Integration
  - 5.3.2. Flight Control Systems
  - 5.3.3. Advanced Cockpit Technologies And Concepts
  - 5.3.4. Damage Monitoring Technologies
- 5.4. Aerodynamics And Flight Mechanics
  - 5.4.1. Computational Fluid Dynamics Development And Validation – Aircraft
  - 5.4.2. Advanced Aerodynamic Profiles Analysis And Design Integration
  - 5.4.3. Wing/Nacelle/ Propulsion Integration
  - 5.4.4. Advanced Aircraft Aerodynamics and Handling
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  - 5.5.7. Digital Electronic Fuel Control Design And Validation
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  - 5.7.6. Active Noise And Vibration Control
  - 5.7.7. Ice Detection, Management and Control Systems
- 5.8. Simulation And Modeling
  - 5.8.1. Simulation And Modeling For Acquisition (Mission) Rehearsal And Training (SMART)
  - 5.8.2. Image Generation
  - 5.8.3. Display Technologies Including Fiber-Optic Head Mounted Systems, Micro-Laser Projection, And Flat Panels
  - 5.8.4. Advanced Synthetic Training Environments and Concepts
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  - 5.10.1. Gas Turbine Repair Technologies
  - 5.10.2. Advanced Materials Non-Destructive Evaluation
  - 5.10.3. Health And Usage Monitoring Systems
  - 5.10.4. Repair Of Metallic Systems
  - 5.10.5. Repair Of Composite Systems
  - 5.10.6. Coatings And Surface Modifications For Repair
- 5.11. Space Systems Including Communications
  - 5.11.1. Smart Systems For Space Structures
  - 5.11.2. Satellite Communications
  - 5.11.3. Earth Observation
  - 5.11.4. Surveillance Of Space
  - 5.11.5. Electrochemical Power Sources

Figure 3 - Technology Partnerships Canada - Technology Framework

5. Critical Technology Areas and Technology Descriptions

Brief descriptions of each critical technology area, and of each technology element are provided below:

5.1. Advanced Industrial Methods and Practices

The Advanced Industrial methods and Practices critical technology area addresses objectives that are not necessarily technology specific, but which do play a key and widely applicable role in the development of the Canadian Aerospace and Defence industrial base. Investment is supported that introduces new processes or practices that improve the quality and productivity of Canadian manufacturers and the personnel who are employed in the industry.

The technology elements within the Design Technologies critical technology area are described below:

5.1.1. Quality Standards and Practices

Quality is an issue whose importance is universally recognized but often is ignored or receives diminished attention when problems begin to occur – exactly the time when quality should be the primary focus. There are a number of philosophical concepts older, but no less relevant, and new. Kaizen, a combination of two Japanese words for continuous good or improvement has been mechanized into processes that encourage the continuous and effective reflection, questioning and improvement of corporate functions. Total Quality control under its various names then provides the implementation. If quality is the driving force, then the customer will obtain the best value possible and use your product. This maximizes profit by focusing on increased revenue. If you also design for minimum cost you will increase profit further.

To accomplish these goals tools must be developed which give the competitive edge in designing for quality and cost. The seven old tools enhance the application of statistical process control which measures the quality of the product. By definition, these measures are product specific surrogates for quality. The seven new tools strengthen the planning process which is used to guide the process of designing quality into the product. Quality function deployment links customer defined value to the product and to the processes which bring forth, sustain, and retire the product. Quality is allocated to the various aspects of the product and the process to bring forth the product. This allocated value is used to prioritize and focus efforts on activities which will provide the most quality for the customer. Taguchi methods, response surface methodology, or multidisciplinary optimization are then used to optimize the value to the customer. Design for quality is a simple, effective, efficient, and elegant strategy. (From E.B. Dean).

Six Sigma is a design philosophy that originated with Motorola and is increasingly being incorporated by the Canadian aerospace industry. Six Sigma first stresses customer satisfaction in that the supplier must truly understand what the customer wants in addition to what is actually asked for – If the customer is unhappy with the product then a flaw exists even if the customer has received exactly what was specified. The supplier must understand the processes and materials that are used in satisfying the customer – both internal and supply chain. This understanding must include such factors as process variation as a result of machine wear, material characteristic tolerances or other variables. With this knowledge a robust design process is developed and applied to create a product that accommodates all customer expectations both at delivery and throughout the life cycle of the product. Six Sigma tools development will be required and will often be specific to the design and production environment.

5.1.2. Environmental Standards and Processes

The focus for Environmental Standards and Processes will be on the incorporation of environmentally responsible processes as embodied in the ISO 14000 family of standards by the aerospace and defence sector. ISO 14000 series is a family of environmental management standards developed by the International Organization for Standardization (ISO).

The ISO 14000 standards are designed to provide an internationally recognized framework for environmental management, measurement, evaluation and auditing. They provide organizations with the tools to assess and control the environmental impact of their activities, products or services. The standards are designed to be flexible enough to be used by any organization of any size and in any field. They address the following subjects:

- environmental management systems;
- environmental auditing;
- environmental labels and declarations;
- environmental performance evaluation; and
- life cycle assessment.

These technologies will not be product specific and will address the full range of Canadian aerospace and defence manufacturing processes.

5.2. Design and Analysis Technologies

The Design and Analysis Technologies critical technology area includes technologies or processes that are pervasive within the aerospace and defence sector. In many cases the more generic technology descriptors provided under the Design and Analysis Technologies heading are amplified later in technologies or processes specific to a separate discipline, segment or process in other critical technology areas as well. An example would be advanced analytical modeling and design which is a pervasive technology relating to computer aided design tools. Computational fluid dynamics is an advanced analytical modeling and design tool that in specialized forms is discussed under both Aerodynamics and Flight Mechanics, and Aeropropulsion and Gas Turbine Technologies.

The technology elements within the Design Technologies critical technology area are described below:

5.2.1. Multidisciplinary Design and Optimization (MDO)

Multidisciplinary design and optimization is as the name implies, the process of combining a full set of computational design tools to create an optimum design. The process is necessarily iterative in nature and each of the disciplines normally utilized in an aircraft design is computationally intensive. An MDO approach for an aircraft could include aerodynamics, structures and systems Computer Aided Engineering (CAE) tools. Initial design assumptions would be input to each CAE toolset and the constraints and parameters to be optimized defined. Each CAE suite would then compute design parameters that would be utilized by the other CAE tools as a subset of their required inputs. The ultimate design would theoretically be structurally more sound, lighter and more cost effective to fabricate. The design timeframe would be also very much shortened. The challenges to this process are in the exchange of data between the CAE applications, and the tuning of the entire process to achieve convergence on the final solution set in an efficient manner.

5.2.2. Structural Analysis, Design and Optimization – Aircraft Structures

The optimization of analytical design tools is a process that will lead to shortened design time frames, lighter and more efficient designs, with reduced production and life cycle costs of the final design. The many analytical tools now available have been typically developed for specific applications and are often not readily applicable outside of their original design target arena. Computational fluid dynamics as used in the internal, highly compressible flow path of a gas turbine will differ greatly from a CFD application intended for a low speed aircraft wing analysis. Another example lies in the structural analysis field where tools developed for metallics will be much different from those developed for composite materials where material properties vary according to axis.

The ability to rapidly define an optimized aircraft structure having light weight, and improved fatigue and damage tolerance capabilities, is a critical technology to maintain competitive leadership in future new aircraft. This will be achieved by the extensive use of computerized methods for structural analysis and design optimization, and for the analysis of failure and fracture mechanics. The methods must be integrated with the in-house design and manufacturing databases and the 3-D CAD/CAM systems, and also be easy to use. Suppliers and partners will have access to the resulting design information via Electronic Data Interchange (EDI). This will ensure consistency with an up-to-date knowledge of the requirements for loads, interfaces and the space envelopes available for their products. The immediate dissemination to suppliers of information on design changes will help diminish subsequent redesign activity and the time and cost penalties incurred for rework.

The preliminary structural design will use detailed Finite Element Methods (FEM) for analysis, coupled with constrained optimization, and the system must be highly automated for rapid creation of FEM meshing for models. In order to achieve shortened design cycle time the loads and dynamics stiffness requirements must become available much sooner than at present. This will require early development of MDO models for the overall aerodynamic and structural optimization which will define the static and dynamic loads for flight and ground operations. Trade-off studies must rapidly search for the best designs and arrive at realistic structural sizes, providing space envelopes and accurate weights to minimize subsequent redesign.

5.2.3. Product/Technical Data Interchange (PDI/TDI)

Product, technical or electronic data interchange is a key element in the electronic collaborative design concept which is the fully implemented Integrated Product and Process Development. This involves the electronic linking of the supply chain elements into a consolidated and concurrent design process where the prime, suppliers, and often customers are involved in a rapid design development and approval environment (whiteboarding, e-mail, computer telephony, and drawings exchange). The elimination of paper in this process dramatically speeds up the design process and reduces costs significantly. The challenge for the aerospace sector lies in the electronic exchange of drawing packages, including Computer Aided Engineering, Computer Aided Design and Manufacture files, that are extremely complex and for regulatory compliance must offer virtual 100% accuracy. Technology demonstration projects that explore the communication of product data are still required as are the research and development projects that identify the bandwidth requirements and exchange protocols.

5.2.4. Concurrent Engineering and Virtual Design

Winner, Pennell, Bertrand, and Slusarezuk (1988) define concurrent engineering as “a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.”

Jagannathan, V., K. J. Cleetus, R. Kannan, A. S. Matsumoto, and J. W. Lewis (1991) define concurrent engineering as “the process of forming and supporting multifunctional teams that set product and process parameters early in the design phase.” According to Dean and Unal (1992), “Concurrent engineering is getting the right people together at the right time to identify and resolve design problems. Concurrent engineering is designing for assembly, availability, cost, customer satisfaction, maintainability, manageability, manufacturability, operability, performance, quality, risk, safety, schedule, social acceptability, and all other attributes of the product.”

Virtual design in its ultimate form essentially means that no prototype or test hardware is required prior to the yield of production units. A completely paperless design, analysis and qualification process such as this would result in much shorter design periods, much less wastage in material and physical resources, and a more environmentally benign development process – all of which equates to significant cost reduction. This concept necessarily is far from practical at this stage, perhaps approaching feasibility in the post 2015 time period. There are even more challenges to virtual design in the highly regulated aerospace world where hardware testing, although typically yielding little in real safety value, is an ingrained paradigm. Necessary enabling technologies are information technology for data transfer and computational modeling, development of computational analysis tools, and experimental validation of design and analysis tools.

5.3. Advanced Avionics and Electronics

Avionics systems include such aircraft systems as the Electronic Flight Instrumentation System or otherwise described instrumentation systems, Navigational Systems, Communications systems, Automated Flight Control System, Inertial Navigational System etc. These systems are becoming almost universally processor controlled with significant amounts of software or associated firmware. Avionics and electronics systems represent an appreciable portion of the acquisition cost and weight of an aircraft, and for a military fighter this can approach 40% of both the cost and weight of the aircraft. Additionally, advanced avionics systems offer the potential for reducing aircrew workload and improving flight safety. A dominant requirement exists to develop affordable and highly integrated avionics systems for aircraft. Increasingly, fault tolerant, modular designs must be developed to allow the reduction in costs, weight and power requirements while accommodating rapid and reliable system customization.

The technology elements with the Advanced Avionics and Electronics critical technology area are described below:

5.3.1. Advanced Avionics Systems Development and Integration

Typical aircraft avionics systems include: flight management, communications, navigation, radar, weather instruments, cockpit display units, landing aids, Traffic and Collision Avoidance Systems (TCAS) etc. Military specific avionics suites include systems for reconnaissance, electronic warfare, and stores management.

Integrated avionics refers to avionics systems that perform or contribute to the performance of multiple aircraft functions. A recurring theme in integrated avionics has been the attempt to use common electronic modules or components with multi-functional Single Board Computers and standard CPUs being the most obvious examples.

