RIADI RYERSON INSTITUTE for AEROSPACE DESIGN and INNOVATION

A Research Assessment Report
on
Integrated Technology Demonstration
&
the Role of Public Policy

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1. Executive Summary

A technology demonstration is defined as a project to demonstrate how technology may be operationally integrated and exploited for a specific end-use application, or range of applications. The purpose of this report is to assess whether or not there exists a sufficiently strong public policy rationale for the creation of a federal program to support system and integrated technology demonstrations in this industry. The assessment presented in this report is conducted via a research means by consulting various Canadian aerospace stakeholders and resorting to relevant publications.

In the past, a great deal of review work on this underlying issue has been conducted by various organizations through extensive consultations, including the Future Major Platform (FMP) initiative led by the Aerospace Industries Association of Canada (AIAC) in 2007 [1], and the Canadian Aviation Environment Technology Road Map (CAETRM) initiative led by the Institute for Aerospace Research of National Research Council (NRC IAR) in 2009 [2]. All these efforts pointed to a fact that the aerospace industry needed to develop new technologies in the face of global competition and new environmental regulations. Aerospace is a value-added technology-intensive industry and the winner in this industry hinges heavily on new or improved technologies. For this reason, there has been a growing demand for technology demonstration in order to bring new technologies up to the level for commercialization.

The previous reviews called for government supports to aid technology demonstration. However, the existing federal programs, such as the Green Aviation Research and Development Network (GARDN) and the Sustainable Development Tech Fund of Sustainable Development Technology Canada (SDTC), do not provide the amount or type of support requested by the industry.

Due to the physical size and complexity of aerospace systems plus rather stringent safety regulations, the projects of full technology demonstration are usually on a large scale, very resource-intensive for both manpower and equipment. Decisions on project “go or no go” are often boiled down to the question of funding availability. Prioritization seems to be the only way in project selection by the companies. In the worldwide race for new technologies, time is of the essence. Unfunded worthwhile technologies will become obsolete and fail by time in vain. Additional funding would definitely improve technology development and maturation.

This report attempts to consolidate the previous efforts and focus on technology demonstration from the view point of technology development cycle. It first looks at the contents of technology demonstration to give a sense of what is involved and why cost is so high; then followed by discussions on the impact of a new federal program to support system and integrated technology demonstrations.

A number of benefits are perceived for the potential users of this program including original equipment manufacturers (OEMs), Tier 1 integrators, suppliers (small & medium enterprises SMEs) as well as universities and research organizations. The most significant one is to help maximize the net benefits of the investment jointly made by government and industry. The platforms that this program provides will bring all the users together to work collaboratively and collectively towards the same goal, thereby encouraging multidisciplinary interaction across diverse expertise for the betterment of technology and early business dialogues across different partners for the betterment of business.

A number of industrial examples are provided to illustrate the significance of aerospace technology demonstration projects. These are large scale projects that have already undergone substantial research and development in the past. However, due to a lack of funding for system and integration technology demonstrations, they were either delayed or abandoned, putting the industry at a competitive disadvantage. Investments at this stage would have provided tangible technological benefits to these companies, thereby supporting our nation's economy for years to come

A survey study is also conducted by looking at similar programs around the world. Since aerospace is of high risk and long-term return, it is not uncommon that a government supports aerospace technology development in its own country. Internationally, all the traditional aerospace countries including US and EU have established government-funded technology demonstration programs, such as NextGen and Clean Sky.

It should be noted that this report is of observing nature, by no means conclusive.

2. Context of Technology Demonstration

2.1 Definition

Functionality is what technology demonstration (briefed as Tech Demo hereafter) is concerned about. In the FMP report [1], Tech Demo is defined as a project to demonstrate how technology may be operationally integrated and exploited for a specific end-use application, or range of applications. Tech Demo projects aim to accelerate the maturation of advanced technologies and enable development of the next generation *products*, which is the end goal of Tech Demo.

Two types of Tech Demo are considered, together called system and integrated Tech Demo and defined as below:

- A system Tech Demo consists of the testing, in a realistic simulation environment, of new or improved technologies within a complete system, such as a landing gear, engine or avionics system. Such demonstrations typically involve collaboration among several firms and may also involve universities and research institutes.
- An integrated Tech Demo is a larger-scale testing phase in which several new or improved systems are combined on an aircraft in order to test each of them (and their sub-components) in a real-life operating environment through test flights. These demonstrations typically involve higher costs and risks than system technology demonstrations, and therefore are often carried out through a consortium of partners from industry, universities and government laboratories.

