Advanced Gas Turbines

R&D FOR SUSTAINABLE AVIATION AND POWER GENERATION

Virtual Congressional Briefing
Wednesday, March 23, 2022

Introduction and Moderator:

Dr. Nateri Madavan
Deputy Director, Transformative Aeronautics Concepts Program
Aeronautics Research Mission Directorate
National Aeronautics and Space Administration (NASA)

Introduction

- Why are gas turbines so important?
  - Indispensable to aviation, power generation, and other industry sectors
  - Power nearly all global aviation (civil and military) and deliver 40% of U.S. electricity
  - Critical to U.S. economy, national security, energy transition, and environmental goals
- Why investments in gas turbine R&D are critically needed?
  - Maintain U.S. competitiveness and leadership
  - Deliver economic impact (manufacturing, exports, high-skilled jobs)
  - Address national sustainability and decarbonization goals
- What is the best path forward for gas turbine R&D ?
  - Public-private partnerships across government, industry, and academia
  - Accelerate technology maturation
  - Build the workforce of tomorrow

Briefing Agenda

- **Primer on Gas Turbines – Concepts & Applications**
  Dr. Zoltán S. Spakovszky, Professor of Aeronautics and Astronautics; Director, Gas Turbine Laboratory
  Massachusetts Institute of Technology

- **R&D Challenges for Sustainable Aviation**
  Dr. Sean Bradshaw, Fellow, Sustainable Propulsion, Pratt & Whitney

- **R&D Challenges for Power Generation**
  Guy DeLeonardo, Executive Product Manager, GE Power & Water

- **Advancing Technology and Workforce Development**
  Dr. Karen Thole, Distinguished Professor, Department of Mechanical Engineering
  Pennsylvania State University

- **Wrap-up and Q&A**
  Dr. Nateri Madavan, Deputy Director, Transformative Aeronautics Concepts Program,
  NASA Aeronautics Research Mission Directorate

ASME GAS TURBINE TECHNOLOGY GROUP

Zolti Spakovszky, MIT / Chair ASME GTTG

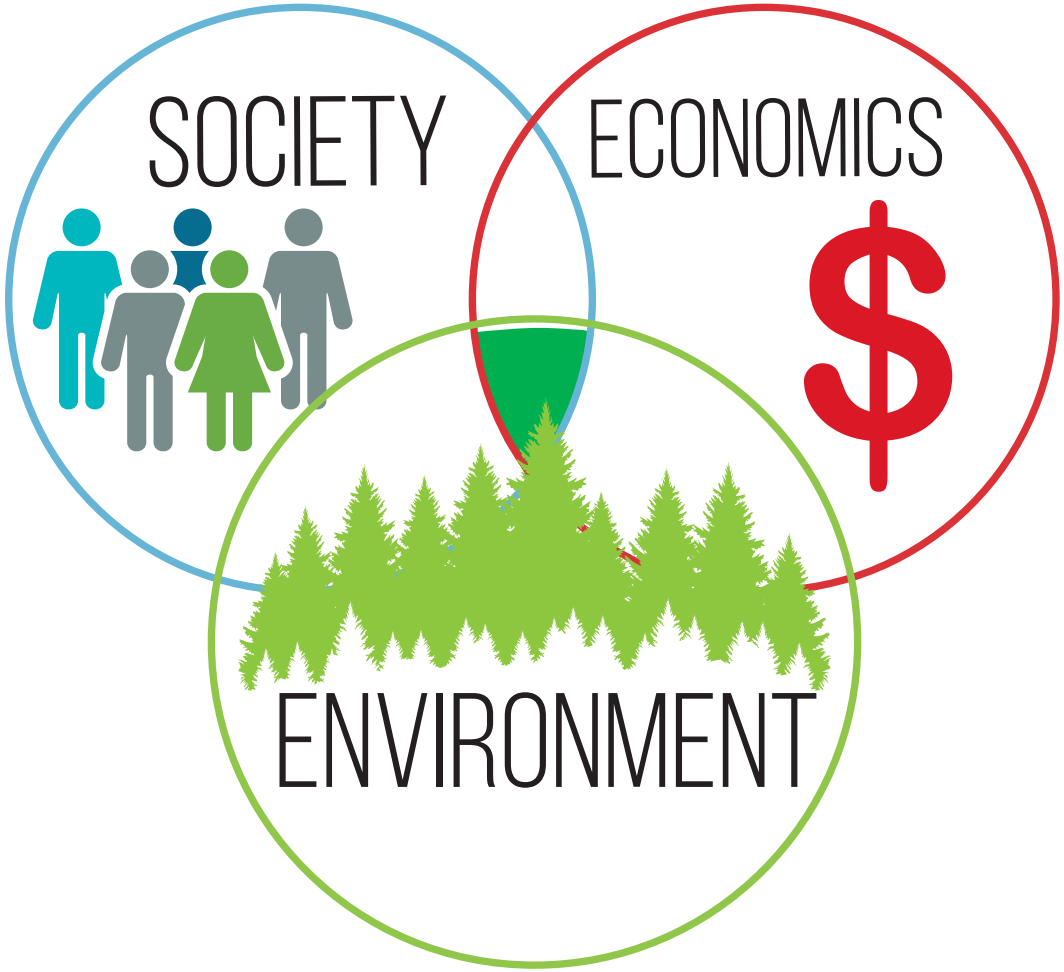
"The world's leader and champion of innovative gas turbine technologies powering a sustainable way of life."

Our mission is to advance **clean, reliable,** and **affordable gas turbine technologies** by:

- building a global technical community for knowledge sharing and collaboration,
- inspiring the next generation of engineers and technologists,
- fostering and promoting innovation, thought leadership, and professional development

ASME
SETTING THE STANDARD

SUSTAINABILITY – A GLOBAL VIEW

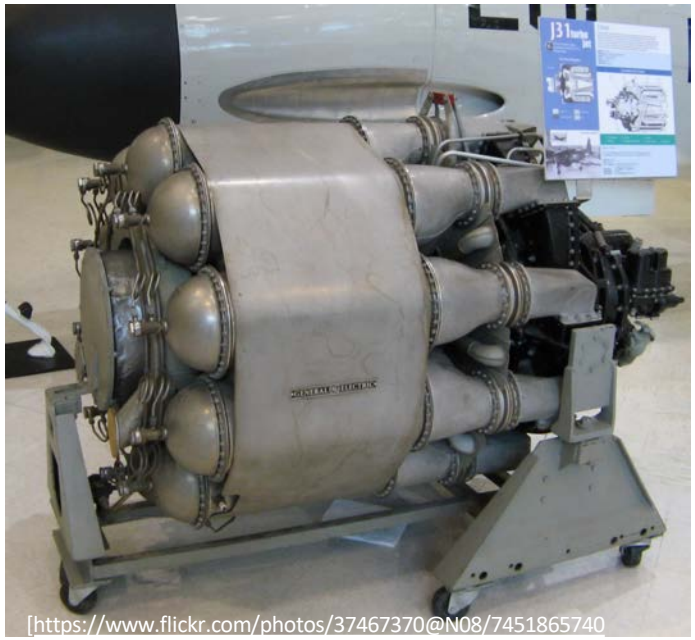


"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

- UN World Commission on Environment and Development

[slide courtesy NASA]

FIRST US GAS TURBINES FOR POWER & PROPULSION (1940s)



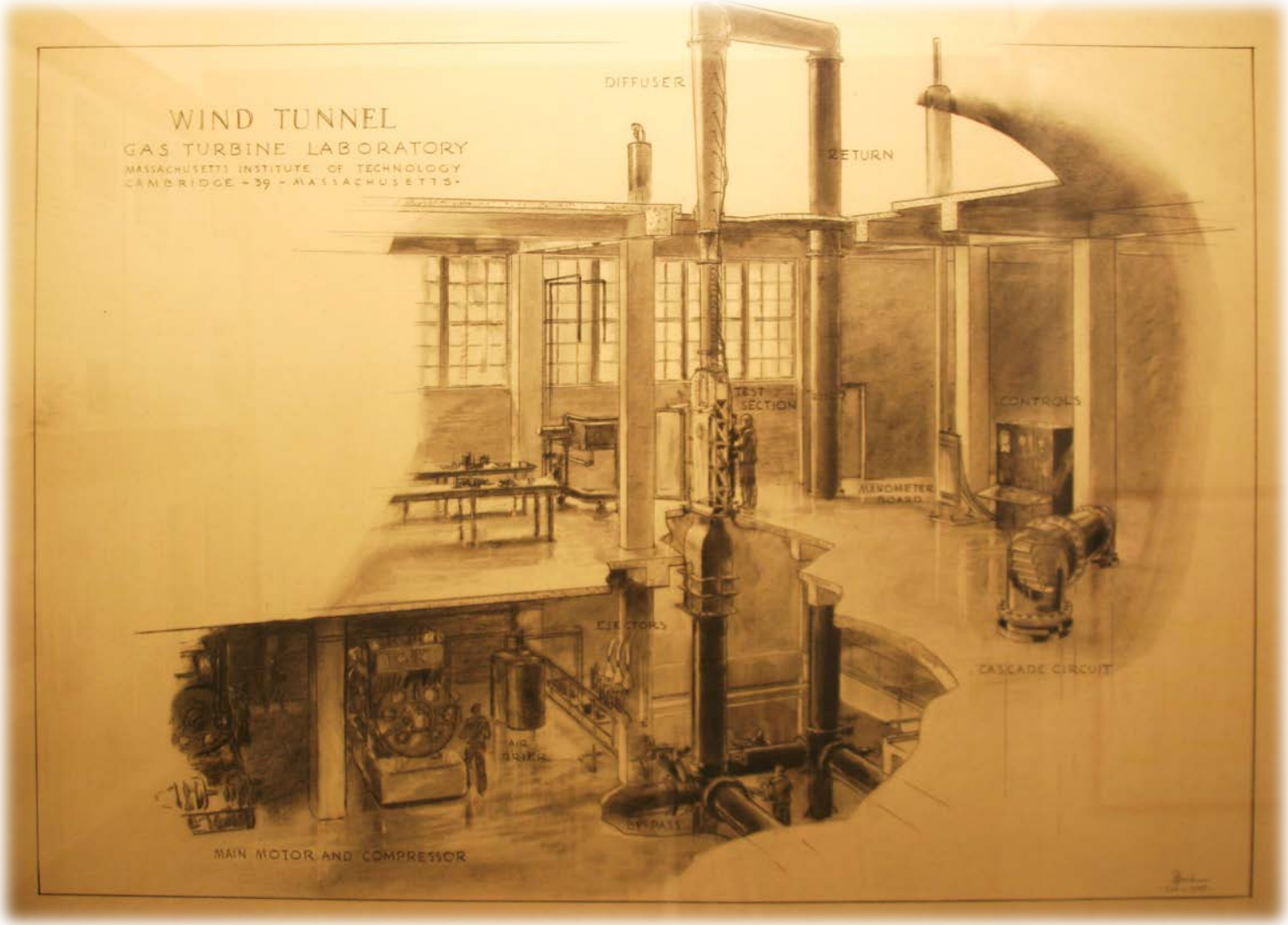
[https://www.flickr.com/photos/37467370@N08/7451865740

GE J31 (GE 1-A)


[GE]

