

Aviation Leadership for the Environment



Fassi Kafyeke

Director Strategic Technology

Bombardier Aerospace

Co-Chair

Canadian Aviation Environment

Technology Road Map

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

BOMBARDIER

Contents

- **Bombardier Aerospace Products**
- **Aviation Effects on Global Warming**
- **Aviation Position on the Environment**
- **The Canadian Aviation Environment Technology Road Map (CAETRM)**
- **Bombardier Contribution**
 - Short-Term Execution: Bombardier CSeries
 - Mid-Term Execution: GARDN
 - Long-Term Execution: SAGE, FMP
- **Conclusions and Recommendations**

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*

BOMBARDIER



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



Bombardier's Commercial Aircraft portfolio is aligned with current market trends

Turboprops



Q400 and Q400 NextGen

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

Regional jets



CRJ700 NextGen



CRJ900 NextGen



CRJ1000 NextGen

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

Single-aisle mainline jets



CSeries CS100/CS300

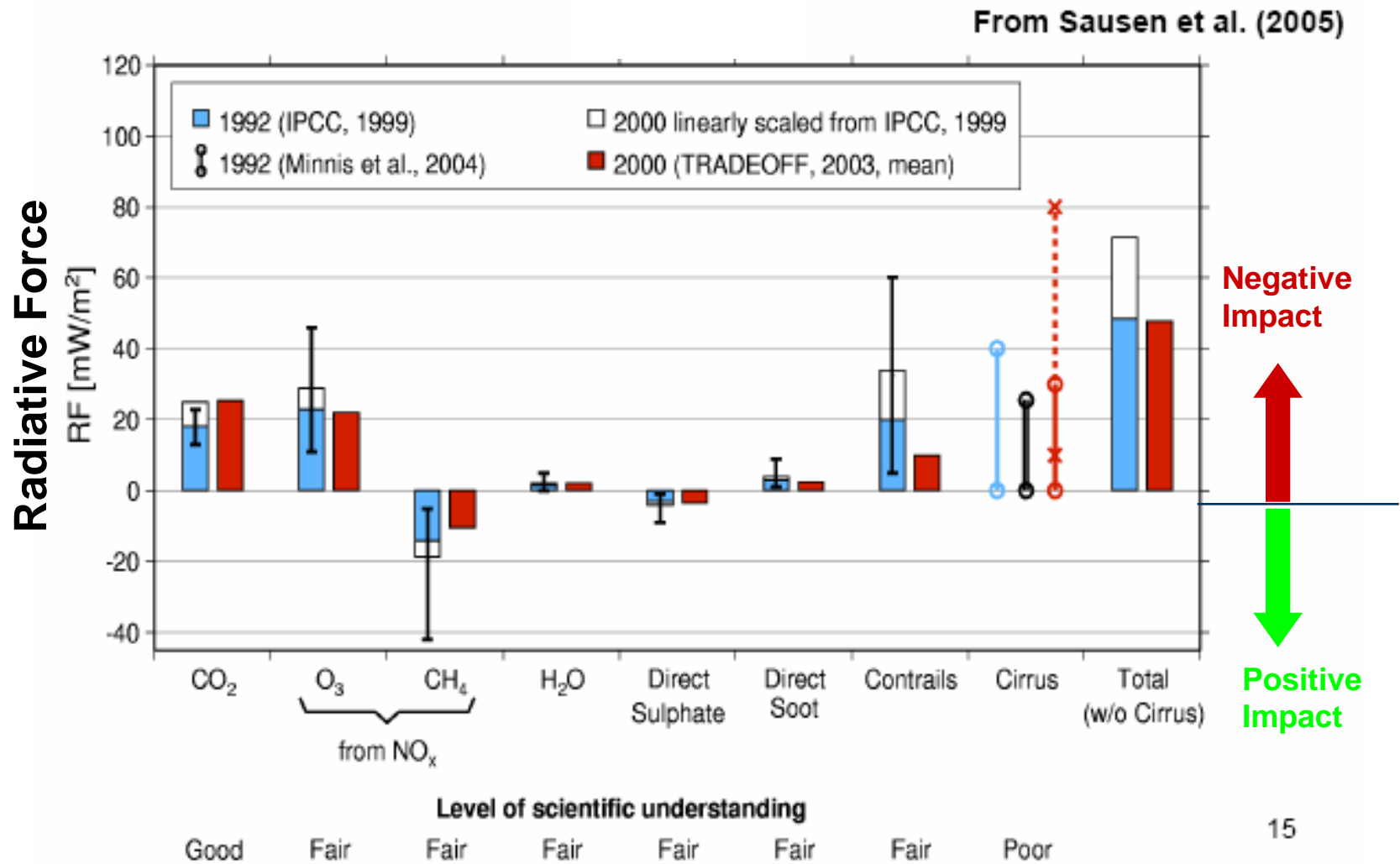
*** As of Jan 2010**

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

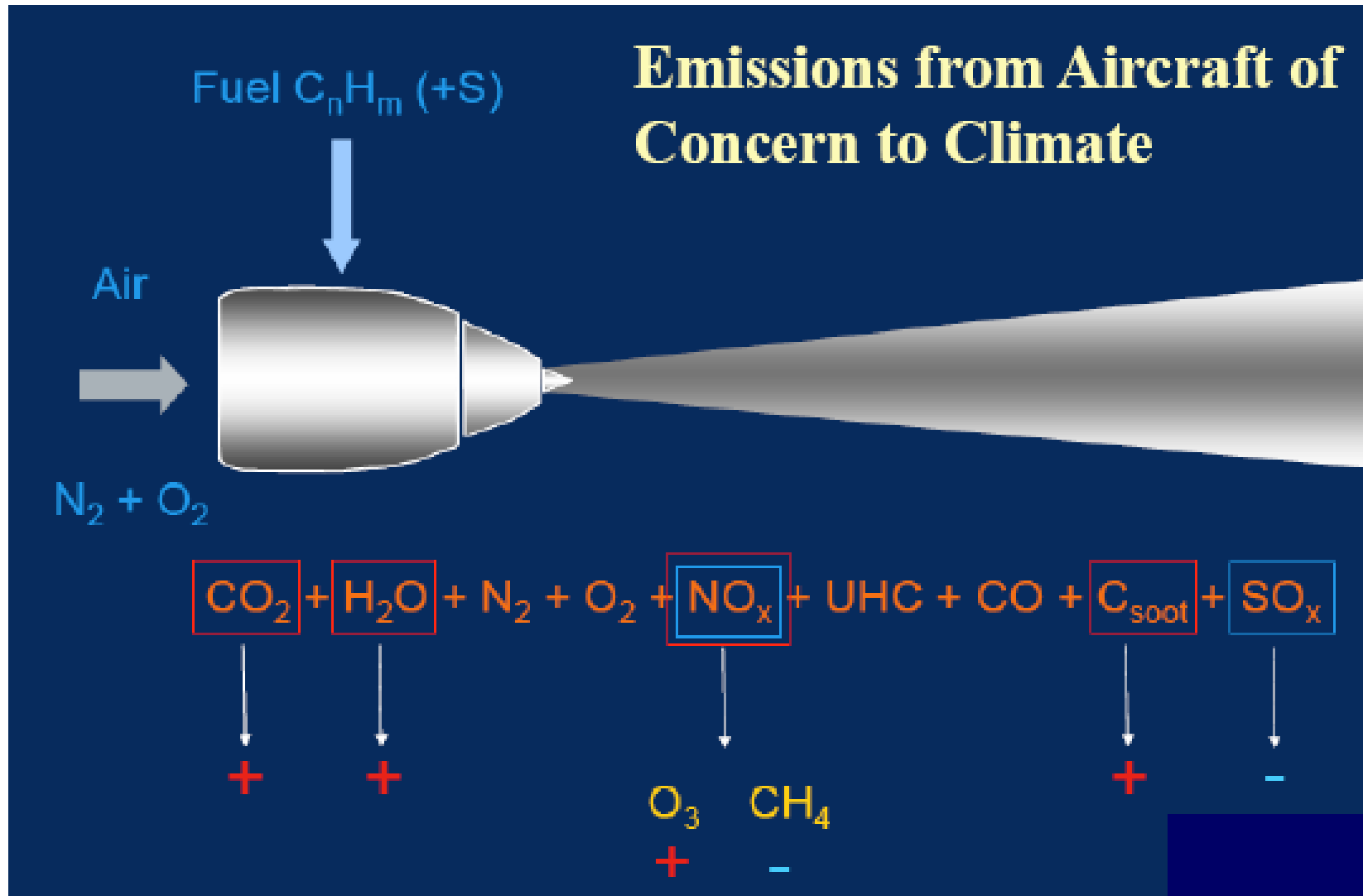
BOMBARDIER

Aviation Effects on Global Warming

Aircraft Radiative Force



Aviation Emissions



Contrails and Cirrus Clouds

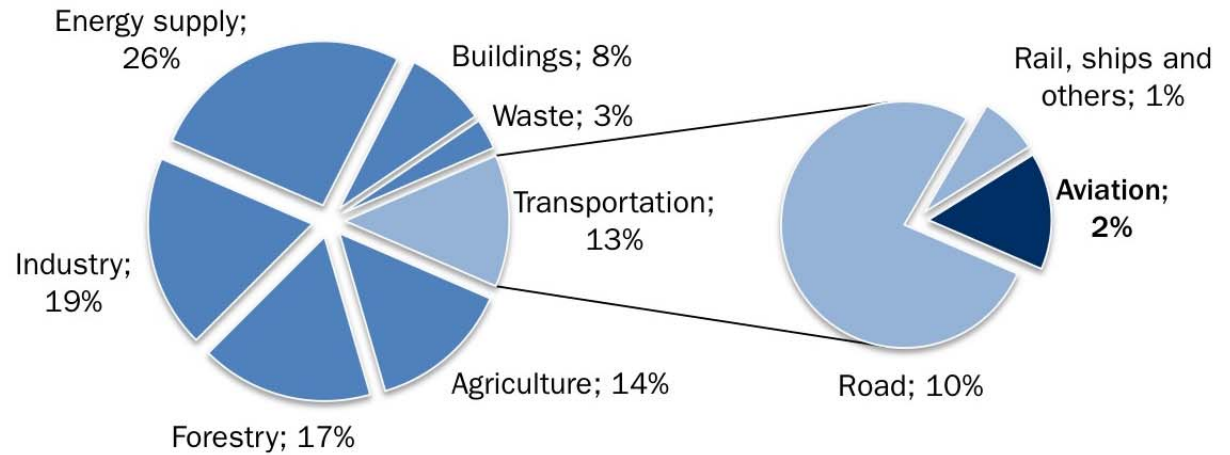
- Basic physics of contrail formation reasonably well understood, but important parameters (e.g., temperature, humidity in UT, optical properties) remain uncertain.
- There remain significant issues with the scale of climate models versus the size of the plume
- Aviation-induced persistent contrails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



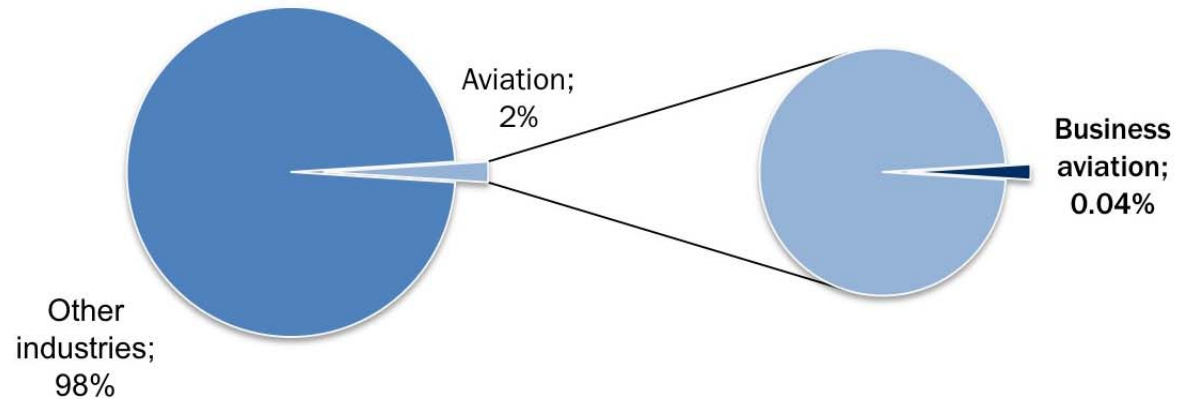
Contribution of Aviation to Man-Made CO₂

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.