2.2 The Content of Tech Demo

Tech Demo consists primarily of testing a new technology. To explain this, we need to look at technology development cycle in light of Technology Readiness Level (TRL), a commonly used descriptor developed by NASA [3]. Table 1 lists all nine TRLs pertaining to technology progression that can be broadly categorized as three main phases: research and development (R&D) between TRL 1-4, Tech Demo between TRL 5-7, and commercialization between TRL 8-9. Tech Demo is in the middle and its role is to bridge the front and the end. Without it, it is impossible for any technology to reach the end, which is why called the *valley of death* [4].

To relate TRL to the aerospace industry, a translation is provided for two main aerospace technology groups (briefed as Tech Group hereafter): airframe and engine. As narrated in Table 1, Tech Demo for aerospace is essentially made of two types of tests: *ground test* and *flight test*, both under operating conditions. Though computer simulation may help to minimize the number of tests needed, physical tests will never be replaced. Therefore, Tech Demo is utterly hardware-dependent.

Generally speaking, *a ground test is associated with a system Tech Demo*, while *a flight test is associated with an integrated Tech Demo.*

Table 1 Translation of TRLs to Tech Groups

TRL	***NASA Definition***	***Airframe***	***Engine***
1	Basic principles observed and reported	Technology research and conceptual design	Technology goal and concept study
2	Technology concept and/or application formulated	Application research and detail design	Concept advancement considering system advancement, tool availability, engine space
3	Analytical and experimental critical function and/or characteristic proof of concept	Modeling, analysis and simulation; prototype building for proof-of-concept test	Engine system study including compressor, combustor, turbine, exhaust
4	Component and/or breadboard validation in laboratory environment.	Various laboratory tests such as structure and wind tunnel tests, leading to the first test article	Validation through laboratory tests
5	Component and/or breadboard validation in relevant environment	**Ground test** on the first test article in a hangar or the like with simulated loads	Component test in engine test rig (**ground test**)
6	System/subsystem model or prototype demonstration in an operational environment	**Flight test** of short distance on the first test article with basic systems (extended ground test)	Component with system test in engine test rig and gas generator (**ground test**)
7	System prototype demonstration in an operational environment	**Flight test** on more test articles with more systems, converging to a final system	Component with system test in engine **flight test** bed
8	Actual system completed and "flight qualified" through test and demonstration	Complete flight mission test of long distance and under different weather conditions	Flight test with a fully integrated engine
9	Actual system flight proven through successful mission operations	Entering production	Entering production

2.3 Main Issue

The *high cost* of Tech Demo is a main issue. Figure 1 shows two curves. On one hand, as TRL goes higher, a number of technology concepts are narrowed down to a feasible one for Tech Demo, as indicated by the downward curve. On the other hand, costs will soar as soon as TRL enters the Tech Demo phase, as indicated by the upward curve. The *first reason* for high cost is because of sizable and sophisticated equipments required. These costs are proportional to the size of aerospace systems that a technology is developed for.

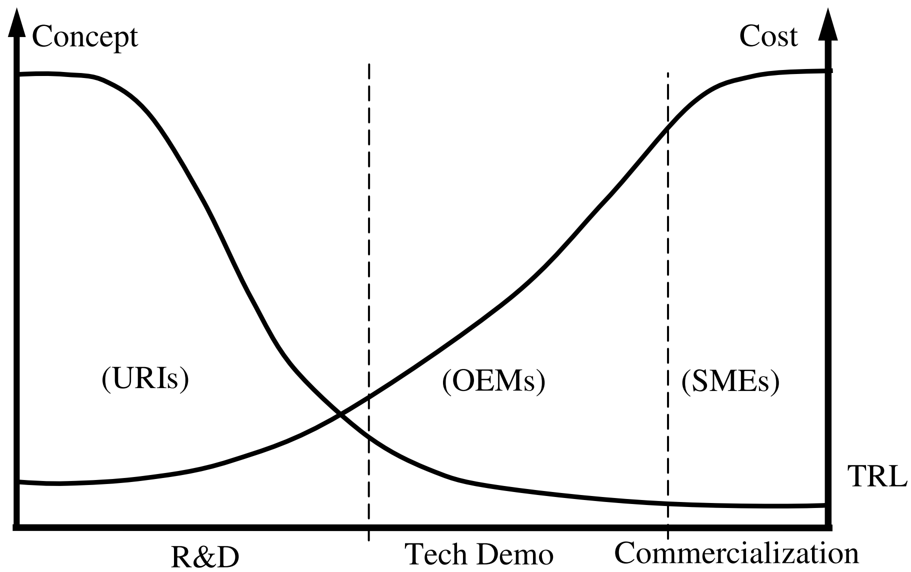

Figure 1 TRL vs Cost & Concept

The *second reason* is lengthy time. An average technology development cycle for aerospace is 10-15 years. A Tech Demo phase is typically 3-5 years. In addition to a long period of time for preparation, certification is another nail-biting factor.