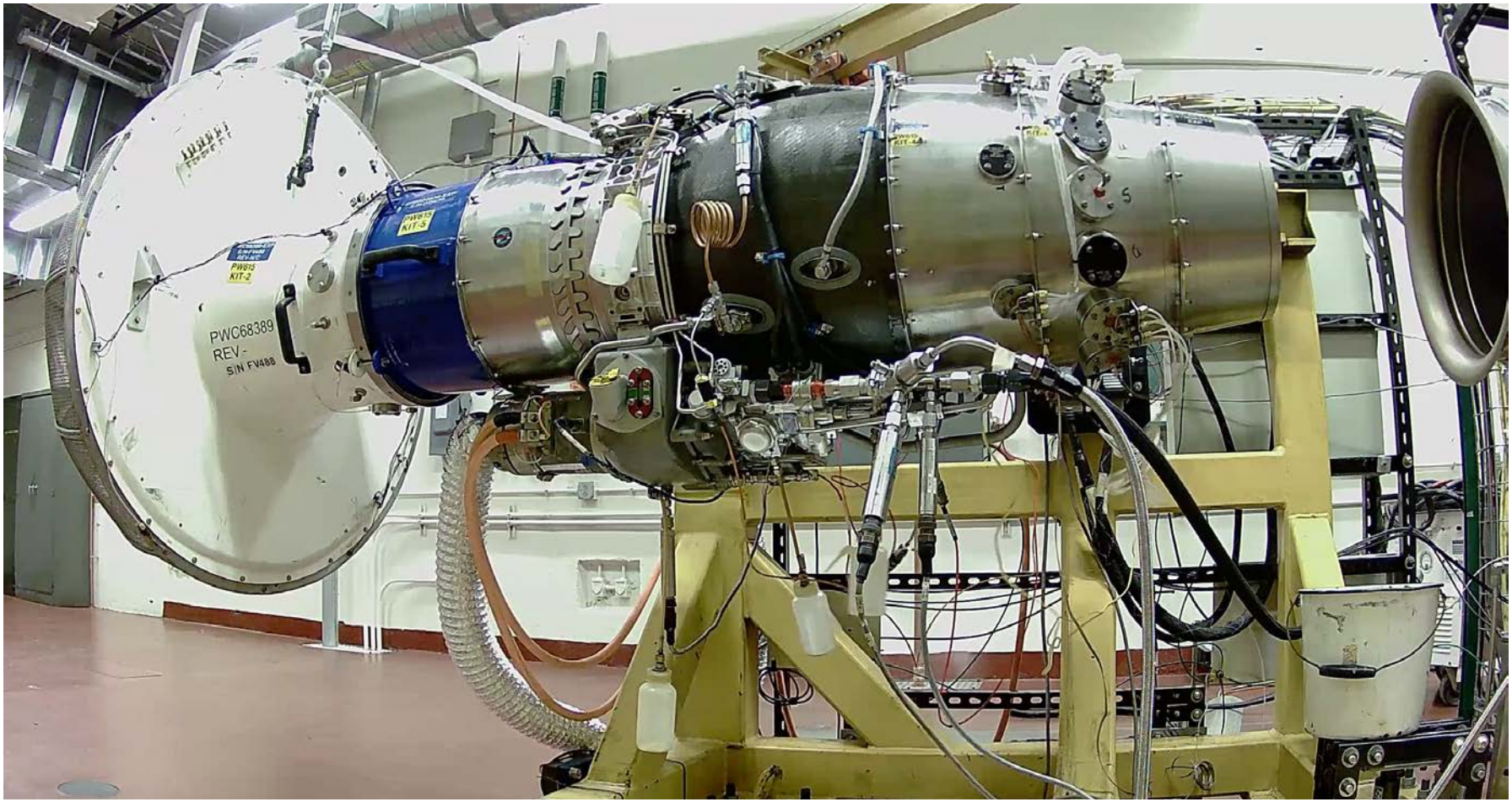
3,500 kW GT for Belle Isle Station of Oklahoma Gas and Electric Co.

FIRST US LABORATORY FOR RESEARCH AND INSTRUCTION IN GAS TURBINES (1947)

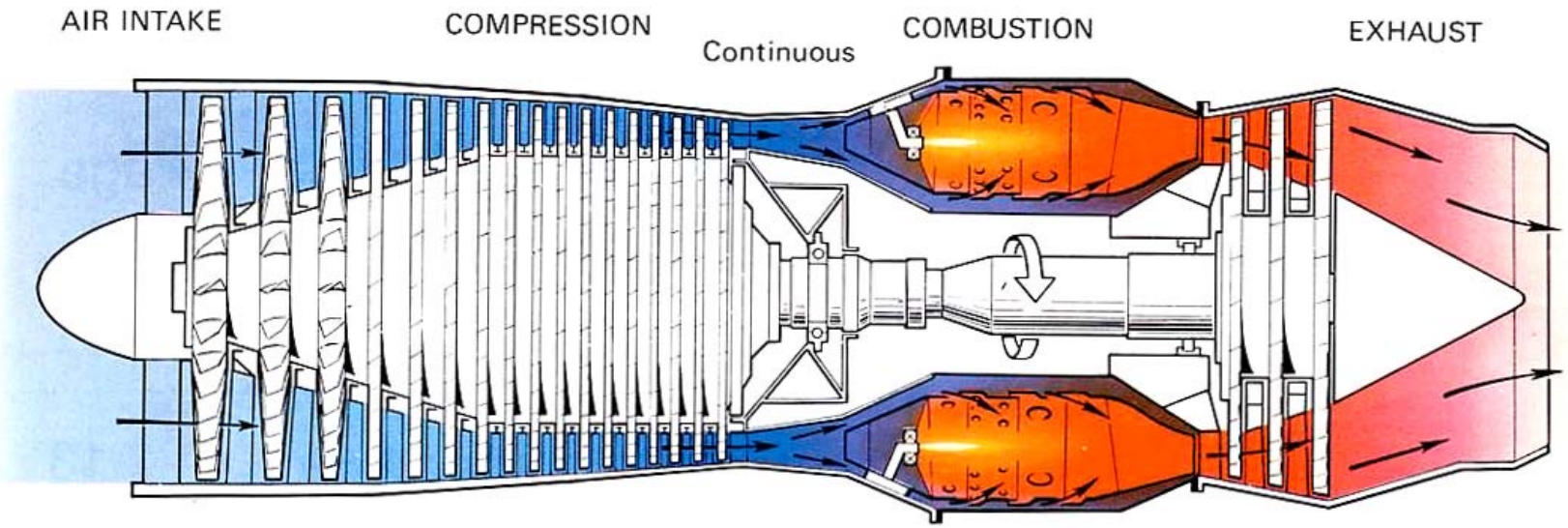


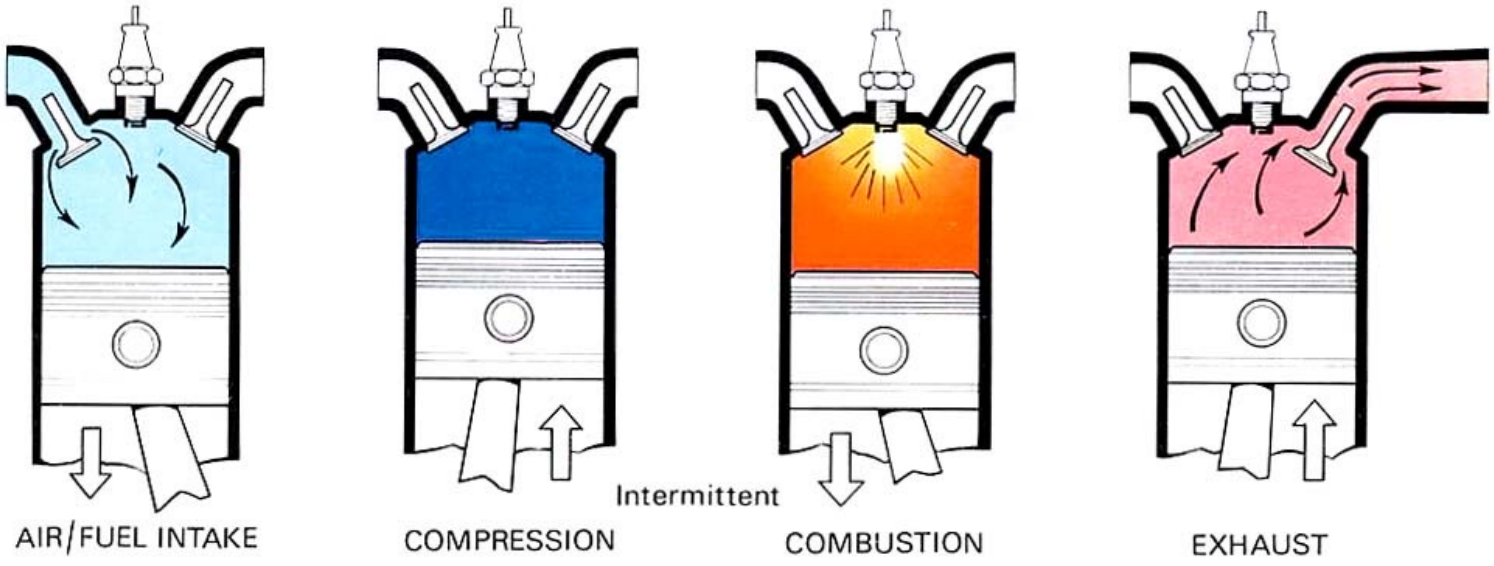
MIT Gas Turbine Laboratory

75 YEARS OF RESEARCH AT THE MIT GAS TURBINE LABORATORY



GAS TURBINE WORKING PRINCIPLE

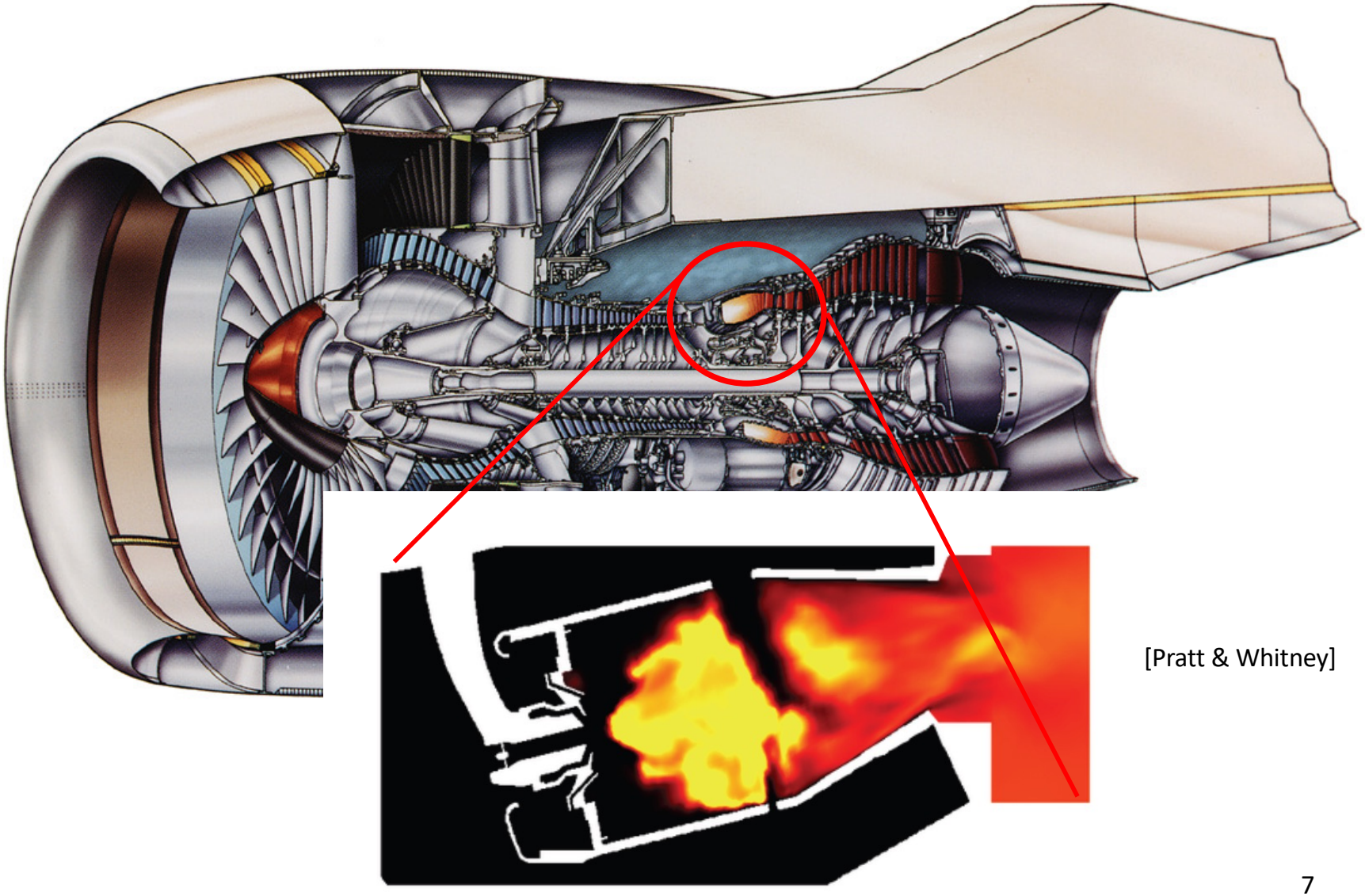




[Rolls-Royce]