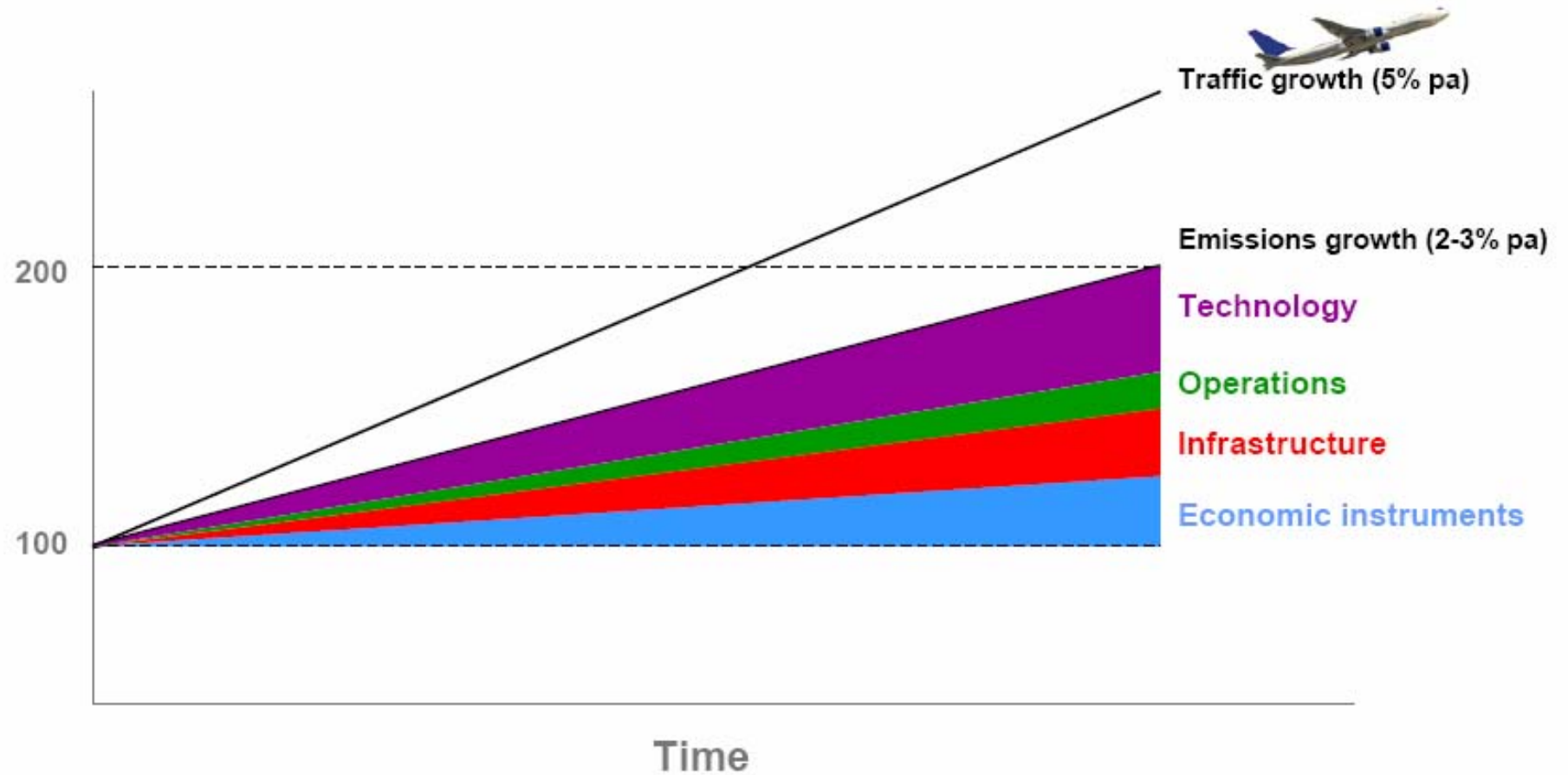


The business aviation contribution was estimated at 2% of aviation emissions by IBAC, or at **0.04% of global emissions**.



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 CO₂ emissions by 50% by 2050, relative to 2005