Even though Tech Demo is only concerned about functionality and not required for certification, both are closely related as eventually products will have to be certified. *Safety i*s the foremost concern of aerospace systems. Certification is an official process to ensure high *reliability* and *durability*. All aeronautical products whether new or modified at the end must be approved by the National Aircraft Certification (NAC) branch of Transport Canada according to FAA standards such as FAR25 [5]. NAC is involved in various stages of product development starting from component testing all the way to flight tests by providing oversight through interacting with Design Authority Delegates (DADs) on company sites. Because of this consideration, the process of Tech Demo becomes even more test demanding and incurs extra costs. For example, R&D cost for the re-engined Boeing 737 is around $2.5 billions, at least $1 billion needed to meet US FAA standards [6].

A government funded Tech Demo program will undoubtedly alleviate the financial burden on the aerospace industry's shoulder and give the industry a competitive edge to succeed on global market.

3. Assessment of Technology Demonstration Program

This report assumes is that a new federal program to support Tech Demo in the aerospace industry would include:

- 50/50 cost sharing of eligible expenses between industry and government;
- non-repayable funding;
- a mandatory requirement for collaborative research among multiple firms (including small and medium enterprises) and with universities and research institutes.

3.1 Users and Uptake

The *prospective users* of a Tech Demo program are specified in light of TRL. There are three main user groups, Universities and Research Institutes (URIs), Original Equipment Manufacturers (OEMs), and Small & Medium Enterprises (SMEs). Traditionally, these user groups tend to work sequentially and individually in each of three technology development phases, URIs for R&D, OEMs for Tech Demo, and SMEs for commercialization, as depicted in Figure 1.

The likely *uptake* of a Tech Demo program would help to create an *Integrated Product and Process Development (IPPD)* environment throughout entire technology development cycle, as used and recommended by US Department of Defense (DoD) [7]. Under a Tech Demo program, these user groups would work collaboratively and collectively towards the same goal, encouraging multidisciplinary interaction across diverse expertise for the betterment of technology and early business dialogues across different partners for the betterment of business.

Table 2 Tech Groups and Industrial Subsectors [8]

Tech Group	***Industrial Subsectors***
Airframe	Complete Aircraft: *Regional Aircraft, Business Jets, Commercial Helicopters, Special Purpose, Training, Recreational, and Utility Aircraft.*
Engine	Aircraft Engines and Aircraft Parts: *Turbofan, Turboprop and Turboshaft Engines, Aircraft Engine Systems, Aircraft Parts & Aircraft Equipment*
System	Aircraft Systems and Aircraft Parts: *horizontal and vertical stabilizers, wing and fuselage components, subassemblies, landing gears, avionics.*
Space Technology	Space Technologies: *Satellite Communications and Navigation Systems*, *Space Robotics and Automation. Earth Observation and Remote Sensing*

The *first group of users* comprises OEMs including Tier 1s. These companies entail the industrial subsectors as listed in Table 2. In terms of technology, the entire Canadian aerospace industry can be broadly categorized by four Tech Groups: *airframe*, *engine*, *system* and *space technology*. These Tech Groups serve their respective subsectors whose mandate is to make commercial products. In terms of industry, the Canadian aerospace companies can be broadly classified into four categories: OEM, Tier 1 (system integrators), Tier 2 (equipment integrators), and Tier 3 (suppliers). Big4 is the nick name for the Canadian OEMs that include Bombardier, Pratt & Whitney Canada (PWC), Bell Helicopter Textron Canada (BHTC), and CAE. There are a handful of Tier 1s. Geographically, Quebec has a strong presence of OEMs, while Ontario has a strong presence of Tier 1s, especially landing gears. Table 2 shows a connection between the Tech Groups and the Canadian aerospace subsectors. It was suggested by the FMP initiative that *Tech Demo projects be organized according to Tech Groups.* OEMs and Tier 1s are the companies that can frame and structure substantial Tech Demo projects, thus have the capacity to lead them.

The *second group of users* consists of SMEs in OEMs and Tier 1s' supply chains including Tier 2s. Once products are designed based on a new technology, how to produce them is totally dependent on process. From a practical point of view, process is another word of saying manufacturing. Both the FMP report [1] and CAETRM reports [2] identified a number of new technologies needed for each Tech Group and addressed relevant manufacturing issues. These reports showed the needs for the integrated product development and process development (IPPD). Due to high sophistication of aerospace systems, a Tech Demo leader, either OEM or Tier 1, will have to search for suppliers as part of process development. Supply chains are made up of many SMEs.

The *third group of users* is URIs. Traditionally, universities and research institutes are active players only in the R&D phase for product development. They should be considered to take part in the Tech Demo phase. Their participation would form a complete team with a whole range of expertise being able to address the issues pertaining to integrated product development and process development.