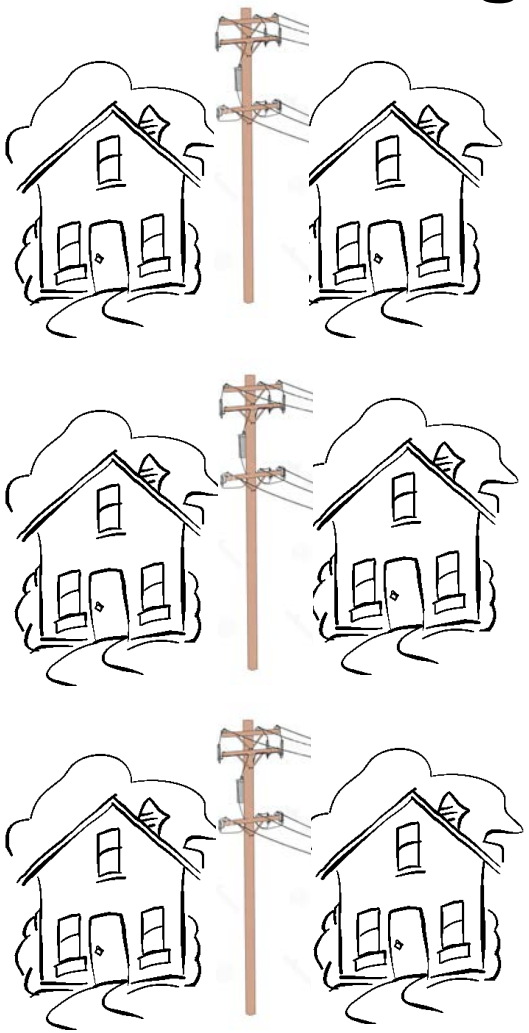
THE GAS TEMPERATURE AT COMBUSTOR EXIT EXCEEDS THE METAL MELTING TEMPERATURE

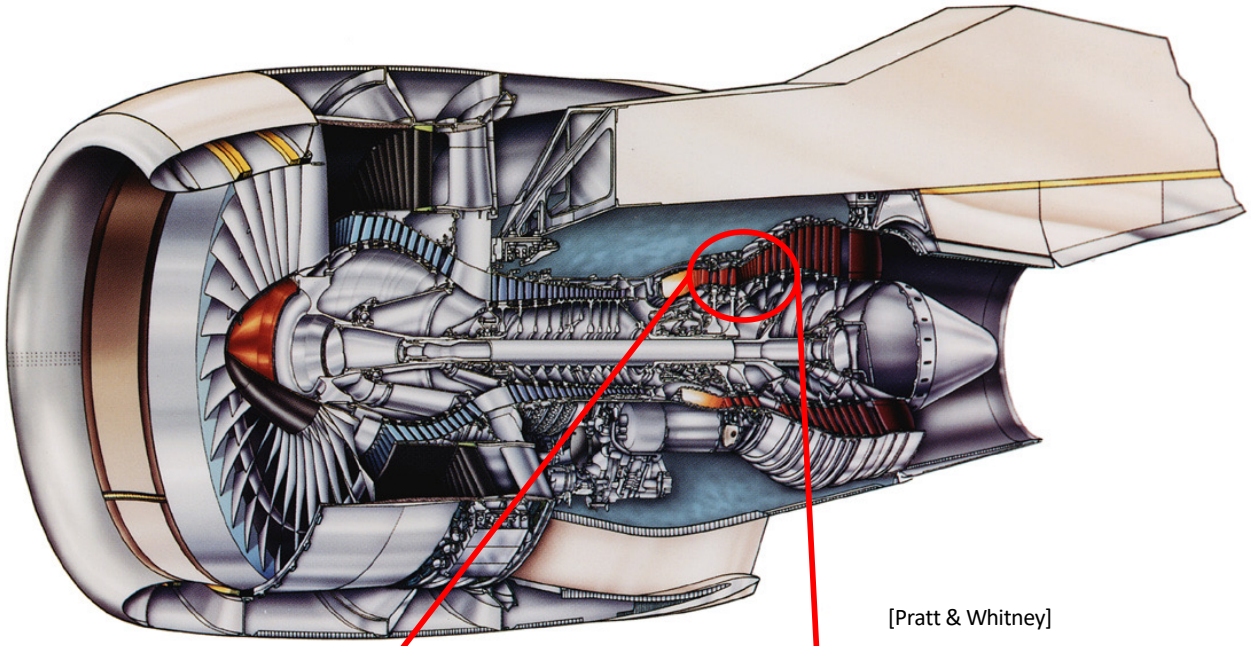
Gas Temperature > 2800 F



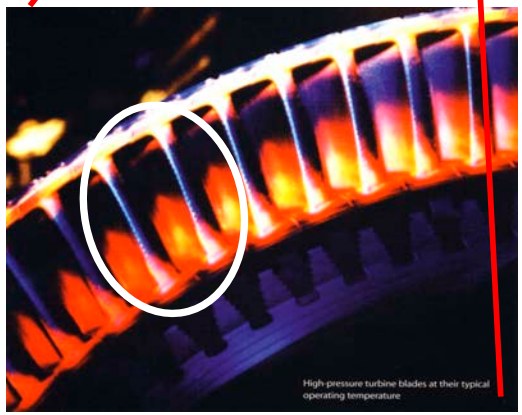
[Pratt & Whitney]

THE HEAT FLUX IN ONE TURBINE BLADE IS EQUIVALENT TO THE ELECTRIC POWER USAGE OF A CITY BLOCK



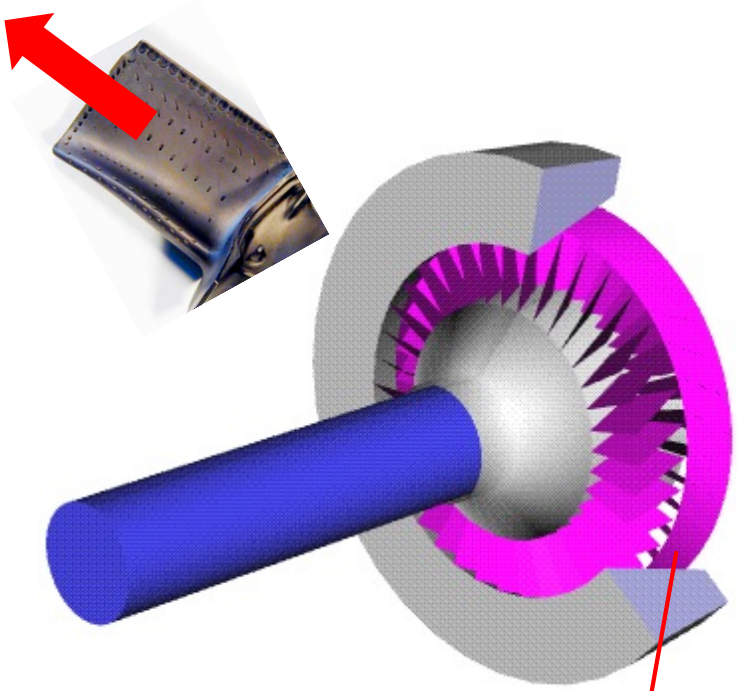


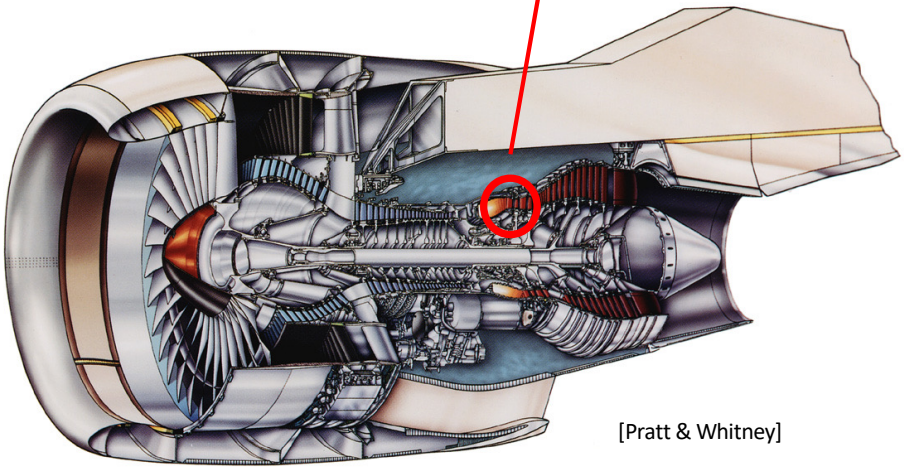
[Pratt & Whitney]



THE CENTRIFUGAL FORCE OF ONE TURBINE BLADE EQUALS THE WEIGHT OF 6 SPORTS CARS

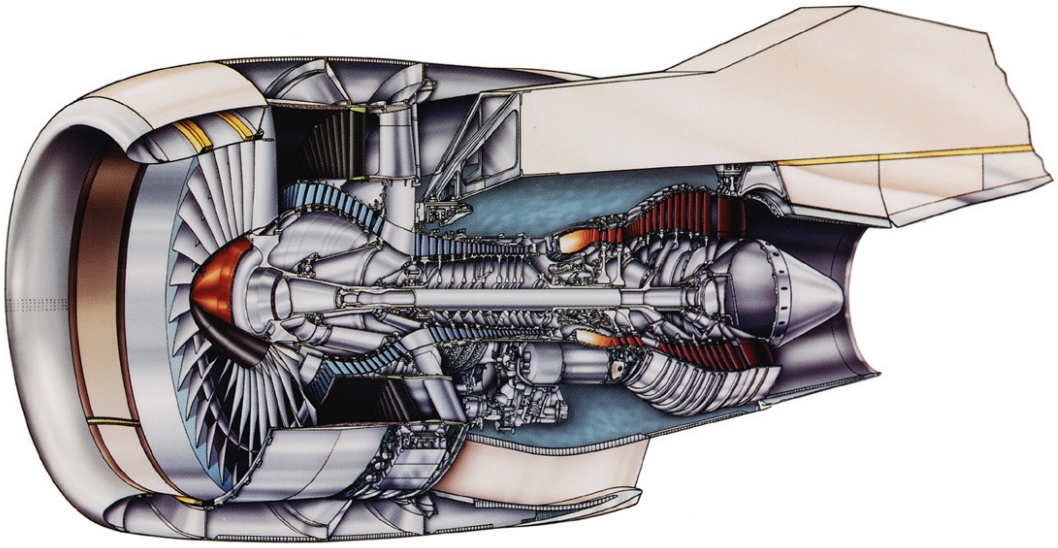
[Ferrari]





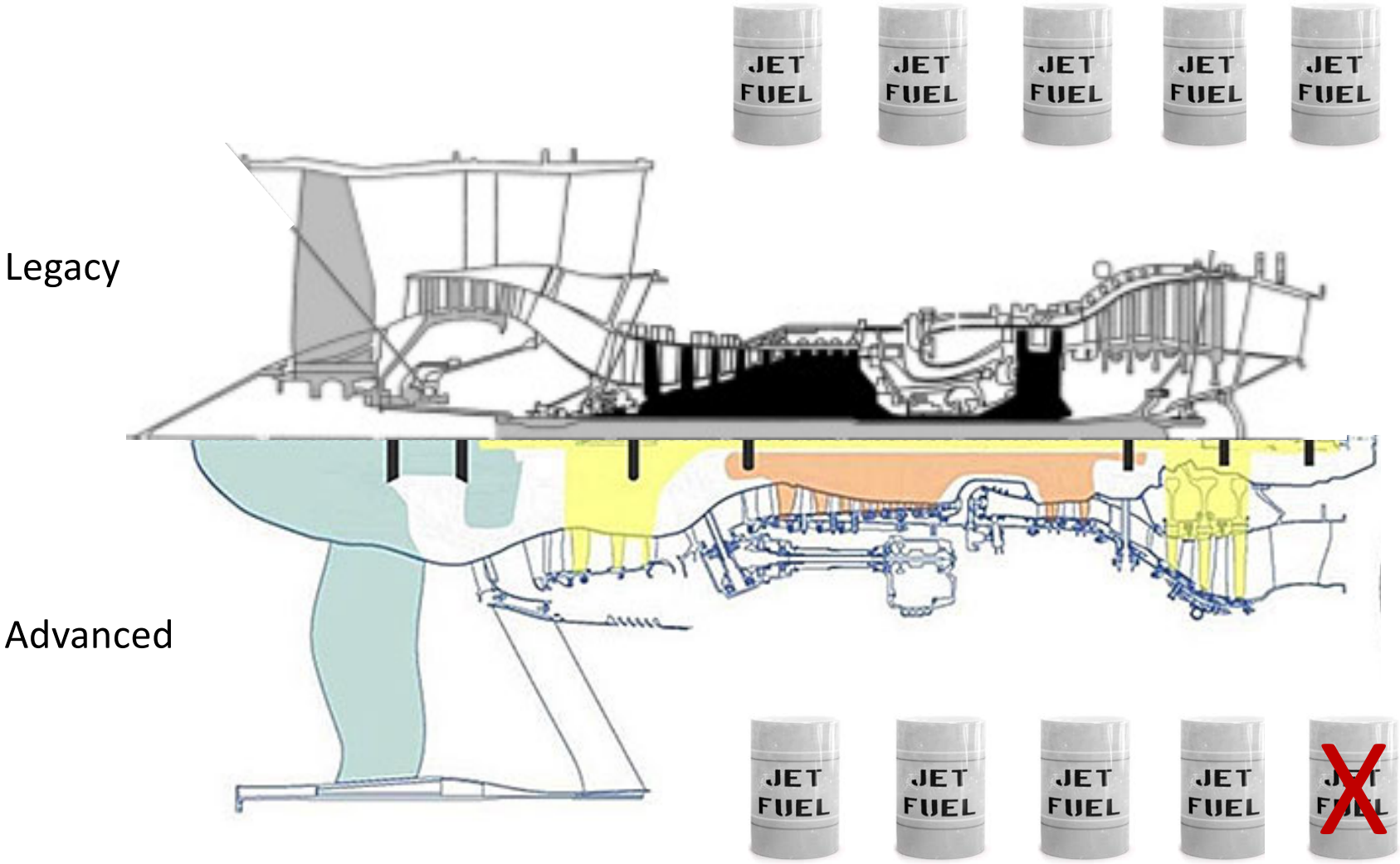
[Pratt & Whitney]

