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Aging Aircraft: A R&D Opportunity For Canada

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ABSTRACT

As many aircraft fleets throughout the world, both military and civilian, are operated for increasingly longer periods of service, the unique challenges of aging aircraft must be addressed. Of all the structural problems facing aging aircraft, the greatest concern is the detection of corrosion. While existing nondestructive testing techniques have been used to detect many surface and sub-surface deformaties including corrosion, the inspection of aging aircraft, especially those components constructed with composite materials, necessitates the search for additional detection methods. The development of these new detection methods can only be accomplished by substantial research and development investment in emerging technology. Since the Research and Development (R&D) investment by Canada is unlikely to significantly increase, the focus must be on specific niche areas. For the Department of National Defence, the R&D investment by the Canadian Defence Research and Development Agency must be focused on niche areas where the operational requirements cannot be satisfied by existing technology. A successful example of focused research is the development of a neutron radiography facility at the Royal Military College of Canada for the inspection of CF188 composite flight control surfaces, where for a modest R&D investment, this emerging technology has been developed so that small amounts of water or corrosion can be detected before significant structural damage occurs. To detect corrosion and effectively inspect our aging aircraft, Canada and DND should invest in emerging technologies to develop new nondestructive inspection techniques.

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Introduction

When aircraft were first introduced into military service, they were plentiful and relatively inexpensive. The same characteristics are certainly not the case today, as the complexity of modern aircraft, together with their various systems, have certainly reduced the overall number of aircraft, and dramatically increased the costs for both initial purchase and in-service support. These increased costs, together with reduced national defence budgets in many North Atlantic Treaty Organization (NATO) countries, will force aircraft to remain in service for many years beyond what was anticipated several years ago. For example, over 51% of all the aircraft operated by the United States Air Force (USAF) are older than 15 years, with 44% having greater than 25 years in service. Of even greater concern is that some aircraft, namely the B-52, C-135, and T-37, are expected to remain in service until 2015, when they will have been used for over 50 years![1] Similar trends exist for the Canadian Forces (CF), where most of our existing fleets will not be replaced for many years to come. This trend of “aging aircraft” has been widely recognized, with most countries and air forces initiating aging aircraft programs to deal with the unique issues of maintaining these aircraft. Embedded within these aging aircraft programs are research and development (R&D) initiatives to address many problems, the most significant of which deal with aircraft structural integrity. In Canada, the National Research Council of Canada (NRC) has an Aging Aircraft Structures Section, albeit with very limited R&D funding.

One of the greatest threats facing the structural integrity of aging aircraft is corrosion. While corrosion is a general term that encompasses many specific types, the net result is a material degradation, which can lead to a greatly reduced structural integrity. Both corrosion control and corrosion detection are vital in an effective aircraft maintenance program. While some forms of corrosion can be detected visually, most types require the use of nondestructive testing (NDT) methods, which are inspections completed without dissembling the part being inspected. While NDT methods such as X-radiography and eddy current have been, and continue to be, used to detect corrosion, the introduction of newer materials, as well as the problems of aging aircraft, has necessitated the search for additional detection methods. Many of these newer inspection methods have come from the newer technologies, referred to as emerging technologies. As stated by Matthias Stoermer of the Air Material Office of the German Air Force, "It is expected that if the level of effort devoted to inspection is to be kept within reasonable bounds, increased effort will be needed to develop improved NDT techniques."[2] The difficulty, especially in Canada and within the Department of National Defence (DND) is that there has been a drastic reduction in the R&D funding for emerging technology in the past few years. This reduced funding has, in turn, led to Canada's slippage on the World Competitiveness Scoreboard to eighth place, and also on the technology rating of the World Economic Forum to eighth.[3] Canada's future competitiveness depends on improving these rankings, and a key to any improvement is an increase to R&D funding for emerging technology. Similarly, DND must improve both the funding and the direction of its research program. As there is no doubt that funding will continue to be a problem, Canada, and specifically DND, should focus on specific niche areas. Therefore, instead of sponsoring twenty-one R&D Activities, DND's Research and Development Branch should refocus their funding into more directed programs where the operational need is the greatest. For aging aircraft, the investment into emerging technology to develop specific NDT methods is key, and is the cornerstone for continued safe operation of our aircraft. Therefore, it is essential that DND invest in emerging technology in order to develop nondestructive inspection techniques to effectively inspect our aging aircraft.

In order to develop this viewpoint, the paper will begin with an examination of aging aircraft and various aging aircraft programs. Next, the impact of corrosion on structural integrity will be presented, followed by an overview of NDT and associated conventional techniques. The promise of emerging technology will be discussed, followed by an examination of the R&D situation in Canada and DND. Specific suggestions of how to focus the reduced R&D funding will follow, culminating in a case study which presents the development of a novel NDT method for the inspection of CF188 flight control surfaces, as well as an examination of the funding received and the resultant level of activity.

Aging Aircraft

The reality of aging aircraft, and the consequences of aging, was first established on March 13, 1958 when the United States Air Force (USAF) lost 2 B-47 aircraft because of fatigue cracking in the wing.[4] The USAF had not previously established a service life for the B-47, and had based the aircraft design on the assumption that a failure from overload was the only threat to its structural integrity. These failures prompted the USAF to establish the Aging Aircraft Program, and the USAF Aircraft Structural Integrity Program (ASIP).[5] In fact, throughout NATO, national defense budgets are being reduced, and NATO air forces will have to continue to operate existing fleets for many years beyond what was anticipated several years ago.[6] Therefore, the discussions surrounding aging aircraft have begun to take on even greater urgency than in the past.

Depending on the literature cited, aging aircraft may be defined in various ways and can have several connotations. Succinctly listed, these connotations include:

a. Technical obsolescence;
b. The need for system upgrading;
c. Changing mission requirements unanticipated during design specification and development;
d. Exponentially increasing maintenance costs;
e. Decreased safety;
f. Impairment of fleet readiness; and
g. The unavailability of third line repair facilities.[7]

Regardless of the connotation selected, there is one common denominator among the possibilities, namely the cost of operating aging aircraft.[8] These ever-increasing operating costs affect both military and civilian aircraft operators, since the percentage of aircraft that are being operated beyond their design lives is increasing.[9] As illustrated in Figure 1, current fleet utilization plans will steadily increase the average age of the USAF aircraft through the year 2020. According to USAF calculations, in Fiscal Year 1989, more than three-quarters of USAF aircraft were over 20 years old.[10] The numbers are even more dramatic when specific fleets are considered: by Fiscal Year 2015, the B-52, C-135, and T-37 will be, on average, over 50 years old.[11]

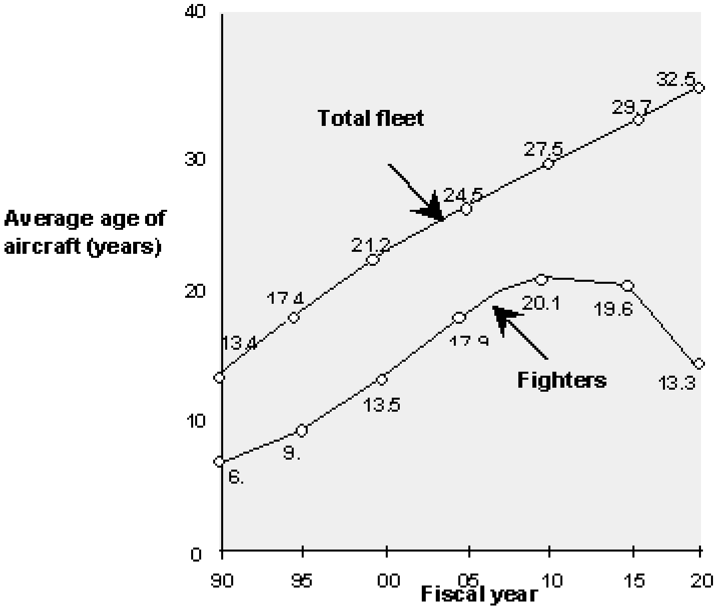


Figure 1: Aging USAF Aircraft [12]

As a result, various organizations and projects have been established to address the many concerns of aging aircraft. The USAF Aging Aircraft Program, for example, is committed to establishing and integrating a full suite of technical and fleet management capabilities in support of diverse structural requirements. The overall goal of the USAF Aging Aircraft Program is to ensure flight safety, to reduce maintenance requirements, and to increase operational readiness. This Program has been sub-divided into five technical categories:

1. Structural integrity;
2. Nondestructive examination;
3. Avionics;
4. Propulsion; and
5. Subsystems, such as cockpit controls and displays, and hydraulic actuators for flight controls and landing gear.[13]

The five technical categories presently encompass fourteen specific areas of interest, as listed in Table 1.

Enabling structural classification capabilities (corrosion sensitivity and/or detect ability/probability of detection)	Crack detection involving multiplayer structure and/or fastener holes
Engineering processes & capabilities for evaluating static, residual strength, & life in the presence of corrosion	Enhanced fleet management processes for in-service aircraft
Advanced corrosion suppression technologies	Non-intrusive secondary layer inspection capabilities
Embedded corrosion detection sensors	Cycle time reduction for large area inspection
Alternative materials in support of extended life/corrosion containment and/or minimization	Remanufacturing tolls & capabilities (part emulation)
Reduce conventional forging & process lead times	Optimize titanium forming technologies
Enhanced corrosion prevention compounds	Damage tolerance assessment tools

Table 1: Specific Areas of Interest [14]

In order to determine what R&D efforts should be undertaken, the USAF also formed the Aging Aircraft Technologies Team (AATT). The Team has formulated the following overall strategy:

a. The R&D must be directed towards the needs of USAF aircraft;
b. The R&D must be orientated towards flight safety, maintenance cost reduction, and/or enhanced availability;
c. R&D must be output-oriented and cost-focused;
d. The technology must be able to be transitioned from the lab to the flight line; and
e. The USAF labs must maintain organic competencies in key areas related to aging aircraft.[15]

As a roadmap to selecting R&D programs, the AATT has identified six steps:

1. Conduct surveys to determine problems;
2. Identify and prioritize solutions requiring R&D;
3. Establish R&D roadmaps;
4. Obtain management and customer approval;
5. Execute R&D efforts; and
6. Transition technology to the operator.[16]

The first three steps are designed to identify problems and to develop a plan for their solution. The final three steps engage the USAF management to implement plans, and to carry the R&D through to technology transition.

In addition to the USAF efforts, the United States Naval Research Advisory Committee has sponsored their own Aging Aircraft Study. As part of the Study, the US Navy (USN) is examining progress in the following areas:

a. Nondestructive testing (NDT) technologies;
b. Diagnostic and prognostic technologies;
c. Relationships to open systems architecture;
d. Improvements in defined technology, manufacturing technology, training, automated work instructions, and remote liaison; and
e. The benefits offered.[17]

For the commercial aircraft operators, the Federal Aviation Administration (FAA) mission's scope was increased in 1988 to include aging aircraft. The FAA developed the National Aging Aircraft Research Program (NAARP) to conduct research to "ensure the continued airworthiness of high-time, high-cycle aircraft."[18] Under the NAARP, research is on-going in structural integrity, corrosion, inspection systems, aircraft engines, airborne data monitoring systems, maintenance and repair, and rotorcraft structural integrity.[19] The research is being conducted largely at two major centers. The first, called the Center for Systems Reliability, was established in 1990 at Iowa State University to "develop new and innovative inspection methods to solve the unique inspection challenges facing commercial aviation."[20] The second center is the Airworthiness Assurance Nondestructive Inspection Validation Center, established in 1991 at Albuquerque International Airport for the FAA by Sandia National Labs, to "conduct independent inspection and maintenance validation, reliability, and technology transfer activities to facilitate the use of improved practices into the industry."[21]

In Canada, the National Research Council of Canada (NRC) also has an Aging Aircraft Structures Section. Under this Section, the NRC researchers are working with industry and government collaborators to investigate aging aircraft issues, including corrosion and fatigue damage,[22] with the overall goal of the research to move from a 'find-and-fix' approach to a 'predict-and-manage' approach.[23] This research is focused on developing new tools and systems to "predict the impact of damage on structural integrity, improve corrosion resistance, and repair damaged structures."[24]

In addition, the Research and Technology Organization (RTO), formerly known as the Advisory Group For Aerospace Research and Development (AGARD), regularly sponsors meetings on aging aircraft. In sponsoring these meetings, the Applied Vehicle Technology Panel (formerly known as the Structures and Materials Panel) began with five objectives, namely:

a. To review recent developments in the science and practice of nondestructive inspection, and to identify opportunities whereby new techniques can be used to address problems of practical importance;

b. To review practical experience gained during the design, manufacture and operation of advanced aircraft structures where nondestructive inspection technology created either an obstacle to progress or an opportunity for advancement;

c. To identify outstanding needs for, or opportunities for, the development of new inspection methods;

d. To identify deficiencies with respect to available inspection equipment and the need for standardization with respect to inspection equipment and devices; and

e. To review both positive and negative experiences with efforts to transition new technology to applications, and to examine efforts to expedite the implementation process.[25]

While each of the individual aging aircraft programs have slightly different areas of interest, most include structural integrity, nondestructive testing, and advanced technology. The foundation of an effective preventative aging aircraft programme, therefore, must include these areas.