3.2 Benefits to Users

The *potential benefits* to the users of a Tech Demo program can be foreseen for short term and long term. As pointed out in [9], a young technology can have *technology-driven* products. Products of a mature technology must be *customer-driven.*

The *short term benefits* are perceived for customer-driven projects with technologies ready for Tech Demo. Not only will a Tech Demo program provide a venue to showcase the existing Canadian technologies for more business opportunities but also a concerted effort as a stronger contender in form of a Tech Group on global market. The FMP initiative [1] identified top five future commercial aircraft platforms by looking at the capacity and potential of the Canadian aerospace industry. The intention was to develop Tech Demo projects to help Canadian aerospace companies to compete for work. So far, there is no dedicated program supporting this effort. Table 3 lists the five FMP proposed platforms and their current status. Obviously, things have changed since the FMP report was released. Airbus A350 and Bombardier CSeries platforms are close to delivery, but opportunities still exist for Canadian companies to participate in other three platforms. New opportunities emerge from the non-traditional aerospace countries, such as China, Japan, Russia and India. Table 4 lists the aircraft projects from these countries, all government-backed.

Table 3 Five Major Platforms [1]

Platform	***Current Status***
Boeing 737 Replacement	*Boeing 737 (short-to-medium-range, narrow-body airliner, up to 180 seats):* Boeing may re-equip with improved engines if a new plan for the development of a new plane is not in place by 2012 [10].
Airbus A320 Replacement	*A320 (short-to-medium-range, narrow-body airliner, up to 220 seats):* Airbus launched the A320neo at the end of year 2010 as the successor to the A320, targeting 2015 for the first delivery and planning to deliver 4,000 A320neo over 15 years [11].
Embraer Business Jets	Embraer sells medium-to-long range business jets. The long-term vision is to develop ultra long range and very large cabin aircrafts [12].
Airbus A350	*A305 (long-range, wide-body airliner, up to 350 seats):* The first A350 static test model was started in April 2012, but the delivery date was rescheduled to the second half of 2013 due to a longer transition phase from design to manufacturing. Redesign doubled the original cost from $5.3 billions to approximately $10 billions [13].
Bombardier CSeries	*CSeries (medium-range, narrow-body airliner, up to 130 seats):* The first flight test is slated towards the end of 2012 and the first delivery is scheduled towards the end of 2013 [14].

Table 4 Non-Traditional Aerospace Country Platforms

Country	***Platform***
China	*Comac C919*: a planned family of 168-190 seat airliners to be built by the Commercial Aircraft Corporation of China (COMAC). The first flight is expected to take place in 2014, with deliveries scheduled for 2016 [15].
Japan	*Honda Jet HA-420*: a small jet of 5-6 passengers. The first plane was scheduled for November 2010, and the first delivery is planned for the third quarter of 2012. *Mitsubishi Regional Jet (MRJ)*: a passenger jet aircraft of 70–90 seats to be manufactured by Mitsubishi Aircraft Corporation. The first flight is scheduled for 2013, and the first delivery is planned for 2015 [16].
Russia	*Sukhoi Superjet 100:* a regional jet of 75-95 seats, designed by the civil aircraft division of the Russian aerospace company Sukhoi. The jet undertook its first commercial passenger flight in April 2011 [17].
India	*Indian Regional Jet (IRJ*): planned 70-100 seat capacity to be jointly developed by Hindustan Aeronautics Ltd and National Aerospace Laboratory for delivery in 2019 [18].

The *long term benefits* are perceived for technology-driven programs to foster technology clusters, create niche products, and generate knowledge-based industry and economy. The platforms that Tech Demo programs provide will gather different user groups to work together on the technologies around an industrial subsector or a product line. For example, the European Clean Sky program is made up of six Integrated Technology Demonstrators (ITDs) [19], each for either a product line or a subsector. These ITDs consist of between 10-40 partners covering OEMs, SMEs and URI. The European government funded projects have strengthened the aerospace clusters in Toulouse of France and Hamburg of Germany, and fostered some new ones, such as one in Andalusia of Spain [20]. In North America, a similar study was conducted [21]. A dozen of cities were identified as aerospace clusters in terms of the number of aerospace jobs. Toronto and Montreal were the two for Canada. Toronto has a concentration on business jets and landing gears, while Montreal on regional jets and engines.

Not only do technology clusters help to develop niche products but also assist to train new generation of engineers and workers. By integrating universities into a Tech Demo project, students will receive first-hand practical training. There are a number of student project based institutes in Canadian universities that have aerospace education programs, such as CIADI at Concordia University, RIADI at Ryerson University and AeroETS at ETS. Tech Demo programs will enable more supports for students to work on the projects related to the needed technologies. These students are the next generation of engineers responsible for future product development. Experiential learning is vital for their education.

