Aviation Leadership for the Environment

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Canadian Aviation Environment Technology Road Map

2nd UTIAS-MITACS International Workshop on Aviation and Climate Change
Toronto, May 27, 2010
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**Fields of activity**

**Aerospace**

- F10 revenues: $9.4 billion
- 48% of total revenues
- Backlog: $16.7 billion*
- Employees: 28,900*

*As at January 31, 2010

**Transportation**

- F10 revenues: $10 billion
- 52% of total revenues
- Backlog: $27.1 billion*
- Employees: 33,800*

*As at January 31, 2010
Bombardier’s Business Aircraft portfolio is centred on three families

**LEARJET FAMILY**
- Learjet 40 XR
- Learjet 45 XR
- Learjet 60 XR
- Learjet 85

**CHALLENGER FAMILY**
- Challenger 300
- Challenger 605
- Challenger 850

**GLOBAL FAMILY**
- Bombardier Global 5000
- Global Express XRS

Learjet, Learjet 40, Learjet 45, Learjet 60, Learjet 85, Challenger, Challenger 300, Challenger 605, Challenger 850, Global, Global 5000, Global Express, XR and XRS are trademarks of Bombardier Inc. or its subsidiaries.
Bombardier’s Commercial Aircraft portfolio is aligned with current market trends

Turboprops

Q400 and Q400 NextGen

Regional jets

CRJ700 NextGen
CRJ900 NextGen
CRJ1000 NextGen

CRJ Series:
1,695 ordered,
1,587 delivered*.

Q-Series aircraft:
1,034 ordered,
959 delivered*.

Single-aisle mainline jets

CSeries CS100/CS300

* As of Jan 2010

CRJ, CRJ700, CRJ900, CRJ1000, CS100, CS300, CSeries, NextGen and Q400 are trademarks of Bombardier Inc. or its subsidiaries.
Aviation Effects on Global Warming

Aircraft Radiative Force

From Sausen et al. (2005)

Radiative Force

RF [mW/m²]

CO₂, O₃, CH₄, H₂O, Direct Sulphate, Direct Soot, Contrails, Cirrus, Total (w/o Cirrus)

Level of scientific understanding

Good, Fair, Poor

Negative Impact

Positive Impact
Aviation Emissions

Fuel $C_nH_m (+S)$

Emissions from Aircraft of Concern to Climate

Air

$N_2 + O_2$

$CO_2 + H_2O + N_2 + O_2 + NO_x + UHC + CO + C_{soot} + SO_x$

$O_3 + CH_4$

Source: Don Wuebbles
Contrails and Cirrus Clouds

• Basic physics of contrail formation reasonably well understood, but important parameters (e.g., temperature, humidity in UT, optical properties) remain uncertain.
• There remain significant issues with the scale of climate models versus the size of the plume.
• Aviation-induced persistent contrails and aerosols may affect cirrus, but this is poorly understood.
Contribution of Aviation to Man-Made CO₂
A Small but Growing Fraction

Most stakeholders acknowledge civil aviation’s contribution of 2% of global CO₂ and 3% of GHG emissions, as per the IPCC report estimates.

The business aviation contribution was estimated at 2% of aviation emissions by IBAC, or at 0.04% of global emissions.
IATA Commitment to Carbon Neutral Growth

*The growth of Aviation Makes Action Necessary*
Commercial Aviation Goals for the Environment
As presented to ICAO by ACI, CANSO, IATA and ICCAIA

The agreed aspirational goals of commercial aviation include:

- Achieving carbon-neutral growth by 2020
- Improving fuel efficiency by an average of 1.5% per year from 2009 to 2020
- Reducing CO$_2$ emissions by 50% by 2050, relative to 2005
A Global Approach to Reducing Business Aviation Emissions
Business Aircraft Installed Base
*Units, Actual and Forecast 1965-2050*
Sources of Lifecycle Carbon Reductions

Reductions in % of 2005 Baseline

TECHNOLOGY
EXPECTED CO₂ EMISSION REDUCTIONS FOR NEW AIRCRAFT

OPERATIONS AND INFRASTRUCTURE
EXPECTED CO₂ EMISSION REDUCTIONS FOR IN-SERVICE AIRCRAFT

ALTERNATIVE FUEL
EXPECTED CO₂ EMISSION REDUCTIONS FOR IN-SERVICE AIRCRAFT
Business Aviation CO2 Emissions

*Metric Tons of CO2, Actual and Forecast 1965-2050*
Business Aviation Goals for the Environment
As presented in the General Aviation Position on the Environment

Business aviation improved its fuel efficiency by 40% over the past 40 years and today contributes only 0.04% of total CO₂ emissions.