Aircraft Design

There are two basic philosophies used in the design of new and in-service aircraft, namely safe life and damage tolerant. Damage tolerant structural design is an approach used to ensure structural safety of flight by assuming that undetected flaws or damage can safely exist in critical structural components despite the design, quality assurance, and inspection efforts intended to eliminate their occurrence.[26] Damage tolerant designs are categorized into the two general concepts of fail safe and slow crack growth structures. Fail safe is a design concept where unstable crack propagation is locally stopped through multiple paths or tear stoppers. For slow crack growth, flaws or defects are not allowed to reach the size required for unstable rapid crack propagation. [27]

Safe life aircraft design, on the other hand, is an approach that requires analysis or testing to show that the probability of any failure is extremely remote for the assumed life of a structure. Components designed using this approach cannot normally be designated or qualified as damage tolerant unless sufficient additional testing is performed. Typically the safe life design is used for safety critical parts, which are normally inaccessible or uninspectable. Placing a discard limit that ensures that the item is removed from service before failures are expected ensures the reliability of a safe life structure. The safe life of aircraft structural components is usually determined from component and full-scale fatigue tests, which simulate the loads encountered in service. The safe life value is typically attained by assigning a scatter or safety factor to the crack initiation life obtained by a full-scale test.[28]

The choice of design philosophy employed is a major determinant in an Aircraft Structural Integrity Program (ASIP). The USAF's ASIP is a program that defines a sequence of tasks that progressively reduce the risk of an aircraft structural failure. The original approach was based on a safe life philosophy, and while applicable in the lab, did not account for the use of low ductility materials operating under high stress. Unfortunately, it was at this time that aluminum companies were introducing high strength alloys to improve aerodynamic performance, and the safe life approach did not account for the subsequent fatigue cracking in these high strength alloys.[29] After the crash of an F-111 in December 1969 due to a wing failure in the lower plate of the left wing pivot fitting, the damage tolerant approach was incorporated into the ASIP in 1975.[30] As a result, the goals of an ASIP were revised as follows:

a. Control structural failure in operational aircraft;
b. Devise methods of accurately predicting service life; and
c. Provide design and test approaches that will avoid structural fatigue problems in future weapon systems.[31]

Thus, for the past 40 years, the USAF, and subsequently the Canadian Air Force, has used the ASIP to maintain safe and economical operation of aging aircraft. As articulated by John Lincoln, a renowned expert on aging aircraft, "This program has been supported over the years by USAF laboratory programs in the areas of fracture mechanics, corrosion prevention, flight loads, nondestructive evaluation, human factors, and maintenance and repair. These efforts provided the Air Force with the technology required to support the operational aircraft maintenance programs based on damage tolerance."[32]

For in-service aircraft, structural degradation may be due to wear, corrosion, impact damage, or fatigue.[33] To estimate the remaining life of an aircraft, it is necessary to first examine detailed data on its current condition, as well as each of these structural degradation factors. Although an assessment of all these factors would be required for a comprehensive life extension study, the impact of corrosion on structural degradation is of critical importance.

Corrosion

Corrosion is a relatively slow material degradation process to which metallic aircraft structures are subjected during service. As explained by Bar-Cohen, “Corrosion is a general term that describes the oxidative degradation of metals caused by a local galvanic cell between the base metal (acting as anodic sites), at sites of defective protective coating, having the passive sites sustaining cathodic reaction.”[34] He further explained,” The corrosion process converts the metal into its oxide or hydroxide forms resulting in deterioration of its mechanical properties.”[35] As detailed in Table 2, corrosion can appear in many forms, depending on the type of metal, how it is processed, the surrounding structure, and how the aircraft is operated.

Aircraft corrosion is a never-ending challenge. Corrosion accounts for 60% of all maintenance and repair costs, and thus is a major determinant of the overall maintenance and repair costs of a fleet.[36] In fact, the USAF spends about $800 million per year on corrosion detection, prevention, and repair.[38] Therefore, corrosion prevention and control strategies are critical for all aging aircraft and essential for an effective maintenance programme.

Corrosion type	Source	Appearance	By-Product	Notes
Galvanic Corrosion	Corrosive condition that results from contact of different metals.	Uniform damage, scale, surface fogging or tarnishing.	Emission of mostly molecular hydrogen gas in a diffused form.	Slow growth rate. Expressed as penetration/year or weight loss per unit-area/day, e.g. the rate for aluminum in open atmospheric conditions of Los Angeles, CA is 0.02- mil/yr. For Ti and Al alloys the rate is slow and therefore it does not pose serious structural problems. The metal with the most negative potential has most damage.
Pitting	Impurity or chemical discontinuity in the paint or protective coating.	Localized pits or holes with cylindrical shape and hemispherical bottom.	Rapid dissolution of the base metal.	Expressed in terms of pitting depth (i.e. pitting factor). Pitting can be critical to the structural integrity. Can be detected by AC impedance or electrochemical impedance
Thermo-galvanic Corrosion	Caused by thermal gradients parallel to the metal surface.	Localized attack correlated with temperature.	Produces scale indications.	Hot portion of the metal serves as cathode whereas the cold portion as anode.
Crevice	Afflicts mechanical joints, e.g., coupled pipes or threaded connections. Triggered by local environment composition differences.	Localized damage in the form of scale and pitting.	Same as scale and pitting.	Caused by differential aeration. Difference in oxygen concentration produces potential difference and leads to flow of electrical currents across aerated (cathode) and derated (anode) portions of the metal. Causes localized corrosion failure.

Corrosion control and prevention are both required for an effective maintenance program. Corrosion control includes detection, removal, and the renewing of protective systems. Conversely, corrosion prevention is devoted to material design, surface treatments, finishes and coatings, inhibiting compounds and sealants, as well as preservation techniques.[39] In both prevention and control, R&D continues to yield many advances. When considering the ever-increasing maintenance and repair costs, early detection of corrosion, and the subsequent reduced repair costs, becomes increasingly important. Of the many aircraft areas where corrosion has been identified, the following are the more common areas where corrosion detection is important:

a. Floor and structure in the vicinity of lavatory systems and galleys;
b. Structures surrounding doors, particularly landing gear doors;
c. Wing skin adjacent to countersunk fastener heads;
d. Aluminum-faced honeycomb panels used for exterior panels and floors;
e. Wing-to-body joint fittings;
f. Fuselage lower structure (bilge area);
g. Areas having environmentally unstable materials; and
h. Structures susceptible to protective treatment damage during installation and repair, abrasion, fretting, and erosion.[40]

Nondestructive Testing

The primary method of detecting aircraft corrosion is through the use of nondestructive testing, the field of which is very broad and interdisciplinary. As defined by the American Society For Nondestructive Testing, NDT comprises “those test methods used to examine an object, material or system without impairing its future usefulness."[41] Because it allows inspection without interfering with a product's final use, NDT provides an excellent balance between quality control and cost effectiveness. In addition, NDT is mostly concerned with nonmedical examinations. In a purist sense, this definition of NDT does include noninvasive medical diagnostics, such as ultrasound, X-rays, and endoscopes, but most NDT and medical professionals do not refer to these procedures as nondestructive.[42]

NDT plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. NDT technicians and engineers define and implement tests that "locate and characterize material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and a wide variety of less visible, but equally troubling events."[43]

In much of the literature, the term "nondestructive evaluation" (NDE) is used interchangeably with NDT, especially in the United States. However, NDE technically should be used to describe measurements that are more quantitative in nature. To illustrate, an NDE method would not only locate a defect, but would also be used to measure something about the defect such as its shape, size, and orientation. In addition, NDE may be used to determine material properties (such as fracture toughness) and other physical characteristics.[44] Finally, the American Society For Testing and Materials (ASTM) sub-committee on NDT has recommended that all documentation use only the term NDT, even when NDE would more completely describe the examination.[45] Therefore, for the remainder of this work, only the term NDT will be used.

Since the 1920's, NDT has developed from a laboratory curiosity to an indispensable test of production. Modern nondestructive tests are used for many purposes, including:

1. To ensure product integrity, and in turn, reliability;
2. To avoid failures, prevent accidents and save human life;
3. To make a profit for the user;
4. To ensure customer satisfaction and maintain the manufacturer's reputation;
5. To aid in better product design;
6. To control manufacturing processes;
7. To lower manufacturing costs;
8. To maintain uniform quality level; and
9. To ensure operational readiness.[46]

Of these, product integrity and reliability, the prevention of accidents, and ensuring operational readiness are of greatest importance for the Air F

The number of inspection methods is rapidly expanding. Each method, however, can be completely characterized in terms of 5 principle factors:

1. Energy source or medium used to probe the test object (such as X-rays, ultrasonic waves or thermal radiation);
2. Nature of the signals, image or signature resulting from interaction with the test object (for example, attenuation of X-rays);
3. Means of detecting or sensing resulting signals (such as photo emulsion);
4. Method of indicating or recording signals (meter deflection, oscilloscope trace, or radiograph); and
5. Basis for interpreting the results (direct or indirect indication, qualitative or quantitative, and pertinent dependencies).[48]

The National Materials Advisory Board Ad Hoc Committee on NDT has adopted a system that classifies methods into six major categories: visual, penetrating radiation, magnetic-electrical, mechanical vibration, thermal, and chemical-electrochemical.[49] A version of this classification system is presented in Table 3, with additional categories included to cover new methods. The first six categories involve basic physical processes that require transfer of energy or matter to the test object, while the two auxiliary categories provide for the transfer and accumulation of information.

Basic Categories	**Objectives**
Mechanical and optical	Colour, cracks, dimensions, film thickness, gauging, reflectivity, strain distribution and magnitude, surface finish, surface flaws, through-cracks
Penetrating radiation	Cracks, density & chemistry variations, elemental distribution, foreign objects, inclusions, micro porosity, misalignment, missing parts, segregation, service degradation, shrinkage, thickness, voids
Electromagnetic and electronic	Alloy content, anisotropy, cavities, cold work, local strain, hardness, composition, contamination, corrosion, cracks, crack depth, crystal structure, electrical & thermal conductivities, flakes, heat treatment, hot tears, inclusions, ion concentrations, laps, lattice strain, layer thickness, moisture content, polarization, seams, segregation, shrinkage, state of cure, tensile strength, thickness, disbands
Sonic and ultrasonic	Crack initiation & propagation, cracks, voids, damping factor, degree of cure, degree of impregnation, degree of sintering, delaminations, density, dimensions, elastic moduli, grain size, inclusions, mechanical degradations, misalignment, porosity, radiation degradation, structure of composites, surface stress, tensile, shear & compressive strength, disbands, wear
Thermal and infrared	Disbanding, composition, emissivity, hear contours, planting thickness, porosity, reflectivity, stress, thermal conductivity, thickness, voids
Chemical and analytical	Alloy identification, composition, cracks, elemental analysis & distribution, grain size, inclusions, macrostructure, porosity, segregation, surface anomalies
Auxiliary Categories	**Objectives**
Image generation	Dimensional variations, dynamic performance, anomaly characterization & definition, anomaly distribution, anomaly propagation, magnetic field configurations
Signal image analysis	Data selection, processing & display, anomaly mapping, correlation & identification, image enhancement, separation of multiple variables, signature analysis

Table 3: Nondestructive Testing Method Categories [50]

Over 80 percent of the inspections completed on an aircraft are visual inspections.[51] At regular intervals, technicians look at various components of the aircraft for signs of damage. However, not all areas of the aircraft can be accessed for visual inspection, and not all damage can be detected by visual means. NDT methods allow technicians to inspect areas of the aircraft that would otherwise be uninspectable without disassembly. In addition, NDT methods allow for the detection of damage that is too small to be detected by visual means. Eddy current and ultrasonic inspection methods are used extensively to locate tiny cracks that would otherwise be undetectable. X-ray techniques are used to find defects buried deep within the structure, and together with other complimentary techniques, used to detect areas of water ingress and corrosion.