A Global Approach to Reducing Business Aviation Emissions



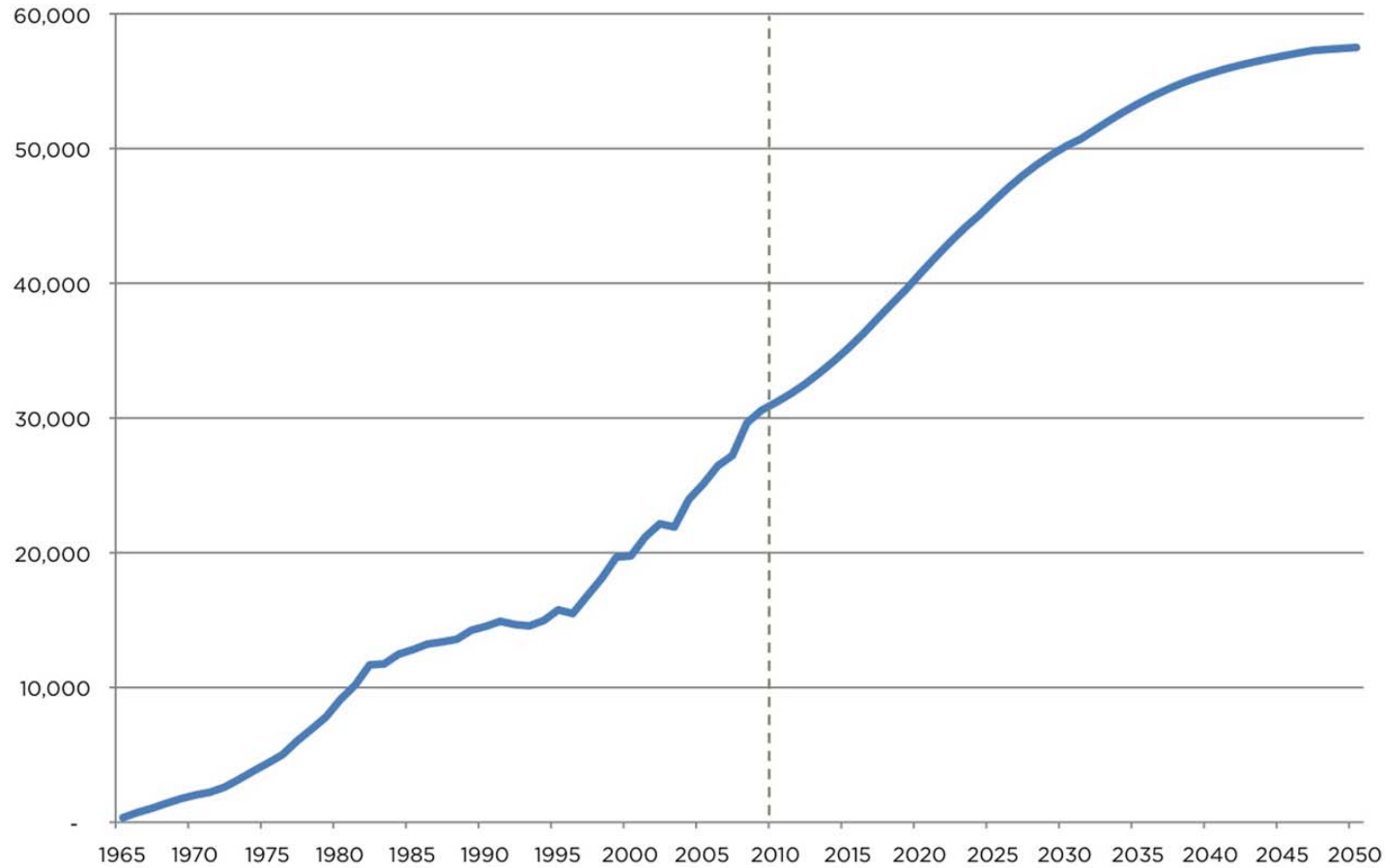
GAMA



BOMBARDIER

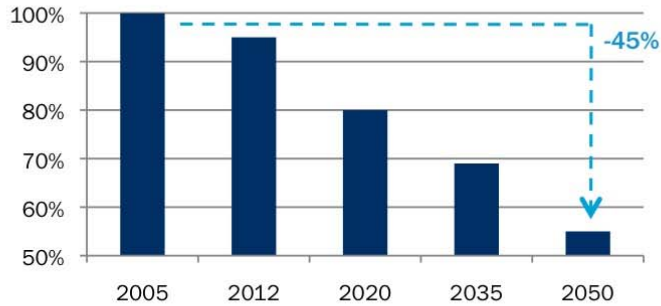
Business Aircraft Installed Base

Units, Actual and Forecast 1965-2050



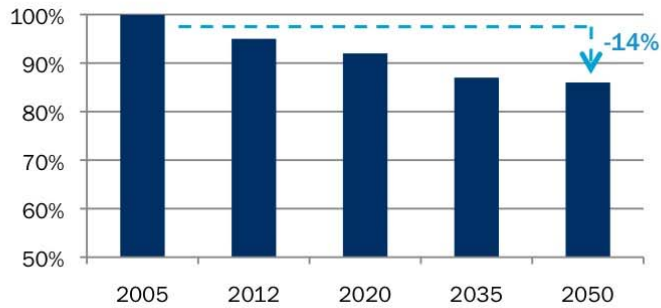
Sources of Lifecycle Carbon Reductions

Reductions in % of 2005 Baseline



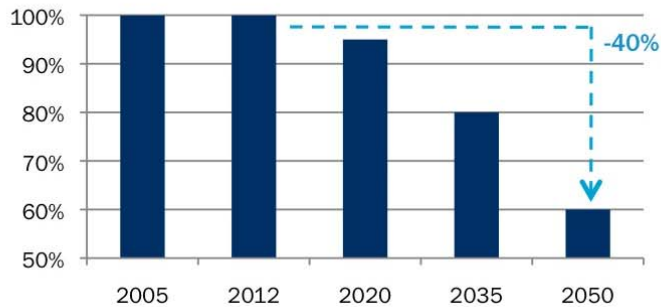
TECHNOLOGY

EXPECTED CO₂ EMISSION REDUCTIONS FOR NEW AIRCRAFT



OPERATIONS AND INFRASTRUCTURE

EXPECTED CO₂ EMISSION REDUCTIONS FOR IN-SERVICE AIRCRAFT



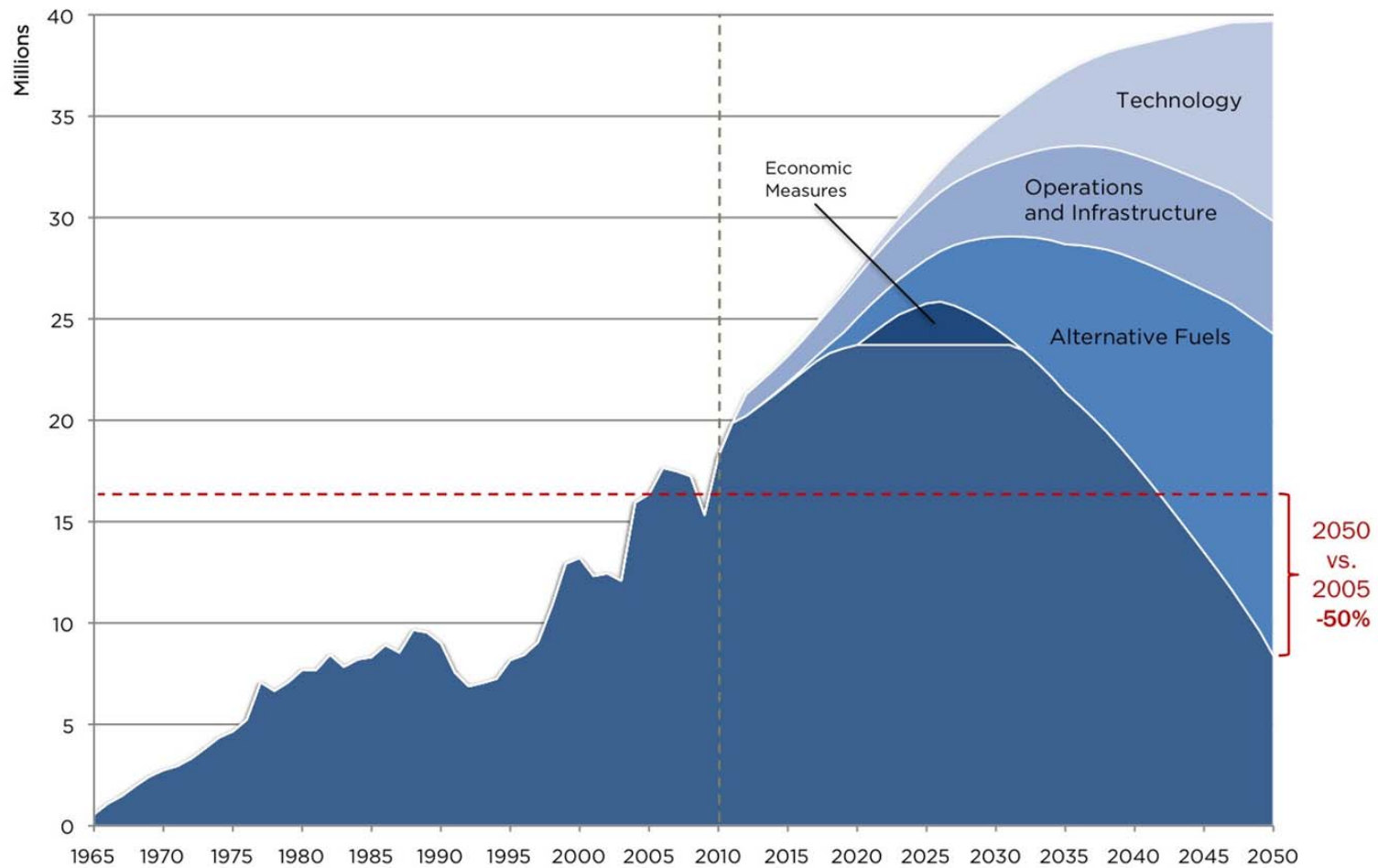
ALTERNATIVE FUEL

EXPECTED CO₂ EMISSION REDUCTIONS FOR IN-SERVICE AIRCRAFT

BOMBARDIER

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

BOMBARDIER

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



Blue-sky thinking for greener aerospace

For some time, there has been widespread agreement among governments and scientists that we must change the way we do things to reduce our environmental footprint. That the ways we have done things in the past are not necessarily the ways we can do them now or in the future.