The Deloitte report [22] revealed that only three Canadian aerospace companies had a revenue over $1 billion and 11 between a quarter $1 billion and half $1 billion; majority is between $5-250 millions or below. By integrating suppliers into a Tech Demo project, SMEs who usually cannot afford R&D will have opportunities to learn new technologies and prepare themselves as serious contenders to compete for work when a technology turns into a product. This is extremely important given the globalization of supply chains, owing to the affordable transportation cost (~2%) for aerospace parts compared to automotive parts (~11%). Tech Demo programs will certainly provide platforms to train SME workers with the skills required for production of new products and help these companies to set up appropriate machines beforehand. Therefore, SMEs will have the advantages of shorter ramp-up time and shorter turn-around time for contract bidding. OEMs and Tier 1s would naturally use the local SMEs already involved in the project because of proximity and early established mutual understanding.

The afore-mentioned training that can be offered through Tech Demo programs will help generate a knowledge-based industry in turn a sustainable knowledge-based economy. In general, this impact could be measured by a ratio of 1:3, i.e. $1 investment would generate $3 return, by considering a nationwide industry base as shown in Figure 2. If cultivation was there for SMEs to grow, these companies would become motivated to develop new technologies and offer innovative components and solutions. The overall industry base would then expand with increasing capacity and capability, a flourish scenario every country dreams about.

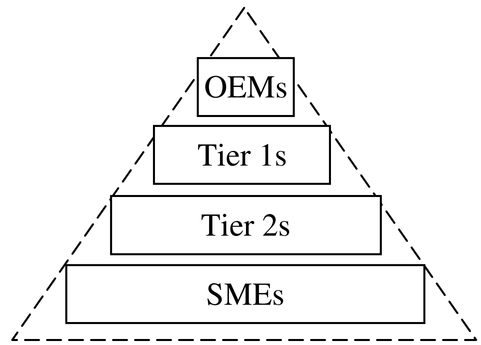

Figure 2 Nationwide Industry Base [23]

3.3 Key Principles

The *key principles* of this program are considered to help maximize the net benefits, including facilitation of knowledge transfer, creation of incentives to involve the collaboration of specifics, and incubation of innovation to realization.

3.3.1 Examples of Industrial Projects Lack of Tech Demo

Provided in the following are three examples of the worthwhile aerospace projects developed in Canada that did not advance or did not proceed fully after the R&D stage due to a lack of financial resources to conduct a technology demonstration that could have been remedied by government support.

1. Bombardier Project on Integrated Composite Fuselage

Composites, such as Carbon Fiber Reinforced Plastics (CFRP), are lightweight materials with high strength-to-weight ratio. Though CFRP has been researched for over two decades, its main applications have been limited to secondary structures of aircrafts that have relatively simple shapes and geometries, such as wing surfaces, fairings. It is until recently that the advancement in manufacturing technology has made it possible to introduce CFRP to primary structures with complex shapes and geometries, such as fuselages. In the modern aircraft a fuselage is constructed based on semi-monocoque design, where the frames of the fuselage in a circular shape are connected by longitudinal and vertical structural members to form a skeleton structure that is covered by skins along with framed openings for windows and doors. Traditionally, a fuselage is made by many individual metallic components joined by numerous fasteners, a very labor intensive and time consuming process.

Bombardier has been attempting to develop a technology that could produce a one-piece CFRP fuselage barrel by integrating all the afore-mentioned components in a "one-shot" process. The benefit of this technology is enormous. First, it would drastically simplify the manufacturing process by getting rid of the need of joining and the use of fasteners, thereby greatly increasing the production throughput. Second, it is a near net shaping method that would eliminate material waste as fuselages could be made directly to final shapes without further machining. A great deal of effort had been spent in the design stage to develop the key technology called multi-disciplinary optimization (MDO) [24] to allow the consideration of multiple design requirements, including structural requirement of material strength, noise requirement of acoustical insulation, thermal requirement of thermal insulation, electromagnetic requirement and lightning protection. Manufacturing is the next step in this development. It is well known that the high material cost of CFRP can only be compensated by a high throughput production system to make composites viable for civil aircrafts. The challenge lies in the development of an automated manufacturing system that can make a complete CFRP fuselage at a desirable layup rate (> 20 kg/hours) [25].