A GAS TURBINE AERO-ENGINE CAN SUCK THE AIR OUT OF A LARGE HOUSE IN LESS THAN 1 SECOND



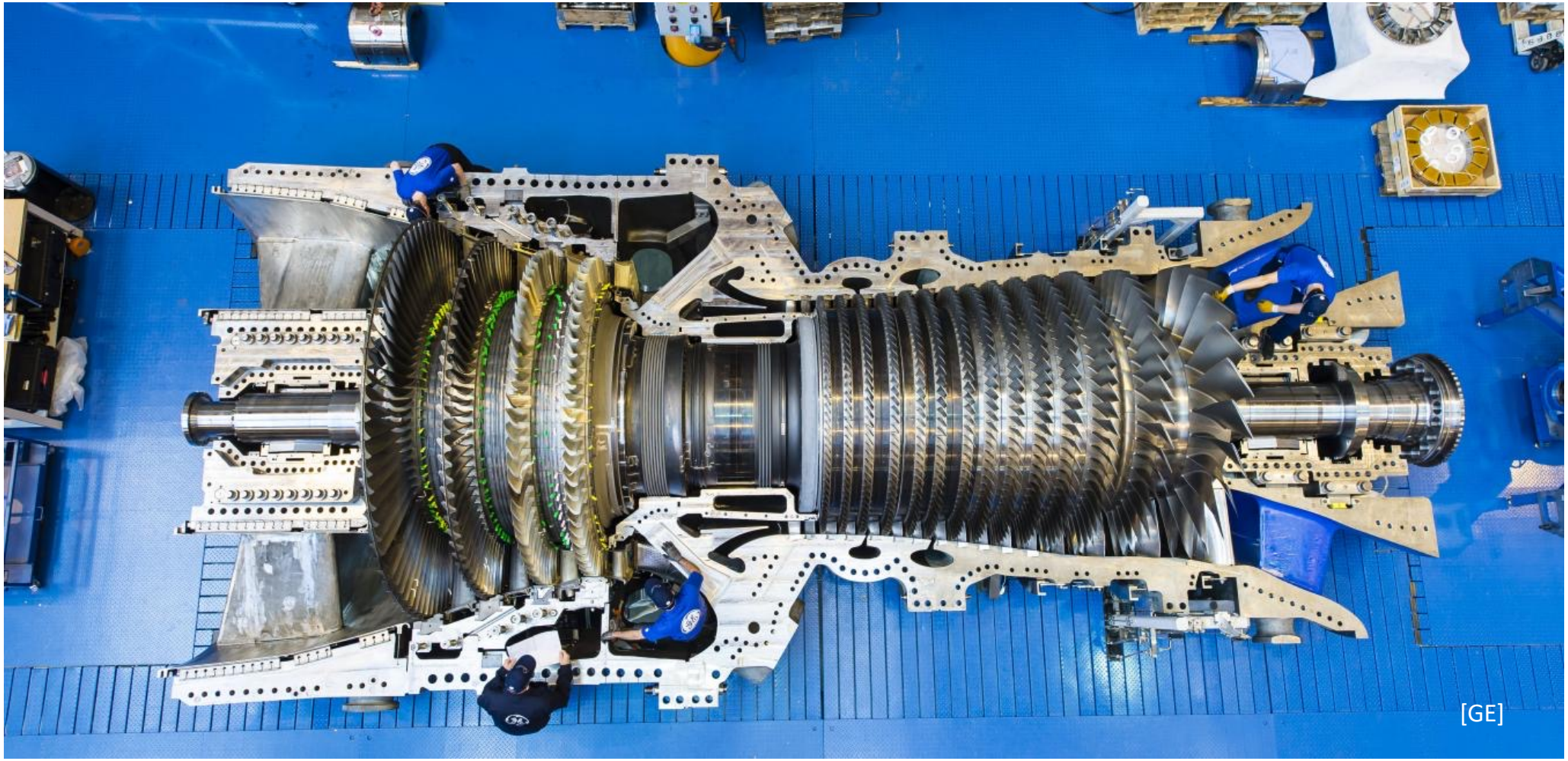
[Pratt & Whitney]

ADVANCED TURBOFAN ENGINES CAN YIELD UP TO 20% REDUCTION IN FUEL BURN / EMISSIONS



[adapted from Spakovszky 2021]

GAS TURBINES FOR POWER GENERATION

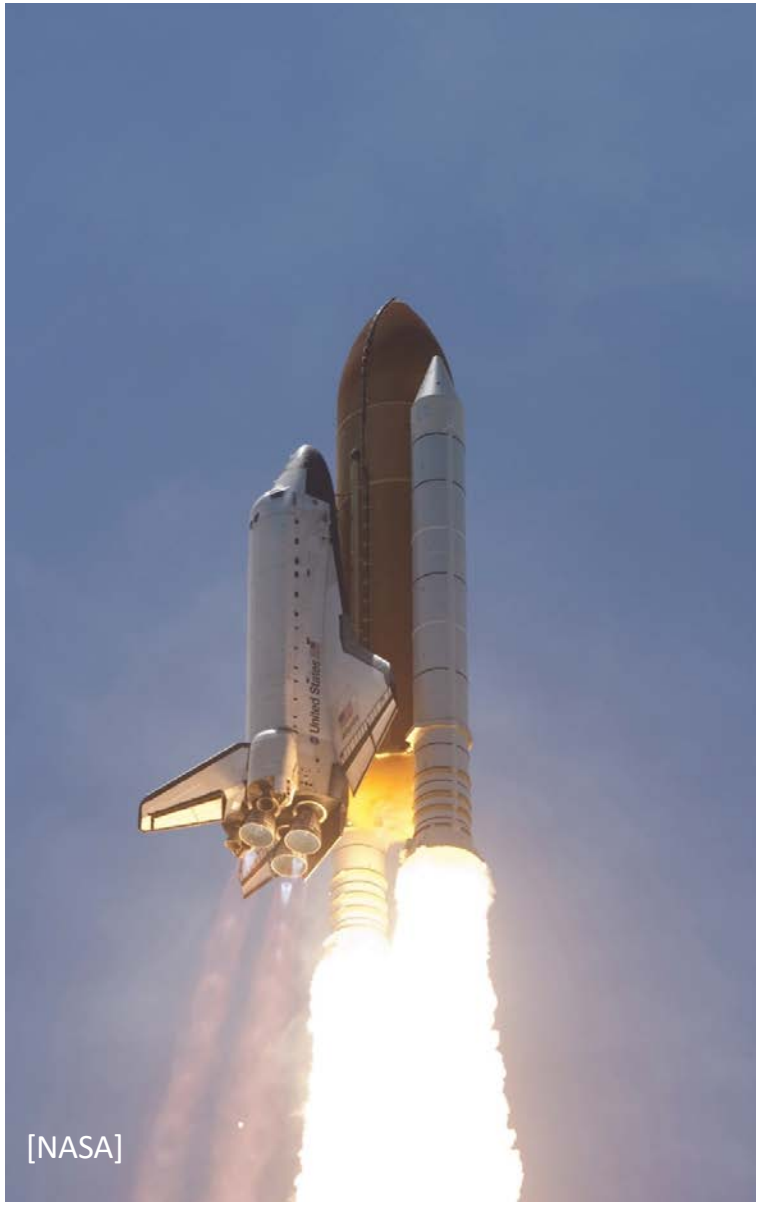


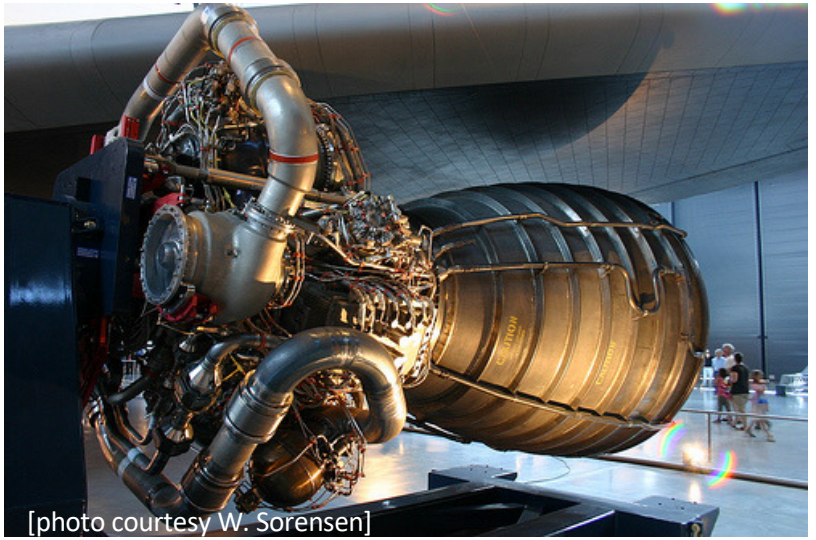
GAS TURBINES FOR MARINE APPLICATIONS


[GE]


[superyachtsnews.com]

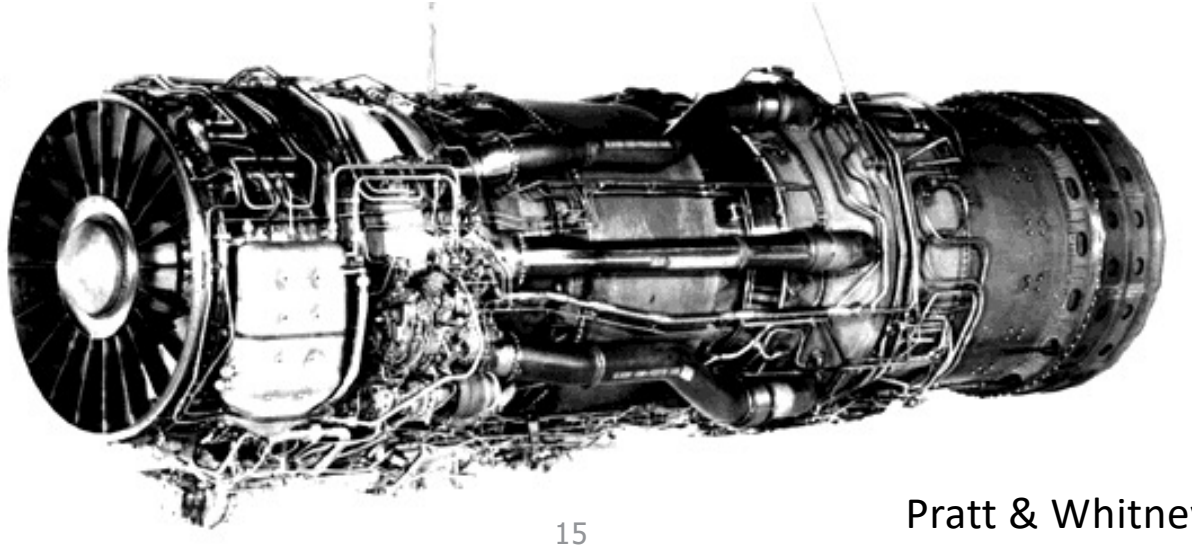
GAS TURBINES IN SPACE PROPULSION


[NASA]