The agreed position statement for business aviation includes:

- Achieving carbon-neutral growth by 2020
- Improving fuel efficiency by 2% per year from today until 2020
- Reducing CO₂ emissions by 50% by 2050, relative to 2005
Canadian Aviation Environment Technology Road Map
The Canadian Vision to achieve the environmental goals

- **CAETRM Vision:** Through critical and timely technology advances, ensure that Canada’s aerospace industry remains a world leader in environmental management and therefore increases the global competitiveness of its products and services.

- **CAETRM Purpose:** To identify those critical enabling technologies and infrastructure which the Canadian aerospace industry will require to meet environmental and sustainability requirements over the next ten to fifteen years.
CAETRM – Committed Participants

- Bombardier Aerospace
- NRC - CNRC
- Air Canada
- OAC
- AQA
- Pratt & Whitney Canada
- Bell Helicopter Textron Canada Inc.
- Rolls-Royce Ltd.
- CRIAQ
- Standard Aero
- Aero Montreal
- Industry Canada
- AIAC
- Messier-Dowty
- Transport Canada
CAETRM Thrust Areas

Steering Committee
(21 Members)

Aircraft Systems and ATM (13)

Airframe Concepts (10)

Fuels and Lubricants (14)

Manufacturing and MRO (23)

Materials and Coatings (15)

Eco Design (6)

Engine Concepts (13)

Ground Operations (2)

Rotary Wing A/C Concepts (4)

Secretariat (4)
CAETRM Thrust Team Templates

- Thrust Teams followed a template for their reports on Critical Technologies that included:
  - Technology Description (critical enabling technology, current TRL)
  - Contribution to Environmental Objectives
  - Importance, Viability, Timing and Breadth of Application
  - Alternatives
  - Availability, Maturity and Risk
  - Collaborators and Development / Implementation Strategy
  - Costs and Timelines
Airframe Concepts Thrust Area

- Technologies to reduce the environmental impact of aircraft through improvements in airframe design.
  - Aircraft Configuration Development
  - Systems Technologies
    - Actuation Technologies
  - Multi-disciplinary Optimization (MDO)
  - Test Facilities
  - Aerodynamics
  - Aero-structural Interaction
  - Noise Reduction Technologies
  - Structures and Material
Airframe Concepts

TRL or Mid-TRL if range provided

0 1 2 3 4 5 6 7 8

0 1 2 3 4 5 6 7 8

Years to required maturity level

Actuation Technologies

Aero-Structural Interaction

Structural Technology

System Technology

Aerodynamics / flight physics

Aircraft Configuration Development

Multi-Disciplinary Optimization

Test Facilities

Noise Reduction

Multi-Disciplinary Optimization

ACTUAL TECHNOLOGY

AEROSPACE

ROAD MAP

BOMBARDIER

22
CAETRM and the Canadian Initiatives
Building the future of aviation technology

Bombardier Contribution

- Bombardier has set ambitious technical & environmental targets for the next decade and after, through its leading role in the definition of the Canadian Aerospace Environmental Technology Road Map (CAETRM):

<table>
<thead>
<tr>
<th>Fuel / CO₂</th>
<th>NOx</th>
<th>Noise</th>
</tr>
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<tbody>
<tr>
<td>- 50%</td>
<td>- 80%</td>
<td>- 20 EPNdB</td>
</tr>
</tbody>
</table>

- To achieve these targets, Bombardier is therefore extending its R&D commitment by supporting and leading ambitious national technology programs, such as:
  - **CRIAQ**: Consortium for Research and Innovation in Aerospace in Québec
  - **GARDN**: Green Aviation Research and Development Network
  - **SAGE**: Quebec Demonstrator Program for Green Aircraft Technologies
  - **FMP**: Future Major Platform (Canada’s Technology Demonstrators)
Bombardier Short-Term Contribution

