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Low Emission Aviation Program (LEAP)

NRC Aerospace Research Centre

CASI Ottawa
Apr. 27, 2022


MYTHBUSTERS

Myth #1: Aviation is only a small contributor to global emissions. And what we do in Canada doesn't matter.

Myth #2: We have electrified cars; it can't be that hard to electrify an aircraft.

Myth #3: Hydrogen is unsafe and can't compete with jet fuel.

AGENDA

1) Aviation and Climate Change
2) Industry Directions
3) NRC Past and Future Activities in Sustainable Aviation

Aviation currently contributes 3.5% of global climate impact.

If no action is taken, aviation's impact on climate change will grow to 10% to 25% by 2050.

Many jurisdictions are now aiming for aviation to achieve "net-zero" by 2050 in order to meet overall greenhouse gas (GHG) targets and limit temperature rise to 1.5°C.

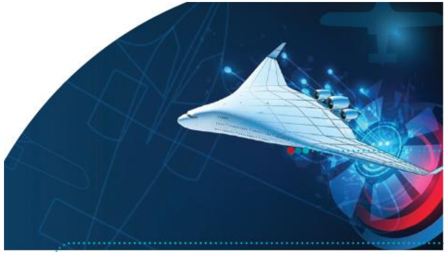
Greening Aviation – The Options

Aircraft Lifecycle Analysis

- *The "use" stage of an aircraft's life accounts for >99% of its lifecycle emissions.*

Better Operations

Advanced Airplanes



Clean Energy

Sustainable Aviation Fuels

Electrification

Hydrogen

Time Frame: **Impact (GHG reduction):**	Near-term <10%	Near-term <10%	Mid to Long-term <30%	Near-term 30-60%	Mid to Long-term 75-100%

Some Progress…

Industry directions

Some other recommended viewing:

https://gem.cbc.ca/media/great-electric-airplane-race/s01

Great success but challenges remain

NEWS

Lilium eVTOL Prototype Damaged in Fire

by Charles Alcock - February 28, 2020, 11:54 AM

The first prototype of Lilium Jet's eVTOL aircraft was badly damaged in a fire during maintenance on February 27. [Photo: Lilium Jet]

Electric plane crash-lands into lake in another setback for electric flight

Siemens electric plane prototype caught on fire in the air before crashing and killing both occupants

Eviation's Electric Alice Aircraft Catches Fire During Ground Tests

by Charles Alcock - January 24, 2020, 6:00 AM

...and has brought ...anges on Earth. We will visit several

...and has ...changes on Earth. We will visit several places of strategic interest and will discuss possible collaborations nationally. Discussion for global warming and terrorism

The Challenge for Low Emission Aviation

1) TECHNOLOGY

Aviation is the most challenging transportation sector to achieve 'Net-Zero'

- Current state-of-the-art electric propulsion systems (batteries, fuel cells, and electric systems) have energy/power densities that are a fraction of modern gas turbines powered by jet fuel.
- To maximize the benefit of new energy sources, novel aircraft configurations are also required (e.g. blended wing body, boundary layer ingestion, etc.).
- Novel technologies introduce new safety risks which need to be fully understood and appropriate safety strategies implemented before they can be adopted for widespread use. This will require new regulatory frameworks and test methods.

2) CANADIAN AVIATION INDUSTRY COMPETITIVENESS

Canadian industry competitiveness at risk as new entrants emerge

- There are many new global competitors entering the market space of electric aircraft (MagniX, Joby, Hyundai, etc.) and other nations are spending billions on hydrogen aircraft R&D.
- Canadian OEM's mainly operate in business and regional jet markets which will be the first to be electrified.
- To strengthen our position as a global aviation leader, Canada must be at the fore-front of a greener aviation industry. A lack of technology development will lead to decreased market share as the world looks to greener transportation solutions.