The total cost that goes into the full development in order to demonstrate this technology is estimated over $50M, unbearable by the normal standard of an average Canadian aerospace company including Bombardier. The reason for this high cost is because there is a long list of subsystems associated with the final automated manufacturing system, including Automated Fiber Placement (ATP) machine or Automated Type Laying (ATL) machine, Vacuum Assisted Resin Transfer Molding (VARTM) machine, thermoplastic processing machine (Pultrusion), prepreg and dry fiber preforming machine, each in millions, plus expensive tooling and non-destructive inspection systems, plus costs and efforts to integrate all these subsystems together. Currently, Bombardier is conducting a scaled down project with Bell Helicopter under SA^2GE [26]. This project only covers some aspects of the automated manufacturing system, no way near the full scale of technology demonstration that includes ground and in-flight tests. Without further sustainable support, this worthwhile technology may not succeed.

2. Messier-Dowty Project on Landing Gear Health Monitoring

Landing gears as a key structure support aircrafts on the ground and allow them to takeoff, land and taxi. In addition to sustaining aircraft weight, landing gears are subject to tremendous impact forces upon landing. Landing/takeoff is one of the aircraft accident threats identified by FAA [27]. In case of emergency landing, landing gears must withstand harsh conditions [28]. Being able to assess the safety of the landing gear is of vital importance to the general public. In civil aircrafts, the current process is based on a subjective assessment by the flight crew to decide if an airplane has had a “hard landing” and thus compromised the safety of the landing gear [29]. In military aircrafts, structural health monitoring (SHM) devices are used but at low sample rates and processed post flight [30]. Because of lack of reliably measurable data, errors are made in these assessments either causing unnecessary grounding or part replacement if over estimate or conversely damages or accidents if under estimate.

For this reason, Messier-Dowty in Toronto has been developing a landing gear health monitoring system (LGHMS). Two types of information are used to assess the safety and health of the landing gear, *structural* and *service*. The structural information is concerned about the structural integrity of the landing gear and the amount of remaining fatigue life in it. The service information is concerned about overall performance including shock strut pressure and fluid volume, tire pressure and temperature, brake condition, as well as all on-board electronics. This system is composed of several subsystems: i) a sensor fusion system with a variety of sensors attached to the landing gear, ii) a communicate system to relay the sensor data to the monitoring system, iii) a data processing method to extract relevant information about the safety and health of the landing gear, and iv) a reporting method to communicate with various users including flight crew, maintenance personnel, airline operators, ground crew and regulatory authorities. This is a very comprehensive and ambitious system.

Messier-Dowty started this technology development about eight years ago by working with universities including Ryerson RIADI on sensors and sensing methods. Continuous efforts on the development of data processing methods resulted in a system prototype. After validation through small-scale tests, the company filed a patent [29] and the contents of this work contributed to SAE standard AIR 6168 on landing gear structural health monitoring [31]. However, this system has not been able to reach the level for commercialization.

One hurdle is cost. Due to lack of Tech Demo, this system has not been integrated with the existing on-board aircraft health management system (AHMS) for airframes. There is a difference between the two systems [29]. AHMS is based on damage tolerance because airframes are made of ductile materials that can tolerate cracks to a certain degree. LGHMS is based on safe life that detects crack initiation since landing gears are made of high strength materials with low ductility that can barely tolerate cracks. A system Tech Demo is needed to show how reliably LGHMS can detect various cracks on different parts and locations of the landing gear. A flight Tech Demo will have to show its capability not only for safety monitoring but also for effective communication. Therefore, the whole spectrum of this Tech Demo will span from OEMs to Tier 1 integrators, aircraft operators, airports, and maintenance personnel. Costs in coordination and implementation of Tech Demo would be in tens of millions. Without funding support, the company could only put this technology under the wish list as one of company's growth strategies [32].

3. Avcorp Project on Robotic Riveting

Riveting is a primary method for joining both metal and composite panels to provide strong joint strength and prevent laminate de-bonding (composite). There are hundred thousands of rivets in a regional aircraft and millions in a large aircraft. Overall, the operation of aircraft assembly is divided into three stages: subcomponent assembly, component assembly, and line assembly. The subcomponent assembly is the first step to construct the base components for four major sections, namely, fuselage, wing, cockpit and empennage. The component assembly is the middle step to join the subcomponents to form an individual major section. The line assembly is the last step to assemble a whole aircraft by connecting the four major sections together. The current riveting processes in aerospace entail a mix of manual riveting, semi-automated riveting, and automated riveting. The use of semi-automated and automated riveting machines is becoming popular in North America and Europe. However, these machines are only limited to component assembly, such as large wing skin panels and fuselage skin panels. Subcomponent assembly and line assembly are still done manually. The labor required producing these subassemblies and assemblies accounts for as much as fifty percent of the total cost. Manual riveting operations are tedious, repetitious, prone to error, and could cause health and ergonomic problems [33].

