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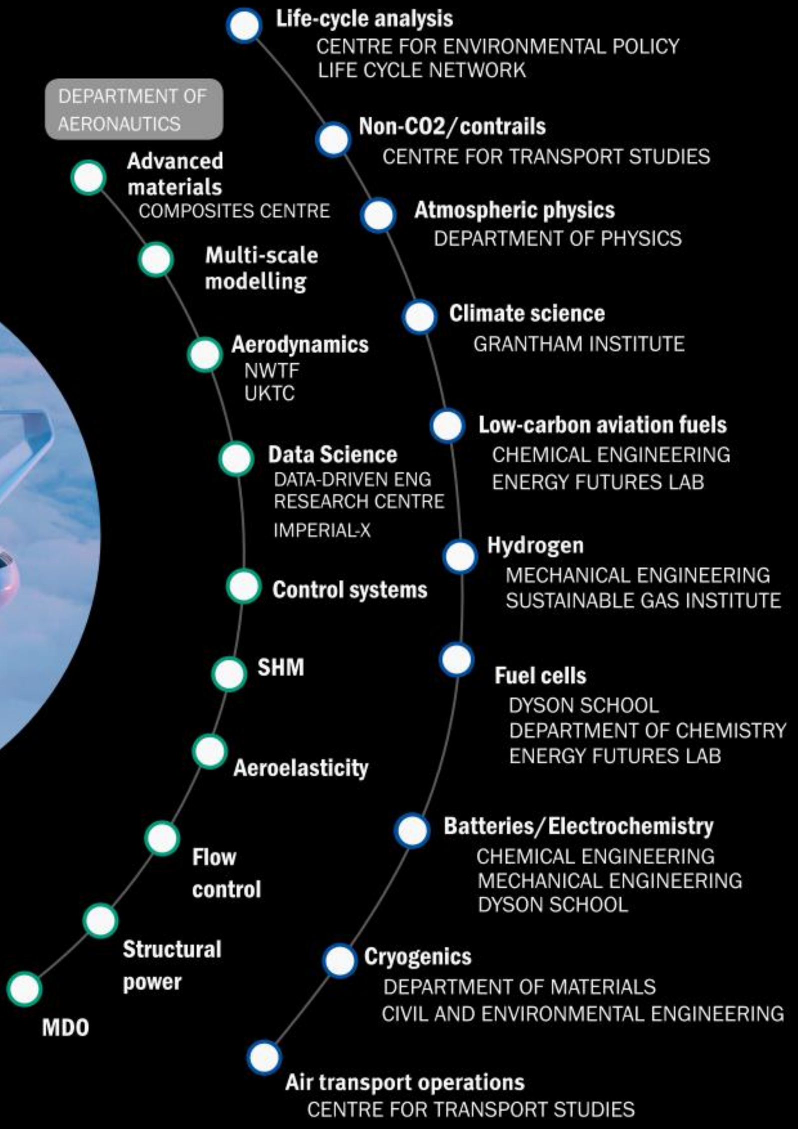
Turbulence in the path of sustainable aircraft

Rafael Palacios
10.10.2024

Imperial College London
Brahmal Vasudevan Institute for Sustainable Aviation

Sustainable aviation research at Imperial College London

SKILLS	DISCOVERY	TRANSLATION
SYSTEMS-LEVEL THINKING		
TOWARDS NET-ZERO AVIATION		
Syllabus review	Core program	Workshops
Doctoral program	Activity enabler	Seminars
		Policy engage



DEPARTMENT OF AERONAUTICS

Advanced materials
COMPOSITES CENTRE

Multi-scale modelling

Aerodynamics
NWTF
UKTC

Data Science
DATA-DRIVEN ENG RESEARCH CENTRE
IMPERIAL-X

Control systems

SHM

Aeroelasticity

Flow control

Structural power

MDO

Life-cycle analysis
CENTRE FOR ENVIRONMENTAL POLICY
LIFE CYCLE NETWORK

Non-CO2/contrails
CENTRE FOR TRANSPORT STUDIES

Atmospheric physics
DEPARTMENT OF PHYSICS

Climate science
GRANTHAM INSTITUTE

Low-carbon aviation fuels
CHEMICAL ENGINEERING
ENERGY FUTURES LAB

Hydrogen
MECHANICAL ENGINEERING
SUSTAINABLE GAS INSTITUTE

Fuel cells
DYSON SCHOOL
DEPARTMENT OF CHEMISTRY
ENERGY FUTURES LAB

Batteries/Electrochemistry
CHEMICAL ENGINEERING
MECHANICAL ENGINEERING
DYSON SCHOOL