Advanced avionics technology development will focus on the development of multi-functional and fault tolerant modules that can be rapidly integrated into new or existing aircraft systems. To be successful, manufacturers will need skills for integrating an entire cockpit avionics suite and managing its installation.

5.3.2. Flight Control Systems

The flight control system of an aircraft comprises all the components that enable the pilot, either human or automatic, to control the aircraft. Basic components are the control stick or wheel, the rudder pedals and the control surfaces (rudder, ailerons, elevators, elevons, spoilers etc.). In the case of rotorcraft, there is also the collective pitch lever and the rotor blades. Depending upon the complexity of the aircraft, these components might be connected by cables and pushrods, with pulleys and bellcranks, and the control surfaces might be moved by the cables and rods directly, or by hydraulic actuators signaled by these mechanical, or other electrical connections, or both. Again, on more complex aircraft, computers fed by signals from various sensors might be included in the flight control system to improve overall stability and maneuverability.

Of greatest interest to Canada is the development of fly-by-wire and active flight control systems for aircraft of less than about 120 seats. Fly-by-wire replaces mechanical control connections with electrical signaling and in the future may be replaced by optical connections or “fly-by-light” (see later). Active control involves a computerized interpretation of the pilot’s flight control inputs. The computer translation selects which control surfaces to deflect to achieve a particular maneuver to enable the least stressful or most efficient change in aircraft attitude to be effected. Also, when there is partial degradation of the flight controls, as in the case of failure or damage, the computer will perhaps still be able to achieve the desired change in aircraft attitude without increasing pilot workload.

5.3.3. Advanced Cockpit Technologies and Concepts

There are a number of key technologies pertinent to advanced cockpit technologies and concepts. Many of these technologies are in the advanced development or limited implementation phase in military aircraft and in some larger commercial aircraft. Advanced commercial cockpit technologies are primarily focused on processing the massive amounts of information and presenting the required information to the aircrew in the most effective and efficient manner. Some concepts involved in advanced cockpit technologies are:

Human Factors Engineering: Human factors engineering is concerned with ways of designing jobs, machines, machine operations, and work environments so that they are maximally compatible with the capacities and limitations of the human operator.

High Speed Processing Environments: Are required to acquire, process and present data derived both by on-board and external systems to the aircrew in a reliable and accurate manner.

Display Technologies: Technologies that include both advanced head down and head up displays are required and include flat panel displays, head mounted displays and 3-d representation. These displays are required for both cockpit and cabin, and back end work-stations in military or scientific aircraft.

5.3.4. Damage Monitoring Technologies for Powerplants

There are a number of technologies and concepts that must be addressed under the heading of damage monitoring technologies. First of all the damage should not be thought of as only the result of an unforeseen occurrence such as the ingestion by an engine of a bird or rock, but also as the accumulation of service life induced wear, or fatigue life related damage.

Usage Monitoring: For aircraft engines typically refers to monitoring start-stop cycles or time at temperature to infer generalized damage accumulation. These data are then used to define component life based on design data and actual usage. For aircraft, usage monitoring normally takes the form of strain gauges or accelerometers placed in strategic locations and which when combined with flight data yield data that can be used to anticipate structural problems in high criticality or design deficient areas.

Health Monitoring: Health or condition monitoring for aircraft engines can cover a wide range of data sources including oil borne debris, vibration monitoring, and gross indicators such as thrust. For aircraft structures condition monitoring will take the form of corrosion detection sensors (local environmental sensors) or perhaps embedded fibre-optic sensors that register leading edge impact as a indicator of residual functional capacity.

Of current interest are the technologies necessary for the sensing of high cycle fatigue damage in aircraft engines. High cycle fatigue is relatively low mean stress loading with load cycles rapidly applied in excess of 100,000 or by some definitions, 1,000,000 cycles. This loading scenario introduces fretting and wear which can in turn result in the generation of crack initiation sites from where failure can initiate and proceed to dysfunction within seconds or minutes.

5.4. Aerodynamics and Flight Mechanics

Aerodynamics is the study of forces on wings bodies and controls due to air pressure and viscous (drag) effects. Flight mechanics is the study of the resulting motion of objects through the air and includes the stability and control behavior. The laws of motion and aerodynamics are combined to ensure that an aircraft flies in the intended manner. Much of the aerodynamics and flight mechanics work that is pursued for the purposes of aircraft designed and built in Canada will pertain to such issues as the design of improved wings, the integration of various components onto an aircraft or issues such as flight in adverse conditions where the handling qualities of an aircraft will be for instance, adversely influenced by the build up of ice on the surface of the wing. Advanced technology development in this field will be directed towards supersonic transports and eventually hypersonic flight. There are considerable differences between fixed wing and rotary wing aircraft aerodynamics and flight mechanics and both areas are of considerable interest to the Canadian aerospace and defence industry.

The technology elements with the Aerodynamics and Flight Mechanics critical technology area are described below:

5.4.1. Computational Fluid Dynamics Development and Validation – Aircraft

CFD has had the greatest effect on both aircraft and engine design of any single design tool over the past twenty-five years. Computational power and cost have enabled widespread application and development of CFD techniques. Computational fluid dynamics is basically the use of computers to numerically model flows of interest. Nodes in the flowpath are identified and equations of motion solved to identify flow parameters.

In essence a grid or mesh is defined over the surface of the object and extends outwards into the flowfield containing the object. Flow equations are then calculated at each node in the grid, and iteratively re-calculated until all results for each node are within an acceptable variance. The equations used are either Euler based and so do not include viscous effects (boundary layers) directly, or use Navier-Stokes equations which include viscous effects in the solution and are more accurate. Such methods can be used for external flows about an aircraft or for internal flows in a gas turbine including combustion. The Euler based analyses are typically less computationally demanding but are less precise for modelling separated flows on wings and bodies, or for internal reversed flows. It should be noted that Navier first developed his equations in 1823 and that Stokes refined them in 1845. The development of solutions to these equations was not feasible until the latter part of this century. Today much R&D effort on NS methods is expended on improving modelling of the turbulent flow terms for specific problems.

Numerous forms of Euler and Navier-Stokes equations have been developed to address particular design problems. Solutions to these equations are dependent on experimentation for both coefficients and for validation.

Mesh selection and node placement is critical to the solution of the flowfield. The automated generation of meshes is now becoming feasible and can often be tied to Computer Aided Engineering and Design tools. Computational demands are determined by the form of the equation used, the density of the mesh or grid and convergence requirements. Complete aircraft solutions require huge computer resources and much R&D is aimed at improving the speed of the solution.

5.4.2. Advanced Aerodynamic Profiles Analysis and Design Integration

Advanced aerodynamics profile development in Canada will be primarily directed at wing design for subsonic aircraft carrying less that 120 passengers. The objective of work done on advanced aerodynamic profiles will be to increase efficiency and cruise speeds through reduced drag while improving structural and control characteristics. Wing profile, control surface effectiveness, airframe and engine interface effects with the wing and wing tip designs are areas of research and development interest. Also developments improving wing-flap high lift performance are important areas for minimizing wing size required and hence costs.

Laminar flow control is a term used in the Ontario Pilot Technology Roadmap. Airflow over wings begins as a laminar or ordered flowfield and will transition to a higher drag producing turbulent flow based on flow characteristics such as speed, and wing influences including wing shape surface roughness etc. It has been estimated that if laminar flow could be maintained on the wings of a large aircraft that fuels savings of up to 25% could be achieved. Wing and flight characteristics of small aircraft are such that laminar flow can be relatively easily maintained over much of the flight envelope. A variety of methods can be used to increase laminar flow regions on aircraft of larger size and having higher Reynolds numbers and sweep angles.

Computational fluid dynamics will be the most important technology relevant to the development of advanced aerodynamic profiles. A number of areas require R&D activity and support for aircraft design particular to Canadian aerospace interests. Large scale CFD code refinement and validation is one area requiring work to improve accuracy and reduce computational times for MDO by more rapid design convergence. These CFD codes will also require validation in laboratories and in wind tunnels.

5.4.3. Wing/Nacelle/Propulsion Integration

The placement of any external object on an aerodynamic body will result in a disruption of the flowfield and interference effects between the two objects. The aerodynamic impact will vary in different parts of the flight envelope and under different aircraft attitudes. The aerodynamic interaction between such bodies at cruise speeds can increase drag and may become unsteady resulting in structural, vibration or noise impact on the airframe and passengers. The placement of a thrust engine on a pylon places a large mass at the end of a beam and it can readily be seen that engine induced vibrations and forces can result in exacerbating the aerodynamic effects.

For a propeller driven aircraft, the consequences can be further worsened due to the propeller induced airflow over the wings. Particularly with advanced propellers systems now in use and advanced ducted propulsors the propeller airflow represents a significant portion of the airflow at low aircraft speed. This may cause both stability and control problems, particularly those arising after engine failure.

Engine placement, and the design of the pylon, inlet, exhaust, nacelle and fuselage near the powerplant are critical to the performance of the aircraft as well as for passenger acceptance and comfort.

Sophisticated analytical design tools are being developed for the proper placement of an engine on an aircraft wing. Typically, CFD, structural and aeroacoustics design codes are used to properly size and place a powerplant and its components on wing.

A related issue is that of powerplant/airframe integration in helicopters and tiltrotor aircraft. The integration issue in the helicopter is presently driven by mechanical design considerations; however, exhaust cooling for reduction of tail boom distress, and the use of residual thrust in modern helicopter design concepts will pose significant technology insertion challenges.

5.4.4. Advanced Aircraft Aerodynamics and Handling

Included are technologies that will enable the Canadian Aerospace industry to contribute to the design of advanced concept aircraft technologies or components or be the lead design integrator. Pervasive and perhaps prime amongst these enabling technologies is that of Product Data Interchange (PDI), elsewhere discussed. These enabling technologies should be pursued dependent on their links to, and pre-positioning for potential to specific aircraft platforms or types as follows:

- Future Transport Aircraft – Future transport aircraft will have to demonstrate increased speed and load carrying capabilities over greatly extended ranges. Specific targets have been set by the US for next generation Transport aircraft although no new advanced concept transport aircraft are currently well advanced. Wing loading factors will double over that of existing aircraft with materials new to the transport aircraft envelope developed. For shorter range aircraft a key enabling technology will be that of high efficiency turboprop engines with cruise speeds above the M.72 range. Propulsion technology and propulsion integration issues, aircraft design optimization, CFD and materials technology development and insertion will be key to the success of the future transport aircraft.
- Hypersonic Aircraft – Hypersonic aircraft are in exploratory or advanced development model stage at this time and will be used initially for low cost space launch and delivery platforms and subsequently for commercial transport. Propulsion technologies are significant to hypersonic vehicle feasibility and are now the limiting factor. Variable cycle engines, advanced materials, endothermic fuels and fuel control technologies are key aeropropulsion technology elements where significant R&D remains unsatisfied. Numerous controls and materials research topics require further investment as well, although less uncertainty remains in these areas due to advances made through the shuttle programs.
- Advanced Rotorcraft – Future rotorcraft will demonstrate increased cruise speeds of 200 kts or greater with tiltrotor speeds approaching 450kts. These cruise speeds will be possible at much lessened vibration levels and with greatly increased range/fuel economy. Many of the design concepts for attaining these performance improvements are already in development, however much work remains undone. A separate technology key to the success of future rotorcraft is in visualization and display technologies which are elsewhere discussed.

5.4.5. Advanced Rotorcraft Flight Mechanics

For both conventional helicopter and tiltrotor blades, the wings and propulsion system, operate in a very complex aeromechanical environment. Aerodynamics, structures, vibration and acoustics parameters are inseparable and typically drive the design of the entire air vehicle. In trimmed forward flight the advancing blade tip will be moving at near sonic velocities whilst the retreating blade is often in near stall conditions.