**CSERIES • Five Aircraft Configurations For Maximum Flexibility**

**CSERIES Aircraft Family**
- Over 95% LRU* Commonality
- Same Type Rating

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Range (NM)</th>
<th>Passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS100</td>
<td>2,200</td>
<td>110</td>
</tr>
<tr>
<td>CS100 ER</td>
<td>2,950</td>
<td>110</td>
</tr>
<tr>
<td>CS300</td>
<td>2,200</td>
<td>130</td>
</tr>
<tr>
<td>CS300 XT</td>
<td>2,200</td>
<td>130</td>
</tr>
<tr>
<td>CS300 ER</td>
<td>2,950</td>
<td>130</td>
</tr>
</tbody>
</table>

* Line Replaceable Unit
CSERIES • Design and Technologies Focused On Optimization

- Best in Class Cabin Comfort and Flexibility
- Superior Field Performance & Range Flexibility
- 70% Advanced Materials
- Advanced Flight Deck FBW with Side Sticks
- Integrated Avionics & Optimized Systems
- Electric Brakes
- Pratt & Whitney PurePower™ PW1000G

Pratt & Whitney
PurePower™ PW1000G
CSeries: 70% Advanced Structural Materials Bring Significant Weight Savings
C-Series Aircraft Composite Wing Demonstrator
Specially Designed Demonstrator Assembly Jig – Bombardier Belfast
CSeries Aircraft Composite Wing Demonstrator

Advantages of Resin Transfer Infusion (RTI)

- Reductions in lay-up time
- No pre-pregging costs
- No out-life constraints
- Improved dimensional tolerances
- Lower raw material costs
- Ability to co-cure stiffeners.

Cseries Aircraft Composite Wing Demonstrator

Inspecting the Inboard Rear Spar
CSERIES •
Wide-body Comfort in a Single-Aisle Aircraft
C SERIES • Advanced Bombardier Flight Deck Design

- Five Large 15.1” LCD Displays
- 2 Large PFD and 3 MFD
- Glareshield Tuning
- Integrated Overhead Panel
- Virtual Panels
- Sidestick with Trim Control
- Auto throttle
- Cursor & Keyboard Control
- Optional Single Or Dual HUD
- Optional Class 2 EFB
- Rockwell Collins Pro Line Fusion™
Fan Drive Gear System Enables Optimization

Conventional Turbofan
- fan speed constrained by low pressure spool
- low pressure compressor & low pressure turbine speed constrained by fan

PurePower™ PW1000G Engine
- ultra-efficient, light-weight, low-speed fan
- low pressure compressor & low pressure turbine speed optimized

Incremental Improvement

Step-Change Improvement
PurePower™ PW1000G Engines Introduce A Step Change in Bypass Ratio

<table>
<thead>
<tr>
<th>Aircraft Model</th>
<th>Bypass Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD80</td>
<td>1-2 : 1</td>
</tr>
<tr>
<td>737-500/-300</td>
<td>5.1 : 1</td>
</tr>
<tr>
<td>A318/A319</td>
<td>5.5-6 : 1</td>
</tr>
<tr>
<td>737-600/-700</td>
<td>5.5 : 1</td>
</tr>
<tr>
<td>E190/195</td>
<td>5.1 : 1</td>
</tr>
<tr>
<td>SSJ100</td>
<td>4.4 : 1</td>
</tr>
<tr>
<td>CSeries</td>
<td>12 : 1</td>
</tr>
<tr>
<td>787</td>
<td>9.5-11 : 1</td>
</tr>
<tr>
<td>A350</td>
<td>10-11 : 1</td>
</tr>
<tr>
<td>787</td>
<td>9.5-11 : 1</td>
</tr>
<tr>
<td>A350</td>
<td>10-11 : 1</td>
</tr>
<tr>
<td>PW1521G @ 21,000 lb.</td>
<td></td>
</tr>
<tr>
<td>PW1524G @ 23,300 lb.</td>
<td></td>
</tr>
</tbody>
</table>

PurePower™ PW1000G engine and “This Change Everything” are Trademarks of United Technologies Corp. – Pratt & Whitney or its subsidiaries.
C SERIES • Four Times Smaller Noise Footprint

70 dB(A) Contours, A-Weighted Sound Level; ISA+10C
The future of the industry lies in the challenge of balancing profitability and reducing the impact on the environment. Designed with vision and conviction, the CSERIES aircraft family combines low operating costs and an unmatched environmental scorecard.
Bombardier Mid-Term Contribution
GARDN (Green Aviation Research and Development Program)

- A new federally sponsored business-led network of centers of excellence
- GARDN mission is to promote the protection of the environment and support the competitive excellence of Canadian aeronautical products and services, the economic success of the member companies and the development and training of highly qualified personnel in the aerospace environmental field.