Avcorp is a Tier 1 integrator and 70% of its workforce is involved in the assembly of various aircraft structures such as wings and tails. To improve the production rate, Avcorp investigated robotic riveting technology in attempt to replace manual riveting back in 2005. Manual riveting rate is very low, between 1-2 rivets/minute, compared to that of machines between 10-20 rivets/minute. In their technology development, an anthropomorphic robot was used to replace human to operate various tools such as drill and rivet gun. A great deal of effort was spent on the development of special tooling, integration and control. With the limited funding, the company succeeded to achieve robotic drilling.

A full-scale automation is rather sophisticated, starting from drilling, deburring, countersinking, riveting, sealing to inspection. Though the technology achieved for robotic drilling provided proof-of-concept, both system and integration technology demonstrations would be required prior to use in production. Each process would need system technology demonstration, such as robotic deburring, robotic riveting. Then, all these processes would have to be integrated to form a final production system. The total cost was estimated over $4 millions [34].

To leverage funding for further development, the company participated as an industrial partner in a NSERC strategic grant application spearheaded by Ryerson where a robotic riveting system is being developed. However, the application was struck down despite research merit and industry relevance. Up to now, robotic automation is still under the company's technology development list [35], while this technology is being picked up very rapidly in Europe. This situation has definitely put Canadian structure companies, such as Avcorp, at a competitive disadvantage.

3.3.2 Examples of Other Government Sponsored Tech Demo Programs

Table 5 summarizes three government programs that support Tech Demo in the traditional aerospace countries, namely, US and EU. As shown in Table 5, all three programs have provided substantial funding for enormously large scale Tech Demo projects. Though ongoing, these projects started to generate impacts that put their aerospace industries at a great competitive advantage because no other country is able to do so.

Table 5 Tech Demo Programs in Traditional Aerospace Countries (US and EU)

Program Name	Description	Technology Demonstrations
US FAA - The Next Generation Air Transportation System (NextGen) [36]	*Mission*: replace a radar-based system of tracking aircrafts by global- positioning satellites; implement Performance-Based Navigation (PBN) routes and procedures for improved safety, access, capacity, predictability, operational efficiency, and environment. *Period*: 2009–2025 *Estimated cost*: US $42 billions	All contractor work to develop two main demonstrators: - Satellite Based Navigation (SBN) - Automatic Dependent Surveillance Broadcast (ADS-B) to be completed in 2014.
EU Clean Sky Integrated Technology Demonstrators (ITD) [19]	*Mission*: develop breakthrough technologies to significantly increase the environmental performances of airplanes and air transport, resulting in less noisy and more fuel efficient aircraft. *Period*: 2008-2017 *Funding:* €1.6 billions, 50/50 shared between government and industry	12 ITD leaders (7 OCEs, 4 Tier 1, 1 research institute) for six demonstrators: - Green Rotorcraft - Regional Aircraft - Eco-design - Engines - Smart Fixed Wing - Green Operations

EU SESAR (Single European Sky ATM Research) programme [37]	*Mission*: develop a modernised air traffic management (ATM) system for Europe to ensure the safety and fluidity of air transport over the next thirty years and make flying more environmentally friendly and reduce the costs of ATM. *Period:*2004-2020 *Funding*: € 2.1 billions**,** shared equally €700 millions Community, €700 millions Eurocontrol, €700 millions industry.	3 phases for the entire program: - Definition phase: (2004-2008) - Development phase: (2008-2012) - Deployment phase: (2012-2020) 16 work packages (WPs) under 4 activities: - Operational activities - System Development activities - System Wide Information Management activities - Transverse activities

3.4 Comparison to Existing Programs

The *key characteristic* of this program is to support large scale Tech Demo projects that involve a number of participants from all user groups and that can generate impacts on an entire aerospace development cycle from design, to manufacturing and operation. Table 6 and 7 list two government-sponsored programs in Canada. Though they touch on some aspects of Tech Demo, these programs are not on the same scale as what this new Tech Demo program is intended to provide.

3.4.1 Green Aviation Research and Development Network (GARDN) [38]

This is a business-led research network from 2009-2013 with total funding of $24 millions under a 50/50 sharing funding model between the federal government and industry. Its mission is to address environmental challenges. There are 13 projects under seven technology themes, covering noise, emission, alternative fuel, composite, and life cycle. In total, 30 partners have participated in this program, including 4 OEMs, 11 SME,s, 1 airline, 2 research centers, and 12 Canadian universities. This program imposes a similar eligibility that requires a minimum of two collaborators, OEM or Tier 1 plus SME, aiming at TRL 3-7. The project success rates were around 30%, a strong indication that there is a growing demand for industrial R&D but a shortage of funding. Table 6 shows all 13 GARDN projects, mainly led by OEMs.