The problems of rotorcraft flight in adverse conditions is of particular interest in Canada because of the frequency of occurrence of icing environments and the helicopter's characteristic inability to handle these conditions.

5.4.6. Advanced General Aviation Aircraft Design and Development

General aviation aircraft pose specific design challenges in all aspects of their design and fabrication. Increasing availability of low cost and high performance avionics, advanced composite designs and powerplant integration all offer opportunities for general aviation aircraft designers and builders.

Many of the technologies being furthered for use in military unmanned aerial vehicles will be of pertinence to general aviation aircraft. Low cost gas turbine technologies and composite structures development and certification issues will likely be the technologies of greatest interest.

The development of technologies for military purposes will underwrite some of the costs of introduction of those design concepts into general aviation use.

5.4.7. Experimental Design and Performance Validation

Analytical design and analysis techniques are a prerequisite to reductions in design cycle time, design and production costs and improved safety and environmental impact. The development of these analytical or numerical design techniques will remain heavily dependent on experimental validation of design codes and performance targets for another 10-15 years. Whereas in the past experimental resources such as wind tunnels were used primarily for design development and refinement, in the future they will increasingly be used for the validation of computational design tools in the future. Notwithstanding the foregoing, there will continue to be a requirement for national facilities including wind tunnels, engine test facilities, flight test resources, and specialized resources including icing tunnels and rig test facilities for some time to come.

Experimental design and performance validation technology investment will be required in the following areas to support the aerospace industry in Canada:

- Data Capture and Analysis Automation - Automated methods for intelligent data capture and analysis will be required to reduce large facility run times and meet the challenges of design tool validation. This will require investment both in sensors and in computational tools;
- Experimental Code Development - Increased data capture rates and fidelity will be required and will necessitate the development of specific codes for experimental design

and performance validation. Facilities and infrastructure will have to be maintained or enhanced to achieve these goals; and

- Infrastructure Support - The maintenance of critical national facilities will have to be supported in concert with other government departments and industry. The objective will not necessarily be to create new facilities but rather improve the functionality of existing resources to meet the needs of new technology developments.

5.5. Aeropropulsion and Gas Turbine Technologies

Aeropropulsion systems and gas turbine technologies pertain to a wide and challenging spectrum of contributory technologies that include aerodynamics, thermodynamics, materials sciences, and controls theory. Computational design requirements for gas turbines tend to be extremely demanding as the flowfields and stressfields are very complex and must be well understood to achieve the required design efficiencies. Canada is in a very select group of countries having the capability to conduct the complete design, development, certification and fabrication of aerospace gas turbines. The gas turbines that Canada has developed in the past have typically been small to medium size engines that have design constraints that are often quite different to those of larger engines. As with other critical technology areas, the primary technology drivers are to reduce design cycle time and cost as well as manufacturing costs. For aeropropulsion technologies there is the additional challenge of environmental effects where both noxious and particulate or visible emissions must be reduced.

The technology elements with the Aeropropulsion and Gas Turbine critical technology area are described below:

5.5.1. Computational Fluid Dynamics Development and Validation – Gas Turbines

CFD is perhaps the single most critical technology for gas turbine engines. Gas turbine CFD needs have typically posed the greatest challenges to engine designers, computational power and code developers. While CFD is of utmost importance to the engine designer it is a very specific disciplinary design requirement and competence is held by a very small number of engine design firms worldwide.

Computation techniques for gas turbine engines also tend to be very module specific – compressor, transition duct, combustor, turbine and exhaust duct/military afterburner are examples. The computational techniques are often also specific to engine size class and thus Canada, focusing on small gas turbines, has a specific set of technology requirements.

Advanced 3D CFD codes will be applied in the following manner:

- In the compressor to develop advanced swept airfoils capable of high compression ratios that in turn yield higher efficiency at less weight and with a smaller parts count (significant life cycle cost factor)
- In the combustor for higher intensity (smaller volumes with much higher energy density) combustors that approach stoichiometric conditions to yield higher efficiency with lower weight, and
- In the turbine to produce higher stage loading with reduced turbine cooling air requirements that again reduces weight and cost while reducing fuel burn.

5.5.2. Advanced Gas Turbine Combustor Design

The combustor of a gas turbine engine is that part of the engine that receives the compressed air from the compressor. Energy is added to the airflow in the combustor in the form of chemical energy derived from fuel. The combustor discharge air is expanded across a turbine or turbines where energy is extracted to drive the compressor and gearbox of a turboshaft/turboprop engine, or to provide jet thrust via a turbofan and core nozzle in a thrust engine.

Small gas turbines, of the size that have been historically designed and built in Canada pose significant design challenges because of their size. Typically these combustors are the highest intensity combustors in the world, where intensity can be thought of as the amount of energy converted per unit volume within the combustor. The design objectives for gas turbine engines, including small ones, are to: increase the overall pressure ratios which leads to increased efficiency and smaller size and weight; and increase cycle temperatures to again achieve increased efficiency at decreased size and weight; while simultaneously producing lesser noise and noxious emissions.

Combustor technology development challenges for Canadian engine manufacturers include:

Computational fluid dynamics: CFD analyses are complicated by the reverse flow designs typically selected to maintain short combustors within small volumes. Cooling flow and chemical additions to the CFD design further complicate the process as the temperatures of gases at the core of the flows are well above the melting temperatures of the combustor materials. Pressure losses and cooling flow requirements must be minimized to improve performance.

Materials: Increasing compressor ratios result in increased compressor discharge temperatures and decreased cooling capability. These increased temperatures also push for higher fuel to air ratios and higher temperatures within the combustor. Stoichiometric ratio is that ratio when all oxygen is consumed in the combustion process leaving less air for cooling. Materials challenges in this environment are the most demanding.

Fuel injection and mixing: CFD and injector specific techniques are required.

Emissions: While not legislated and not contributing significantly in absolute terms, there is a drive for lower emissions which drives designs often in the opposite direction to those factors identified above.

5.5.3. Energy Efficiency and Environmental Design Techniques

Two issues predominate in the environmental design factors technology category for aeropropulsion systems – the external noise and exhaust emissions.

The objective identified in the DMR&O Road Map for noise reduction is in the order of 6 EPNdB (Effective Perceived Noise in dB). This objective can be achieved through the utilization of larger by-pass ratio fans, innovative design concepts for turbo fans and sound conscious designs in the combustor and exhaust nozzles/liners. Generally speaking, noise improvements and fuel efficiency but must be accommodated for future regulatory requirements to be met without sacrifice of overall engine efficiency. Of special interest will be advanced ducted propulsors (ADF) which offer both noise attenuation and increased efficiency potential. This technology area will be heavily dependent on computational design techniques and multidisciplinary design optimization concepts

The reduction in aircraft emissions is also a regulated requirement. While small aircraft engines contribute an insignificant amount of pollution they are still the target of increased environmental scrutiny. Regulatory requirements are targeted at Nitrous Oxides (NO_x), Carbon Monoxide (CO) and visible particulate emissions. CFA analysis techniques specific to combustion processes will be the major tool used to lower aeropropulsion emissions.

5.5.4. Structural Design, Analysis and Optimization – Gas Turbines

Shortened design cycle times are necessary for achieving market advantage in the aerospace and defence sector. Improvements in the structural analysis, design and optimization of gas turbine engines is necessary to achieve these goals while also meeting the overall objectives of increased durability and efficiency at lower costs.

A Multi-disciplinary Design Optimization (MDO) approach is necessary that combines finite element analysis and aerodynamic design techniques. MDO is necessary to rapidly determine the structure of the engine and identify critical areas requiring further and detailed analysis.

Many of the structural and aerodynamic codes as well as industrial art are proprietary in nature. However, the integration and refinement of these codes is an on-going challenge.

5.5.5. High Temperature Materials Development

Advanced materials are of critical importance in meeting the design goals of future engines. Simply stated future engine performance objectives can be summarized as: increased thrust/weight or power to weight ratios; increased overall pressure ratios and cycle temperatures; production cost reductions; and life cycle cost reductions. Materials classes of interest to the engine community are discussed below:

Organic Matrix Composites (OMC): High temperature organic matrix composites are light weight materials capable of operating at up to 650 °F and can be used in compressor static and rotating components. While technically not a high temperature material, increased compression ratios are resulting in high compressor exit temperatures that require materials capable of higher than aircraft structural operating temperatures. High temperature OMCs can replace titanium metal matrix components in some components, and the Ti MMCs are three times as dense.

Ceramic matrix composites (CMC) are high temperature (2000°F), low density (.8lb/in^3), materials that have relatively low strength typically less than 50 KSI. Accordingly, they are used in high temperature low strength components such as the combustion liner, low pressure turbine vanes and blades where their temperature characteristics allow them to be used without cooling. CMCs can either be whisker, fibre or continuous fibre reinforced.

Reinforced Superalloys: Reinforced alloys are not currently available except at the laboratory stage but do offer near ceramic operating temperatures with much higher than ceramics strength of 200 KSI. These materials, if developed, will be used in compressor disks and turbine wheels where their temperature/strength characteristics will achieve significant weight reductions.

Intermetallic Matrix Composites: reinforced intermetallics are likewise not available at this time outside of the lab. They offer operating temperature capabilities of up to 2200°F and densities comparable to current nickel based superalloys

Single Crystal Materials: Advanced titanium aluminide single crystal materials are now being developed with excellent potential for high compressor rear stage applications.

5.5.6. High Temperature Materials Performance and Coatings Development

There is considerable commonality between coatings systems for new components and those developed for repaired components. Coating systems for new parts are designed in and may influence to some degree the design of the component either from a substrate selection perspective, or perhaps in the design of a combustor liner.

Excellent coating systems work has been done in Canada and has involved a number of government departments, coating system R&D organizations, OEMs, and repair organizations.

Essentially a coating system is placed on a substrate to protect the substrate in some manner from its operational environment. Erosion resistant coatings used to protect the substrate from erosion by ingested particles or perhaps hard particulate products of combustion. Corrosion resistant coatings will either protect the substrate from a corrosive environment or act as a sacrificial material corroding preferentially over the substrate. Thermal barrier coatings are, as the name implies, meant to protect a component from temperatures that are beyond the capability of the materials.

Coating systems are typically designed systems that must be compatible with all covered materials including weld or braze materials and not degrade the service life of a component. Types of coating systems used in the Canadian aerospace and defence sector include:

- Physical and chemical vapor deposition
- Diffusion or pack processes
- Thermal spray
- Hardfacing
- Plating
- High energy surface treatments including ion implantation and laser surface treatments
- Flame and induction hardening

5.5.7. Digital Electronic Fuel Control Design and Validation

Based on pilot input for power, external conditions such as air temperature and pressure, and internally sensed parameters such as speed and temperature the control system of an engine automatically controls all the subsystems of the engine to keep it trimmed and operating properly.

The fuel control will control fuel flow, the position of various mechanical parts including bleed valves inlet guide vanes and variable stators to ensure that an engine operates within all required design parameters - acceleration, speed and temperature and in such a manner as to minimize aero-thermodynamic problems including stall.

Digital electronic controls represent a mature technology in terms of actually controlling engine performance within specified limits. Some existing controls provide additional functionality including the monitoring of life usage parameters. Advanced fuel control systems will be required to offer even greater functionality. Advanced controls will further enhance both the performance of an engine and the life cycle costs of an engine. Life cycle costs will be reduced both through the control system monitoring of components and through the smart control of engine parameters to ensure that the required performance is delivered to the pilot in the least damaging mode.

Smart control systems will also be used to accommodate for damage, both severe and gradual to ensure the optimal performance of the engine under these degraded conditions. These smart controllers will have the ability to sense the onset of aerodynamic stall, or a vibration and take appropriate corrective action.

Additionally the engine control system will eventually form a part of an integrated aircraft control system where performance efficiency will begin to approach the best possible for a particular configuration.