Emerging Technology

While the field of NDT will play a key role in maintaining aging aircraft, the discipline is continuing to evolve, with newer technologies offering greater inspection capabilities and reliability. As the pace of development of emerging technologies continues to accelerate, the nature of the field can be summarized by three characteristics: automation, cybernation, and integration. These characteristics have, in turn, contributed to the dramatic increase in costs of new weapon systems, and the increased uncertainty with respect to survivability and sustainability of these new and complex systems.

To produce new weapon systems, there are four organizations that have a role to play. In the first, there are the scientists and engineers working in laboratories and research institutions searching for new materials to improve performance parameters and new technologies to maintain these systems. The next organization is the arms industry, which is primarily interested in the production of the new weapon systems. Their main goal is making profits, and normally producing new high technology weapons and support systems is the most profitable part of the business. Industry, therefore, supports research to discover the new technologies. The third institution is the military, which determines the requirements for new weapons and weapon systems. The armed forces have the task of carrying out missions as effectively as possible, with a high chance of success and against reasonable costs. As well, throughout the postwar period, most NATO countries have put their faith in technology as an important force multiplier. The final organization is the state, where the mix of military and non-military means with which an enemy is to be met is decided. In order to effectively produce and support the new weapons, the state should support the development of the emerging technologies.[52] In Canada, however, this support has not been very strong.

Although the investment into these emerging technologies is certainly non-trivial, the economic payback can be substantial. As illustrated in Table 4, substantial cost savings can be realized through the application of advanced technologies. The original spar of the USAF T-38 wings, for example, had been cracking at around 2500 flight hours. In order to extend the life of the fleet to 2015, two options were available. The first involved replacement and maintenance of the spar as per the original design. The second option was to use a more effective design, different materials, and different NDT inspections. For the fleet of 490 aircraft, the estimated cost savings of the advanced technology solution will be approximately 41.5%.[53] After a lengthy debate, the advanced technology solution was chosen.[54]

Cost Category	Current Solution	Advanced Technology Solution
Base & intermediate maintenance costs	$353,531	$352,531
Depot maintenance costs (repair)	$7,200,060	$3,600,030
Depot maintenance Costs (replacement)		
a. Material costs	$34,805,680	$22,399,860
b. Labour costs	$30,105,600	$16,016,140
Total Depot Costs	$64,911,280	$38,416,000
Total Support Costs	$72,464,871	$42,369,561
Savings (%)		41.5%

Table 4: Cost Analysis For T-38 Spar [55]

Canada's Research and Development

In a study commissioned by the Economic Council of Canada, it was concluded that investment in R&D improves productivity through cost reduction or through market expansion.[56] In addition, the study's author concluded that there are two "spillover" mechanisms from R&D. The first is that a "downstream user" may benefit without paying the full R&D investment. Second, a technical discovery or innovation in one sector may stimulate another sector.[57] In order to ensure comparative analysis, R&D was defined as "Creative work undertaken on a systematic basis in order to increase the stock of knowledge … and the use of this stock of knowledge to devise new applications."[58] After completing an analysis of R&D data, the study discovered the following four conclusions on the returns achieved from R&D investment:

1. The rate of return on private R&D is greater than the rate of return on physical capital;
2. There is a higher rate of return from basic research than from applied research (while a conclusion of the report, the author suggests additional analysis is necessary on this seemingly contradictory result);
3. There is a higher rate of return from company-funded R&D than from publicly funded R&D; and
4. There is a higher rate of return from R&D directed to generate new production processes than from new products (of significant interest to the study of aging aircraft).[59]

In addition, the study found that the return on foreign R&D is more than ten times lower than the rate of return on domestic R&D. As only a very small percentage (2.5 % from 1965 to 1983) of the total Canadian R&D is from foreign sources, Canada cannot rely solely on foreign R&D for the provision of its technical knowledge.[60]

So how is Canada doing compared to other nations? Succinctly put, Canada is having difficulty adapting to the global market. Canada's trade deficit in high-technology products rose from $4.6 billion in 1980 to $7.1 billion in 1987, and of the G-7 countries, Canada has the lowest share of the total manufacturing value-added trade.[61] Therefore, Canada's competitiveness in the world marketplace is in danger due to a lack of technological innovation in the goods and services that is offered.

The World Competitiveness Report is produced by a Swiss-based academic consortium, consisting of the International Management Education Specialists and the World Economic Forum. For their annual report, competitiveness is defined as "the ability of entrepreneurs to design, produce and market goods and services, the price and non-price qualities of which form a more attractive package of benefits than those of competitors."[62] The report is designed to "focus on how national environments are conducive or detrimental to the domestic and global competitiveness of enterprises operating in those countries."[63] The overall score is constructed from 292 elements grouped into ten factors. Figure 2 is the World Competitiveness Scorecard for 2002, with Canada ranked eighth overall. While an improvement from a ninth place in 2001, it nevertheless represents a significant slippage from 1989, where Canada was ranked fourth.[64] In assessing Canada's performance, an editorial in *The Trentonian* concluded that the report "comes as a shock considering Canada has had a stellar economic performance this year and is said by experts to be poised for continued growth."[65] Similarly, the World Economic Forum annual report shows that Canada is also slipping on its technology rating. Canada had been rated second in technology last year, but slipped to eighth this year.[66] Canada's future competitiveness will determine whether Canada prospers or stagnates, and a key to any future competitiveness is the amount invested in R&D. In essence, Canada needs to develop and implement a technology innovation strategy to enhance economic development.

Statistics Canada annually produces a report on the R&D expenditures in Canada as a whole, and separately by province. To produce the report, the Gross Domestic Expenditure on Research and Development (GERD) is calculated by "adding together the intramural expenditures on R&D as reported by the performing sectors."[68] The resulting report illustrates how much R&D each sector performed over a 12-month period, the amount of R&D each sector financed over a 12-month period, and indicates the flow of funds between sectors. The results for 2000 and 2001 are summarized in Table 5, which illustrates that federal and provincial governments only contribute approximately $4.5M each year towards R&D, or about 23% of the total R&D funding, an amount only slightly greater than foreign investment.

But how do these values compare with other countries? As can be seen in Figure 3, the expenditure of R&D in Canada (1.32% of GDP) is significantly lower than in most competing countries.[70]

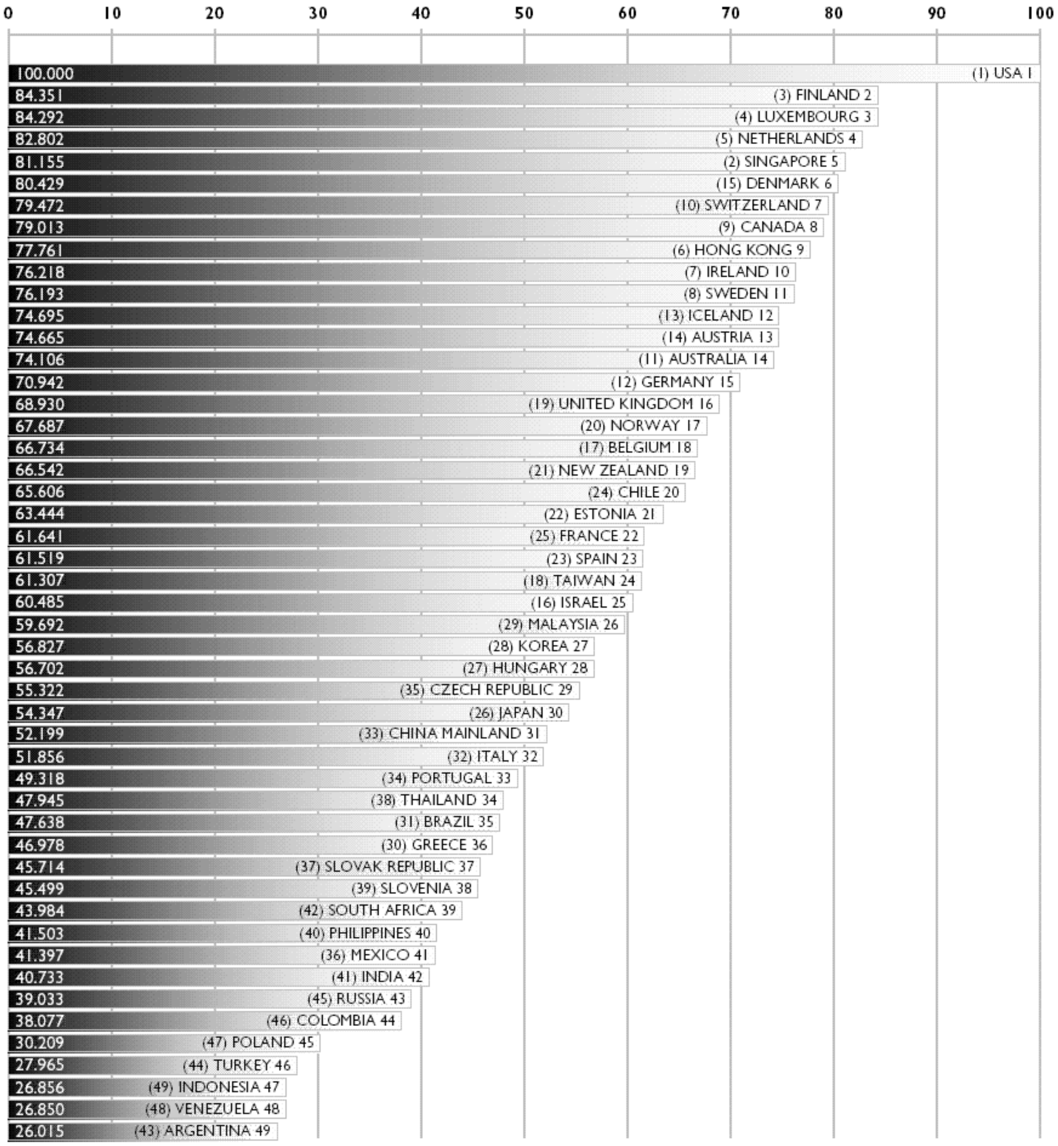
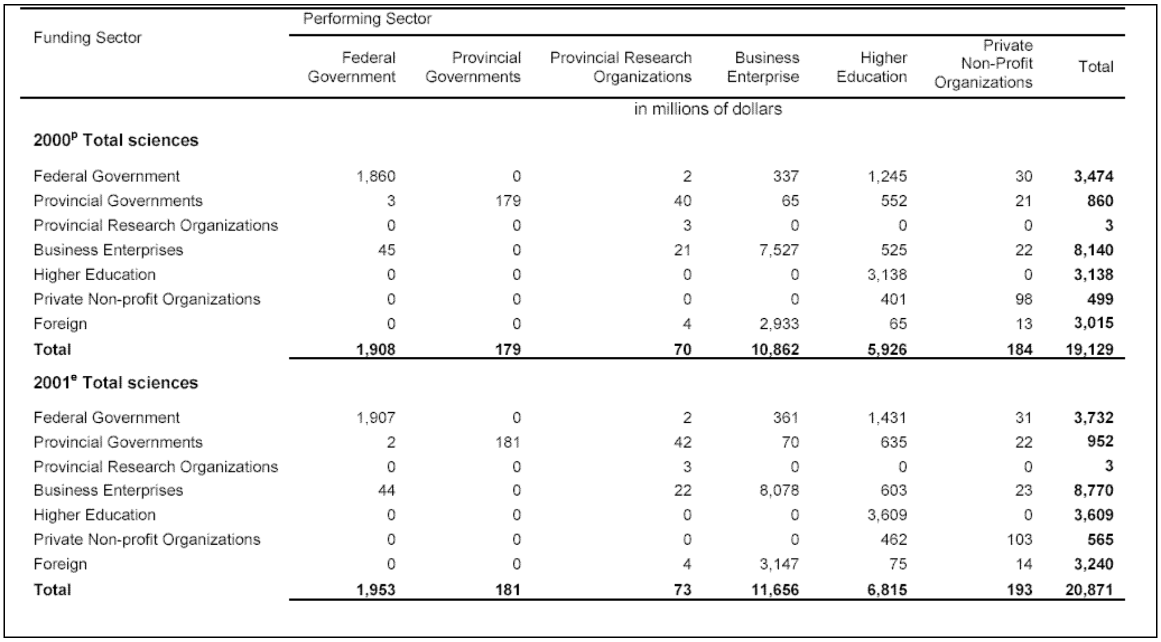