Now the aviation industry has added its voice to the growing movement. At the third Aviation and Environment Summit in April, industry leaders signed a declaration on climate change to lead towards carbon neutral growth and a totally sustainable industry.

They pledged to push forward the development and implementation of new technologies, including cleaner fuels, and optimize fuel efficiency in the air and on the ground. They also committed to looking at ways to improve air traffic management and implement positive economic instruments to achieve greenhouse gas reductions wherever they are cost-effective.

To succeed in these areas and reduce the industry's environmental burden, we need to know where we're going. Initiated and supported by the National Research Council of Canada, leaders in the Canadian aviation industry have started a technology road-mapping process to guide the aerospace industry's response to its pressing environmental challenges. These efforts will have a direct impact on determining priority technologies in the Canadian aerospace industry to meet global environmental mitigation requirements over the next 5 to 10 years.

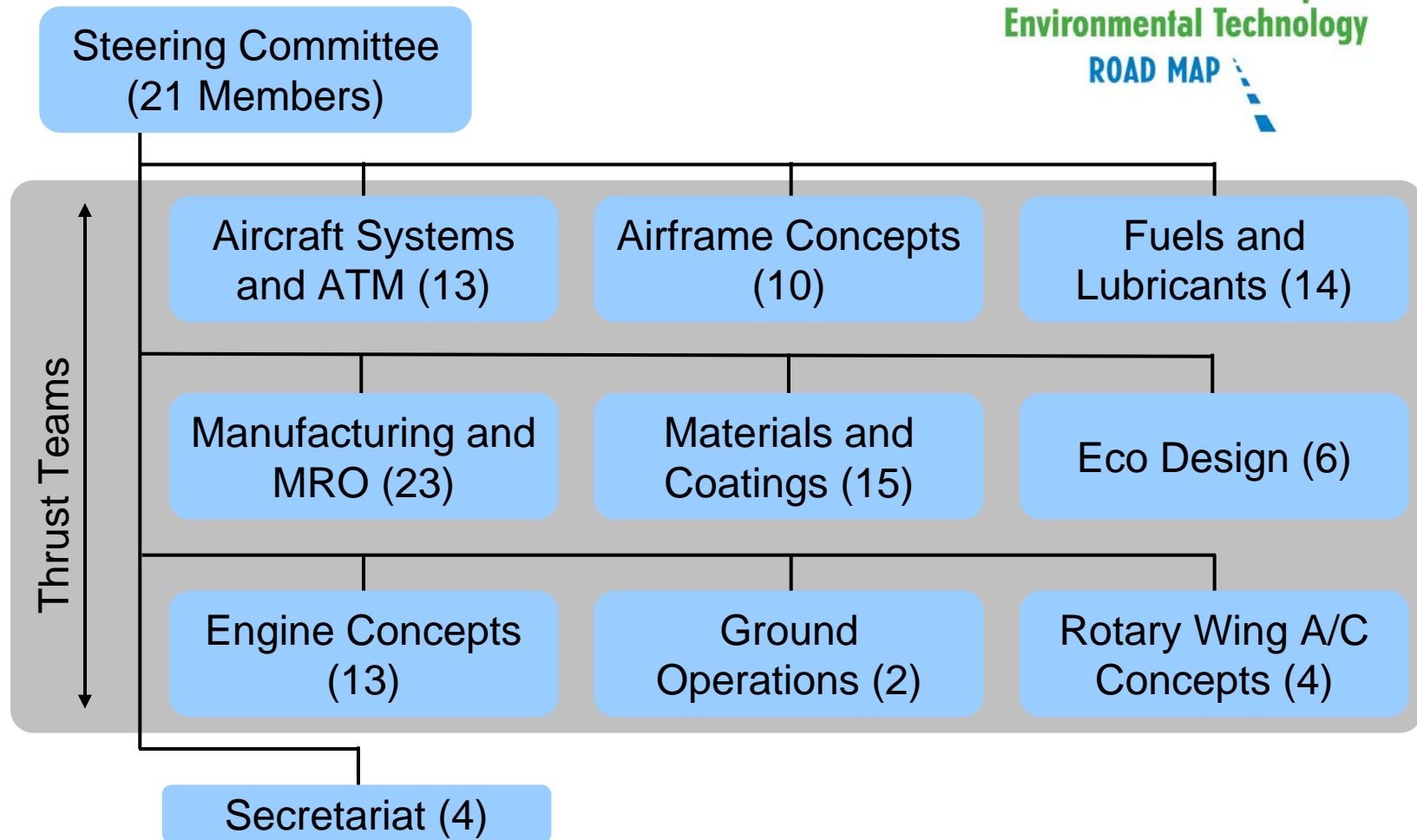
We're ready for new ideas.