5.5.8. Component Integration Concepts

Component integration addresses the concept of efficient matching of the various design elements of a gas turbine engine into the most efficient engine possible. Component integration initiatives will typically be multidisciplinary design optimization activities that involve computational aero-thermodynamic and structural analysis packages.

An example of this concept is in the design of a diffuser section between the compressor and the combustor of an engine. The diffuser will provide significant structural rigidity to the engine but must also provide a very efficient flow path between the compressor and the combustor. The velocity profile on entry to the combustor for low pressure losses and highly efficient and non-damaging combustion to occur.

5.5.9. Health and Usage Monitoring

This is a maturing technology domain that is heavily dependent on having an in-depth knowledge of the design the engine under study. In general health and usage monitoring will generate the following benefits:

- Lower costs of operation as components can be changed when their performance has degraded to a specified limit or when the actual usage of a component dictates that a life limit is nearly reached.
- Lower costs of operation as component degradation can be tracked and replaced on a scheduled basis as opposed to being the result of an unforeseen occurrence at an inconvenient location or time.
- Lower costs as no-fault found inspections are minimized.
- Enabling mission planning based on use of the most appropriate aircraft for a particular mission or flight.

- Increased safety of flight as component degradation will typically be tracked and removed before a catastrophic event can occur.

A wide range of technologies has been applied to this field with varying degrees of success. Increased on-board sensing and data manipulation is providing increasing levels of Health and Usage Monitoring functionality.

5.5.10. Test Cell Design and Performance Assessment Methodologies

Test cells utilized for Canadian aero-engine programs, and also those developed for sale, have typically been sea-level static facilities offering little or no altitude, forward flight velocity or temperature pressure simulation. Some limited flying test bed capability exists in Canada for the testing of engines.

That being said the National Research Council has participated in numerous international projects to ensure that a world leading test cell capability exists both for engine qualification testing, performance testing and for the development of performance assessment techniques.

Engine test cells take a number of forms. Sea level test facilities are used for Engine Qualification Testing which involves the monitoring of a relatively small number of parameters over long periods where in service usage is evaluated in a time compressed manner. Qualification testing also involves the ingestion of ice or water to ensure that unacceptable engine degradation does not occur in those instances.

Altitude test cells, of which there are none in Canada, are used to qualify engines over a full flight envelope as opposed to the endurance type testing previously mentioned.

Test cells can also be used for the analysis of problems or validation of problem resolution. In these cases the test cells often require enhanced instrumentation suites and a much more careful design to ensure that performance parameters are correctly measured.

World interest in advanced test cell technologies is currently directed at those required to support hypersonic vehicles for military uses or for space launch vehicles. This type of test cell is very resource intensive and highly specialized.

5.6. Aircraft Structural Materials

The design of an aircraft structure is driven by the need to provide the required strength, stiffness and durability at the minimum weight and cost. The understanding of the operational environment for a structure is a key to the selection and design of a structural component. That operational environment requires an understanding of the magnitude and frequency of loads, the presence of such modifiers as corrosion or impact damage and various other factors. Materials are increasingly being engineered to meet specific needs and are often fabricated to provide enhanced structural properties in the direction of loading. It is the application of non-axisymmetrical properties of a material that challenges analytical design and analysis techniques. Maintaining the original or anticipated design properties of the materials throughout the life of a component must also be addressed to minimize the chance of failure initiated by corrosion or other service induced failure mechanisms. Finally systems are being incorporated that allow the continuous monitoring of loads and environmental factors such that the maximum safe life can be achieved for every aircraft or component.

The technology elements with the Aircraft Structural Materials critical technology area are described below:

5.6.1. Metallic Manufacturing Processes Development

This critical technology is devoted to the manufacturing processes, including machining methods for three categories of metallic materials. These are lightweight alloys, high strength structural alloys and high temperature alloys.

Although the classification is somewhat arbitrary, the lightweight alloy category includes metal matrix composites (MMCs), aluminum lithium alloys (Al-Li), aluminum-based powder metallurgy and other new alloys such as aluminum scandium (Al-Sc) and foamed aluminum.

High strength structural alloys include Beta titanium and new ferrous alloys.

High temperature alloys include titanium matrix composites (TMC), some of the new titanium alloys like Ti-62222 and titanium aluminide (Ti-Al), new superalloys and the intermetallics like niobium silicide (Nb-Si).

5.6.2. Composite Materials Processes Development

Composite materials considered in this critical technology are characterized by the fibre reinforcement of a polymer matrix. Usually, the matrix is epoxy, although other matrix materials such as PEEK and polyamide are also used. The fibres are usually carbon, although glass and aramid fibres have special applications.

A facet of the R&D effort involves using these materials in advanced structural design concepts. This will involve advanced technology such as stitching, braiding, resin transfer molding, pultrusion and advanced curing concepts such as electron beam cure, low energy cure and induction heating.

One of the objectives of the work is to reduce constraints on allowable design stresses. An improved understanding of the materials, the production processes, structural design concepts, failure modes, and sensitivities to environmental effects, will lead to increased confidence in their use. This is turn will allow more efficient and more appropriate use of the materials. This increased understanding will result in more cost and time efficient material qualification testing and will likely result in higher design allowable stresses. The ultimate goal is to improve the overall cost performance of the resulting airframes.

A particular restraint on higher design allowables for resin composite materials is the resistance to impact damage that requires advances in matrix polymer technology and assembly techniques such as stitching through multiple layers for improving delamination resistance.

5.6.3. Hybrid Materials Systems Development and Characterization

Hybrid materials, the most important for airframe applications are fibre metal laminates. These typically consist of alternating thin layers of structural aluminum alloy and composite pre-preg, material, usually uni-directional glass-epoxy. The first and last faces are always metal. Analytical design techniques, materials characterization of strength, fatigue and damage tolerance needed for regulatory acceptance of these materials will require significant levels of R&D. Suitable production methods will need developing for component fabrication and assembly.

5.6.4. Environmentally Friendly Coating Systems and Surface Treatments

This critical technology is directed primarily at the replacement of chromium and cadmium coating and their associated processes for environmental reasons.

Cadmium metal as an electrodeposit has been in industrial use as a corrosion preventative for many years. It gained particular prominence in the aerospace industry because of its galvanic similarity to aluminum and for that reason, has been applied to many substrate metals.

Chemical and physical vapor deposition of aluminum, and alkaline/acid zinc-nickel plating processes are common replacements for cadmium plating. Aluminizing – the process of coating materials with a thin layer of aluminum includes such traditional methods as batch or continuous hot dipping, cladding and slurry processes usually followed by heat treatment providing aluminum diffusion in the bulk metal and formation of a protective diffusion layer. The direct diffusion process, pack diffusion (pack cementation), is one of the most common for large scale aluminizing. The use of diffusion aluminum coating by the pack cementation technique showed satisfactory protection of metals against oxidation at temperatures 500 – 700° C. However, pack cementation also involves the use of hazardous materials and processes.

Chromium electroplating processes are routinely used to coat aircraft parts for wear and hydraulic applications. Alternative processes such as high velocity oxy-fuel (HVOF), physical vapor deposition (PVD) and other processes exist which neither require the use of toxic substances nor create toxic byproducts.

The HVOF process is a powder process which eliminates the liquid and mist (hexivalant chromium) toxic waste. This process essentially ignites combustive gases heating and propelling the new molten powder towards a fixtured part in a specially designed spray booth. The molten metal impacts the parts creating a dense coating on the surface.

HVOF coatings (WC Co) have demonstrated properties similar to hard chromium for fatigue debit corrosion, wear, adhesion and friction. However, industry standardization is still in the development phase and design data for aircraft is being created.

5.6.5. Smart Structures and Materials

A smart structure consists of a structure with integrated sensors and actuators connected to signal processing and device controlling electronics. The smart structure uses the sensors to measure changes in its condition or environment. The attached processor monitors the changes and either logs them to a storage device, recommends corrective or diagnostic action or commands the actuators to adjust the properties of the structure. The advantage of the smart structure over more conventional structures is that it can adapt to its environment as the conditions around it are changing. The on-line ability of the smart structure means that it can remain ‘tuned’ and effective where other more conventional systems would have to be constantly maintained or operated at less than optimum conditions. This is a very attractive feature for most aeronautical applications, where in-flight controls must be precisely adjusted and yet may vary by great degrees depending upon flight conditions such as weather, loads, or even takeoff and landing. Of the different smart structure technologies undergoing development, shape control, flutter suppression, vibration control, loads alleviation and loads and health monitoring are considered the most promising for aeronautical applications.

5.7. Aircraft Systems

Wymore (1993) defines systems engineering as "the intellectual, academic, and professional discipline the principal concern of which is the responsibility to ensure that all requirements for a bioware/hardware/software system are satisfied throughout the life cycle of the system."

Systems engineering is described as the process where overall functional requirements are translated into sub-component specifications which when combined, achieve the overall design objectives. The sub-components, or building blocks to the full system are more efficiently designed and developed. The integration of those sub-systems is key to the success of the process. The aircraft systems critical technology area addresses the technologies necessary for the optimization and application of specific functionality to an aircraft. These technologies either address unique technology requirements as in the case of icing detection systems, or are characterized by a high level of integration requirement with other aircraft systems to ensure optimal design is achieved.

The technology elements with the Aircraft Systems critical technology area are described below:

5.7.1. Landing Gear Design and Airframe Integration

This critical technology is focused on enhanced landing gear performance; improved materials and manufacturing processes; more sophisticated design and analysis methods; and increased system integration capability. Other critical technology areas have a significant impact on the design, testing and manufacture of landing gear.

The following text elaborates on the elements of the landing gear critical technology:

<u>Landing Gear Performance</u>

- Active, semi-active and passive damping systems to minimize landing and ground handling loads;
- Main gear landing gear may include steering to meet ground maneuvering requirements; and
- Use of health monitoring features/diagnostics. This technology is particularly well suited to military aircraft but is also applicable to commercial aircraft (ie. this technology allows load distributions to be monitored among multiple gear on large aircraft with redundant landing gear).

<u>Materials and Manufacturing Processes</u>

- New materials need to be investigated which can address the need for balance among competing requirements such as: weight, cost, strength, damage tolerance, environmental resistance and machinability issues;
- Materials that currently have limited utilization include Titanium 10.2.3, Aermet, AF1410 and Hy-Tuf. Titanium matrix and aluminium matrix composites have potential as well as polymer composites and hybrid metal/polymer composites, albeit in a less immediate timeframe;
- Material property database development and machinability issues must be addressed; and

- Wear and corrosion protection coatings also require improvements and replacements to meet design and environmental compliance goals.

Decision and Analysis Methods

- Analytical design and analysis methods must be improved to obtain better accuracy and therefore greater productivity;
- Advanced technologies need to be applied to damage tolerance analysis, crack growth rate determination;
- Improvements in dynamic simulation techniques, eventually utilizing finite element analysis (FEA) approaches, are needed for analyses such as shimmy, taxi performance and passenger ride;
- Experimental validation methods must be enhanced to improve design and analysis methods; and
- Future Large Transport Aircraft weight, flotation and ground maneuvering requirements will require the development of specific design and analysis methods.

Increased System Integration Capability

Landing gear system and subsystems includes many of the following elements: shock strut assembly, drag brace assembly, uplock and downlock assemblies, retraction actuator assembly, hydraulic pipes and electrical harnesses, wheels, tires and brakes, brake control/antiskid, brake temperature monitoring system, landing gear control and indication system (hydraulic and electrical), manual release system, tire pressure indication system, bay overheat detection, weight and balance system, and landing gear doors and mechanisms. To be competitive, landing gear manufacturers must be capable of managing integration the whole system through to the associated cockpit controls.

5.7.2. Environmental Control Systems Design and Integration

The environmental control system is the on-board aircraft system that maintains cabin pressurization and temperature as well as providing ancillary cooling for avionics systems.