Figure 2: The World Competitiveness Scoreboard For 2002 [67]



Funding Sector	Performing Sector Federal Government	Provincial Governments	Provincial Research Organizations	Business Enterprise	Higher Education	Private Non-Profit Organizations	Total
	in millions of dollars						
2000ᵖ Total sciences							
Federal Government	1,860	0	2	337	1,245	30	**3,474**
Provincial Governments	3	179	40	65	552	21	**860**
Provincial Research Organizations	0	0	3	0	0	0	**3**
Business Enterprises	45	0	21	7,527	525	22	**8,140**
Higher Education	0	0	0	0	3,138	0	**3,138**
Private Non-profit Organizations	0	0	0	0	401	98	**499**
Foreign	0	0	4	2,933	65	13	**3,015**
Total	**1,908**	**179**	**70**	**10,862**	**5,926**	**184**	**19,129**
2001ᵉ Total sciences							
Federal Government	1,907	0	2	361	1,431	31	**3,732**
Provincial Governments	2	181	42	70	635	22	**952**
Provincial Research Organizations	0	0	3	0	0	0	**3**
Business Enterprises	44	0	22	8,078	603	23	**8,770**
Higher Education	0	0	0	0	3,609	0	**3,609**
Private Non-profit Organizations	0	0	0	0	462	103	**565**
Foreign	0	0	4	3,147	75	14	**3,240**
Total	**1,953**	**181**	**73**	**11,656**	**6,815**	**193**	**20,871**

Table 5: National GERD For 2000 and 2001 [69]

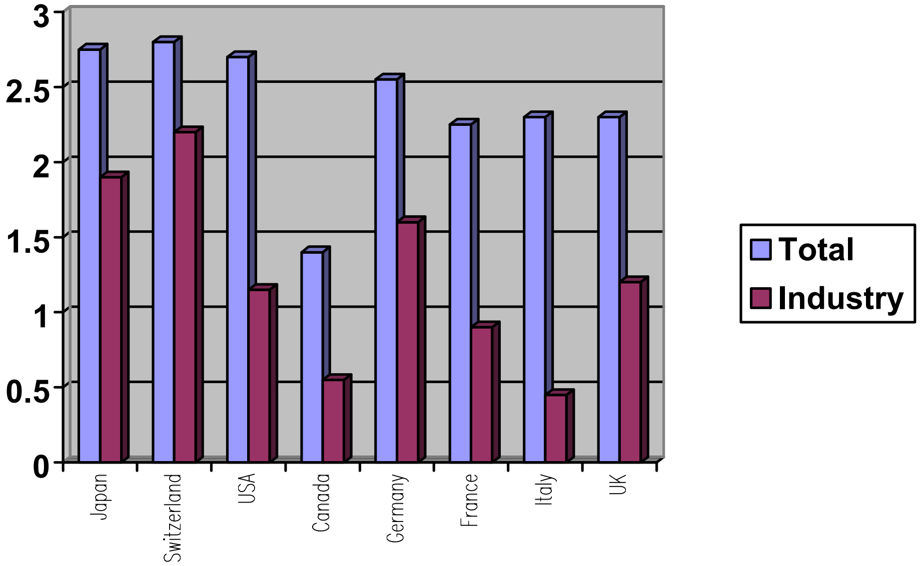


Figure 3: R&D Expenditure[71]

Under-funding is not the only reason for the weakness of Canadian R&D. As can be seen from Figure 4, the number of R&D personnel in Canada has consistently been less than one percent of the total labour force.[72] By way of comparison, Japan has an R&D participation rate almost twice that of Canada, and the United States R&D participation rate is 1.5 times larger than Canada's.[73]

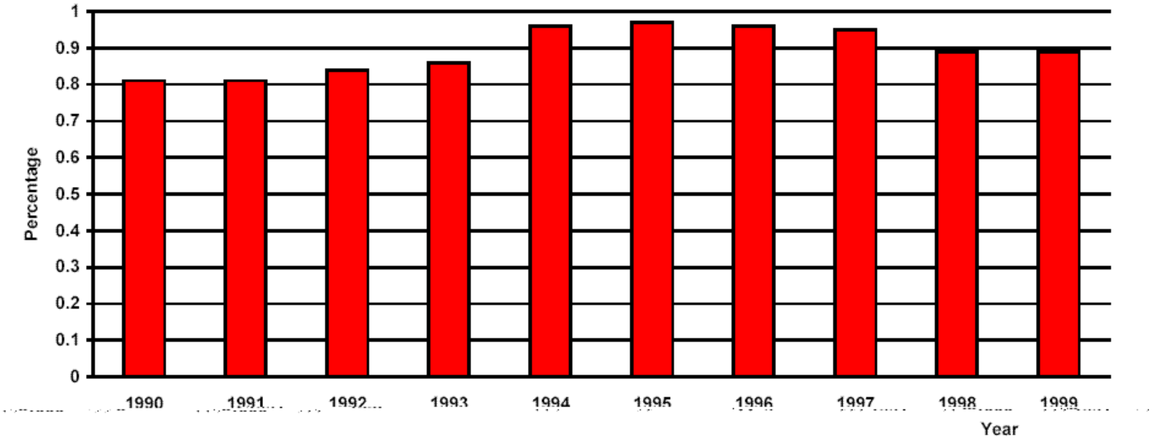


Figure 4: R&D Personnel In Canada[74]

Based on the number of research papers originating from these countries, Dr. Ingar Moen, at the Canadian National Defence College, concluded that the Canadian researcher was five times more productive than the Japanese researcher, and 1.5 times more productive than the US researcher, even though in terms of the number of patent applications, the Japanese researcher was five times more productive, and the US researcher 1.7 times more productive.[75] Based on personal experience in the field of NDT, these comparisons are equally valid for a comparison of Japanese, U.S, and Canadian NDT researchers. Thus, Canadian scientists and engineers are making significant contributions to the advancement of knowledge, but they do not contribute competitively to technological innovation.

In an earlier investigation by Dr. Moen, he concluded that "Canada lacks the R&D capacity and the commitment to science and technology to advance emerging technology in a competitive way."[76] He further stated that, "institutional, procedural and behavioural changes involving input from government, business, and academia will be required to rectify this situation."[77]

To rectify these deficiencies, Dr. Moen proposed four specific changes to the funding and performance of R&D. First, in an effort to encourage industry to invest more in R&D, he suggested an R&D tax, whereby all businesses would contribute at least one percent of total sales to R&D. This tax, he estimated, would produce another $3 billion per year, thereby bringing the total R&D expenditures to about 1.8 % of the GDP. Second, Dr. Moen suggested structural changes to the R&D community, with closer linkages between industry, government laboratories, and universities. Third, he suggested that government research institutes should be restructured to make them more responsive to the R&D needs of industry. Finally, Dr. Moen suggested that the marketing and exploitation of scientific knowledge should be the responsibility of affiliated R&D centers rather than the individual scholar. Thus, the affiliated R&D center would provide the industrial interface without compromising the primary function of academic institutions.[78] In addition, Dr. Moen suggested that strategic R&D funding should be divided into three categories:

1. R&D considered essential to the national interests, including national defence and security, public health, regulatory functions, and development of national standards;

2. International R&D activities involving bilateral or multilateral programs with other countries, such as the Space Program; and
3. R&D that supports the governments strategic plan for emerging technologies: the Centres of Excellence Program and operation of national facilities, for example.[79]

Finally, Dr. Moen concluded that R&D essential to the national interest should primarily be conducted by research institutes, and to a lesser extent, by university affiliated research centres.[80]

DND's Research and Development

In order to determine the feasibility of Dr. Moen's suggested restructuring of strategic R&D funding, the recent changes to R&D within DND will be examined. The relationship between defence R&D and the military is one of service provider and client. As described by Mr. Warren Nethercote, much of the impetus for process-related change in DND's Research and Development Branch[81] came in response to the military's perception that it was not being well served. As explained by Mr. Nethercote, "the R&D Branch's reaction to the dissatisfaction was to develop a client-oriented program formulation process."[82] This change, along with several other organizational and administrational changes, including improvements with external partners, were outlined in the R&D Branch's implementation of Defence 2000.[83]

Defence 2000 was DND's response to the massive change initiative within the federal public service called PS2000. The major philosophical change in PS2000 was the inclusion of the principles of New Public Management. Simplistically stated, New Public Management includes elements of the private sector philosophy to government, and demands a re-examination of all accountability arrangements. Also, the New Public Management Model includes the following key postulates:

1. The private sector is better managed than the public sector;
2. The user is a well-informed individual who makes clear and reasonable demands;
3. An efficient service costs less; and
4. A government service can be compared to a private sector, with the result that the user becomes a client.[84]

While the validity of these postulates could be debated at length, the re-organization of the R&D Branch to DRDA, and the further changes directed by Defence Strategy 2020 resulted in a further realignment of DND's approach to needed technology improvements. These initiatives have been termed a "Technology Investment Strategy," and are in response to a projected set of new capabilities that the CF and DND will need in 2010 and beyond.[85] The development of the Technology Investment Strategy was also used to respond the Report of the Standing Committee on National Defence and Veterans Affairs (SCONDVA). Recommendation 10 from the SCONDVA Report stated, "The Department of National Defence maintain [sic] its strong commitment to research and development in the defence field and its cooperation with Canadian industries to ensure the design and production of state-of-the-art military equipment."[86] The Governmental response to this Recommendation was to state that DRDA's Technical Investment Strategy would ensure that the R&D needs of the CF would be met, and that continued cooperation with Canadian defence industries would continue.[87]

The Technology Investment Strategy identifies technology opportunities (as listed in Table 6) “that will enable the outcomes and sets out a series of R&D Activities that will harness Technology Opportunities through Delivery Vehicles.”[88]

Autonomous Intelligent Systems	Human-systems Integration	Knowledge Management
Artificial Intelligence	Human Performance & Capability	High-Resolution Imagery
Modeling & Simulation	Software Engineering	Wide-Bandwidth Communications & Networks
Embedded Sensors	Nanotechnology & Miniaturization	Smart Materials & Structural Materials
Novel Energetic Materials	Bimolecular Engineering	Massive Computing
Laser Technology	Power Sources	Microelectronic Materials

Table 6: Technology Opportunities [89]

The Technology Investment Strategy further explains that a set of guiding principles is also important for defining future R&D Activities, and are as follows:

1. Develop core competencies;
2. Exploit technology opportunities;
3. Respond to “Outcomes”;
4. Focus on world class niche R&D areas;
5. Espouse quality rather than quantity;
6. Be forward looking;
7. Ensure strategic defence relevance;
8. Avoid fragmentation – integrate; and
9. The sum of niche R&D areas defines all Defence R&D.[90]

Then, based on these guiding principles, the Technology Assessment Working Group has identified 21 R&D Activities, as listed in Table 7.

1.Autonomous Intelligent Systems	**8**.Information & Knowledge Management	**15**.RF Electronic Warfare
2.Chemical/Biological/Radiological Threat Assessment & Detection	**9**.Multi-Environment Life Support Technologies	**16**.Sensing (Air & Surface)
3.Command & Control Information Systems	**10**.Network Information Warfare	**17**.Sensing (Underwater)
4.Communications	**11**.Operational Medicine	**18**.Signature Management
5.Electro-Optical Warfare	**12**.Platform Performance & Life Cycle Management	**19**.Simulation & Modeling For Acquisition, Rehearsal & Training
6.Emerging Materials & Bio-Molecular Technologies	**13**.Percision Weapons	**20**.Space Systems
7.Human Factors Engineering & Decision Support	**14**.Psychological Performance	**21**.Weapon Effects

Table 7: R&D Activities [91]

Finally, as explained earlier, the lack of R&D funding has resulted in a further focusing of each of the R&D Activities into distinct Foci. Aging aircraft and the development of new NDT techniques are addressed under Activity 12 (Platform Maintenance & Life Cycle Management) and Activity 6 (Emerging materials), listed in Table 8.