PARTICIPANTS AND SIGNATORIES

 Bombardier Aerospace Industry Chair, Steering Committee	 Air Canada	 OAC
 NRC Institute for Aerospace Research NRC Deputy Chair, Steering Committee	 AQA S. SARA SA, PRES. & CEO	 Pratt & Whitney Canada
 Bell Helicopter Textron Canada Inc.	 Rolls-Royce Canada Ltd.	
 CRIAQ	 Standard Aero	
 Aéro Montréal	 Industry Canada	 Sustainable Development Technology Canada
 AIAC	 Messier-Dowty	 Transport Canada

BOMBARDIER

CAETRM Thrust Areas



CAETRM Thrust Team Templates



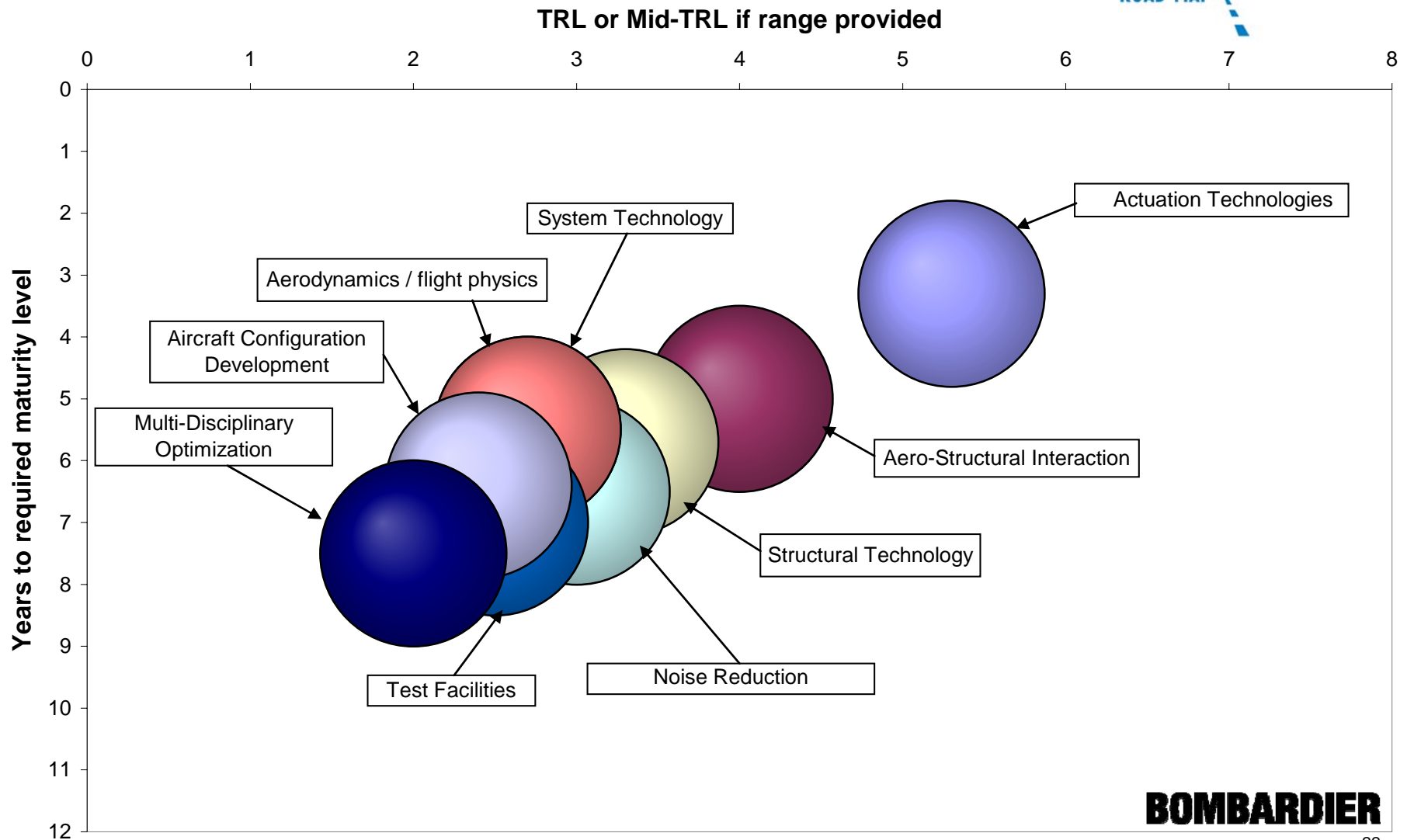
- **Thrust Teams followed a template for their reports on Critical Technologies that included:**
 - Technology Description (critical enabling technology, current TRL)
 - Contribution to Environmental Objectives
 - Importance, Viability, Timing and Breadth of Application
 - Alternatives
 - Availability,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