Green Aviation Research and Development Network consortium (GARDN)
GARDN Eight Research Themes

- Emissions
- Noise
- Icing
- Aircraft Operations
- Alternative Fuels
- Performance
- Product Life Cycle Management
- Materials & Manufacturing Processes
Program Goals and Benefits

- Research is conducted on two applications, a Regional Aircraft and a long-range Business Jet

- **Goal: Develop the Know-How**
  - Develop design capability for alternative aircraft configurations, expanding today’s repertoire
  - Development of people, tools and methods; knowledge capture

- **Goal: Evaluation of Alternative Configurations**
  - Evaluate the potential of alternative configurations to reduce the environmental impact (fuel burn, noise, local air quality at airfields)
  - Sensitivity- and trade-studies for different scenarios (environmental impact, fuel price…)
  - Enable the company to plan for robustness in changing business environments

- **Added Benefit:**
  - Tools and methods developed by the project can be used in Bombardier’s aircraft development projects as soon as they are available
Methodology

Design Processes:

- Two complementary design processes are being developed.
- **Case study** for Business Jet (2/3 of the funding) and **Set-based design** for the Regional Aircraft (1/3 of the funding)

Evaluation of Improvement:

- Current aircraft serve as benchmark
- Unconventional aircraft have to compete with conventional configurations, which get to benefit from the same assumptions and technologies to allow a fair comparison.

Complementary designs processes and fair comparisons are key
Green Aviation Research and Development Network (GARDN)  
Airframe Noise Reduction Project

Priorities based on noise ranking from in-house phased-array microphone flight tests

Ref.: 12th Annual CASI Aerodynamics Symposium, 2007
GARDN Airframe Noise Reduction Project – Landing Gear

- Scale wind-tunnel tests (NRC 2010, 2011) → full-scale (2012)
- CAA and semi-empirical prediction methods being developed
- Analysis and testing of noise reduction treatments
Bombardier Long-Term Contribution

Collaborative Green Technology Demonstrators

- **SAGE (Smart Affordable Green Efficient) Technology Demonstrators**
  - Sponsored by Aero Montreal (Montreal Aerospace Cluster)
  - Composite Structures, Smart and More Electric Aircraft Systems
  - Funded by the Quebec Government starting in 2010

- **FMP (Future Major Platform) Technology Demonstrators**
  - Sponsored by AIAC (Association of Aerospace Industries of Canada)
  - Composite Structures, Avionics, Alternative Fuels, Smart Systems
  - Under consideration by the government of Canada
SAGE: Identifying future aviation technology drivers

*The aircraft of the future will be:*

| **S**mart | Integrated and intelligent systems  
|           | Air transport system optimization  
|           | Enhanced passenger comfort  |
| **A**ffordable | To build: design, manufacturing and materials  
|           | To operate: reduced fuel consumption, maintenance and navigation fees  |
| **G**reen | Reduced noise (5-10dB), CO2 (25%) and NOx (30%), Fuel consumption (25%), Materials of Concern (Chromium, etc)  
|           | Alternative fuel, Hazardous waste elimination, Green metrics for Eco Design  |
| **E**fficient | Advanced aero concepts, Advanced materials, more electric airframe  
|           | Power management systems, Integrated thermal management of propulsion system, Value added innovative design  |
Conclusions

- Bombardier has achieved a position of leader in regional and business aviation through sustained technology development and product innovation.

- The aviation industry is committed to reducing its impact on climate change through technology, infrastructure and fuel lifecycle improvements.

- Our technology program is aimed at developing aircraft that are more comfortable, less expensive to own and operate, and more respectful of the environment (reduced noise and emissions, recyclable products).
Conclusions

- Our first stake in the ground for the environment is the CSeries which will bring in 2013 significant gains for the environment.

- We continue to work on promising technologies through the newly formed GARDN consortium.

- Larger gains will be possible when technologies, demonstrated through the SAGE and FMP initiatives, will find their way on new products.