Foci For Activity 6	Foci For Activity 12
Function Materials for transducers, actuators & smart structures	Extension of reliable computational fluid dynamics to complex vehicle configurations & extreme flows
Substitution of conventional materials by tailored polymers	Structural analysis for life-cycle management & insertion of advanced materials technology
Synthesis of military materials by molecular manufacturing techniques	Extension of aero-propulsion performance & life-cycle
	Materials & materials management for platform & systems safety & life-cycle management
	Modeling of operational limits & safety for military platforms & embarked systems

Table 8: Foci For Activities 6 and 12 [92]

In addition to Activity 12, DRDA has clearly recognized the need for a specific focus on aging aircraft issues. As described in their Technology Investment Strategy, "Canadian military fleets are made of limited numbers of platform types or classes," and that "R&D is critical for mitigating the effects of rapid obsolescence, or operating platforms for periods far longer than would be acceptable in civil practice."[93] Therefore, the issue is one of how to invest the very few R&D dollars to help offset the aging aircraft issues.

In their report "Looking Forward, Staying Ahead," DRDA outlines that their organization is facing the same fiscal challenges as the remainder of DND, and is being forced to carry out their mandate with fewer resources. One strategy to accommodate this fiscal pressure has been to improve their consultation and collaboration processes. As explained in their report, "civilian R&D investment now far exceeds military investment and thus the civilian sector will lead in many developments of new technology."[94] DRDA's investment strategy is based upon:

1. Significant in-house effort in technologies unique to defence (e.g., chemical and biological defence, munitions, countermine, electronic warfare, anti-submarine warfare);
2. Good in-house capability, but significant reliance on partners in areas primarily defence driven but with dual-use potential (e.g., surveillance, materials, naval platform technology, aeronautics); and
3. Reliance on partners, with an in-house capability to monitor, adapt and use civilian-driven technologies (e.g., information technology, biotechnology, simulation and training).[95]

In keeping with these principles, DRDA has been "aggressively following up on the federal government's strategy for partnering and collaboration in science and technology."[96] One of DRDA's new tools to capture the benefits of collaboration is their recent establishment of a Specified Purpose Account (SPA) whereby the private sector can benefit by contributing to the in-house defence R&D program. "This will enable the Branch to manage investment funding in private sector collaborations and increase the amount of research being performed for each 'defence dollar' by sharing costs of specific projects with non-government agencies."[97] The long-term goal for this unique approach is $10 million annually.

In addition to initiatives such as the Specified Purposes Account, DND (as well as DRDA, NRC and others) can sponsor other developments in Canada's defence industry sectors through procurement and export assistance. Historically, DND's most efficient way of sponsoring Canada's defence industry has been its ability to purchase goods and services. However, as explained in a paper produced for ADM (Mat) on Defence Industry, "as business practices evolve and capital goods and support requirements shift, defence purchases offer a less ready means of direct support to Canada-based or indigenous defence industry."[98] The paper further concludes that "in future, it is less likely that government would use purchases, as it traditionally has, to stabilize a particular defence company which faces economic difficulties."[99]

In export assistance, the majority of the traditional assistance by DND has not been monetary. While not an exhaustive list, some of these mechanisms include:

1. Providing technical and policy advice to the Department of Foreign Affairs and International Trade (DFAIT) when companies apply for an export permit;

2. Developing networks with foreign defence departments and military services. This activity normally revolves around ‘easing’ access for Canadian companies by briefing potential buyers about the CF’s experience with the contractor, and taking part in industry missions and trade exhibitions;
3. Developing country-specific materiel cooperation programs and, when it is of clear benefit to the defence organization, helping to develop or identify specific materiel collaboration and/or export opportunities for the Canadian defence industry;
4. Loaning DND resources such as platforms, materiel and personnel, on a cost recovery basis, when there is no impact on operational capability, to support sales;
5. Developing or participating in export-oriented initiatives under a ‘Team Canada’ banner;
6. Providing information on equipment trials and results; and
7. Providing market intelligence and developing strategies for exploiting foreign market opportunities.[100]

As the international defence market continues to shrink, Canada must ensure that any export assistance offered will improve DND’s base of assured commercial support within Canada, including responsive R&D initiatives.

Another method of leveraging the defence R&D investment is through various international collaborations, specifically through the Technical Cooperation Program (TTCP). Listed in Table 9 are the various Technical Panels and Action Groups that are attended or sponsored by DRDA. Of particular interest in Table 9 is the TTCP Technical

Panel Nondestructive Examination for Aging Military Platforms, However, due to a lack of DRDC funding support, no significant Canadian R&D has been sponsored for this important Technical Panel. In fact, with the exception of papers presented from the NRC sponsored Aging Aircraft Structures Section, there have not been any Canadian papers presented at the Research and Technology Organization's Conferences (and formerly AGARD Conferences) from 1989 to 2000.[101]

One recently announced Canadian low-cost initiative is an integration of various aspects of the R&D programs of the Royal Military College of Canada (RMC) and of DRDA. Acting on the recommendations of a study carried out for the Principal of RMC and the Associate Deputy Minister for Science and Technology (who is currently the CEO for DRDA), a strategic alliance has been formed between DRDA and RMC with a particular emphasis in the thrust areas of Communications, Energy, Environment, and Materials. The net effect will be more capability for DND and the CF for the same investment with significant benefits for both RMC and DRDA.

GROUP	TECHNICAL PANELS & ACTION GROUPS
Aerospace Systems	Uninhabited Air Systems
Command, Control, Communications & Information	Space & UAV Comms Technology Space & UAV Comms Information Assurance & Defensive Info Warfare IO Symposium Committee
Chemical & Biological Defence	Medical Countermeasures against Biological Warfare Agents Hazard Assessment Detection of Biological Warfare Agents Low Burden CB Individual Protective Equipment Chemical Toxicology Radiological Hazards Passive Stand-Off Chemical Detection BTWC-Related Analytical Methods
Electronic Warfare Systems	Countermeasures to Advance & Coherent Threats to Air Platforms Countermeasures to Surveillance & Targeting Radars Electronic Support Systems Anti-Ship Missile Countermeasures
Human Resources & Performance	Training Technology Physiological & Psychological Aspects of using Protective Clothing Human Factors in Aircraft Environments Physical & Cognitive Performance Enhancement for Convention & Special Operations Human Factors Integration For Naval Systems Survival Psychology Human Aspects of Command
Joint Systems & Analysis	Land Systems Modeling & Simulation Joint Concepts & Analysis Systems Engineering For Defence Modernization Small Unit Land Operations Unmanned Aerial Vehicle Concepts Defence Science & Tech Management Technology For Effects-based Ops
Maritime Systems	Maritime Command, Control & Info Management Maritime Systems Studies Sonar Technology Maritime Air Systems Mine Warfare & High Frequency Acoustics
Materials & Processing Technology Group	Metals Technology & Performance Nondestructive Testing for Aging Military Platforms Polymers, Adhesives & Coatings Composites Technology & Performance Technologies for Enhancing Individual Combatant Protection
Sensors	Multi-Sensor Integration Signal & Image Processing Radar Systems & Technology Radar Detection of Small Targets in Clutter HF Surface Wave & Line-of-sight radar Surveillance from Space-based & High-altitude Platforms
Conventional	Energetic Materials & Propulsion Technology

Table 9: The Technical Cooperation Program [102]

To facilitate this alliance, a Defence Research Institute (DRI) will be set up at RMC in the near term, with full operational capability scheduled of 2006. While the final details have not yet been finalized, some of the short-term benefits include:

1. Improved ties and shared funding;
2. Some Defence Scientists with DRDA would join the DRI at RMC with the possibility of adjunct status and co-supervision of graduate students;
3. Some senior contract researchers currently at RMC could be hired as DRDA employees to bring long term stability for the four thrust areas identified;
4. RMC/DRI would have access to the expertise of the business practices of DRDA to include managing patents, etc.;
5. The alliance would provide new opportunities for RMC research and postgraduate studies; and
6. There would be additional physical space for research in the four thrust areas.[103]

This strategic alliance is in agreement with the proposed restructuring of strategic R&D funding proposed by Dr. Moen, as well as his proposed changes to the performance of R&D. While certainly a low-cost option, the alliance will hopefully begin to address the R&D shortfalls across the four thrust areas identified. Unfortunately, of all the thrust areas to be investigated, only the Material Thrust Area may be interested in aging aircraft, specifically if corrosion is to be investigated. Therefore, this one initiative will not totally address the R&D shortfalls for aging aircraft.

The RMC/DRDA alliance, and the identification of only four Thrust Areas, is also in agreement with the thesis proposed by Dr. Ira Jacobs in her National Security Studies

Course paper that Canada should follow a 'niche area' strategy to focus its R&D resources. As explained by Dr. Jacobs, this niche area approach is in direct contrast with the DRDA approach of trying to sponsor a myriad of R&D activities.[104] However, as explained earlier, DRDA has acknowledged that the available resources will not even allow the continuation of the presently sponsored R&D activities. Therefore, as concluded by Dr. Jacobs, using the Canada Space Arm's contribution to NASA as an example, Canada should decide on which niche areas to concentrate our scarce R&D dollars, and then declare to our Allies where we will be focusing.[105]

A similar strategy has been suggested by the former Vice Chief of Defence, Vice-Admiral Garnet, in his paper for the Canadian Military Journal on the Revolution in Military Affairs. Vice-Admiral Garnet wrote that the challenge facing the CF from the RMA was to "choose wisely and exploit affordable and effective technological, doctrinal and organizational change."[106] While the choice of which technologies or niche areas to follow would certainly be a difficult selection, the choice should be focused on those areas of greatest CF operational need where significant gains through R&D have already been demonstrated. Since the damage potential of corrosion to aging aircraft is of grave concern, and since DND has already invested R&D funds into the successful development of modern NDT facilities, NDT is a niche area in which R&D support should be continued. Hopefully it will not take a catastrophe, such as the loss of an aircraft that resulted in the start of the ASIP, before such an approach is adopted in Canada.

In the United States, the events of September 11, 2001 have highlighted the need for continued R&D. As articulated by President Bush, "science and technology is the key to homeland security."[107] Todd Steward, the Ohio State University supervisor of international and homeland security programs, in describing the increased need for R&D investment, stated that "we need to make the same sort of commitment to science and technology that we did when we got the wake-up call with Sputnik."[108]

Another initiative has recently been announced for the Canadian university R&D community. At a National Summit on Innovation and Learning conference in Toronto on November 22, 2002, university administrators agreed to do a better job of turning academic research into commercial products, in return for a promise by the federal government to double research funding and to create a permanent fund to pay the overhead costs of conducting federally funded research. As announced by the current Industry Minister, Alan Rock, the Framework Agreement on Federally Funded Research will double the federal R&D budget to $9.2 billion by 2010, and will allocate a one-time funding of $125 million to pay for overhead costs associated with publicly funded research. In return, the Association of Universities and Colleges of Canada agreed to a doubling of the amount of research performed by universities, and a tripling of commercial performance over the same period of time. Before this promise becomes a reality, Minister Rock must successfully negotiate with the other members of Cabinet for the funding, and the exact details of how to measure academia's contribution to commercial performance must be determined. Nevertheless, as the deal gives each side something it needs, all are hopeful that the announcement can become a reality.[109]

successful R&D effort, which for a very modest amount of funding, has fulfilled an operational requirement.