Airframe Concepts Thrust Area

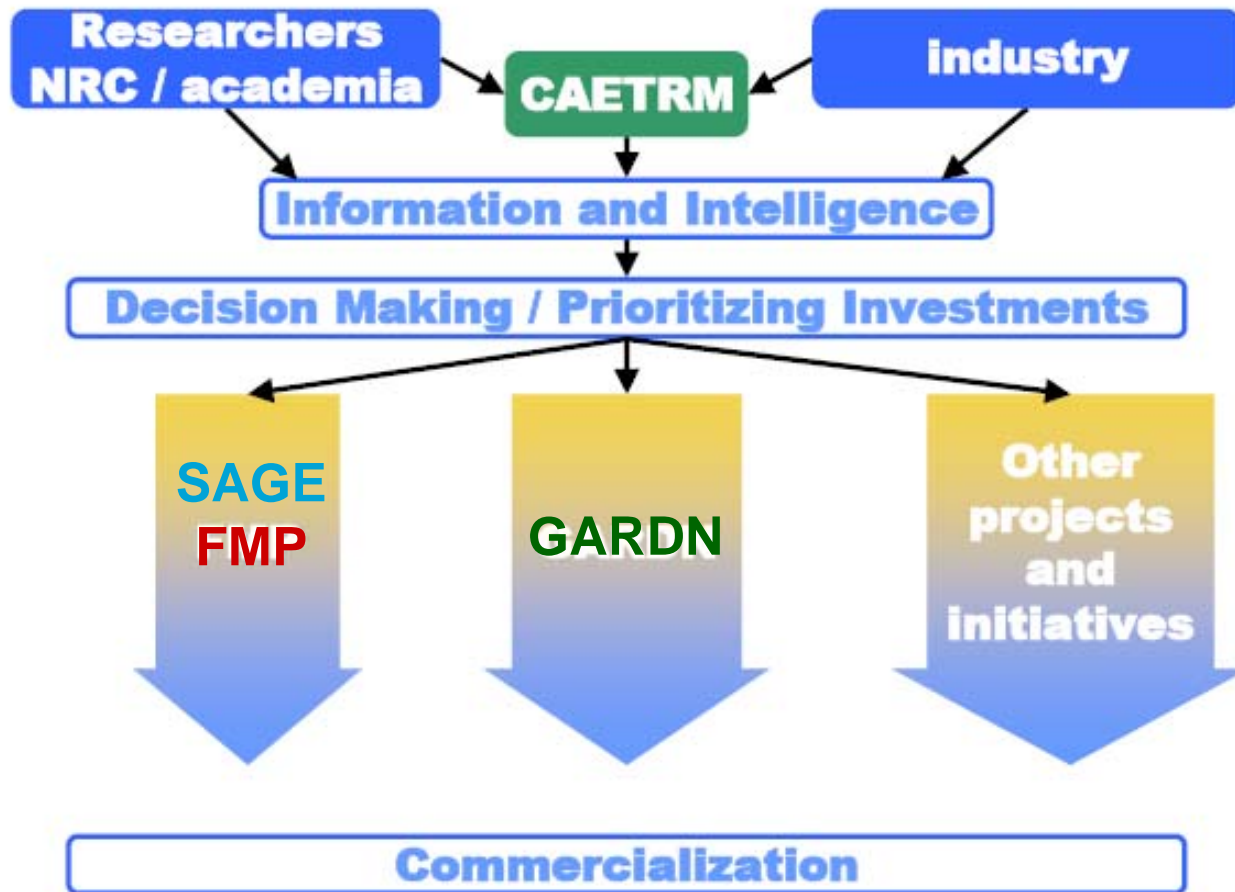


- **Technologies to reduce the environmental impact of aircraft through improvements in airframe design.**
 - Aircraft Configuration Development
 - Systems Technologies
 - Actuation Technologies
 - Multi-disciplinary Optimization (MDO)
 - Test Facilities
 - Aerodynamics
 - Aero-structural Interaction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

Airframe Concepts



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)**:

Fuel / CO ₂	NOx	Noise
- 50%	- 80%	- 20 EPNdB

- 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)

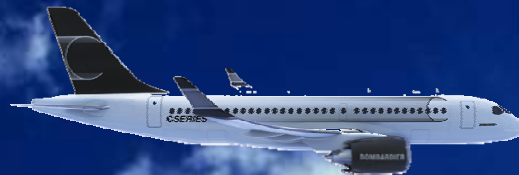
Bombardier Short-Term Contribution

CSERIES • Five Aircraft Configurations For Maximum Flexibility

CSERIES Aircraft Family

Over 95% LRU*
Commonality

Same Type Rating



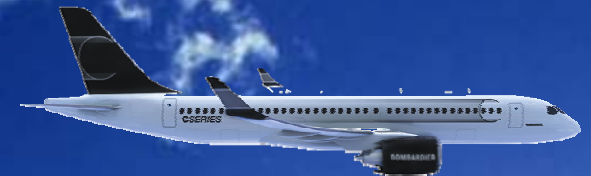
CS100
2,200 NM / 110 pax



CS100 ER
2,950 NM / 110 pax



CS300
2,200 NM / 130 pax



CS300 XT
(eXtra Thrust)
2,200 NM / 130 pax



CS300 ER
2,950 NM / 130 pax

• CS080924

* Line Replaceable Unit

BOMBARDIER

C SERIES • Design and Technologies Focused On Optimization



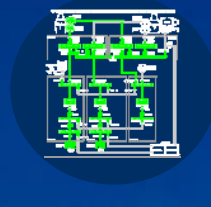
Best in Class
Cabin Comfort
and Flexibility