[photo courtesy W. Sorensen]

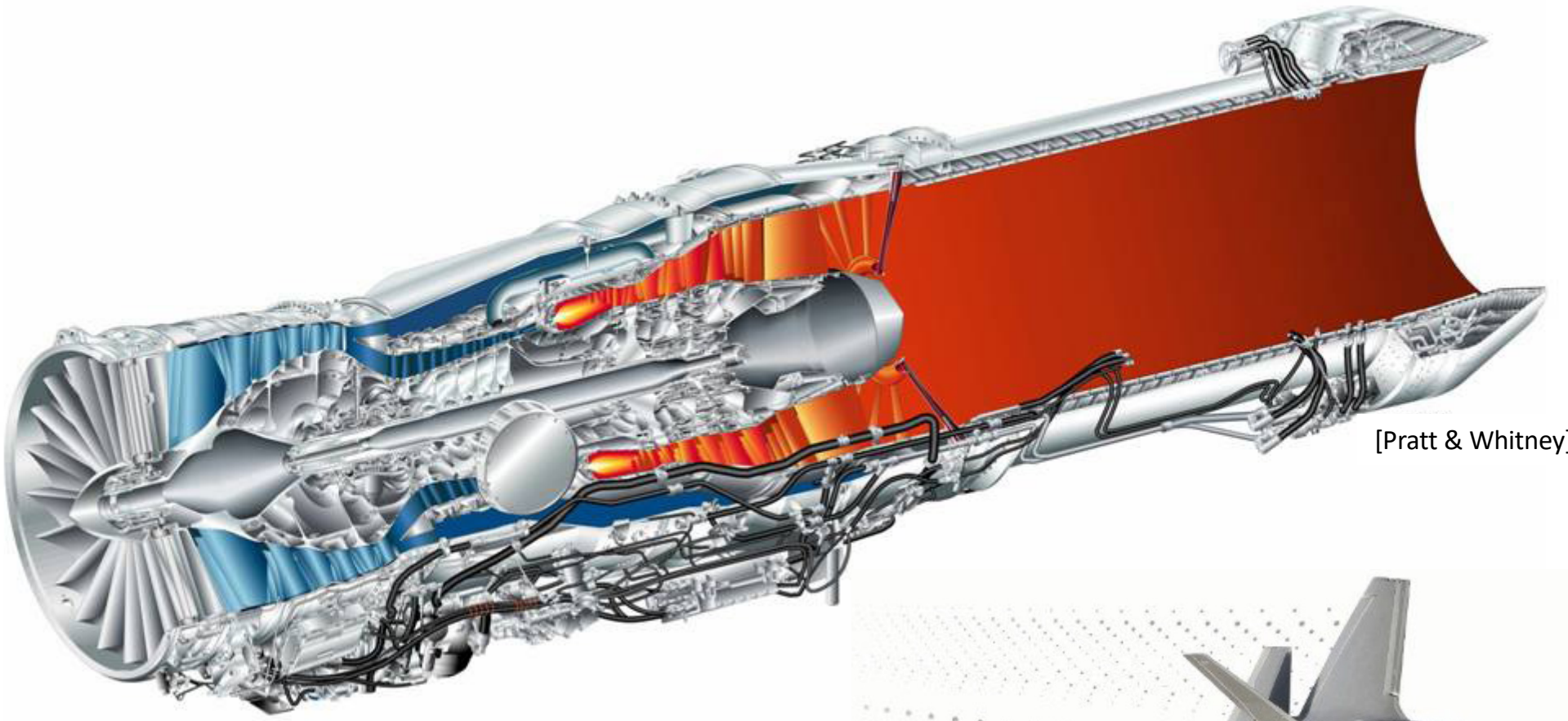

[PW Rocketdyne]

GAS TURBINE AERO-ENGINE FOR THE WORLD'S FASTEST AIRCRAFT
(Mach 3.2)



Pratt & Whitney J58 (JT11D-20)

THE WORLD'S MOST ADVANCED FIGHTER AIRCRAFT ENGINE



[Pratt & Whitney]

[Lockheed]

THE WORLD'S LARGEST GAS TURBINE AIRCRAFT ENGINE

[GE]

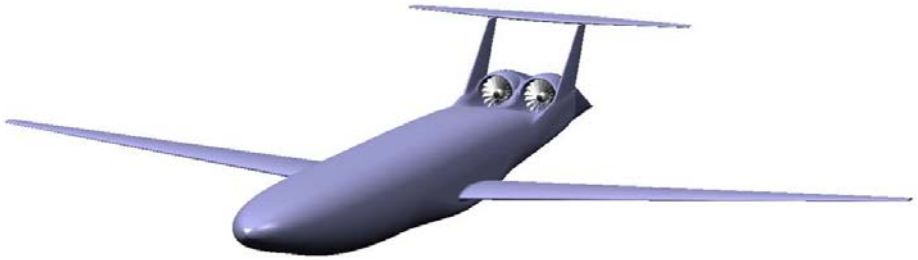
GAS TURBINES TRANSFORMING AVIATION FOR A SUSTAINABLE FUTURE

[AvWeek]

ASME
SETTING THE STANDARD

OUTLOOK & FUTURE OPPORTUNITIES

Integrated Propulsion Systems Potentially Yield > 50% Reduction in Fuel Burn / Emissions



[adapted from Lord et al. 2015]

Conventional Configuration

Integrated Configuration

TAKE AWAY MESSAGES

- Gas turbines provide power and propulsion in land, sea, air and space sectors
- Global aircraft engines market at $67 billion in 2021 with largest share in North America – forecast: $91 billion in 2025*
- Advanced concepts require innovation and significant R&D – drive competitiveness of US jobs
- Gas turbines continue to play critical role in achieving a sustainable future

* ["Aircraft Engines Global Market Report 2021: COVID-19 Impact and Recovery to 2030" May 2021, The Business Research Company]

ASME CONGRESSIONAL BRIEFING: R&D CHALLENGES FOR SUSTAINABLE AVIATION

SEAN BRADSHAW, PH.D.
VICE CHAIR, ASME GAS TURBINE TECHNOLOGY GROUP
FELLOW, SUSTAINABLE PROPULSION, PRATT & WHITNEY

MARCH 23, 2022

GROWTH IN AVIATION FUELS JOBS WORLDWIDE

GLOBAL AVIATION CONNECTS PEOPLE AND GROWS ECONOMIES

143 million jobs supported

$6.3 trillion in global economic impact

8.2 billion passengers

15.3 trillion revenue tonne kilometres

3.4% p/a growth
13.3m jobs
$144bn GDP

4.2% p/a growth
80m jobs
$2.1 trn GDP

2.1% p/a growth
18.6m jobs
$1.5trn GDP

3.2% p/a growth
12.5m jobs
$367bn GDP

4.1% p/a growth
6.7m jobs
$517bn GDP

2.1% p/a growth
11.9m jobs
$7.1trn GDP

LOW GROWTH SCENARIO

5 million
fewer jobs supported in 2038

$300 billion
less GDP supported in 2038

7.4 billion
passengers

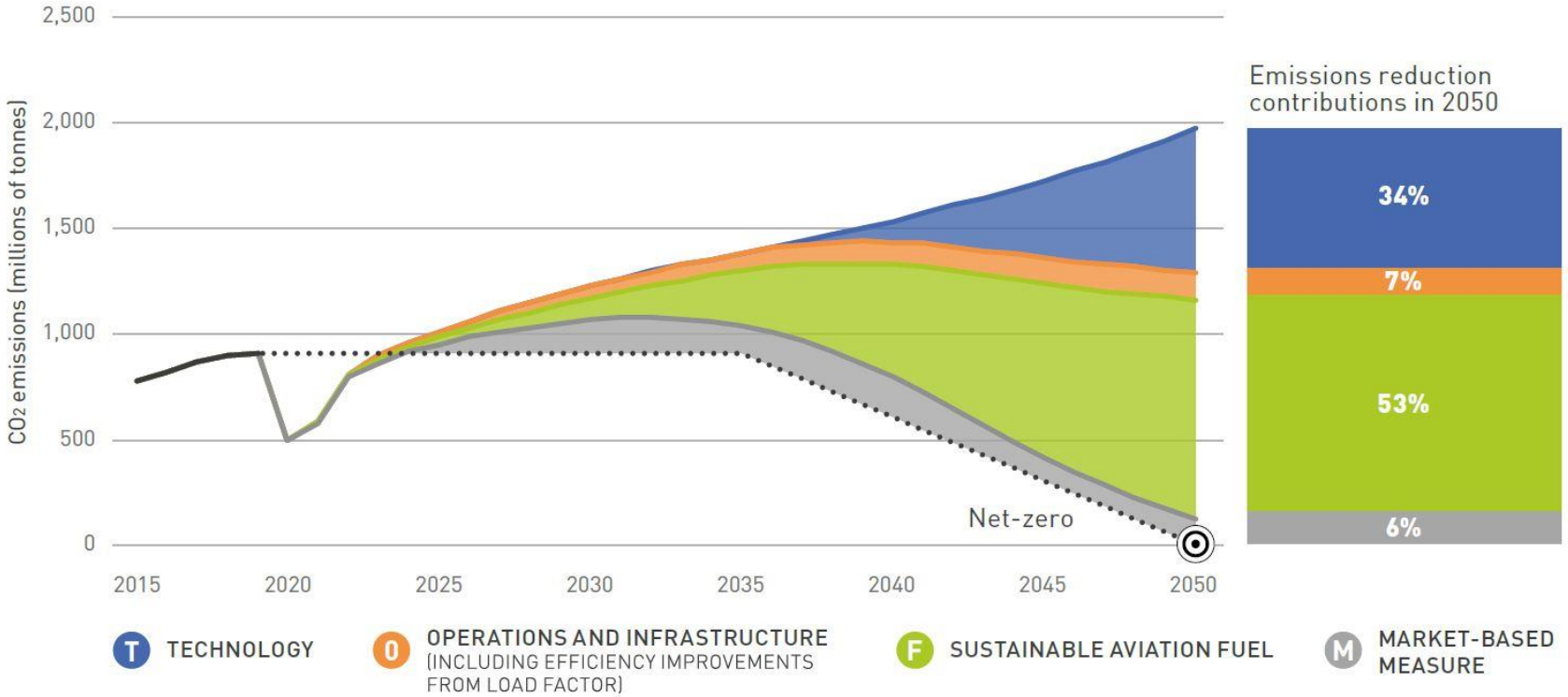
13.6 trillion
revenue passenger kilometres

2.7%
average annual growth rate

Source: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050

CLIMATE CHANGE

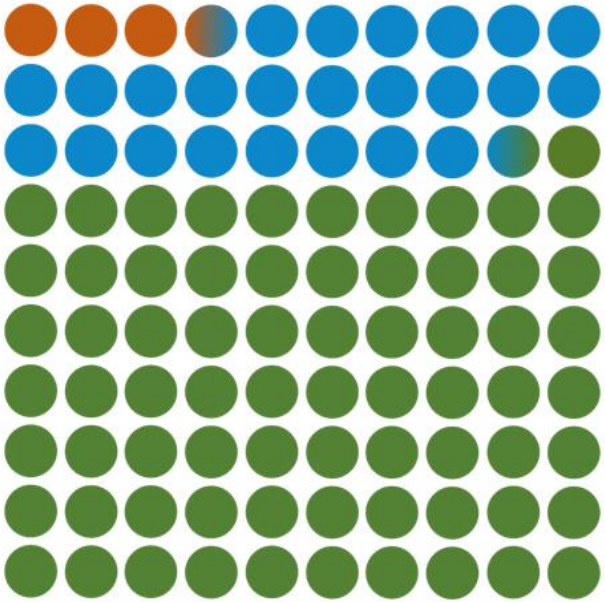
ADVANCED ENGINE TECHNOLOGIES AND CLEANER FUELS ARE KEYS TO ACHIEVING NET ZERO CO2 BY 2050



Source: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050

SUSTAINABLE AVIATION

MOST AVIATION TRAFFIC WILL RELY ON ADVANCED GAS TURBINES THAT OPERATE ON SUSTAINABLE AVIATION FUELS



Even assuming highly optimistic use of **electric** and **hydrogen** energy for short-haul and some medium-haul operations in 2050, the vast majority of traffic (RPKs) will still rely on the use of **sustainable aviation fuel**.