Case Study – Investment In Emerging Technology For NDT

The CF purchased 135 CF188 Hornet aircraft in the 1980's. With the introduction of the Hornet, the CF recognized that there would be a requirement to inspect composite materials covering large surface areas such as the graphite epoxy surfaces, as illustrated in Figure 5. The inspection requirements would be especially challenging and unique as the Canadian usage of the CF188 has, and continues to be, substantially different from that defined in the original design requirements. Without a rigorous and proactive inspection program to manage the structural life of the aircraft, the fleet would not be able to reach its design life.[110]

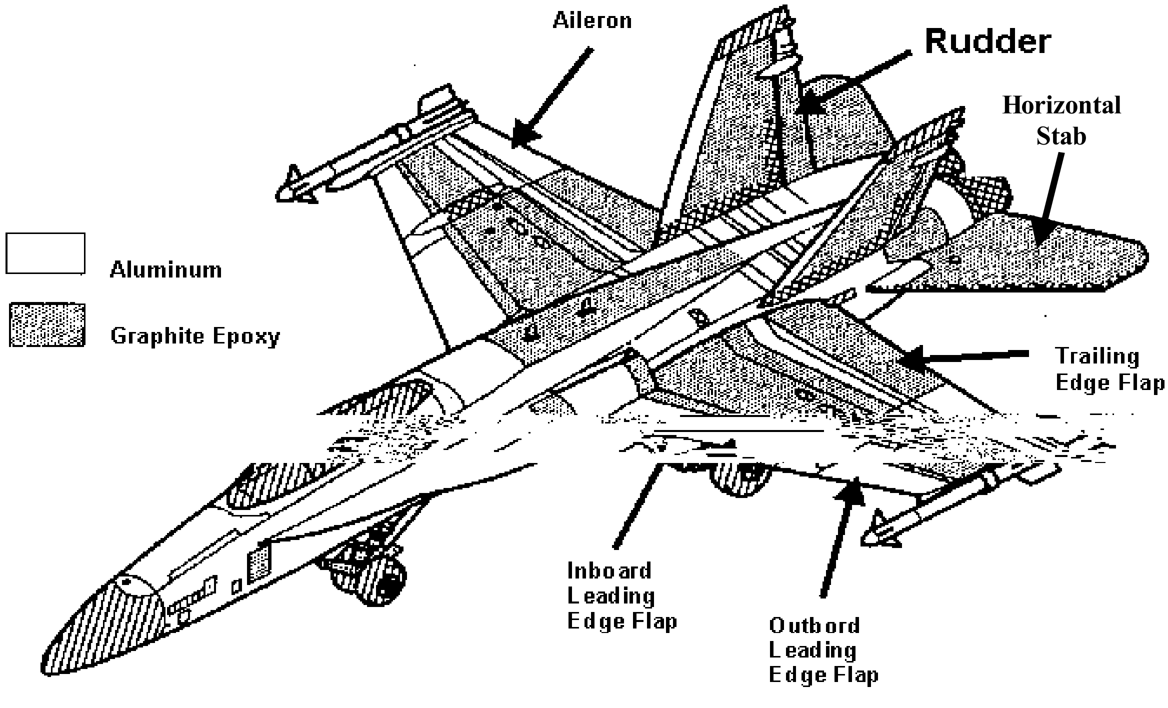


Figure 5: CF188 Material Distribution And Flight Controls [111]

As can be seen in Figure 5, the CF188 has twelve flight control surfaces, each consisting of an aluminium honeycomb core with either an aluminium or graphite/epoxy skin, depending on the component. By way of illustration, Figure 6 shows a cross section of the CF188 rudder.

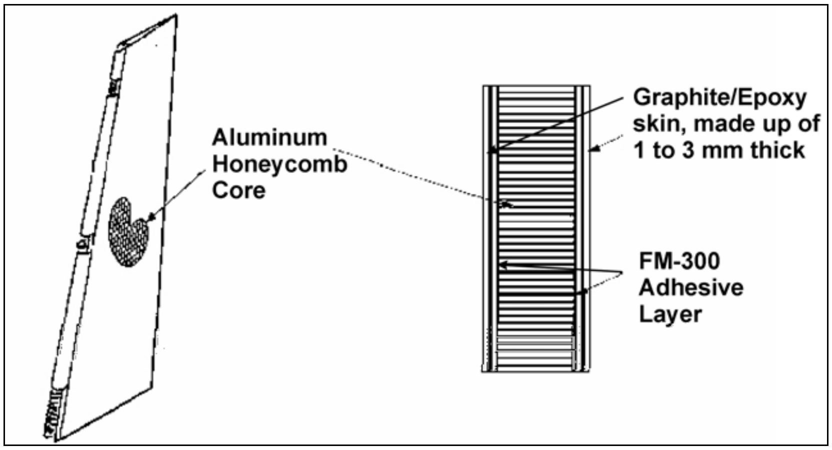


Figure 6: CF188 Rudder And Its Cross Section [112]

In order for an in-service inspection to be of use for the CF, the equipment must be capable of detecting very small quantities of water ingress or corrosion, so that any affected components can be removed and repaired, economically and before catastrophic failure. During the construction and assembly of the flight controls, manufactures have developed large, automated ultrasonic through-transmission equipment for factory inspections of large areas.[113] While effective at manufacturing plants, this type of equipment would not be suitable for in-service inspections due to the cost of the equipment, its size, and the level of corrosion or water ingress detectable.

The CF188 is the first aircraft to be purchased by the CF that makes extensive use of graphite/epoxy composite materials. For the first fifteen years of service, visual, ultrasonic, and X-ray examinations were developed to detect delaminations, disbands, and corrosion. There are a total of 105 approved NDT inspections for the CF188, with the complete list included as Appendix 1. Accelerated by the in-flight loss of a rudder from a US Navy F/A-18 in July 1996 due to corrosion, the CF continued its search for an alternate NDT method to detect small amounts of water ingress or corrosion in all flight controls. In July 1997, the USN had a second rudder depart in flight, while Figure 7 shows the first (and only one to date) CF188 rudder loss due to corrosion, which occurred on March 23, 1999. Had the CF's research program not experienced lengthy delays, perhaps this rudder loss could have been prevented.

Figure 7: CF188 Rudder Loss From Aircraft 188725 [114]

The CF's investigation into emerging technologies to try and find a more suitable NDT inspection for the CF188 flight controls began in late 1995, when the Canadian Forces Nondestructive Testing Centre (NDTC), located at the Aerospace and Telecommunications Engineering Support Squadron (ATESS) at CFB Trenton arranged for the highest flight-hour CF188 to be sent and tested at the neutron radiography and X-radiography facility at McClellan Air Force Base (AFB) in Sacramento, California. While the CF had been using X-radiography inspections since the aircraft had been introduced into service, the McClellan AFB Facility was the first Canadian use of the emerging technology of neutron radiography.

Neutron radiography is considered a complementary nondestructive testing technique to conventional radiography. In X- and gamma radiography, attenuation increases uniformly with mass number and density, whereas, with neutrons, attenuation is random with a tendency for certain light elements such as hydrogen to absorb and scatter neutrons rather well. Thus, neutron radiography is especially well suited to detecting corrosion and moisture entrapment, especially in aircraft structures.

The neutron radiography image can either be stored on film, or digitally, which is usually referred to as radioscopy. For radioscopy, the image is stored in a digital format on a computer for viewing and digital enhancement purposes. The major disadvantage of neutron radioscopy is poor image resolution while the advantages include good image contrast, reduced exposure time, very good image linearity and the ability to manipulate image data. A typical configuration for neutron radioscopy is shown in Figure 8.

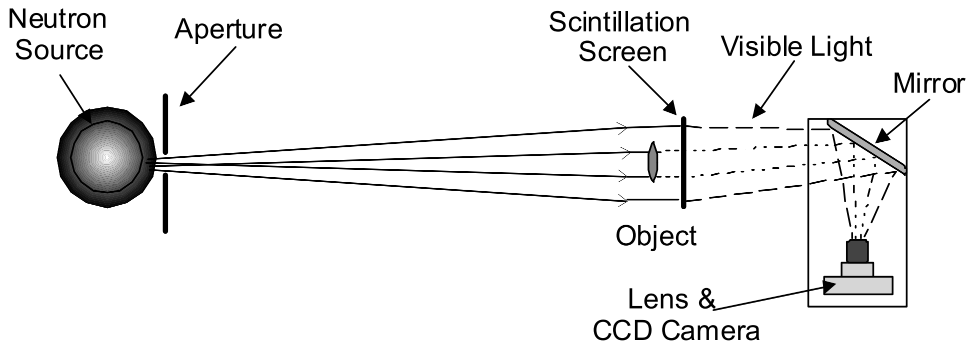


Figure 8 - Neutron Radioscopy Configuration [115]

Using the data from McClellan AFB, a correlation of the results from both X-radiography and neutron radiography would yield indications of water ingress and corrosion, as well as indications about the structural integrity of the flight controls inspected. These inspections revealed indications of water ingress in the graphite/epoxy skin layers and the aluminum honeycomb core structure of the left-hand rudder, as well as the possibility of corrosion in the core.[116] In addition, neutron radiography inspections revealed a total of 93 anomalies, including moisture, cell corrosion, damaged honeycomb core, foreign object material, voids, and repaired areas.[117] An example of a neutron radiograph of a corroded rudder can be seen in Figure 9.

Independent of these inspections, R&D work was underway at RMC to develop an in-house neutron radiography facility, using the small research reactor known as the Safe LOW Power c(K)ritical Experiment (SLOWPOKE-2). The SLOWPOKE-2 was originally installed for undergraduate and graduate experiments in the Department of Chemistry and Chemical Engineering, but was also available for staff research. In order to utilize the neutrons from the reactor's core, a thermal column of heavy water was installed to provide a pathway for thermal neutrons to travel from the core region radially though the reactor container.

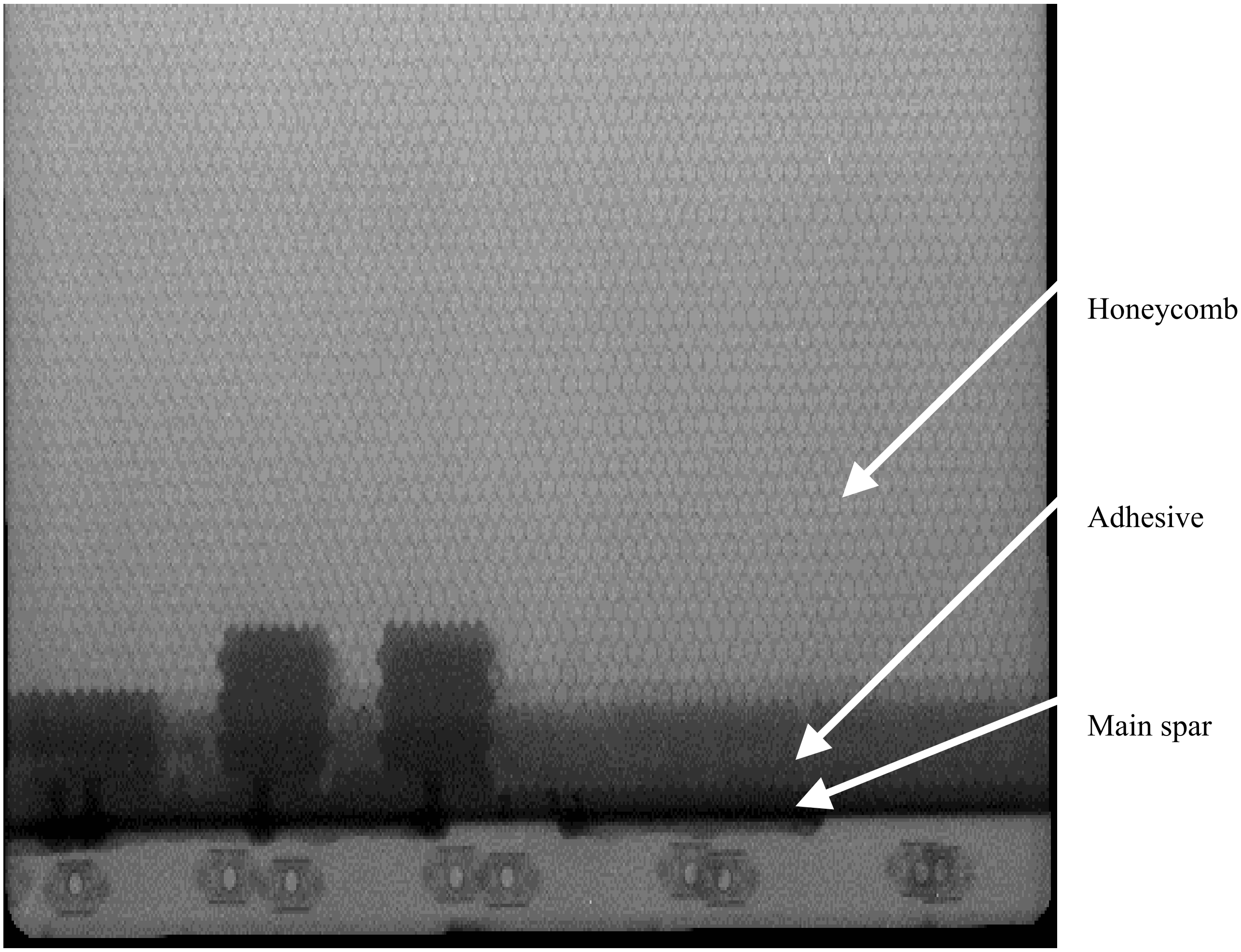


Figure 9: Neutron Radiograph Of A Corroded Rudder [114]

At this point, the bottom end of a beam tube containing a shaped piece of graphite and an aperture was placed in order to extract a beam of neutrons upwards (Figure 10). Many additions and modifications to the shielding, lining and aperture have taken place since the original installation in order to produce a neutron beam adequate for neutron radiography and radioscopy. These developments were funded over a period of 16 years, primarily from the Director General of Aerospace And Engineering Maintenance and DRDA. The R&D funding, which included the major costs for the construction, installation, and commissioning of the neutron radiography facility, has been $836,000 over 16 years[119] – certainly a very modest R&D investment. Due to the SLOWPOKE-2's location at RMC, R&D funding has not been required for the maintenance and operation of the reactor, nor the salaries of the staff. Therefore, the R&D funding has been leveraged so that all of the funding has been available exclusively for the development of the neutron radiography facility, the utility of which will now be presented.