A Healthy Environment and a Healthy Economy

- *Meeting Canada's long-term climate objectives will also require a large transformation of the **aviation**, marine, and rail sectors out to 2050.*
- *Make strategic investments to strengthen Canada's **green aviation** leadership position.*

\- Government of Canada (Dec. 2020)

	State of the Art		Need for Larger Aircraft
BATTERY	~170 Wh/kg	x4	>700 Wh/kg
MOTORS	~2.5 MW & 5 kW/kg	x2	>5 MW & 13 kW/kg with >98% efficiency
SAF	~$5/L	÷5	~$1/L
Non-Conventional Aircraft (e.g. BLI, DEP)	Lab-scale demo		Flight demonstrators
H2 STORAGE EFFICIENCY (mass of fuel / total mass of tank + fuel)	~14.5% (liquid)	x2	>35%

NRC AEROSPACE
THE PAST AND THE FUTURE

Sustainable Aviation at NRC – The past decade

2012

World's first flight on 100% Sustainable Aviation Fuel (SAF)

2014

Participation in NASA ACCESS II SAF contrail flights (multiple NRC campaigns followed)

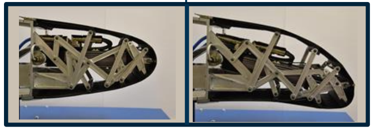
2015

Collaboration started with National Jet Fuel Combustion Program (NJFCP) for faster approval of SAF

2018

Low-pressure hydrogen combustion experiments

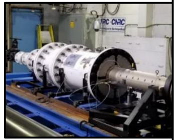
2019

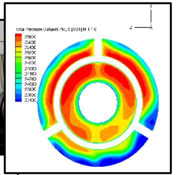


Morphing wing technology developed

2020

Boundary Layer Ingestion scaled experiments





2021

Hybrid-Electric Research Outfit (HERO) Commissioned

Hybrid Electric Aircraft Testbed (HEAT) Developed

Leap forward

Low Emission Aviation Program (LEAP)

Vision

To accelerate the transition to “Net-Zero” for Canada’s aviation industry and strengthen our position as a clean tech leader.

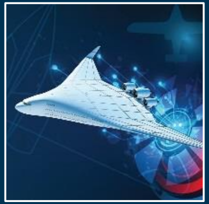
Goals

1) Rapidly develop market-ready solutions and de-risk potential high impact technologies.

2) Establish a collaborative ecosystem that will stimulate Canadian industry’s transition towards low emission aviation.

3) Support other government departments in development of policies by providing science-based recommendations.

NRC Low Emission Aviation Program (LEAP) Focus Areas



Master Project 1: Aircraft Technology Integration

- Develop, evaluate, and integrate low emission technologies safely into aviation applications.

Master Project 2: Electrical Systems

- Advancement of technologies of the electric engine to improve its performance and reliability as well as methods for integration in the aircraft, testing and certification.

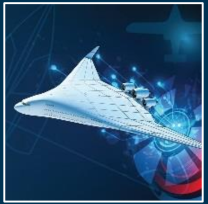
Master Project 3: Hydrogen Technologies

- Hydrogen storage solutions.
- Fuel cell systems for aircraft propulsion and power.
- H_2 safety strategies and regulatory compliance for airborne applications.
- Hydrogen and low carbon fuels for combustion in aircraft gas turbines.

Master Project 4: Battery Safety

- Advancement of safety and suitability of battery technologies to enable aircraft electrification.

NRC Low Emission Aviation Program (LEAP) Focus Areas



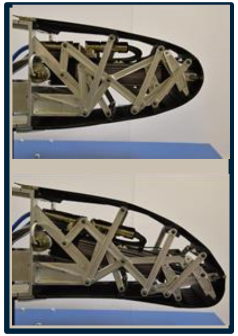
Master Project 1: Aircraft Technology Integration

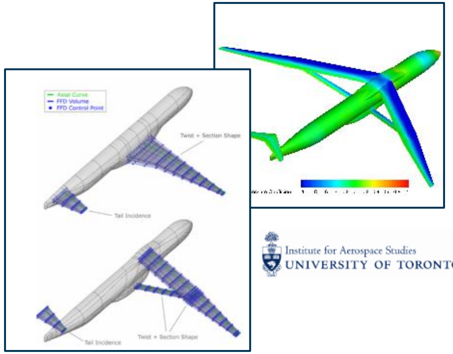
- Develop, evaluate, and integrate low emission technologies safely into aviation applications.