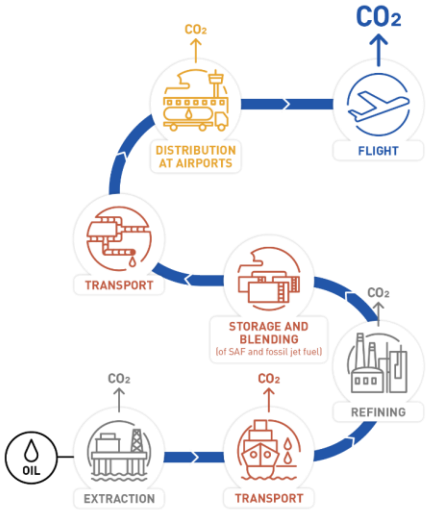
2050 % of operations by energy source (indicative example)

Source: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050

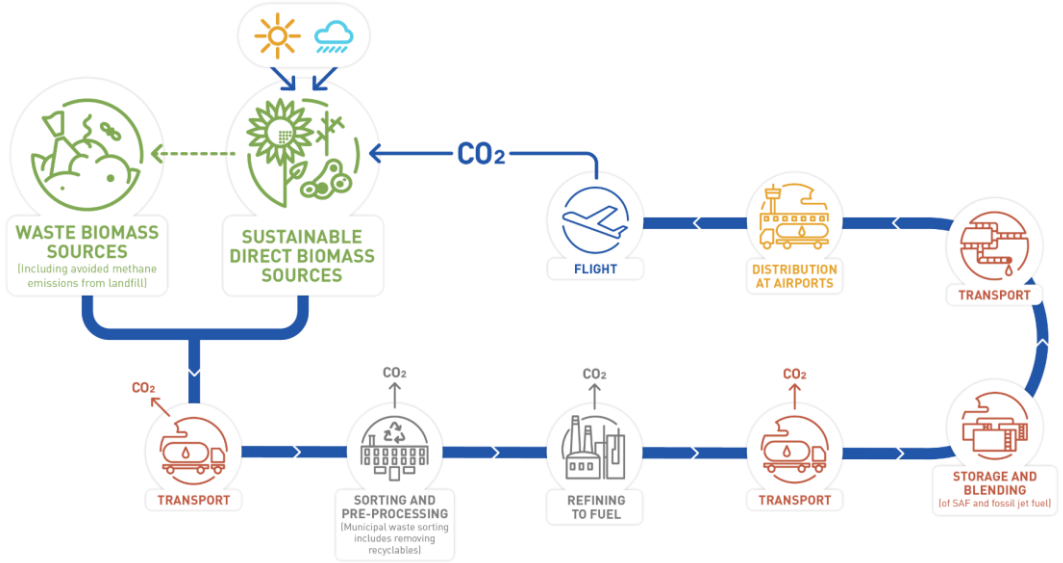
SUSTAINABLE AVIATION FUELS

USING SUSTAINABLE AVIATION FUELS (SAF) WOULD DECREASE AVIATION CO2 EMISSIONS BY UP TO 80%

Fossil-Derived Jet fuel



Sustainable Aviation Fuel



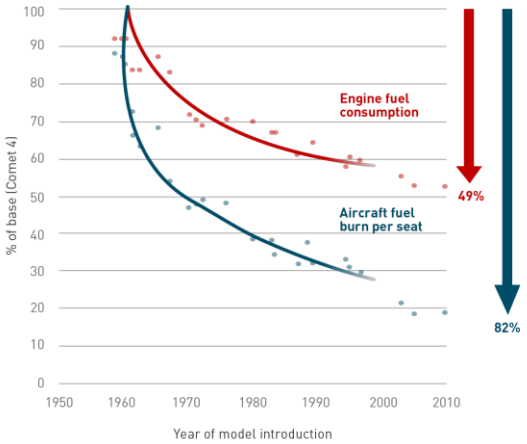
Support incentives to increase SAF production consistent with White House Grand SAF Challenge

Source: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050

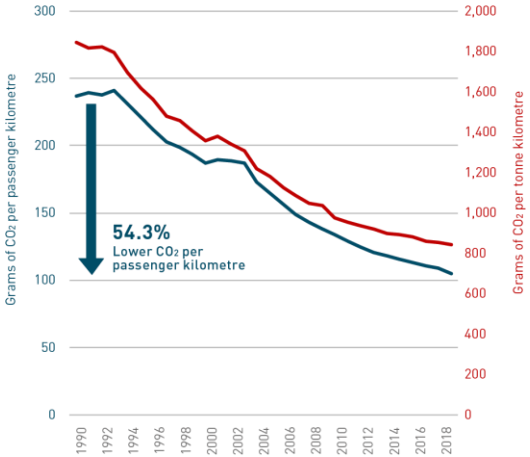
GAS TURBINE PROPULSION

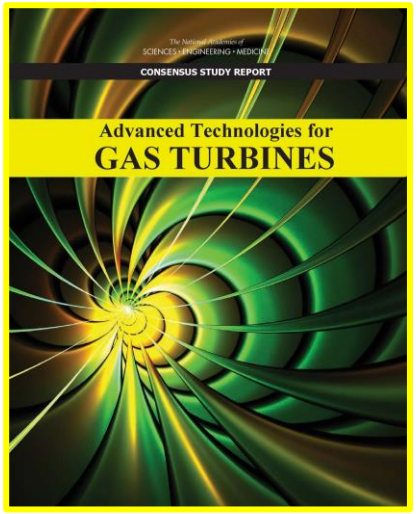
AVIATION TECHNOLOGY IMPROVEMENTS HAVE REDUCED FUEL BURN BY 85% IN THE LAST 70 YEARS

Fuel efficiency through technology since the early jet age



Operational efficiency since 1990, global numbers





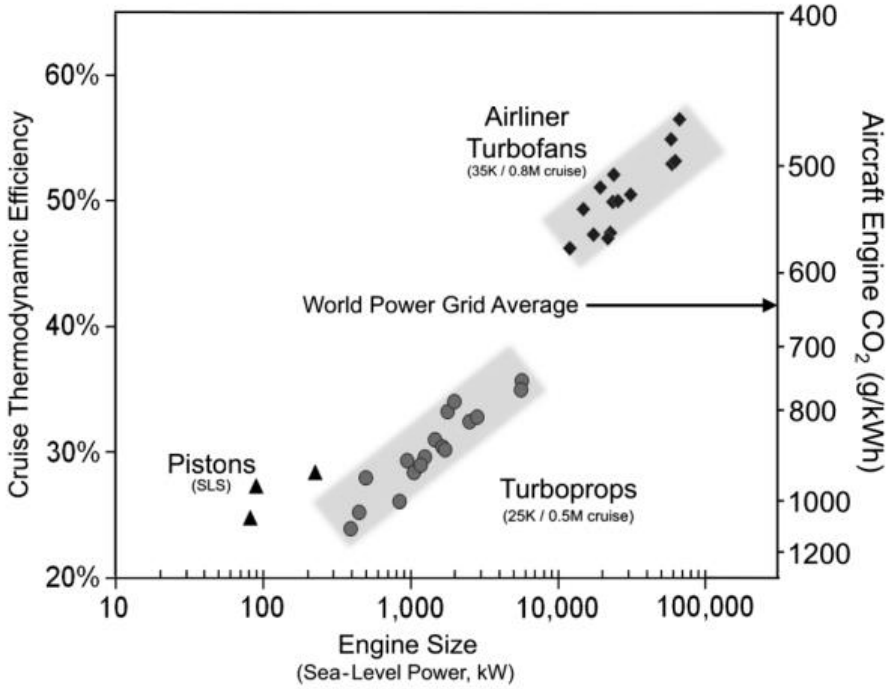
https://www.nap.edu/catalog/25630/advanced-technologies-for-gas-turbines

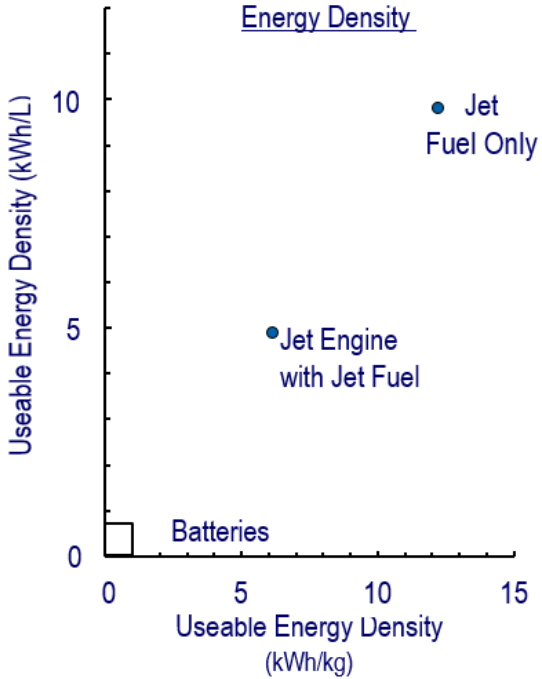
Accelerate technology progress with research in advanced technologies for gas turbines

Source: https://aviationbenefits.org/environmental-efficiency/climate-action/waypoint-2050

GAS TURBINE PROPULSION

HIGHLY EFFICIENT GAS TURBINES POWER AVIATION; JET FUELS HAVE MORE ENERGY DENSITY THAN BATTERIES

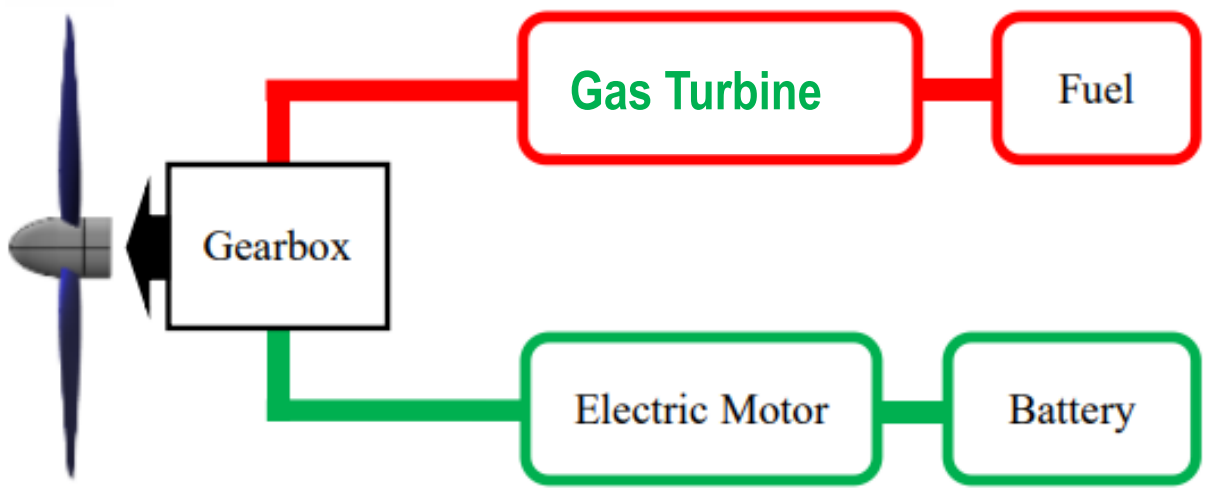




Source: Epstein, Alan H. and O'Flarity, Steven M., "Considerations for Reducing Aviation's CO2 with Aircraft Electric Propulsion" AIAA Journal of Propulsion and Power, Vol. 35, No.3, May-June, 2019

HYBRID-ELECTRIC PROPULSION

ELECTRIC ENGINES INTEGRATED WITH GAS TURBINES ENABLE GREATER SUSTAINABILITY IN AVIATION



Accelerate technology development through partnerships with NASA, DOE, FAA, and universities

Source: *Finger, et al. "Comparative Assessment of Parallel-Hybrid-Electric Propulsion Systems for Four Different Aircraft." AIAA Scitech. January 2020.*