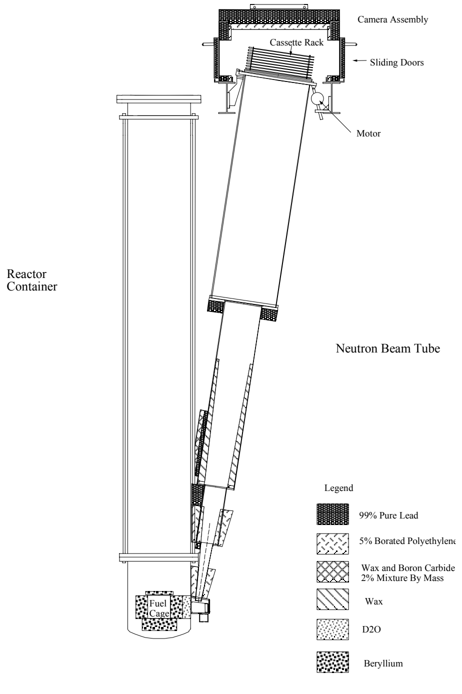


Figure 10: The Neutron Beam Tube and The Reactor Container At RMC [120]

After returning to Canada from McClellan AFB, the component with the greatest structural significance, namely the right-hand rudder from the vertical stabilizer, was removed from the aircraft and put through a rigorous program of numerous NDT inspections. These inspections used both conventional NDT methods and other emerging technologies in order to determine the optimum inspection technique for this problem. After an initial determination of potential NDT solutions, four techniques were selected for additional analysis, namely infrared, through-transmission ultrasonics, X-radiography, and neutron radiography. As can be seen in Figure 11 to 14, of all the techniques investigated, only through-transmission ultrasonics and neutron radiography were able to identify large areas of hydration, and only neutron radiography could identify the small areas of moisture entrapment and hydration. When the rudder was finally disassembled to destructively determine the levels of moisture and entrapment, all areas of moisture entrapment and hydration found during this disassembly were the same areas that had been detected using neutron radiography.

Once these comparative tests had been completed, it was decided that all the flight controls from ten complete CF188's would be inspected with both through-transmission ultrasonics and neutron radiography to finalize which inspection technique was preferred. However, due to a greatly reduced amount of funding, the inspection of the ten sets of flight controls was greatly protracted. Instead of completing the inspections in one year as originally planned, the inspections required over three years to complete. After inspecting all of the flight controls, it was concluded that the through-transmission ultrasonic technique was the best inspection for the location of disbonds between the honeycomb core and the aircraft skin, while only neutron radiography was able to locate the small amounts of water entrapment and corrosion. Therefore, it was decided that if corrosion was suspected in any CF188 flight control, the component would be sent to RMC for the definitive test of neutron radiography.

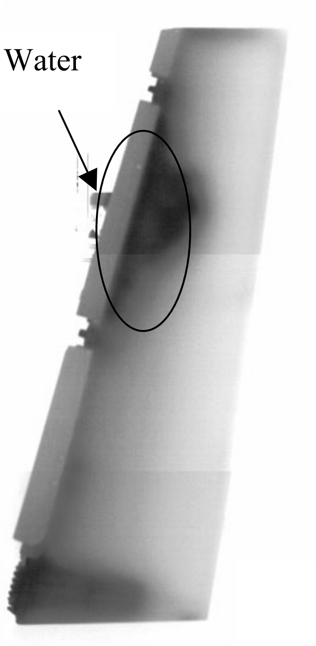


Figure 11 - Infrared Image of Rudder

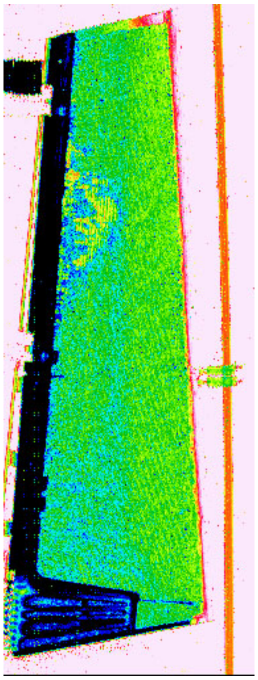


Figure 12- Through-Transmission Ultrasonic Image of Rudder

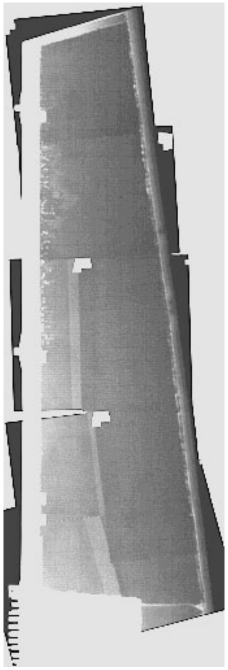


Figure 13-X-Ray Image of Rudder

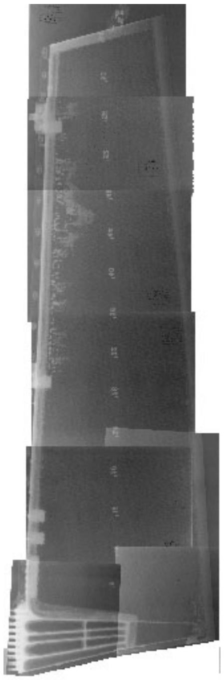


Figure 14-Neutron Radiography Image of Rudder [121]

This procedure of using neutron radiography as the final confirmation of the presence of water entrapment and corrosion has continued over the past two years, including during a trial of infrared imaging. Although neutron radiography is the most sensitive to the location of water and corrosion, its main disadvantage is that the flight control must be removed from the aircraft and shipped to RMC. Therefore, a trial is underway to determine if infrared imaging can be used as an initial screening tool. Infrared imaging is a simple, non-intrusive and inexpensive method of inspecting flight controls without their removal. However, the infrared inspections require that the flight controls to be inspected be cold, so the trials have only been conducted during the winter months. The results of the infrared imaging trial have proven that the technique can be used as an initial screening to detect water and corrosion, but that the final confirmation of the presence of water or corrosion will still use the more accurate technique of neutron radiography.[122]

This case study has presented a success story for niche DND investment in emerging technology. For the CF188 to reach its design life, the detection of corrosion and water ingress in the composite flight controls prior to a catastrophic failure is imperative. While existing NDT inspections were able to detect large areas of corrosion, none were capable of detecting very small amounts. After determining that neutron radiography could successfully detect these smaller amounts of water and corrosion, DND invested a relatively small amount of money to develop an in-house inspection capability. This investment in emerging technology has provided DND a unique capability that may have additional applications, and demonstrates the merits of a niche R&D focus.

Conclusion

The realization that most of the CF's fleets of aircraft will continue to fly for two to three more decades is staggering for some. However, Canada is not alone in facing the issues of aging aircraft – even the USAF with its large budget predicts that some of their fleets will be operating for over 50 years. While many operators, both military and civilian, are beginning to address the many challenges of operating their fleets for periods of time far greater than originally intended, support to R&D is essential.

In Canada, the lead organization for aging aircraft issues is the National Research Council, with its Aging Aircraft Structures Section. The greatest threat facing the structural integrity of aging aircraft is corrosion, which in general terms results in material degradation that can lead to a greatly reduced structural integrity. Therefore, the use of nondestructive examination methods is key to the continued structural airworthiness of aircraft. To date, NDT methods, such as X-radiography and eddy current, have been used to detect corrosion; however, the unique challenges of aging aircraft, especially those with composite materials, necessitates the search for additional detection methods.

Within DND, the Research and Development Branch sponsors 21 R&D Activities, including Activity 12 for Platform Maintenance and Life-Cycle Management, and Activity 6 for Emerging Materials. However, with many budget pressures, DRDA is unable to adequately fund all 21 Activity Areas. As such, DRDA has developed a Technology Investment Strategy, with guiding principles including the exploitation of new technologies and the focusing on niche R&D areas. Supported by a previous work of Dr. Jacobs and statements made by Vice-Admiral Garnet, DND needs to focus on niche areas where the in-house need is the greatest. These niche initiatives can be further emphasized through international and industrial partnerships, but to continue the partnerships and the ability to participate in future coalitions, Canada must contribute significantly to the technology development process. The current availability of R&D funding precludes the possibility for Canada to sustain an independent defence R&D capability across the vast array of strategic technologies, so the proposal of focused efforts is really the only logical choice.

Within DND, the future collaboration between RMC and DRDA is one good example of a low cost initiative that should leverage R&D funding. Similarly, the case study presented a specific R&D effort that has resulted in the development of emerging technology to enable the corrosion inspections of CF188 flight controls. This development effort was made possible by a modest R&D effort, and is a successful example of exploiting new technology to ensure the continued airworthiness of an aging aircraft fleet.

These R&D investments will not only contribute to the defence efforts, but also to the overall competitiveness of Canada. As demonstrated by Canada's performance on the World Competitiveness Scoreboard and its technology rating of the World Economic Forum, without a commitment to developing emerging technologies, Canada will continue to fall behind more committed nations. Therefore, it is imperative that Canada and DND invest in emerging technologies, specifically to develop technologies to effectively inspect our aging aircraft fleets.

Recommendation

There is no doubt that there will be continued pressure on an already too scarce R&D budget within DND. To continue to contribute effectively to collaborative partnerships, however, Canada must develop an R&D strategy that maximizes our contributions. Therefore, it is recommended that DND and DRDA pursue niche R&D opportunities where the operational need cannot be satisfied by existing technologies. Specifically, it is recommended that DND invest in emerging technologies in order to effectively inspect our aging aircraft fleets.