Table 6 GARDN Projects

Project and Leader	**Project Title**
1st Round -$18M	
BA1 (OEM)	Environmentally-focused regional jet
BA2 (OEM)	Environmentally-focused business aircraft
BA3 (OEM)	Airframe noise reduction
PWC1 (OEM)	Life-cycle improvements
PWC2 (OEM)	Forced mixer and nozzle noise reduction
PWC3 (OEM)	High speed fan noise reduction
PWC4 (OEM)	Engine core technologies / combustion/compressor

PWC5 (OEM)	Altitude emissions control for aviation
CMC1 (Tier 1)	Optimized descents and cruise
2nd Round ~ $4M	
TGC1 (Airline)	Biologic and process technologies for renewable jet fuel
AER1 (SME)	Landing gear noise diagnostics and prediction
UOA1 (University)	Developing particulate measuring methods for non-volatile particulate emissions from aircraft
BHTC1 (OEM)	Development of a cradle to grave : environmental impact evaluation methodology and database of aeronautical products
3rd Round ~$2M	
MARQ1 (SME)	Project out-of-autoclave fan case manufacturing process
BA4 (OEM)	Environmental benefits of new nomex / Kevlar core technology for aircraft interior panels

3.4.2 Smart Affordable Green Efficient (SA²GE) [26]

This is a Quebec program from 2010-2013 with total funding of $150 millions, shared between the Quebec government of $70 millions and the industry of $80 millions. The mission is to maintain Quebec's competitive position as a world leader in the rapidly changing aeronautics market by addressing the challenges of climate change, and resulting environmental regulations. There are 13 companies, 4 universities, 5 research institutes, involved in five Tech Demo projects, as summarized in Table 7.

Table 7 SA^{2}GE Projects

Industrial Leader, Project Title	Demonstrator
Bell Helicopter Textron Canada (BHTC), Bombardier (BA) – (OEMs) *Aircraft composite fuselage structure*	*Demonstrator*: manufacturing composite fuselage parts. *Innovations*: - Reduction of cycle time for shell fabrication and assembly systems - Reduction of number of parts and joints - Reduction of tooling and material waste
Esterline CMC Electronic – (Tier 1) *Integrated avionics for cockpit applications*	*Demonstrator*: open architecture computing (OAC) platform for avionics. *Innovations*: - Integrated modular avionics (IMA) - Integration of system and software based on IMA - New technologies for virtual integration of very large sets
Heroux Devtek – (Tier 1) *Landing gear of the future*	*Demonstrator:* a lighter, quieter and cost effective landing gear. *Innovations*: - Integrated design and manufacturing

	- Innovative materials - Real-time condition monitoring - Simulation-based design for noise reduction - Electrical actuators
Pratt Whitney Canada (PWC) – (OEM) *Next generation compressor*	*Demonstrator:* a single-spool, high performance compressor and associated enabling accessories, manufacturing and materials technologies. *Innovations*: - Performance improvement of the compressor and high pressure turbine
Thales Canada – (Tier 1) *Integrated modular avionics for critical systems*	*Demonstrator:* IMA with a minimal set of standards and reduced hardware infrastructure. *Innovations*: - Optimized avionics systems - Single unit for multiple applications - Weight optimization, reduced power consumption, improved life cycle cost

3.4.3 Sustainable Development Tech Fund of Sustainable Development Technology Canada (SDTC) [39]

Commenced in November of 2001, this federal government program has been created to provide two funds with the mission for Tech Demo in the area of clean technologies. The first one is the $590 million SD Tech Fund™ that supports projects in climate change, air quality, clean water, and clean soil. The second one is the $500 million NextGen Biofuels Fund™ that supports large demonstration-scale facilities for the production of next-generation renewable fuels.

4. Concluding Remarks

The following remarks are drawn based on the assessment conducted through this research:

1. The establishment of a Tech Demo program will help the aerospace industry to demonstrate the existing technology capabilities for competing work on global market in short term and foster technology clusters, create niche products, and generate knowledge-based industry and economy in long term.
2. The Tech Demo projects under this program will provide opportunities for all the user groups to develop innovative technologies and products, especially for SMEs who usually cannot afford R&D.
3. The Tech Demo projects under this program will provide opportunities for all the user groups to engage in the training of the next generation of engineers and skill workers, in particularly enabling more interaction between universities and companies through project-based institutes in Canadian universities such as CIADI at Concordia University, RIADI at Ryerson University and AeroETS at ETS.
4. Compared to other government programs, this Tech Demo program should focus on large scale projects towards ground tests and flight tests that consume substantial resources and funding supports.

5. The FMP initiative identified a number of Tech Demo projects under three aeronautical Tech Groups, namely, airframe, engine and system, each in a range of $100 millions, aiming at short term platforms. There should be additional funding for Tech Demo projects aiming at long term development.

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