Technology Performance Assessment

Next Generation Aircraft Configurations

Technology Demonstrators





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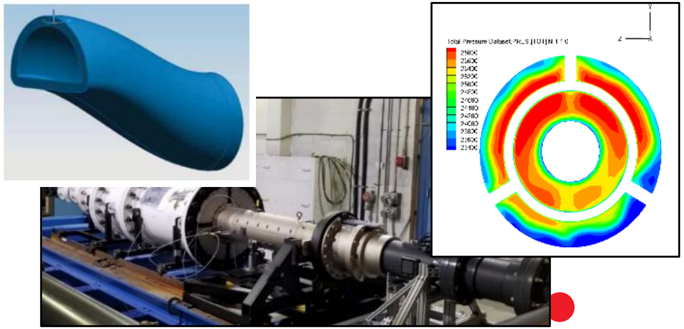


Lessons Learned from Small Aircraft Electrification

A real-world example: NRC Hybrid Electric Aircraft Testbed (HEAT)

Conversion of rear engine to battery-electric

*Estimated values. Real values will be shown in future publications.	Internal Combustion Engines (x 2)	Hybrid (ICE + battery electric)
Occupancy	6	2
Endurance	~ 6-8 hrs	~0.7 hrs
Useful Load (a.k.a. the pilots)	1925 lbs	~ 400 lbs
Propulsion System Efficiency (through operational profile)	~20-30%	~90% (for EPS)

- **Battery energy density** LOW compared to internal combustion engine
- **Battery & High Voltage Safety** is a challenge (do not underestimate the risks)
- **EV automotive components** <u>not suitable</u> for aviation operating environment
- **Multi-disciplinary team** with non-traditional aerospace capabilities.
- **Training** for next generation needed (university level)
- **Means of Compliance** for certification (industry challenge)

Still work to do…

NRC Low Emission Aviation Program (LEAP) Focus Areas

Master Project 2: Electrical Systems

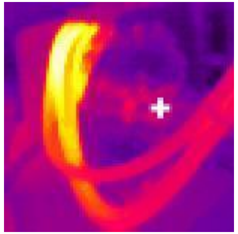
- Advancement of technologies of the electric engine to improve its performance and reliability as well as methods for integration in the aircraft, testing and certification.

Hybrid-Electric Demonstrations

Reliability, Safety and Certification

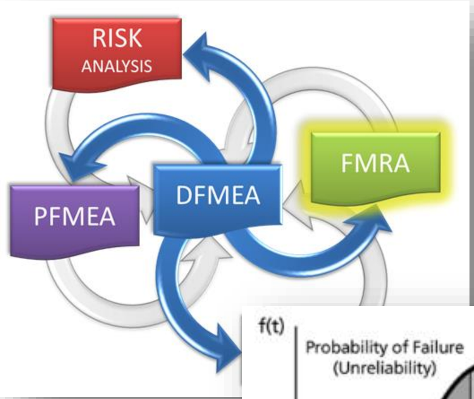
Technology Advancement

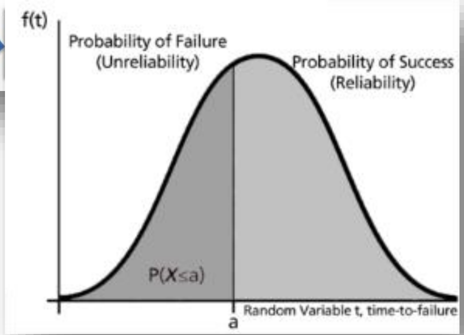




Challenges of Electrification for Aviation

We have electrified cars; it can’t be that hard to electrify an aircraft.





Reliability Aspects (New Technologies/Certification)

Weight

Altitude

NRC Hybrid Electric Research Outfit (HERO) Video

Conversion of a legacy combustion test cell to a pilot-scale electric propulsion test facility.

NRC Low Emission Aviation Program (LEAP) Focus Areas

Master Project 3: Hydrogen Technologies

- Hydrogen storage solutions.
- Fuel cell systems for aircraft propulsion and power.
- H_2 safety strategies and regulatory compliance for airborne applications.
- Hydrogen and low carbon fuels for combustion in aircraft gas turbines.

Hydrogen Storage and Distribution for Airborne Applications

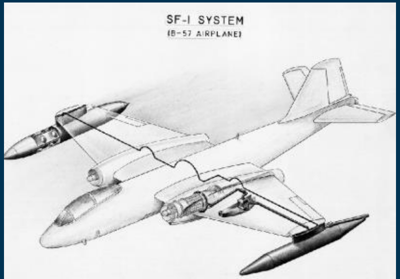
Hydrogen Safety Systems and Regulatory Considerations for Airborne Applications

Fuel Cell Propulsion and Power Generation for Airborne Applications

Hydrogen Combustion Technology for Airborne Applications

Several examples on feasibility of hydrogen flight

1957 — 1988 — 2008 — Future



Martin B-57B Canberra Bomber

A B-57B twin engine bomber, powered by Curtiss Wright J-65 turbojet engines. The aircraft would take off using jet fuel, switch to liquid hydrogen while over Lake Erie, then after burning the hydrogen supply switch back to jet fuel for the landing. The test flight, in February 1957, was successful.