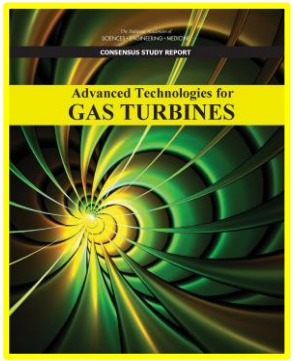
SUMMARY

Global aviation connects people and grows economies

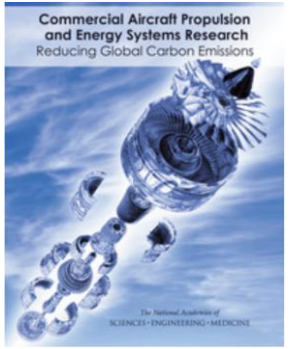
Aviation technology advancements have reduced aviation fuel burn by 85% since the 1950s

Advanced engine technologies and cleaner fuels are keys to achieving net zero CO2 by 2050

- Gas Turbine Propulsion
- Hybrid-Electric Propulsion
- Sustainable Aviation Fuels
- Hydrogen Propulsion



https://www.nap.edu/catalog/25630/advanced-technologies-for-gas-turbines



https://www.nap.edu/catalog/23490/commercial-aircraft-propulsion-and-energy-systems-research-reducing-global-carbon

Advanced gas turbines will continue to play a central role in sustainable aviation

30 YEAR VIEW

Capacity vs. Generation

Wind capacity grows ~3X
Solar capacity grows ~8X

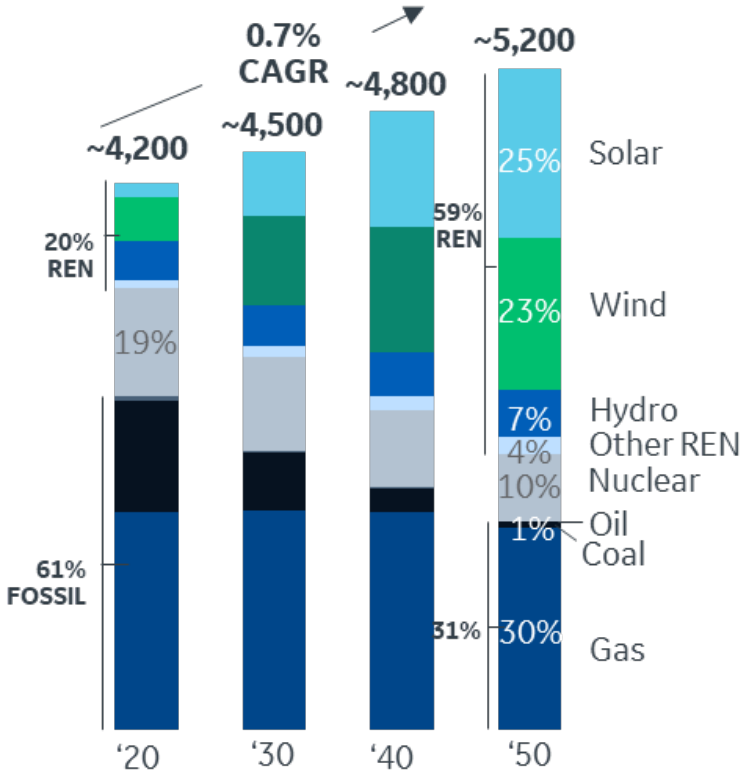
Coal generation down ~95%

Gas capacity increases ~23% and will play a critical but changing role, as **flexible, affordable, reliable and lower CO_2 power**

*Decarbonization as used herein is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis | Source: IEA WEO 2021 – Stated Policies Scenario

USA Electricity generation

Twh/y



Neither **RENEWABLES** nor **GAS POWER** are as effective alone at decarbonization* at the pace and scale needed to meet the goals of the Paris Agreement

Gas Power

Accelerating the transition to a **lower carbon future**

US Power Sector CO_2 ↓40%

GAS ENABLED ~40%

of net reduction since ’07

Flexible to complement renewables

FAST START TIMES AND RAMP RATES,

low minimum turndown

Reliable, dependable capacity

WHENEVER NEEDED,

day or night, regardless of weather

Abundant and affordable natural gas

TRADED LNG TO INCREASE 80%

by 2050, leading to increased availability everywhere

Less space required in urban areas

HUNDREDS MORE MW/ACRE

than renewables + storage

Multiple pathways to decarbonize* GTs

H2 FUEL, CARBON CAPTURE, BIOFUEL

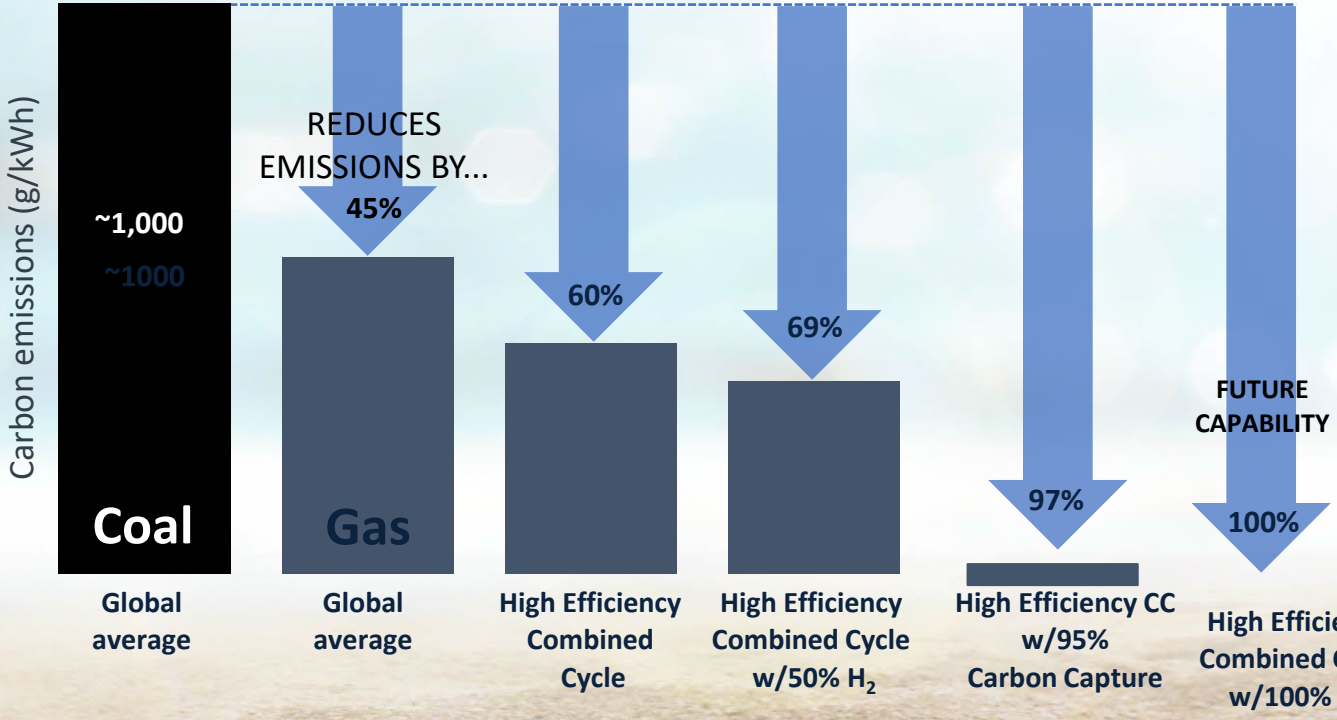
Avoid CO_2 lock-in or stranded assets

Society is demanding aggressive action to address climate change … **NATURAL GAS WILL PLAY A CRITICAL ROLE**

*Decarbonization as used herein is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis.

Sources: US Energy Information Administration, *Monthly Energy Review*, June 2020; International Energy Agency World Energy Outlook 2020; Renewables and Battery Options, Portland General Electric, October 10, 2018

A decade of action | Pathway to low or near-zero carbon power

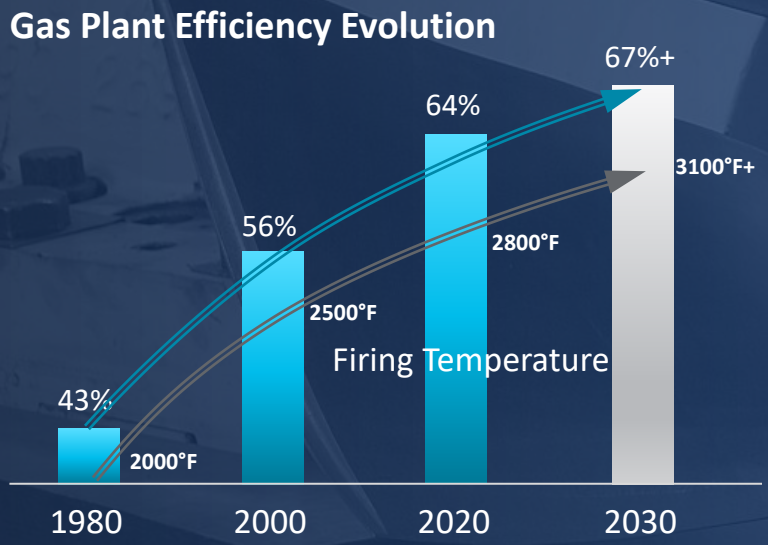


Coal-to-Gas Switching, Hydrogen, Carbon Capture and Sequestration

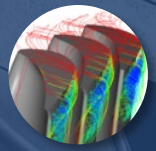
are viable pathways to low or zero carbon power

Source: GE Future of Energy White Paper Dec 2020

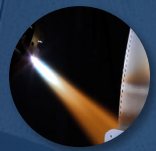
Continued advances & benefit for gas combined cycle efficiency



Enabled by advances in engineering and manufacturing sciences


Aerodynamics & Heat transfer


Combustion


Materials & metal additive


Design

Impact of **1 point efficiency** in the US*

$7B economic benefit

Equivalent CO2 of 2M cars

Technology investment in gas turbomachines is key to lower carbon future

** Estimated using the Energy Information Administration 2015 average US gas generator heat rate*

R&D Needs for use of hydrogen as fuel

» Fuel System

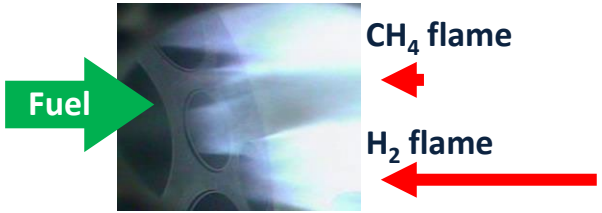
Methane (CH_4): 912 lb/ft^3
Hydrogen (H_2): 275 lb/ft^3

To deliver the same energy content, hydrogen requires 3X more volume flow

Hydrogen has a higher propensity to leak and requires improved sealing

» Combustion System

Methane (CH_4): ~30–40 cm/sec
Hydrogen (H_2): ~200–300 cm/sec

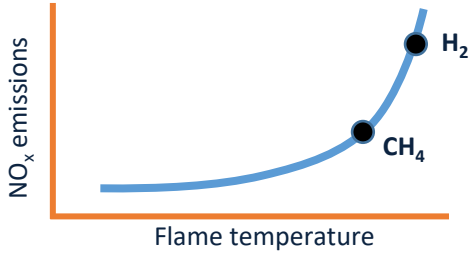


Hydrogen produces higher flame temperatures potentially impacting combustor hardware temperatures

The wider flammability range of hydrogen requires upgrades to safety systems

» Emissions Aftertreatment

Methane (CH_4): ~3,565 °F
Hydrogen (H_2): ~4,000 °F



Operating on hydrogen may increase NO_x emissions

Operating a gas turbine on blends of hydrogen or on 100% hydrogen requires changes to key power plant systems, but this has been successfully demonstrated

Gas Power Role in the Future of Energy

- **Strong renewable growth continues** … flexible gas generation is the best complement
- **Gas generation key for national & energy security** … dispatchable & reliable
- **Coal to gas switching & higher gas generation efficiency** … effective path for decarbonization
- **U.S. economic benefits significant** … high quality jobs & high value exports
- **Significant needs for gas technology R&D** … requires investment & support

Position the U.S. to lead in gas turbine technology

Advances Needed in Gas Turbine Research and Development:

Industry, Universities, and Government Collaborations Lead to Success

Professor Karen A. Thole

PennState

START

ASME
SETTING THE STANDARD

Gas Turbine R&D: Industry, Universities, and Government

Why is it important?