To remain competitive, the next generation of ECS controls can be a part of the integrated utility subsystem. Customers will continue to demand normal ECS cabin pressure, cabin temperature and avionics cooling functions to be performed at a lower life-cycle-costs (LCC). In addition, distributive avionics cooling functions on demand with higher efficiency, lower weight and lower volume will be required to cool thermal loads associated with the rapidly growing avionics capabilities. These new functions will require a highly reliable electronic controller and new heat exchanger technologies. To operate a highly integrated utility system, the reliability and availability of the control system must be significantly higher than those of the present generation of control electronics. The Minimum Time Between Failures (MTBF) objective of the new generation of controllers is in the order of 100,000 hours. To meet these objectives, Fault Tolerant Electronics (FTE), packaged using the Integrated Modular Avionics (IMA) approach, with matching software capabilities must be developed. The goals would be to provide highly reliable control and mechanical hardware (HW) systems to the aircraft companies. These new systems would have significantly lower LCC but with initial acquisition costs comparable to the present generation of equipment.

5.7.3. Advanced Flight Control System Development

Fly-by-wire control systems refer to those systems where pilot control input is made to a computer which interprets the pilots commands into aircraft control surface movements and thus affects the aircraft attitude. The signals to the control surfaces are carried electrically over cables. This type of system allows the computer to select the optimal controls movement for a particular maneuver, and allows the control system to compensate for system degradation or damage. However a wire based system is susceptible to electromagnetic impulse effects and extensive shielding is needed for protection against lightning strikes.

Technology development objectives for the Canadian Aerospace and defence sector for advanced flight control systems development can be summarized as:

- Define an architecture for a cost effective, fault tolerant, 3-axis Fly-By-Wire (FBW) flight control system suitable for a 70-120 passenger aircraft;
- Define control laws appropriate to such a FBW system;
- Examine and analyze the man/machine interface necessary for an optimum, cost effective solution, likely using fixed base simulators and/or virtual reality means;
- Evaluate cost effective actuation methods to be used in the selected architecture;
- Define the interfaces with the sensors, flight guidance, avionics, aircraft power supplies, etc.; and
- Formulate a flight demonstrator program and perform flight testing for validation of the above.

FBW is now an accepted technology in commercial aircraft sized from 120 passengers upwards, however it is probably not viable costwise in airplanes smaller than those carrying 50 passengers. The challenge is to produce a FBW system that meets the necessary cost criteria while achieving the benefits of FBW in terms of aircraft operational parameters.

FBW flight control systems have been in use for many years in some form or other. The Concord SST and military were relatively early users of this technology. Other commercial airplanes adopted FBW somewhat later with Airbus being the first company to adopt FBW for the A-320 followed by Boeing on the B777. Airbus then continued FBW with the A-330/340 models. FBW systems will be superseded next by Fly-by-light systems discussed later.

5.7.4. All-Electric Aircraft Concept Development

The all-electric aircraft concept involves the replacement of hydraulic system components with electric components. The intent is to save weight and increase reliability. In essence electrical generators would provide power to electric actuators for flight control surface movement. Electric power cables are typically lighter and less prone to damage or service induced degradation such as fitting vibration that results in leakage in hydraulic systems. Alternate power supply redundancy is an additional advantage of this concept.

Challenges associated with this type of technology insertion would be related to electromagnetic interference (EMI).

5.7.5. Fly-By-Light Concept Development

The Fly-by-Light (FBL) concept offers significant weight savings and safety of flight improvement potential. Fibre-optic cables are immune to electromagnetic interference and therefore are not affected by the fields generated by other lines or electrical devices in close proximity or by lightning strikes. For flight controls, hydraulic or electric actuators are still employed but receive their command inputs via fibre-optic cables.

Weight reductions are significant as the fibre-optic cables need only be protected from physical damage, whereas electric cables must be shielded which increases weight significantly. Also with a FBL connection multiple routes can be readily provided that are well separated to provide control redundancy.

There are a number of enabling technologies that must be developed in order to allow the insertion of this technology. Fibre-optic connectors for in-line and end connections must be developed that are durable and insensitive to in service maintenance activities. Fibre-optic sensors development will also be necessary to allow the achievement of the full range of benefits that can be obtained in fly-by-light aircraft.

This technology is usually associated with smart structures concepts such as smart skins where fibre-optic cabling can be readily embedded in a composite lay-up to achieve dispersed damage, stress, temperature or vibration sensing capability.

5.7.6. Active Noise and Vibration Control

Active noise and vibration control systems (ANVC) can improve passenger comfort and crew effectiveness by simultaneously reducing cabin and cockpit noise and vibration levels. They can increase the performance characteristics of commercial and military aircraft by reducing vibration levels; and, increase the service of aircraft and improve component life cycle costs by decreasing noise and vibration induced fatigue loading.

ANVC works on the basic principle of destructive interference, where the undesirable sound wave or vibration is countered with a wave of equal amplitude and 180 degrees out-of-phase. The result is that cancellation occurs and the undesirable sound or vibration is eliminated. This principle is implemented in small structures, including noise cancellation headsets, transformer quieting systems, and interior noise reduction in automobiles and aircraft.

ANC technology consists of sensors, signal conditioning, a control system, power amplifier and actuators. In a typical ANC system operating in a steady harmonic noise field would be sensed with any array of microphones, the signals from which would be analyzed by a central processor unit/digital signal processor combination. An optimization algorithm then determines the best distribution of sound intensity and phase from the speakers for overall noise reduction.

A number of different sensors and actuators are used in these applications. The sensors utilized in smart Active Noise and Vibration Control (ANVC) systems include eddy current proximity sensors, tachometers (velocity sensors), accelerometers, microphones and piezoelectric sensors.

The most common actuator used in the active control of sound is a relatively simple loudspeaker with a variable baffle. The loudspeakers are primarily involved in the cancellation of noise or sound waves by applying a “mirror image” sound wave to counter to the undesirable noise. A second approach to active noise control involves cancellation of the noise at the source. In these applications, piezoelectric ceramics and electromagnetic shakers are popular, especially when used in the control of panel vibrations. These applications are considered to be examples of active noise control since the goal is to reduce the amount of auditory acoustic noise. However with ANVC the passenger also benefits from reduced vibration levels and perceives improvements in comfort.

5.7.7. Ice Detection, Management and Control Systems

Regional airliners and helicopters operating in lower level airspace are increasingly exposed to hazardous icing conditions. This has increased the need for technologies for proactive and reactive ice detection and protection. Reactive technologies are those related to the detection of runback icing and attempt to monitor real-time or infer likely aerodynamic performance degradation. Proactive systems forecast the potential for icing conditions and provide on-board avoidance advisory information. Reactive systems provide reasonable protection of the aircraft within the regulated flight envelope but are essentially go/no-go decision aids. Defence aircraft on Search and Rescue Missions and most civil transport aircraft often do not have the option of avoiding hazardous icing conditions and should have pro-active pilot advisors and ice removal systems

Reactive ice detection devices include: embedded sensors that are mounted on the wing surface in a critical location and monitor ice build-up; and aerodynamic performance sensors that typically monitor pressure within the boundary layer of the wing to determine lift performance degradation.

Proactive systems require the remote measurement of Liquid Water Content (LWC), Outside Air Temperature (OAT) and Mean Volume Diameter (MVD) of the liquid water. Knowledge of these three parameters is required to predict hazardous icing conditions. Additional R&D work on MVD measurement is required.

Ice control and removal systems may use heated air from the engines or electrical heat elements to remove ice from airfoil surfaces. Coatings that are termed “iceophobic” may also be applied to minimize ice build-up. CFD tools are needed to analyze ice-buildup characteristics, assess aerodynamic degradation, and improve ice removal air supply performance.

This technology area is of particular interest because of the types of aircraft produced in Canada and because of climatic conditions.

5.8. Simulation and Modeling

Simulation and modeling technologies include a number of interdependent technologies that are applicable to both on-board and ground based needs. The visualization technologies include the generation and manipulation of digital images based on calculated or multiple sensor sources on-board the aircraft or linked to the aircraft from the ground, another aircraft or space. Visualization technologies include advanced display systems such as flat panel displays and such items as micro-laser projection for simulators as well as advanced concepts for 3-D representation using 2-D displays. These visualization techniques extend beyond the operational or training environments into the manufacturing centres where power rooms are used for large scale manufacturing process development in virtual factories. Visualization technologies are also closely linked to simulation and modeling for acquisition, mission rehearsal and training. System trades studies will increasingly be employed in the design process through development and application of novel simulation techniques. Mission rehearsal has produced significantly increased levels of survivability for military pilots who can fly extremely realistic practice missions several times prior to the real one. This mission rehearsal aspect takes on another dimension in the commercial aircraft world where increasing time could be taken during automated flight segments to practice emergency situational response.

The technology elements with the Simulation and Modeling critical technology area are described below:

5.8.1. Simulation and Modeling For Acquisition (Mission) Rehearsal and Training (SMART)

The SMART concept takes simulation and modeling to its ultimate potential. At the beginning of the cycle, simulation and modeling is used to determine the required functionality of a system prior to its development. This trades study is conducted within highly capable generic synthetic environments that allow the full exploration of system functionality requirements either for commercial or for military operations where existing and future threat scenarios can be exercised. That input is fed into the acquisition phase, where again simulation and modeling is used to identify acquisition and life cycle cost trades. An iteration occurs back to the performance specification phase if acquisition trades studies indicate that specified functionality cannot be fully achieved or if slight modifications that reduce cost factors do not greatly change the functional capabilities. Simulation and modeling is then used throughout the design and fabrication stage to reduce cycle times and process costs. Finally many of the same simulation and modeling tools are used for training of operators, commanders and support personnel. This multi-phase approach poses significant challenges for human factors, software and system integration engineering as well as information technology and psychological disciplines.

Technology investment is required to achieve the linking of dispersed virtual environments. Distributed Interactive Simulation is the concept and also the term used for the basic US DoD standard that was developed for the utilization of dispersed synthetic training devices into a single virtual training environment. High Level Architecture (HLA) is the term applied to the current DIS standard.

5.8.2. Image Generation

The overall goal is to present to the operator, particularly the pilot in the cockpit environment, a view of the outside world which is enhanced to simulate “clear vision”, uncluttered by extraneous data and annotated automatically to provide value-added cues and references.

Sophisticated image generation and manipulation is considered key to visualization technologies because, if image generation/manipulation issues are not resolved, then the other visualization technologies cannot follow. The generation and manipulation of imagery for aerospace applications can be divided into the following general activities:

- Image acquisition and preprocessing;
- Image processing, including enhancement;

- Image fusion from several sensor sources (e.g. FLIR, LLTV, MM Wave Radar, SAR); and
- Image synthesis and rendering (e.g. synthetic vision systems and engineering applications such as CFD-based flow visualization).

One particular imaging/display technology still in the research phase is the stereoscopic, or 3-Dimenstional, display. Conventional techniques of forming three dimensional (3-D) images on a two dimensional screen involve the use of electronic or optical tricks, such as the use of special eyewear. In a 3-D space display, however, the images are formed directly from luminous points distributed in all three spatial dimensions. Instead of pixels, one has voxels (volume-pixels). There are a number of approaches currently under development for 3-D space displays, some holographic and others mechanical, but the goal is to achieve a 3-D space display with no moving parts and a full 360 degree view requiring no special eyewear.

5.8.3. Display Technologies Including Fiber-Optic Head Mounted Systems, Micro-Laser Projection, and Flat Panels

Advanced display media for use in the cockpit can be grouped into two categories.
One category of displays would be general head-down instrument panel displays such as flat-panel displays, multi-function displays, EFISs and instrument conformal displays. The other category of display media would be projection/overlay systems such as Head-Up displays (HUD), Helmet-Mounted Displays (HMD) and enhanced/synthetic vision systems. Many of these same display technologies may be useful for ground-based aircraft design, manufacture, repair and overhaul – HMDs are prime examples, since they can be used in various virtual reality and augmented reality ground-based engineering applications.