70% Advanced
Materials



Advanced Flight Deck
FBW with Side Sticks



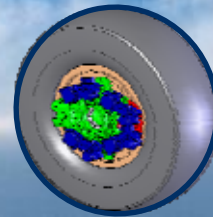
Integrated
Avionics &
Optimized
Systems



Superior Field
Performance &
Range Flexibility



Electric
Brakes



Pratt & Whitney
PurePower™
PW1000G

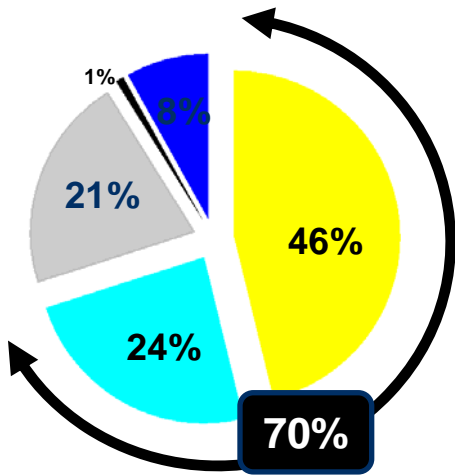


I5806001

BOMBARDIER

6/16/2009

C Series: 70% Advanced Structural Materials Bring Significant Weight Savings



- Advanced Composites
- Aluminum Lithium
- Standard Materials
- Titanium
- Steel



C SERIES
NOW IS THE FUTURE

BOMBARDIER

CSeries Aircraft Composite Wing Demonstrator

Specially Designed Demonstrator Assembly Jig – Bombardier Belfast



BOMBARDIER

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



BOMBARDIER

C SERIES •

Wide-body Comfort in a Single-Aisle Aircraft



BOMBARDIER

6/16/2009

C SERIES • Advanced Bombardier Flight Deck Design



Sidestick with Trim Control

Auto throttle

Cursor & Keyboard Control

Optional Single Or Dual HUD

Optional Class 2 EFB

Rockwell Collins Pro Line Fusion™

Five Large 15.1" LCD Displays

2 Large PFD and 3 MFD

Glareshield Tuning

Integrated Overhead Panel

Virtual Panels

Y2371011

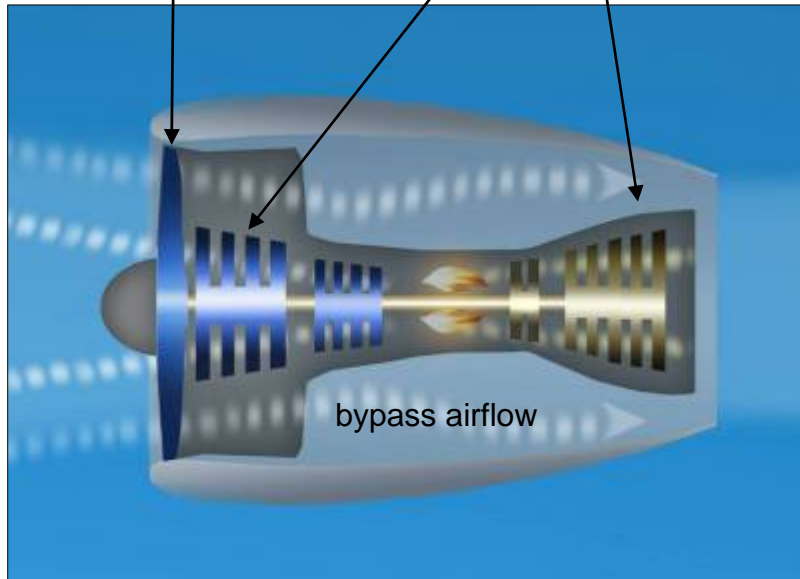
BOMBARDIER

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

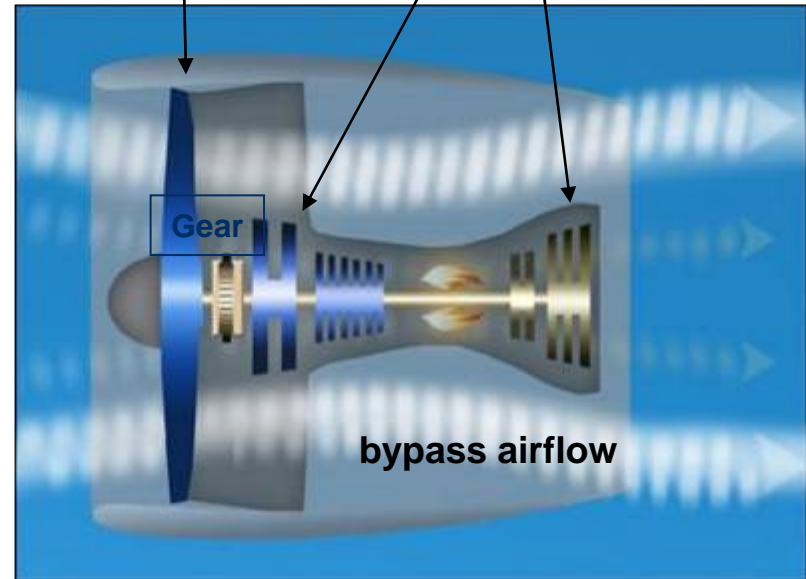


Incremental Improvement

PurePower™ PW1000G Engine

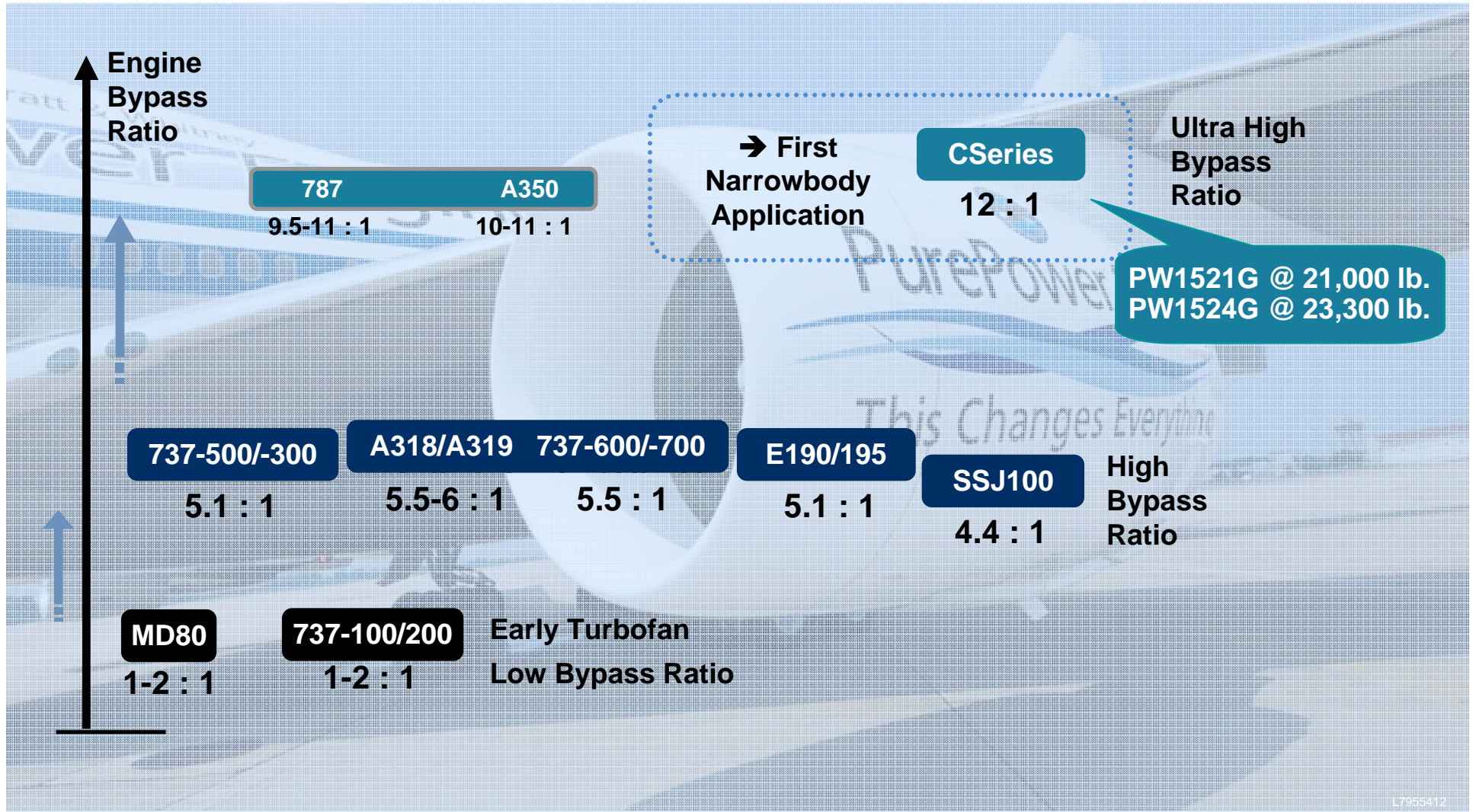
ultra-efficient,
light-weight,
low-speed fan

low pressure compressor
& low pressure turbine
speed optimized



Step-Change Improvement

PurePower™ PW1000G Engines Introduce A Step Change in Bypass Ratio



PurePower™ PW1000G engine and “This Change Everything” are Trademarks of United Technologies Corp. – Pratt & Whitney or its subsidiaries.

BOMBARDIER

CSERIES • Four Times Smaller Noise Footprint



70 dB(A) Contours, A-Weighted Sound Level; ISA+10C

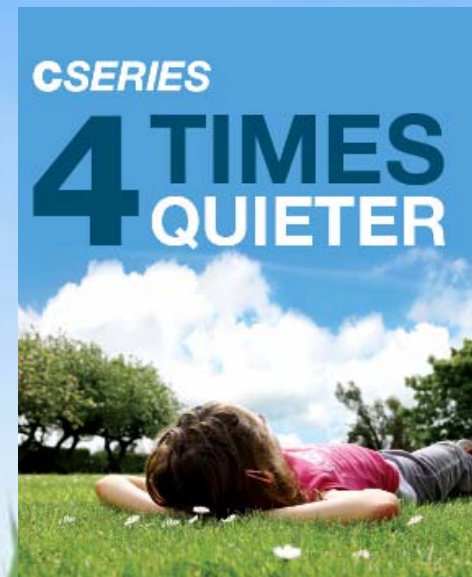
BOMBARDIER

N9127047
6/16/2009

C SERIES •

Unmatched Reduction in Environmental Footprint

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 C SERIES aircraft family combines low operating costs and an unmatched environmental scorecard.