Universities research ways to reduce emissions through efficient turbines supported through industry and government

Universities educate the future workforce where advanced degrees with practical experience are a requirement

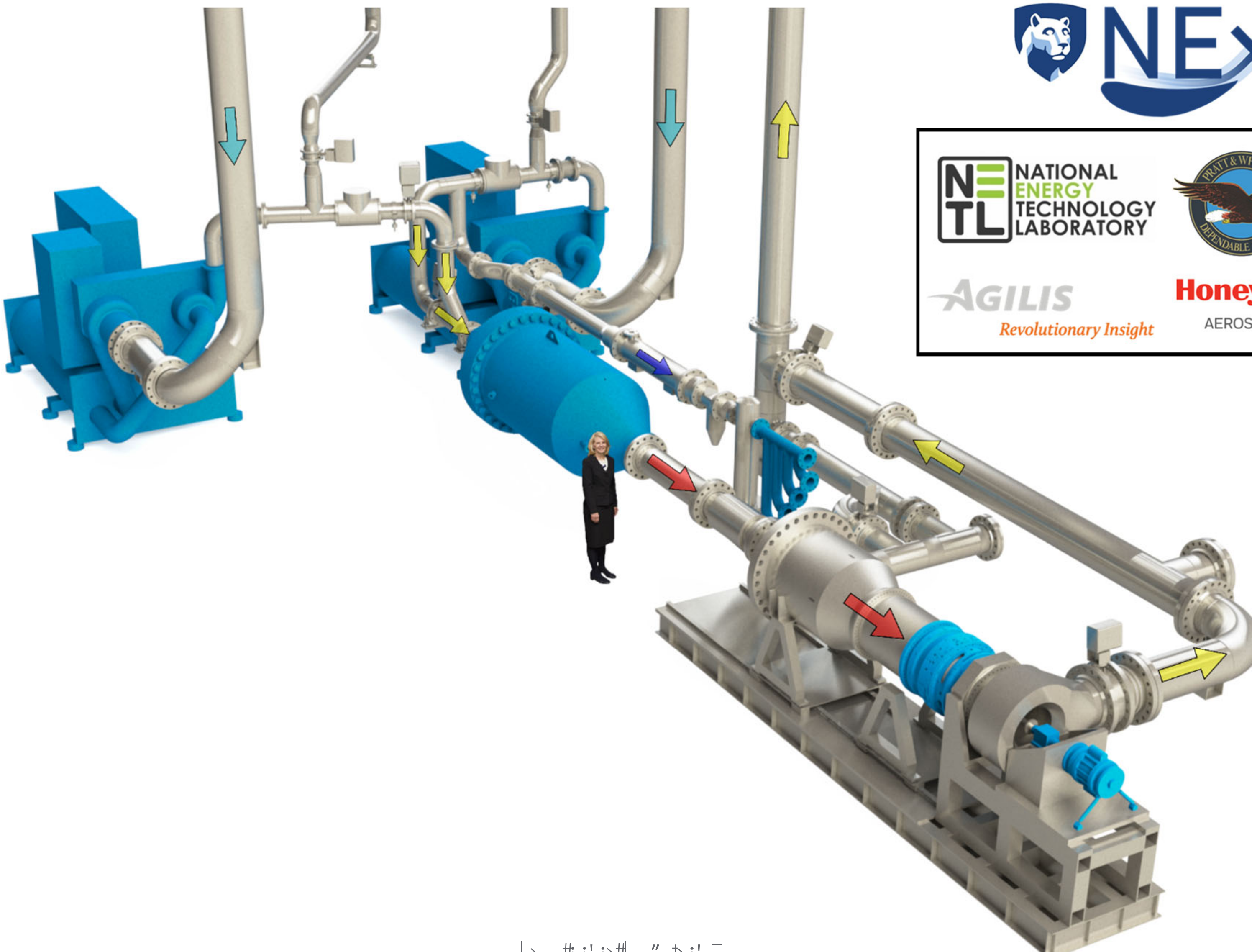
To achieve DOE's clean energy goals, DOE catalyzes strong partnerships with industry and academia

Courtesy of DOE-NETL

START
PennState
Steady Thermal Aero Research Turbine

PRATT & WHITNEY
DEPENDABLE ENGINES

NATIONAL ENERGY TECHNOLOGY LABORATORY



NExT

NATIONAL ENERGY TECHNOLOGY LABORATORY

PRATT & WHITNEY
DEPENDABLE ENGINES

Solar Turbines
A Caterpillar Company

AGILIS
Revolutionary Insight

Honeywell
AEROSPACE

SIEMENS
Ingenuity for life

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NASA's University Leadership Initiative is engaging the university community in aeronautics

ULI
UNIVERSITY
LEADERSHIP
INITIATIVE

5 rounds of solicitations
$157M of awards

Seeking & awarding proposals addressing all Strategic Thrusts and Special Topics

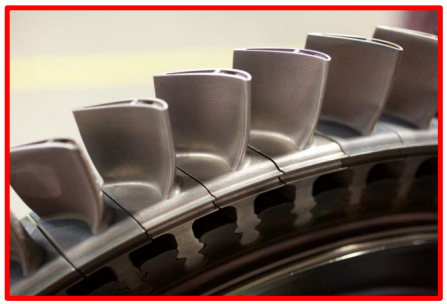
- 23 awards with 64 universities
- 7 HBCUs and 10 other MSIs
- 406 proposals submitted
- 280 different proposing Principal Investigators
- 3189 team members
- 1921 different people
- 20–50 students per team

In ULI, the universities take the lead, build their own teams, and set their own research path.

Leading Advanced Turbine Research for Hybrid Electric Propulsion Systems

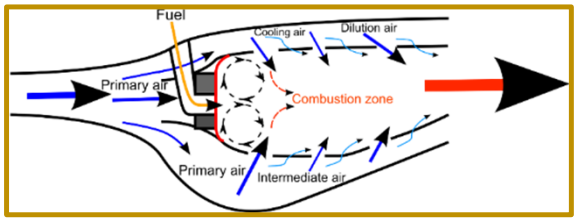
Four possible solutions to sustainable aviation:
- **Sustainable jet fuels (small efficient turbine)**
- **Hydrogen fuels (small efficient turbine)**
- **Hybrid electric (small efficient turbine)**
- Fully electric

Advanced Manufacturing; High Temperature Materials



Novel Airfoil Cooling Technologies

Advanced Combustors Flexible Fuels



PennState Georgia Tech HOWARD UNIVERSITY MESOSCRIBE TECHNOLOGIES Collins Aerospace

FAA ASCENT Center of Excellence

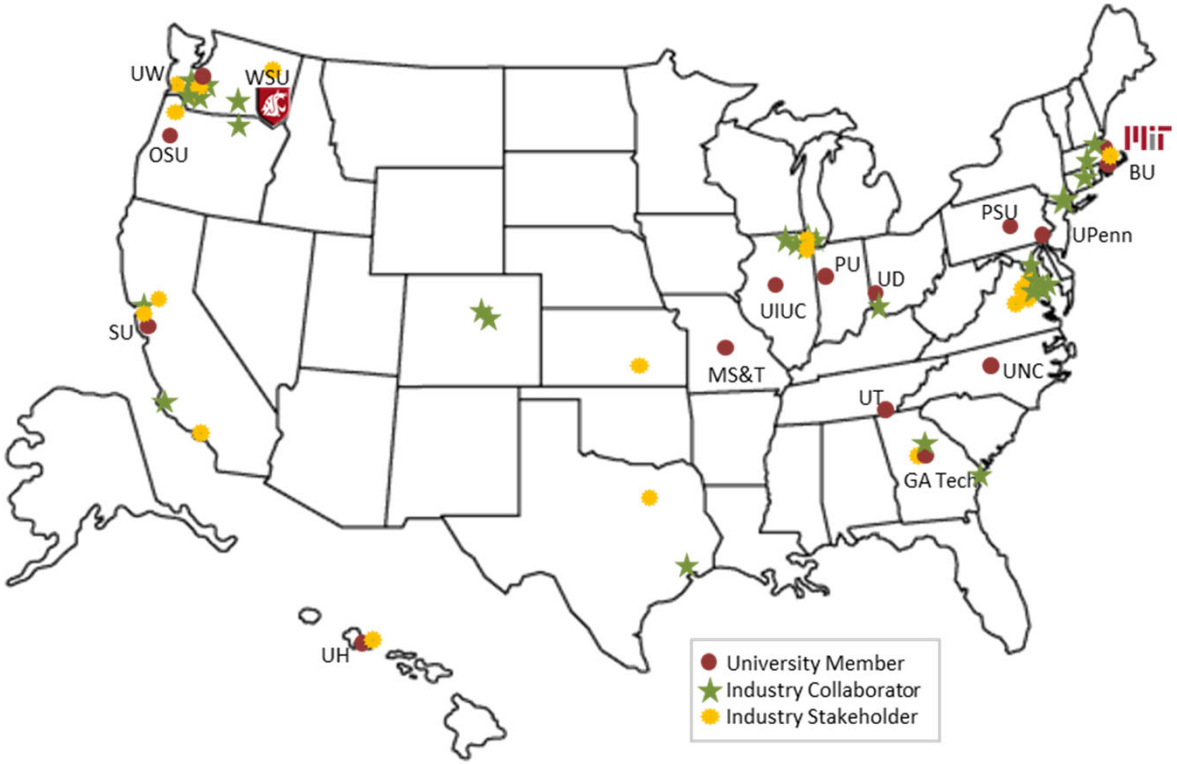
In 2013, FAA established ASCENT to conduct research on environment and alternative jet fuels

Portfolio covers broad range of topics on Alternative Jet Fuels, Emissions, Noise, Operations, and Analytical Tools

Over 80 research projects with over $15M annual budget

ASCENT Support

- Federal Aviation Administration
- Transport Canada
- NASA
- Environmental Protection Agency
- Defense Logistics Agency - Energy
- U.S. Dep't of Energy
- U.S. Dep't of Agriculture
- Air Force Research Laboratory



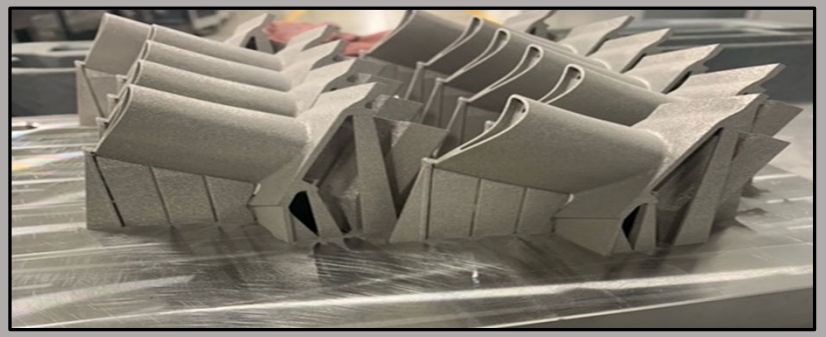
FAA's ASCENT Program is bringing together industry and academia to advance turbine technologies faster through advancing manufacturing

3 years
$1M for 50 blades

3 months
$200K for 50 blades

Conventional Manufacturing for Development Blades

3D Metal Printing for Development Blades



Investment is needed to advance turbines to meet carbon emission goals

Research through federal-industry-academic collaborations has direct impacts

Educating the future US work force requires significant investments

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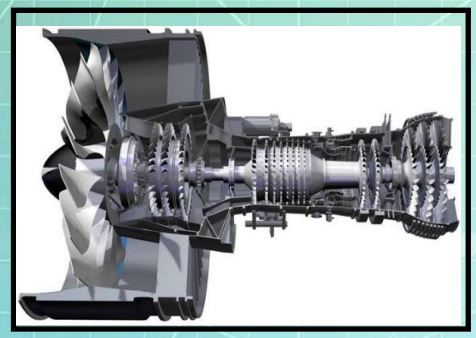
Summary



Gas turbines are integral to global aviation and to our power system today and will remain critical to both well into the future

Gas turbines offer multiple technical pathways to lower and zero carbon emissions

Significant R&D needed for gas turbine efficiency, hybridization, hydrogen combustion, and carbon capture

Adapted from a slide by GE. Images courtesy of GE, Pratt & Whitney, NASA Aeronautics. Used with permission.

Thanks for attending! Additional Questions?

Contact Paul Fakes, ASME Government Relations
FakesP@ASME.org