Modern aircraft (with military combat aircraft leading the way) typically employ a complex suite of avionics equipment and require the crew to assimilate large quantities of information, often under extreme stress. The need for improved displays and enhanced operator-machine interfaces is now generally accepted throughout the aviation industry. Future aircraft, in order to be operationally and commercially successful, will incorporate more capable, integrated displays. It is vital that the human factors and human-machine interface aspects of these displays be addressed at the design stage.

For the head-down cockpit application, flat-panel displays appear to be taking over the market, with AMLCD (Active-Matrix Liquid Crystal) the current industry standard. However, other flat-panel display technologies such as ELD (Electroluminescent Display), FED (Field-Emissive Display), DMM (Digital Micromirror Projection Display) and AC Plasma show potential too.

New flat panel display technologies must be developed for both modern commercial and military aircraft , multi-functional flat panel displays are becoming predominant. Active matrix Liquid Crystal (AMLCD) are the current norm with other flat panel display technologies being developed that include: Electroluminescent Display (ELD), Field-Emissive Display (FED), Digital Micromirror Projection Display (DMM), and AC Plasma. Technologies that increase the size and visual fidelity of the displays while reducing cost and complexity are required.

For military applications, HUDs have replaced conventional weapons sights, and they are usually present in all modern fixed wing combat aircraft. The trend in technology improvements has been toward enlarging the instantaneous and total field-of-view (FOV) and providing both stroke and raster capability in order to support electro-optical sensors and weapons systems. HUDs are starting to appear in combat rotary wing aircraft and have been introduced in some civil business jets. There are still problems with the limited FOV and off-boresight capability, the clutter of symbology and the general visual obscuration of HUDs. HUDs can be considered a short term solution for most applications – once all of the present problems with HMDs are resolved, it is expected that they will take over from HUDs for virtually every application.

HMDs were first used in combat rotary wing aircraft, and are still more prevalent there than in fixed wing aircraft. As this technology matures, it is anticipated that there will be a dramatic increase in the number of HMDs in the cockpit. Applications, so far, have been for the display of electro-optical sensor data, weapons sights and some flight symbology.

5.8.4. Advanced Synthetic Training Environments and Concepts

This technology area can be further sub-divided into those technologies needed for design and manufacturing and those devoted primary to military operational needs. The former is discussed primarily under SMART and also under advanced manufacturing technologies, while the technology investment requirements for military synthetic training environments are discussed below.

Military simulations are currently considered to fall into three classes as follows:

- Constructive Simulations - These simulations employ simulated people using simulated equipment;
- Virtual Simulations - These simulations have real people using simulated equipment; and
- Live Simulations - Real people using real equipment.

In the past simulations typically relied on a single simulation device that enabled the evaluation of an operational concept for a single weapon system or formation in virtual isolation to external factors. Rapid advances in computational power and the development of simulation tools have introduced the possibility for much broader linking of simulations, the extension of concepts simulated, and even the potential mix of real and simulated systems within one synthetic environment or concept evaluation process.

Technology development and investment is required in the following areas:

- Cost Reduction - The cost of the various modules required for a synthetic training environment must be reduced while ease of use, re-use and reliability are increased;
- Interface Standards - Common open architectures and standards for distributed interactive simulation must be developed that allow the linking of geographically dispersed components of a simulation;
- Human Factors - better models of human performance with the capability for personality typing, fatigue, training level etc must be developed and validated;
- Concept Evaluation Processes - Processes for the design and validation of larger scale simulations are required. The technologies that expand the simulated environment must be paced with the ability to develop synthetic exercises that properly explore target concepts and then analyze and understand the outcome of these large scale synthetic operational exercises.

5.8.5. Database Tools

Database tools refers to those techniques associated with the design and access to databases containing information that is specific to simulation and modelling requirements. This is an IT intensive area that is particularly challenged by such requirements as visual databases or distributed interactive simulation.

The databases associated with aerospace simulations are typically enormous and require state-of-the-art computational power to develop, and exploit for simulated environments. The development of common database standards and the creation of validated databases of for environments and systems is required.

5.9. Advanced Manufacturing Technologies

The Advanced Manufacturing Technologies critical technology area includes numerous elements devoted to the development of affordable, low-risk design processes, development and production. The technology elements selected for inclusion within this area were taken from the DMR&O Road Map.

The technology elements with the Advanced manufacturing Technologies critical technology area are described below:

5.9.1. Information Technologies for Manufacturing Processes

Information technologies will have the greatest impact on manufacturing processes of any single technology area. This section of the Technology framework addresses the DMR&O Road Map issues but draws heavily on the approach and documents of the Integrated Manufacturing Technology Roadmap (IMTR) initiative conducted in the U.S. The aerospace and defence industry in Canada has made limited advances in the adoption of information technologies for manufacturing. Considerable investment and support in this area is necessary particularly to support the appropriate and effective involvement of companies at all tiers. The following identifies the three particularly relevant IMTR Information Technology elements for TPC Technology Framework consideration.

<u>Manufacturing Enterprise Information Systems Processes</u>

This technology category incorporates the following components:

- Product Design, Definition and Data Interchange - This area addresses the topic s covered earlier in this document under Product/Technical Data Interchange (PDI/TDI), and Concurrent Engineering and Virtual Design. The primary focus is on the collaborative design process and issues that are associated with Configuration Management (CM).
- Manufacturing Planning and Execution - This technology area id directed primarily to the manufacturing process and Enterprise Resource Planning (ERP) issues.
- Enterprise Resource Management - This aspect included client relationship management concepts and addresses supply chain integration issues.
- Enabling Infrastructure - Included are infrastructure issues at the micro and national levels. Of primary interest to Canada are the national infrastructure requirements that address data exchange issues and network bandwidth requirements. Excellent work has been conducted in both of these areas and has been strongly motivated and supported by Industry Canada.

Manufacturing Enterprise Modelling and Simulation

This category is also discussed under the heading of Concurrent Engineering and Virtual Design and is also relevant to Simulation and Modelling for Acquisition (Mission) Rehearsal and Training (SMART). It addresses all issues of manufacturing simulation and modelling including: product physical and life cycle performance M&S, manufacturing process, and the business side of modelling and simulation.

Intelligent Controls

This technology area address process control issues that include: sensing, Human/Machine and Machine/Machine interfaces and intelligent machining implementation. This is a key area for cost reduction in all resource areas - human, machinery and materials.

5.9.2. Casting Technologies

Canadian casting vendors are typically dependent on US subcontractors or OEMs for advanced casting technology design. There is generally a lack of computational aids and the competencies with which to profitably apply those technologies. There will likely be incremental or evolutionary improvements to casting technologies in the future but nothing of a revolutionary nature.

The above para may need updating to reflect recent improvements in casting alloys that allow very large airframe components to be cast in one piece such as entire door frames and their surrounds, with major savings in costs and weight through parts reduction. Certification and quality control inspection are critical issues needing development work.

A few of the more common casting types are described below:

Die Castings: Die casting is a manufacturing process for producing accurately dimensioned, sharply defined, smooth or textured-surface metal parts. It is accomplished by forcing molten metal under high pressure into reusable metal dies. The term, “die casting,” is also used to describe the finished part. The term “gravity die casting” refers to castings made in metal molds under a gravity head. It is known as permanent mold casting in the U.S.A. and Canada. What we call “die casting” here is known as “pressure die casting” in Europe.

Centrifugal Casting: Casting made in molds which are rotating so as to produce a centrifugal force on the casting material.

Sand Casting: Is the most basic method of casting ferrous and many non-ferrous metals. A mold is placed in a specially treated sand bed. The mold is then removed and the sand baked prior to pouring the molten metal into the remaining cavity.

Investment Casting: Investment casting converts molten metal in a single operation to precision engineered components with a minimum wastage of material and energy and subsequent machining. It has a versatility approached by few other metal forming processes. Intricate or re-entrant contours can be incorporated. These features offer great freedom of design with the process. The versatility of the technique extends to materials, since virtually any alloy can be cast. The IC process is distinguished by the use of an expendable pattern. A metal die is usually used to produce the pattern, now almost universally of wax. These injection dies are normally made of duraluminum or brass. Preformed ceramic or water soluble cores may be used to give precision internal cavities and these are located in the wax die prior to injection. Patterns can be mounted onto a runner system to give an assembly ready for subsequent coating with refractory materials.

5.9.3. Powder Metallurgy

Powder Metallurgy or P/M is a method of manufacturing reliable ferrous and nonferrous parts. These are made by mixing elemental or alloy powders and compacting the mixture in a die, the resultant shapes are then sintered or heated in a controlled-atmosphere furnace to bond the particles metallurgically. Basically a “chipless” metalworking process, P/M typically uses more than 97% of the starting raw material in the finished part. Because of this, P/M is an energy and materials conserving process.

The P/M process is cost effective in producing simple or complex parts at, or very close to, final dimensions in production rates which can range from a few hundred to several thousand parts per hour. As a result, only minor, if any, machining is required. P/M parts also may be sized for closer dimensional control and /or coined for both higher density and strength.

5.9.4. Joining All Metals

Major goals for this technology include:

- Increased ease of fabrication;
- Fewer welded joints with highly improved quality;
- Weight reduction. Minimized part count;
- The ability to take advantage of the dissimilar properties of different materials;
- Repair to near-new condition.

Joining processes can be sub-divided into the following categories;

- Liquid-Phase Joining – where some part of the joint becomes fully liquid during the joining operation (e.g. conventional welding);
- Solid-State Joining – where none of the joint becomes fully liquid during the joining operation (e.g. Hot Isostatic Pressing);
- Transient Liquid-Phase (TLP) Joining – where part of the joint reaches a point between the solidus and liquidus temperatures (e.g. TLP Bonding and Stir Welding); and
- Adhesive Bonding – where a curing compound is introduced into the joint that will bind the joint together (e.g. epoxy bonding).

Stir Welding: Stir welding is an emerging technology which uses a rotating pin type of tool to generate heat locally by friction as it passes along a butt joint. The materials either side flow together and high quality joints are created. Considerable development is required for application to aerospace components.

The fundamentals of these various processes are reasonably well understood. However, the specific techniques required to produce useable products from new materials, with higher strength and temperature capabilities, require considerable development.

5.9.5. Coating Systems and Processes

Coating processes have many applications in the aircraft industry:

- To improve durability, reliability and performance of various components;

- To resist erosion, sliding and fretting wear or to improve surface quality; and
- To produce corrosion resistant coatings for combating pitting, exfoliation, oxidation and hot corrosion.

A brief description is provided for the following coating processes:

Physical Vapor Deposition (PVD) Involves the application of a thin coating of a material for wear resistance, corrosion protection or enhanced surface lubricity. Pure metals can be deposited, but the majority of coatings consist of hard, dense carbides and nitrides. The process involves careful cleaning of the object which is then placed in a vacuum chamber and heated (typically between 350 - 400°C). The article is coated by a stream of particles coming from the source of the coating material called the “target”. This is a “line-of –sight” process and often the parts are rotated within the chamber to achieve maximum coating coverage. PVD typically provides a hard, dense, uniform layer of coating material.

Chemical Vapor Deposition (CVD) is a technique for producing hard wear-resistant surface coatings on tools and wear parts. The difference between Plasma CVD and conventional CVD lies mainly in a process temperature of about 500°C against the 1000-1100°C of the conventional CVD process. PCVD coatings supplement and complement PVD coatings, and can be applied where PVD coatings can be used i.e. on tools and machine elements with the purpose of improving e.g. friction, corrosion and wear properties, thereby increasing the life and productivity of production tools. Compared to the PVD process, Plasma CVD offers better possibilities of coating more complex geometry's.