BOMBARDIER

6/16/2009

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

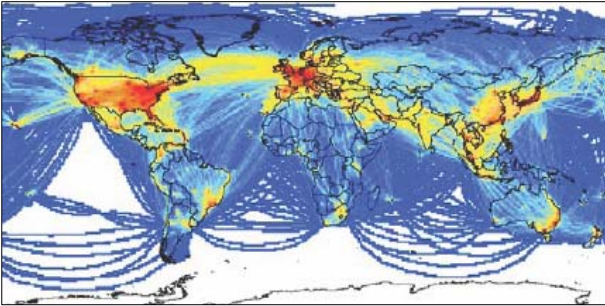
Aircraft Operations

Performance



Alternative Fuels

Product Life Cycle Management



Materials & Manufacturing Processes



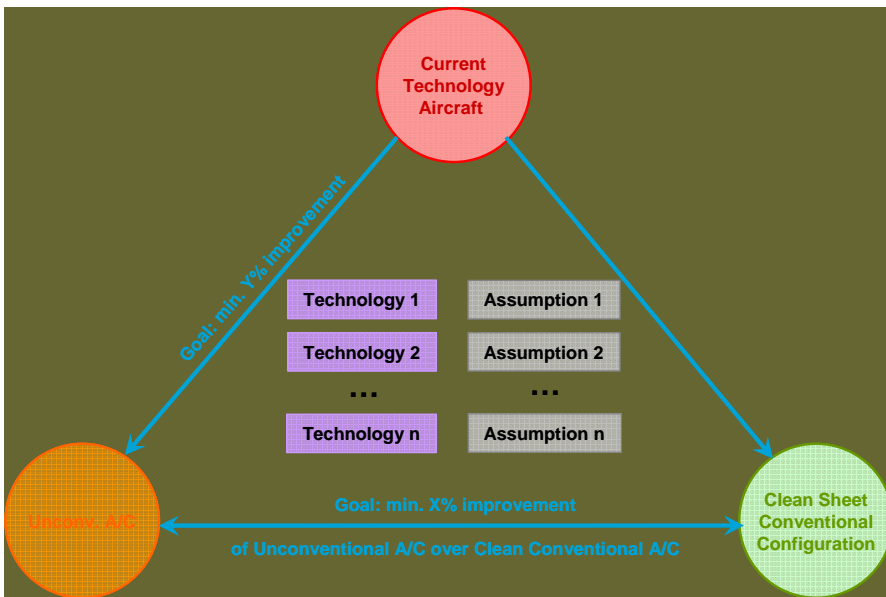
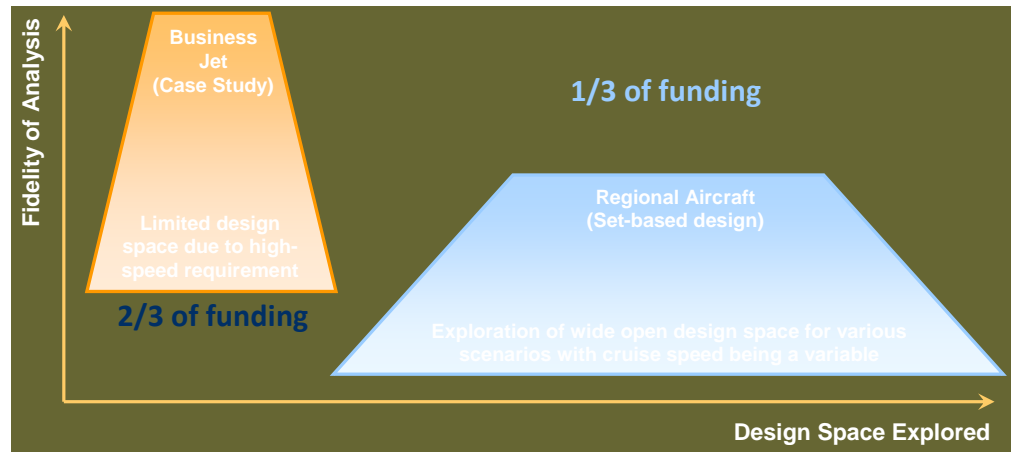
Program Goals and Benefits

- **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)



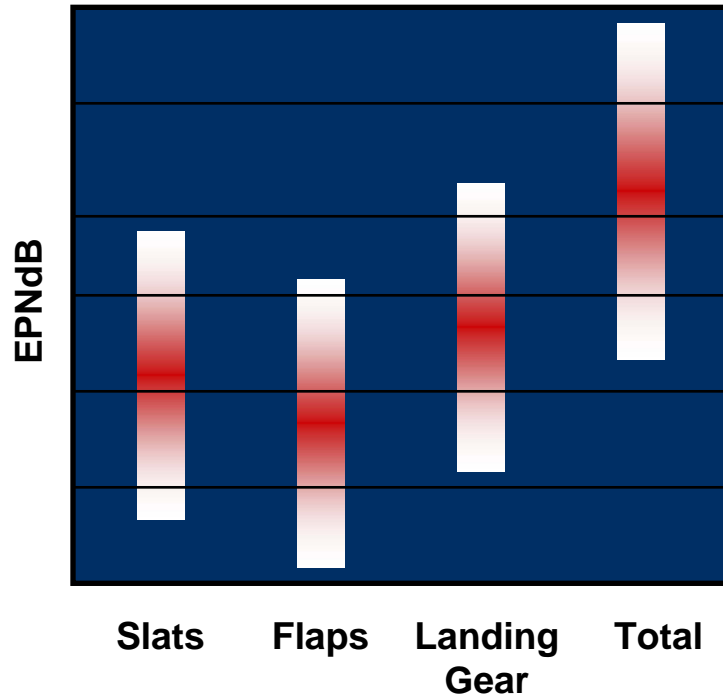
Evaluation of Improvement:

- 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

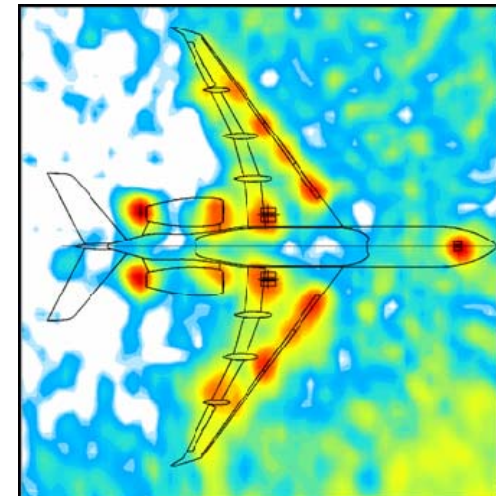
Green Aviation Research and Development Network (GARDM) Airframe Noise Reduction Project

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



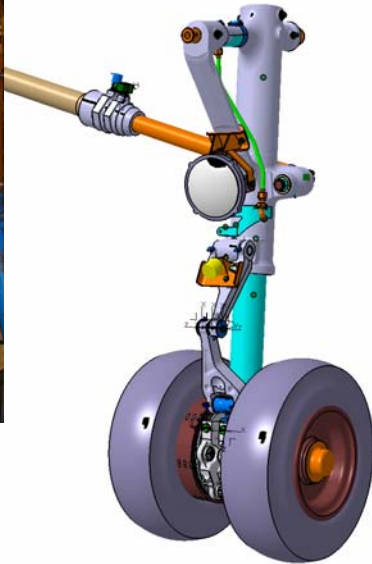
BOMBARDIER
Global Express

Ref.: 12th Annual
CASI Aerodynamics
Symposium, 2007



BOMBARDIER

GARDN Airframe Noise Reduction Project – Landing Gear



Scale testing – 2010-2011



Full Scale testing – 2012



- 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

NRC-CMRC

ONERA
THE FRENCH AEROSPACE LAB

Messier-Dowty
SAFRAN Group

BOMBARDIER

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:

SMART Intelligent Systems	<ul style="list-style-type: none">▪ Integrated and intelligent systems▪ Air transport system optimization▪ Enhanced passenger comfort
AFFORDABLE Initial and Operating Cost	<ul style="list-style-type: none">▪ To build: design, manufacturing and materials▪ To operate: reduced fuel consumption, maintenance and navigation fees
GREEN Environmentally Friendly	<ul style="list-style-type: none">▪ 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
EFFICIENT Performance and Operation	<ul style="list-style-type: none">▪ 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).**

BOMBARDIER

Conclusions



- Our first stake in the ground for the environment is the **C Series** 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.



BOMBARDIER