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PART 4		APPROVED NON DESTRUCTIVE TESTING TECHNIQUES				
ITEM	TECHNIQUE NUMBER	REPLACED TECHNIQUE NUMBER	PUBLICATION DATE (NDTO APPROVAL)	DESCRIPTION	INSPECTION FREQUENCY	WUC
1	188-249-X		25-MAR-88	INBOARD LEADING EDGE FLAPS		ADAV
2	188-249-X		25-MAR-88	INBOARD LEADING EDGE FLAPS		ADAT
3	188-252-X		29-MAR-88	VERTICAL STABILIZER LH & RH		AAHD
4	188-253-X		14-APR-88	AILERON		ACAF
5	188-253-X		14-APR-88	AILERON		ACAE
6	188-254-X		14-APR-88	OUTBOARD LEADING EDGE FLAP		ADAU
7	188-254-X		14-APR-88	OUTBOARD LEADING EDGE FLAP		ADAW
8	188-255-X		15-MAR-88	UPPER INBOARD INTAKE STRUCTURE		AAG
9	188-259-X		12-APR-88	SPEED BRAKE LH & RH		ADCB
10	188-265-X		05-AUG-88	WING CABLE ASSEMBLY PN 74A754621		ADDZZW
11	188-267-X		04-OCT-88	LH & RH VERTICAL STAB T-BONE FITTING & TITANIUM		AAHD
12	188-269-X		21-JUL-89	LH & RH VERTICAL STAB 54.25% AND 70.5% SPARS	1-2-3-4	AAHD
13	188-37-X REV 1		14-JUN-85	HORIZONTAL STABILATOR		ACBD
14	188-42-X		28-MAY-85	TRAILING EDGE FLAP		ADBE
15	188-42-X		28-MAY-85	TRAILING EDGE FLAP		ADBD
16	188-43-X		28-MAY-85	VERTICAL STAB LEADING EDGE		AAHDB

PART 4		APPROVED NON DESTRUCTIVE TESTING TECHNIQUES				
ITEM	**TECHNIQUE NUMBER**	**REPLACED TECHNIQUE NUMBER**	**PUBLICATION DATE (NDTO APPROVAL)**	**DESCRIPTION**	**INSPECTION FREQUENCY**	**WUC**
17	188-44-X		28-MAY-85	VERTICAL STAB LEADING EDGE		AAHDB
18	188-45-X		28-MAY-85	RUDDER		ACCE
19	188-48-X REV 1		28-MAY-85	LEADING EDGE EXTENSION		AABJ
20	188-52-X		20-MAR-87	F404 ENGINE MAIN FUEL NOZZLES (18)		BEGG
21	188-8-X		05-JAN-83	HORIZONTAL STABILATOR (BALLAST AREA) PN 74A210004		ACBD
22	188-129-U		05-JAN-83	HORIZONTAL STABILATOR BALLAST AREA PN 74A210004		ACBD
23	188-137-U		02-APR-85	ENGINE AIR INLET RAMP SPLITTER VANE		AAGA
24	188-140-U		16-SEP-86	F404 ENGINE SECOND STAGE LEVER ARMS & IGV		BEJQ
25	188-151-U REV 1		10-JAN-91	OUTER LOWER WING WINGFOLD RIB FASTENERS		AAJF
26	188-247-U		08-JAN-88	OUTER WING FOLD RIB, AND MISSILE SUPPORT RIB SKIN AREAS		AAJF
27	188-248-U		14-MAR-88	INNER WING FOLD RIB AND LEADING EDGE FLAP DRIVE AREAS		AAJH
28	188-250-U		15-JAN-88	ULTRASONIC PULSE ECHO INSPECTION FOR GRAPHITE/EPOXY COMPOSITE LAMINATE MATERIAL USING A DELAY LINE TRANSDUCER		AAK

PART 4		**APPROVED NON DESTRUCTIVE TESTING TECHNIQUES**				
ITEM	**TECHNIQUE NUMBER**	**REPLACED TECHNIQUE NUMBER**	**PUBLICATION DATE (NDTO APPROVAL)**	**DESCRIPTION**	**INSPECTION FREQUENCY**	**WUC**
29	188-256-U		09-JUN-88	WING ROOT SPLICE, UPPER AND LOWER OUTBOARD PYLON AND LOWER INBOARD PYLON		AAJH
30	188-257-U		13-APR-88	INNER WING UPPER AND LOWER SURFACES COMPOSITE LAMINATE AND DOOR SILL INSPECTION AREA		AAJH
31	188-260-U		01-JUN-94	HORIZONTAL STABILATOR LEADING EDGE CLOSURE		AAHB
32	188-261-U		25-MAR-88	UPPER AND LOWER LH INBOARD LEADING EDGE FLAP SKIN TO SPAR AREA BOND		ADAV
33	188-261-U		25-MAR-88	UPPER AND LOWER RH INBOARD LEADING EDGE FLAP SKIN TO SPAR AREA BOND		ADAT
34	188-262-U REV 1		29-APR-88	LH INBOARD LEADING EDGE FLAP (LEF) SKIN TO HONEY COMB BOND		ADAV
35	188-262-U REV 1		29-APR-88	RH INBOARD LEADING EDGE FLAP (LEF) SKIN TO HONEY COMB BOND		ADAT
36	188-268-U		19-DEC-88	LH & RH OUTBD LOWER LONGERON, FWD HINGE RECESS FOR DOOR 64		AAF
37	188-274-U		21-APR-92	LH & RH MLG RETRACT ACTUATOR PISTON ROD		AHDVA
38	188-279-U		26-JAN-93	LH & RH HORIZONTAL STABILATOR	TLIR	ACBD
39	188-280-U		23-MAR-93	LINK ASSY-SHRINK (PLANING MECH MLG) (PN 74A410670-1005)		AHDPF

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ITEM	TECHNIQUE NUMBER	REPLACED TECHNIQUE NUMBER	PUBLICATION DATE (NDTO APPROVAL)	DESCRIPTION	INSPECTION FREQUENCY	WUC
40	188-284-U		22-OCT-93	Y488.0 CENTRE FUSELAGE BULKHEAD DOUBLERS	OSI	AAFA
41	188-285-U		30-JUN-94	Y488.0 LH & RH BULKHEAD LOWER WING ATTACHMENT LUG BONDED DOUBLERS	OSI	AAFA
42	188-290-U		28-JUL-94	TE FLAP OUTBOARD HINGE LUG		ADBE
43	188-290-U					

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ITEM	TECHNIQUE NUMBER	REPLACED TECHNIQUE NUMBER	PUBLICATION DATE (NDTO APPROVAL)	DESCRIPTION	INSPECTION FREQUENCY	WUC
53	188-273-E REV 1		01-DEC-97	RH AILERON OUTBD HINGE FITTING FLANGE	1-2-3-4	ACAFA
54	188-273-E REV 1		01-DEC-97	LH AILERON OUTBD HINGE FITTING FLANGE	1-2-3-4	ACAEA
55	188-276-E		14-OCT-92	CANOPY UNLATCH THRUSTER BRACKET	1-2-3-4	ABAGE
56	188-277-E REV 1		14-JUL-93	Y488.0 BULKHEAD FLANGE & WEB IN THE INBOARD SECTION OF LH & RH, MLG WHEEL WELL		AAFA
57	188-278-E		14-OCT-92	RH ELECTRICAL CUTOUT AT Y442 DORSAL DECK FLOOR		AAFH
58	188-281-E REV 1		18-JUN-93	BULKHEAD Y470.5	1-2-3-4	AAFA
59	188-282-E		29-MAR-93	Y497.0 ENGINE INLET DUCT FLANGES		AAFA
60	188-283-E		23-FEB-94	AFT END LONGERON & SPLICE PLATE		AAF
61	188-286-E		18-JUN-93	LH & RH Y470.5 BULKHEAD FLANGE FASTENER HOLES		AAFA
62	188-288-E		28-JUL-94	MLG TRUNNION PIN (LH)	1-2-3-4	AHDBB
63	188-288-E		28-JUL-94	MLG TRUNNION PIN (RH)	1-2-3-4	AHDCB
64	188-289-E		08-JUN-94	MLG UPLOCK MECHANISM (LH)	1-2-3-4	AHDU
65	188-289-E		08-JUN-94	MLG UPLOCK MECHANISM (RH)	1-2-3-4	AHDV
66	188-292-E		21-APR-95	TRAILING EDGE FLAP OUTBD ROLLER FITTING	1-2-3-4	ADBEGA
67	188-292-E		21-APR-95	TRAILING EDGE FLAP OUTBD HINGE FITTING	1-2-3-4	ADBDGB

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ITEM	TECHNIQUE NUMBER	REPLACED TECHNIQUE NUMBER	PUBLICATION DATE (NDTO APPROVAL)	DESCRIPTION	INSPECTION FREQUENCY	WUC
68	188-293-E		21-APR-95	TRAILING EDGE FLAP OUTBD HINGE LUG	1-2-3-4	ADBEC
69	188-293-E		21-APR-95	TRAILING EDGE FLAP OUTBD HINGE LUG	1-2-3-4	ADBDC
70	GEN-63-E REV 2		12-JAN-93	BULKHEAD Y470.5	1-2-3-4	AAFA
71	GEN-63-E REV 2		12-JAN-93	V STAB ASSY 54.25 AND 70.5% SPARS	1-2-3-4	AAHD
72	GEN-63-E REV 2		12-JAN-93	FORMER Y518	1-2-3-4	AAFL
73	GEN-63-E		12-JAN-93	HINGE ASSY-T/E FLAP OUTBD	1-3	ADBH
74	GEN-63-E REV 2		12-JAN-93	FORMER 580.5 (AFT FUS)	1-2-3-4	AAH
75	GEN-74-E REV 1		18-NOV-88	GENERAL BOLT HOLE TECHNIQUE FOR METALLIC STRUCTURES		AA
76	188-298-L		15-JUL-96	CARRIER ASSY-BRAKE		AHFFA
77	188-299-L		15-JUL-96	TORQUE TUBE ASSY		AHFFC
78	188-300-L		15-JUL-96	WHEEL ASSY-MLG		AHDQ
79	GEN-90-L		17-AUG-94	MLG AXLE LH	1-2-3-4	AHDMD
80	GEN-90-L		17-AUG-94	SUPPORT-SIDE BRACE MLG	1-2-3-4	AAFB
81	GEN-90-L		17-AUG-94	MLG AXLE RH	1-2-3-4	AHDND
82	GEN-90-L		17-AUG-94	LH ENGINE THRUST MOUNT	2-4	BEMB

PART 4		APPROVED NON DESTRUCTIVE TESTING TECHNIQUES				
ITEM	**TECHNIQUE NUMBER**	**REPLACED TECHNIQUE NUMBER**	**PUBLICATION DATE (NDTO APPROVAL)**	**DESCRIPTION**	**INSPECTION FREQUENCY**	**WUC**
83	GEN-90-L		17-AUG-94	RH ENGINE THRUST MOUNT	2-4	BEMD
84	188-264-M		03-AUG-88	ATTACHMENT LUGS TRANSMISSION MECHANICAL (WING FOLD)		ADDE
85	188-264-M		03-AUG-88	ATTACHMENT LUGS TRANSMISSION MECHANICAL (WING FOLD)		ADDH
86	188-296-M		15-JUL-96	NOSE WHEEL BOLT		AHBD
87	188-297-M		15-JUL-96	MAIN WHEEL BOLT		AHDQ
88	GEN-91-M		17-AUG-94	LH ENGINE THRUST MOUNT	2-4	BEMB
89	GEN-91-M		17-AUG-94	RH ENGINE THRUST MOUNT	2-4	BEMD
90	188-258-U/E REV 1		26-JUN-90	LAUNCHER GUIDED MISSILE LAU-7/A-7	1-2-3-4	HCBB
91	188-258-U/E REV 1		26-JUN-90	LAU-7( )LAUNCHER (UPPER AND LOWER GUIDE RAILS)	1-2-3-4	HCB
92	188-266-X/E		30-SEP-88	LH & RH VERTICAL STAB 62.5% & 77.5% SPARS AT DOORS 100 AND 124		AAHD
93	188-263-L/U		04-MAY-88	MLG TRUNNION LOWER RADIUS OUTBOARD TRUNNION POST		AHD
94	188-270-L/U		19-DEC-89	LH MLG AXLE INBOARD END	1-2-3-4	AHDMD
95	188-270-L/U		19-DEC-89	RH MLG AXLE INBOARD END	1-2-3-4	AHDND
96	188-245-M/U		12-NOV-87	MLG TRUNNION		AHDB

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ITEM	TECHNIQUE NUMBER	REPLACED TECHNIQUE NUMBER	PUBLICATION DATE (NDTO APPROVAL)	DESCRIPTION	INSPECTION FREQUENCY	WUC
97	188-245-M/U		12-NOV-87	MLG TRUNNION		AHDC
98	188-246-M/U		01-DEC-87	MLG LEVER		AHDNA
99	188-246-M/U		01-DEC-87	MLG LEVER		AHDMA
100	188-251-M/U		13-JAN-88	HOR STAB SPINDLE LEFT AND RIGHT		ACBC
101	188-313-E		30-FEB-00	CF188 MAIN LANDING GEAR UPLOCK ATTACHMENT LH & RH	OSI	AHDU & AHDV
102	188-315-U		30-SEP-00	Y470.5 BULKHEAD BONDED DOUBLER, BOTTOM FLANGE	1-2-3-4	AAFA
103	188-317-U		22-FEB-01	L/R INNER WING ACCESS DOOR 79 AND WING TRAILING EDGE PANEL	2-4	AAJG AAJH
104	188-318-X		28-FEB-01	RAM LVDT ANTI-ROTATION PLATE ASSEMBLY ON STAB SERVO	OSI	ACBA
105	188-GEN-9-0L-002		31-OCT-01	TEF SERVOCYLINDER TRANSFER TUBE		ADBB