Plasma Spraying: A variety of metals, carbides, and ceramics can be deposited by the plasma process. These coatings are applied to provide: corrosion protection, part restoration and mismachining correction. Ceramic coatings provide wear resistance, electrical insulation and thermal barriers. Carbides provide wear and abrasion protection. Thermal spraying consists of feeding a material into a heat source, melting it, and accelerating it towards a target. In plasma spraying, the feedstock is a fine powder and the plasma flame is both the heat source and accelerating medium. The plasma flame is created by passing an electric arc through an inert gas in a gun shaped apparatus. The plasma, as it is known, is created when the inert gas atoms are stripped of their electrons by the arc. When the plasma exits the gun, the electrons recombine with the gas atoms and a tremendous amount of energy is released. This energy results in a plasma flame burning at temperatures of up to 13000°C, with spray velocities approaching Mach 2. With these conditions the plasma spray process is capable of depositing the widest range of materials. Bond strength and coating integrity are maximized, while porosity and oxide inclusions
are minimized.

Ion Implantation: This process involves bombarding the surface of a material with ions at very high energy levels. This process derived from the electronics industry where material changes were required on the nano scale. Essentially, atoms are inserted within the atomic lattice of the material being modified to produce improved wear resistance, hardness etc. During ion implantation the temperature can be kept below 180°C and can be carried out on tools and components in a finished state, i.e. hardened, tempered, ground and/or polished. Ion implantation is not a coating, and so no flaking occurs, nor will it influence the surface finish. Another advantage is that dimensional tolerances can be maintained throughout the process.

Hard Chrome Plating: Hard or industrial chromium are terms applied to thick electrodeposits (0.1 - 60 mils) used for engineering purposes and to differentiate it from decorative chromium, which is generally very thin (0.005 - 0.050 mils) and is used for cosmetic purposes, often over nickel.

Electrodeposited industrial chromium is an extremely hard coating used in many applications where low coefficients of friction and excellent resistance to wear and abrasion are required. Chromium retains its hardness after heating to 400°C. Corrosion resistance in oxidizing atmosphere is excellent. Hard chrome plating is used extensively in the aerospace industry and is considered to be an environmentally damaging process. Significant efforts have been underway for some time to find an environmentally more benign process.

Anodizing: Hardcoat anodizing is the electrochemical process for producing an extremely hard, dense and wear resistant oxide of aluminum. The process enhances the aluminum characteristics by modifying its basic properties such as dielectric strength, lubricity and color.

High Velocity Oxy-Fuel (HVOF): The HVOF unit uses an oxygen-fuel mixture consisting of propylene, propane, or hydrogen, depending on users coating requirements to produce a hard dense coating with negligible porosity and very high bond strength. Fuel gases are mixed in the front portion of the HVOF gun and are ejected from the nozzle and ignited externally to the gun. Ignited gases form a circular flame configuration which surrounds the powdered material as it flow through the gun. Combustion temperature is between 5000F to 6000F depending on fuel. The circular flame shapes the powder stream to provide uniform heating, melting, and acceleration.

5.9.6. Laser Based Manufacturing Techniques

Overall, laser processing technologies can be divided into three groups: laser fabrication (drilling, cutting/trimming, welding, micro-machining); laser surface modification (shock hardening, cladding, alloying, glazing, transformation hardening, laser Physical Vapor Deposition (PVD); and laser forming (re-fabrication, free-form consolidation).

Laser Fabrication:

Currently, lasers are used to drill small, high aspect ratio, low entrance angle cooling holes for gas turbine engine components made of stainless steels, Co-, Ni- and Ti-alloys.

Laser cutting/trimming and welding are widely used in the automobile industry for JIT production. In the aircraft industry, the use of these processes is expected to increase over the next few years.

Due to its accurate process control and minimal distortion, laser welding can be used to join formed sheet metal components with complex contours (e.g. engine manifolds, aircraft ducts) and pre-machined components. It also has significant capabilities in the welding of dissimilar metals. It is also being evaluated for welding large airframe components including fuselage skins.

Laser Surface Modification:

Laser surface modification has significant potential for specific applications in the aircraft industry. For example, laser shock hardening can produce residual compressive stresses in Ni-, Al-, Ti-alloy surfaces, combined with the production of much smoother surface finish that that possible using shot peening. This process reportedly improves fatigue and fretting fatigue life.

Laser cladding has advantages over plasma spraying (e.g.: accurate control, fully dense coating with metallurgical bonding to substrate) and can be used to produce coatings with improved thermal, corrosion, oxidation and wear resistance for engine and landing gear components.

Laser transformation hardening can be used to improve wear and fatigue resistance of steels and irons (such as landing gear components). However, applications are limited, since hardenable steels and irons are not widely used in the aircraft industry.

5.9.7. Fibre Composites

Fibre composites consist of dry fibre material (usually carbon, aramid, or glass in the form of uni-directional rovings, cloth, or multi-directional weaves) which are impregnated with resins, moulded to the required shape, and then cured. Relative to metal construction, they offer reduced structural weight through density reduction, higher allowable operating stresses, and design innovations made possible through the ability to “tailor” their material properties. Most aircraft composite components are formed from partially-cured, pre-impregnated materials (pre-preg), which are kept refrigerated until use, and which require high compaction pressures and curing temperatures.

JIT pre-preg is suitable for small aircraft where stress levels are not high. It differs from conventional pre-preg by impregnating the fibres just prior to putting them in the mold. JIT materials are less expensive, do not require refrigerated storage and may be cured at lower pressure and temperature, with less expensive molds and tooling. For high performance or large aircraft, Resin Transfer Molding is used with lay ups of dry materials in matched molds and it is also more economical on material costs than pre-preg. On-going developments in the technology of through-stitching dry fabric assemblies enables the interply strength to be increased against impact damage and promise greatest savings in overall life cycle costs versus weight reduction performance.

The use of composite structures in civil aircraft design is currently hampered by the inability to utilize the full potential of material properties, resulting in metal structures remaining competitive with composites. For each material used in aircraft construction, the allowable maximum stress level for design is set by the statistical capability of the manufacturing process, with knock-down factors for the degradation in hot-wet conditions and the residual strength after impact. The “design allowable strength” is the value which some percentage of the material population (usually 95% or 99%) can be expected to exceed with 95% confidence. Manufacturers must perform a significant amount of testing in order to establish the allowable strength for each material and manufacturing process. Currently, the full capability of the materials cannot be utilized, due to process variability and knock-downs for environmental effects and impact damage.

5.9.8. High Velocity Machining

HVM employs spindle speeds and feed-rates which are 5-10 times faster than conventional rates. Machining time is reduced proportionally, reducing both the machining cost and the lead-time for manufacturing. This is achieved be:

- Higher spindle speeds – 50,000 rpm. Or greater, compared to 3,000 rpm at present;
- Higher effective feed rates – currently in the 200 inches per minute (ipm) range, being increased to 1,200 ipm;
- Vastly improved acceleration/deceleration of the work-piece or cutting head – currently in the 0.1 g rang, being increased to 1-2 g, and;
- "Look-Ahead: type computer controls which enable the machine to avoid work-piece over-travel, thus preventing consequential tool, or part damage.

The greatly increased metal removal rates associated with these higher speeds allow design engineers to produce novel, one piece designs with reduce parts counts, (especially fasteners), eliminate assembly, and reduce weight, fretting and corrosion. Realizing these advantages requires a new design philosophy that takes into account the capabilities of this new manufacturing process.

5.9.9. Advanced Metal Forming

The DMR&O Technology Road map identified two types of metal forming as areas deserving of interest within the Canadian aerospace sector: cold forming of metal, and forging.

Cold forming processes can be analyzed with commercially available, general purpose Finite Element Method Analysis applications that are computationally intensive and typically not utilized. The majority of cold forming work is done in Canada based on operator expertise as opposed to computational tools. There is considerable automotive industry expertise in sheet metal forming and the aerospace sector has relied on this element of the industrial base extensively. Advanced materials, or complex shapes require analytical support tools that will become increasingly required with future Product Data Interchange. Considerable core competency development in the use of analytical tools is required as is the ability to use advanced forming techniques including explosive or hydro forming.

The forging industry is small and also focused on lower technology requirements in the automotive industry. Forging is a manufacturing process where metal is plastically deformed under great pressure into high-strength parts known as forgings. The process is normally (but not always) performed hot by preheating the metal to a desired temperature. Isothermal forging refers to forging where the temperature of the work piece is maintained at a constant temperature and is generally used in the forging of complex thin shapes in aluminum, nickel, titanium and superalloys.

5.9.10. Near-Net Shape Forming

Near net shape forming is of particular interest for complex shapes made of materials that are either very expensive in their unprocessed form, or which are very difficult and therefore expensive to reduce to final design shape. This is of particular interest for ceramics, superalloys, ceramic matrix composites and metal matrix composites. In the latter case the forming process must ensure that the reinforcement material is properly distributed and oriented. Near net shape forming typically utilizes metallic, ceramic and polymeric powders and their composites and is used to form higher value items where previous forming processes required a number of finish machining steps.

5.9.11. Intelligent Process Control

Intelligent Process Control technology can be used by all manufacturing processes controlled by computers, such as multi-axis milling, laser processing, conventional welding, blasting and peening, painting, grinding and rapid prototyping. Advances in CAD/CAM and motion control systems over the last few decades have eliminated some of the accuracy problems in the fabrication of complex aerospace components. Today, process capability is the key factor in determining the quality and cost of these parts. In milling, problems such as tool/part deflection and vibrations, tool wear and chipping, cutting temperature, etc., are mostly handled by off-line methods, based on the experience of the programmer. This results in non-optimized control by the machine's controller, which requires close attention by the machine operator. Therefore, Intelligent Process Control should address both part quality (dimensional integrity, surface finish quality, etc.) and cost (cycle time, cutting-tool cost, etc). This can be best accomplished by using precise process models and sensory information in an open-architecture control environment.

Achieving Intelligent Process Control requires the development and integration of a variety of support technologies. In addition to the process models described above, active control, specific process sensors, control algorithms, condition monitoring technology, and machine controllers must all be developed.

5.9.12. Metal Matrix Composites

The three types of MMCs used and/or considered for general engineering applications include particle reinforced MMCs, whisker reinforced MMCs and fibre reinforced MMCs. Most particle reinforced MMC components are produced via casting MMCs. While the particle reinforced MMC castings are finding increasing acceptance in engineering sectors dealing with consumer products, they are only being considered for non-critical applications by aircraft manufacturers due to their poor fatigue strength. The whisker and short fibre reinforced MMCs are still in developmental stages for providing better properties than particulate reinforced MMCs and are the only MMCs which are currently being considered for applications by aircraft manufacturers.

5.9.13. Ceramic Matrix Composite

CMCs provide significantly higher fracture toughness and higher strain to failure than do monolithic ceramics. These attributes reduce the principal limitations that have heretofore limited the use of ceramics in highly stressed structural applications.

Two types of ceramics matrix composites exist: discontinuously reinforced and continuously reinforced CMCs. Discontinuously reinforced CMCs consist of a matrix phase (usually alumina, silicon nitride, silicon carbide or zirconia) to which a reinforcing phase (for example silicon carbide whiskers, platelets or particles) is added. The principle use of discontinuously reinforced CMCs is in wear parts (for example valve guides, bearings), cutting tools for machining aerospace alloys (high nickel alloys) aircraft and land armor and extrusion dies.

5.10. Maintenance Repair and Overhaul Technologies

The DMR&O Road Map identified two categories of constituent technologies for the Maintenance Repair and Overhaul critical technology area. The first area includes those techniques necessary to determine if repair or rework action is required. This involves the quantification of defects, an assessment of residual safe life remaining. These techniques/technologies include such items as health and usage monitoring or non-destructive evaluation of components where such techniques are feasible. The second area of consideration pertained to those technologies necessary to effect a repair or rework that either returns a used component to service or prevents further damage accumulation from occurring. A critical aspect of maintenance repair and overhaul technologies is the ability to certify the repair as being safe for flight. As an example, consider a damaged integrally bladed titanium rotor or Blisk ©. This is an expensive component that is often damaged by Foreign Object Damage (FOD). Although it is possible to weld in a new blade or a portion of a new blade, original design information or reverse engineering is required on materials low cycle fatigue etc, considerable repair development must be undertaken, and a subsequent re-certification effort mounted that may include coupon, component and full engine test.