Tupolev Tu-155

The Tupolev Tu-155 is a modified Tupolev Tu-154, which was used as an alternative fuel testbed. The Tu-155 first flew on April 15, 1988 using liquid hydrogen. The Tu-155 flew ~100 flights until it was placed in storage.

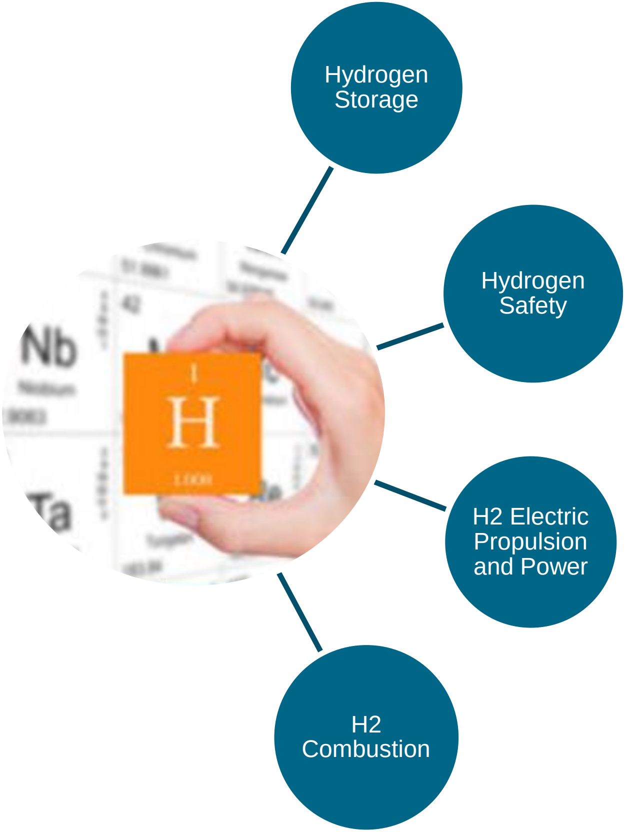
The Boeing Fuel Cell Demonstrator

Boeing converted a 2-seat Diamond DA20 to hydrogen fuel cells. It achieved straight-level flight on April 3, 2008

Alaka'i Skai - eVTOL

Airbus ZeroE Concepts

Hydrogen Technologies – Why H_2?



Hydrogen Gravimetric Density:

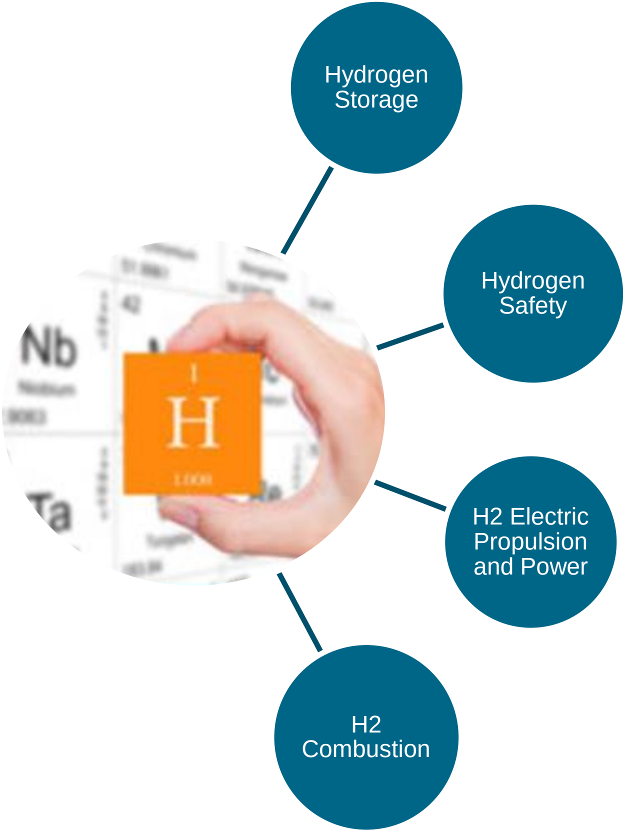
- Almost 3X specific energy of jet fuel (but 4X more volume needed)
- Potential for higher efficiencies energy conversion (FCs eff. >> engine eff.)
- Lower charging times (relative to batteries)
- Potential option for larger aircraft (largest polluters)