The technology elements with the Maintenance Repair and Overhaul critical technology area are described below:

5.10.1. Gas Turbine Repair Technologies

The repair and re-certification of gas turbine structures requires essentially all of the original design competencies only perhaps complicated somewhat by degraded material properties and reverse engineering requirements. This section is devoted to the key competencies required to conduct an aero-engine repair or rework. The manufacturers of gas turbine engines have historically generated significant margins on the sale of replacement components. The OEMs hold the design information and control the airworthiness certification test data for their engines and components. There is a significant push to reduce the costs of ownership of aeropropulsion systems and large users, particularly military operators, are increasingly exploring the repaired component option even for flight critical rotating components. Competencies are required in the following areas:

- Health and Usage Monitoring Technologies - Knowledge of component damage modes and rates of damage accumulation are required prior to any decision being made to repair a particular component. The installation of life usage tracking devices on most modern aeropropulsion systems provides the majority of the required information. An analytical capability must, however, exist which allows the correlation of damage rates with design data.
- Failure Mode, Effects, and Criticality Analysis (FMECA) – The probability of failure of a component and the consequences of that failure will determine the desirability of a repair and also dictate the required certification process requirements for the repair.
- Certification Process – If a repair is being pursued by a firm other than the OEM then that firm must be qualified to carry out the repair in terms of analytical capability, facilities, accredited design process and personnel qualifications.

- Metallurgical Technologies – the metallurgical challenges to a repair or rework are often greater than those of the original design. Degraded properties such as internal voids or dislocations within the microstructure must be accommodated in the repair design.
- Aero-thermodynamic Technologies – repairs or reworks to sections within the gas path of the engine will require that the repair designer be competent to assess the effects of the repair on the performance and efficiency of the engine
- Mechanical Properties – Any repair design will require a full structural analysis that will vary in complexity dependent on the component being repaired. Once again a full suite of FEM tools will be complimented by various other specialized analytical applications.
- Coupon, Component and Full Scale Testing Competency for Certification – test facilities must be available for the certification of gas turbine repairs or reworks, these facilities range from coupon test, to component and full engine testing where a full engine block test may be required to certify a repair or rework.

5.10.2. Advanced Materials Non-Destructive Evaluation

The non-destructive testing of composite materials poses special challenges to the aircraft operator. Current inspection techniques are characteristically low technology manual inspections that are time consuming and unreliable. The damage modes being inspected for include: delaminations, where there is localized separation of the various plys in a composite lay-up; disbonds where for instance a composite skin separates from the aluminum honeycomb; or perhaps water ingress in a composite/honeycomb structure. Regardless, the inspection techniques will vary considerably from those of metallic components for which non-destructive techniques are well developed and probabilities of detection reasonably well established.

Non-destructive evaluation techniques that have been developed for composite materials include:

- Enhanced visual techniques such as D-sight where surface imperfections resulting from delaminations, disbonds or even low energy impact damage become clearly recognizable.
- Radiographic techniques have also been developed that can characterize composite defects in special circumstances. Neutron radiographic techniques in particular are applicable to composite inspections for water ingress.
- Ultrasonics has also been pursued with laser based inspections enabling large area scans in a short time frame.

The development and characterization of reliable low cost non-destructive evaluation of composite structures is a necessity for the further application and design optimization of composites.

5.10.3. Health and Usage Monitoring Systems

Health usage and monitoring systems have been under development and implemented in an irregular fashion for some time. High visibility requirements, North Sea helicopter operations spawned significant work in this area several years ago.

Terminology associated with this technology area is discussed below:

Usage Monitoring: For aircraft engines typically refers to monitoring start-stop cycles or time at temperature to infer generalized damage accumulation. These data are then used to define component life based on design data and actual usage. For aircraft, usage monitoring normally takes the form of strain gauges or accelerometers placed in strategic locations with outputs combined with flight data to yield information used to anticipate structural problems in high criticality or design deficient areas.

Health Monitoring: Health or condition monitoring for aircraft engines can cover a wide range of data sources including oil borne debris, vibration monitoring, and gross indicators such as thrust. For aircraft structures condition monitoring will take the form of corrosion detection sensors (local environmental sensors) or perhaps embedded fibre-optic sensors that register leading edge impact as an indicator of residual functional capacity.

5.10.4. Repair Of Metallic Systems

The repair of metallic aircraft components other than gas turbine structures is most often now carried out using composite patch or hybrid sheet materials. Low cost metallic repairs are typically used on low technology systems where composite patch capability does not exist or where major segments of a metallic structure are being replaced.

Bonded composite repairs are used for:

Under-design compensation – to stiffen components and strengthen undamaged components that were designed with inadequate strength;

Fatigue life enhancement – in areas where cracking is occurring, a composite patch can be used to reduce stress levels to the point where cracking does not continue, or when placed on an undamaged surface preclude the onset of cracking;

Design performance recovery – in areas where corrosion or damage repairs have removed material, a patch can be used to recover its original design strength or stiffness.

The design and implementation of bonded patch repairs to metallic structures requires a separate set of analytical design tools and for use in the field a portable repair and inspection capability that is still quite restricted in availability.

5.10.5. Repair Of Composite Systems

Cost effective and reliable repair of composite structural damage is extremely difficult. The discussion of a few typical damage modes will illustrate the complexity of the repair environment and the technology refinement that is yet required.

Delamination repair – This is the localized separation of two or more plys in a composite skin. Entry holes must typically be drilled around the damage to allow entry/flow through of a repair resin. High localized pressures must be applied to ensure that the resin permeates the delaminated portion of the skin whilst suction is applied at the extremities of the damaged section to encourage flow through, and while the entire area is being heated. If the damage is deep or large in area the repair is complex. Multiple layers must be removed entirely in a progressive stepped down fashion to ensure good repair bonding is achieved.

Repair of curved honeycomb sandwich beam – Requires the recovery of design strengths through the use of a patch that is ideally of the same material as the original skin and core. This will require the replacement of the honeycomb as well. This repair will be carried out using vacuum only as opposed to the original component that was cured in an autoclave. The repaired section will accordingly be more porous and susceptible to voids etc. Additionally the repair carried out using a heating element may damage the bond between the honeycomb and composite material in the vicinity of the repair.

Additional R&D is required to develop low cost and practical repair processes for composite structures. Patch materials must be developed and qualified.

5.11. Space Systems Including Communications

This critical technology area pertains to those technologies contributing to the accomplishment of Canadian national space program objectives. The technology elements and descriptions are taken from the Canadian Space Agency Publication entitled “The New Canadian Space Program”. Two space technology elements not identified in the CSA publication, but included in this technology area are Surveillance of Space, and Electrochemical Power Sources. The former having more direct military objectives and the latter not being specific to space but potentially having an impact on space programs.

The technology elements with the Space Systems including Communications critical technology area are described below:

5.11.1. Smart Systems For Space Structures

There have been a number of smart structural applications for space systems. Examples include the development of smart or multi-functional skins that serve a s structural members as well as antennas for sensing incoming radiation or radiating signals from the space vehicle. Smart structures have also been explored for damping of damaging vibrational modes in long unconstrained thin structures, shells and struts. Further exploration of these technologies is dependent on national priorities as set by the Canadian Space Agency.

5.11.2. Satellite Communications

The satellite based communications industry is growing extremely quickly. Technologies identified by the Canadian Space Agency to be supported include: analogue and digital on-board processing, multibeam antennas, and high data rate inter-satellite communications.

5.11.3. Earth Observation

As taken from the CSA Website:

"The two major factors influencing the earth observation business are: world-wide emphasis on global environmental monitoring and natural resources protection; and a trend towards the separation of earth observation satellites into low cost or free low resolution satellites for global environmental monitoring and commercial high resolution satellites for mapping, surveillance and local applications."

Technology development is accordingly focused on global environmental monitoring technologies and on earth observation on a much more detailed level.

5.11.4. Surveillance Of Space

Surveillance of space is primarily a defence oriented technology and will be pursued by Canada in partnership with U.S. or European partners. Investment in this technology by the government is necessary both to achieve national and industrial strategic objectives. The identification of objects by both earth based and space based sensors requires considerable development. The number of objects, the volume of space in which they exist and their activity status all pose challenges to both sensors and data analysis methodologies. Sensor techniques developed for earth based observation typically require some to significant modification to function effectively from a space based platform. Data is required on a virtual real-time basis which adds to the technology development challenges. Communications, sensors, and computational technology development will be required.

5.11.5. Electrochemical Power Sources

Four separate electrochemical power source technologies are identified:

<u>Advanced Primary Batteries</u>- Lithium sulphur dioxide and lithium thionyl chloride are the only batteries that will meet many military applications requiring high energy density and high power density. While these systems have been under development for more than 20 years, high operational costs, safety problems and disposal issues continue to limit their use.

<u>Advanced Rechargeable Lithium Battery Systems</u>- Despite the promise of high energy density, safety problems have prevented the use of rechargeable lithium sulphur dioxide and lithium molybdenum disulphide batteries in military applications. To avoid these problems, lithium ion cells have been developed and are now used in some civilian applications. Investigations on the use of polymer electrolytes in rechargeable lithium batteries also show promise.

<u>Other Advanced Rechargeable Batteries</u>- Canadian R&D on sodium sulphur and lithium aluminum ferrous sulphide batteries has been progressing for at least 10 years. The target market for such batteries is the electric vehicle. Rechargeable alkaline manganese dioxide (RAM) batteries and nickel hydride batteries have recently been introduced in some commercial applications. There are significant potential military applications, particularly of interest to the land and maritime elements, for these systems.

<u>Fuel Cells</u>- While the primary target market for this technology is electric vehicles, space and military applications range from propulsion power to field power plants. Recently, interest has been revived in the development of small alkaline fuel cells for person portable power supplies.

Abbreviations and Symbols

Al	-	Aluminum
AMLCD	-	Active Matrix Liquid Crystal Display
ATD	-	Advanced Technology Demonstrator
C	-	Carbon
CFA	-	Computational Fluids Analysis
CFD	-	Computational Fluid Dynamics
CMC	-	Ceramic Matrix Composite
Co	-	Cobalt
CVD	-	Chemical vapor Deposition
DMM	-	Digital MicroMirror (Projection Display System)
DoD	-	Department of Defense (US)
EFIS	-	Electronic Flight Instrumentation System
ELD	-	Electro-Luminescent Display
EPNdB	-	Effective Perceived Noise in decibels
FE	-	Finite Element
FED	-	Field Emissive Display
FEM	-	Finite Element Method
FMECA	-	Failure Mode, Effects and Criticality Analysis
FOD	-	Foreign Object Damage
HIP	-	Hot Isostatic Pressing
HMD	-	Head (alternatively Helmet) Mounted Display
HUD	-	Heads Up Display
HVOF	-	High Velocity Oxy-Fuel (Plasma Spray)
IMC	-	Intermetallic Matrix Composite
Ipm	-	inches per minute
Kts	-	stands for Nautical Miles Per Hour (Nautical Mile = 6,080 ft)
Li	-	Lithium
MMC	-	Metallic Matrix Composite
Ni	-	Nickel
NO_x	-	Oxides of Nitrogen
OMC	-	Organic Matrix Composite
PCVD	-	Plasma Chemical Vapor Deposition
PVD	-	Physical Vapor Deposition
Si	-	Silicon
Ti	-	Titanium
TLP	-	Transient Liquid Phase
W	-	Tungsten