'Cleaner' fuel:

- Zero-carbon emissions: $H_2 + O_2 \rightarrow H_2O$

(however, total lifecycle and other emissions need to be assessed)

Hydrogen Technologies - Challenges



Hydrogen Storage:

- Storage Efficiency (GH2: 5.7%, LH2: 10 – 55%?)
- GH2 vs LH2 storage systems (state specific challenges)
- Refueling (thermal, material, fueling rates, purging)
- Crashworthiness, aviation environment

Hydrogen Safety:

- Pressure relief, leaks, and boil-off management (LH2)
- H_2 compatibility (permeability, embrittlement)
- Material fatigue / failure (H_2 induced cracking, thermal)
- Codes, Standards, and Regulations (CSRs)

H_2 Electric Propulsion and Power:

- Fuel Cell (FC) system specific power (incl. BOP)
- FC operation at altitude
- Thermal management (e.g. 50-60% FC system efficiency)
- FC degradation in aviation environment

H_2 Combustion:

- Acoustic instability, auto-ignition, and flashback
- Turbine materials
- Emissions (contrails & NOx)

NRC Low Emission Aviation Program (LEAP) Focus Areas

Master Project 4: Battery Safety

- Advancement of safety and suitability of battery technologies to enable aircraft electrification.

Battery Performance

Battery Health Monitoring

Thermal Management

Certification

Advanced Battery Technology

Battery Safety Strategy Validation Test

What Does an Aviation Propulsion Battery Look Like?

Li-Ion cells all produce ~4.1V. Series adds voltage, parallel adds capacity

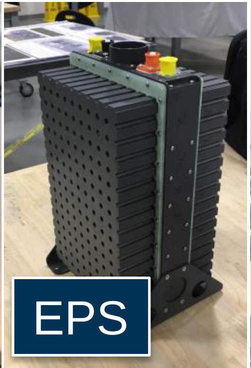
Cells have various form factors: cylindrical, prismatic, pouch

Modules stack multiple cells; Packs from modules

Pack burden includes: connections, structure, thermal management, sensors, thermal runaway mitigation

H55

H55



EPS

NRC

What is Thermal Runaway and Can it be Managed?

Thermal Runaway (TR) is an exothermic reaction (burning) of the battery that is accelerated by increased temperature

TR can be managed, and has been managed. The challenge is to make it more weight and volume efficient

NRC developed a thermal runaway risk mitigation system for the HEAT aircraft

Segregate battery sub-systems

Contain and vent combustion products outside

Accommodate pressures and temperatures

Top: NRC system destructive validation
Bottom: Component validation

Will take a multi-sectoral approach with all stakeholders involved (fuel/electricity producers, airports, regulators, OEMs, etc.).

October 9, 1903 *NY Times predicted it would take 1 million to 10 million years for machine flight.*

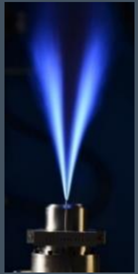
December 17, 1903 *Wright Brothers first successful flight.*

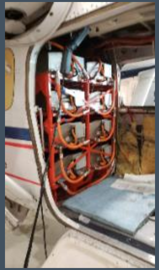
Mythbusted? ☺

International Society for Air Breathing Engines

https://conference.isabe.org/

Early bird discounted pricing available until July 31st.
Student discounts available.



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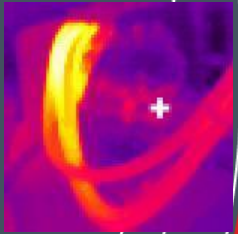



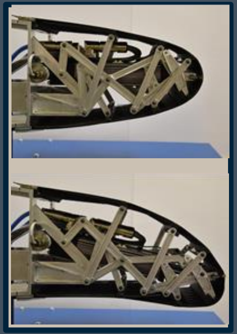
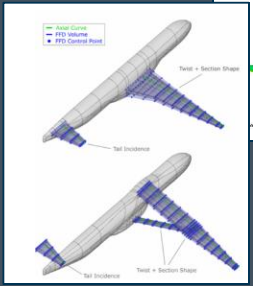
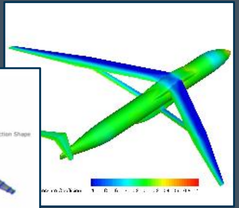

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