Cryogenics
DEPARTMENT OF MATERIALS
CIVIL AND ENVIRONMENTAL ENGINEERING

Air transport operations
CENTRE FOR TRANSPORT STUDIES

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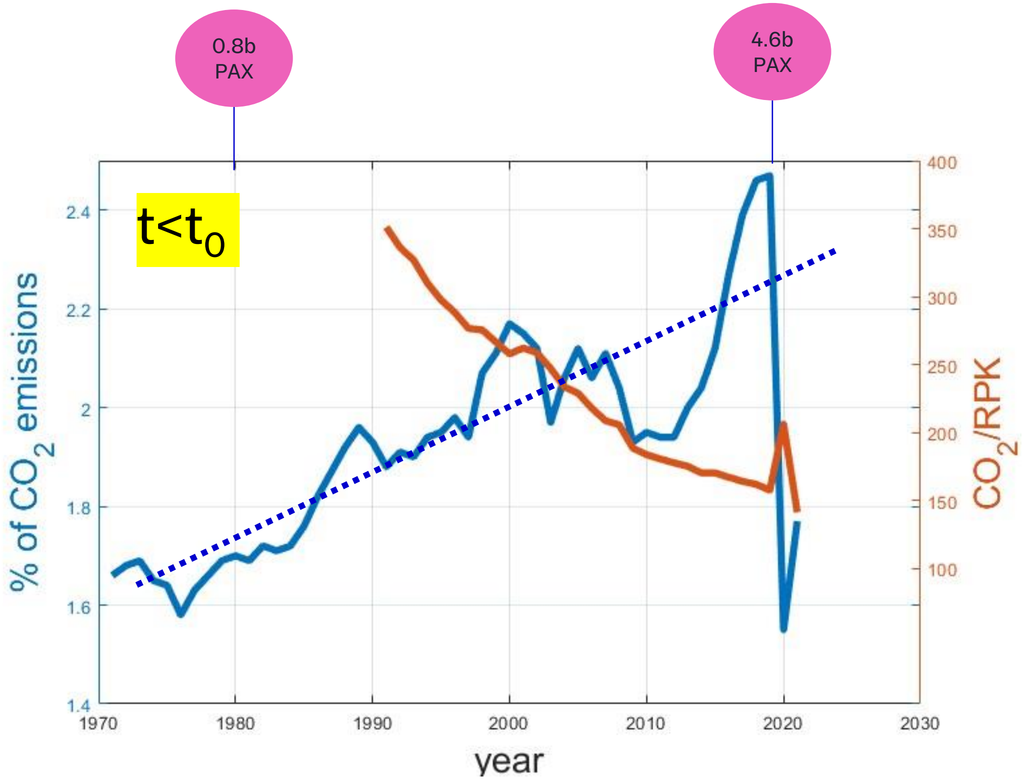
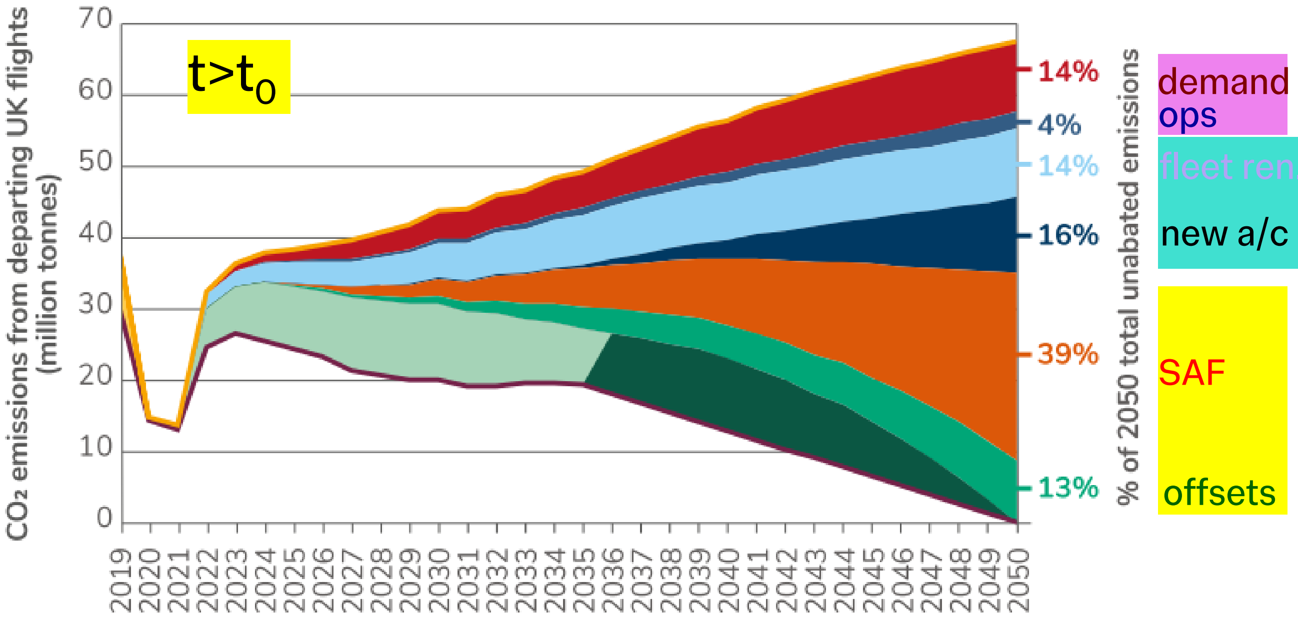
From fuel efficiency to emissions targets

$$\text{aviation } CO_2 = \overbrace{\frac{CO_2}{MJ}}^{\text{fuel carbon intensity}} \times \overbrace{\frac{MJ}{RPK}}^{\text{aircraft energy intensity}} \times \overbrace{RPK}^{\text{traffic}}$$

+ non-CO2 climate forcing



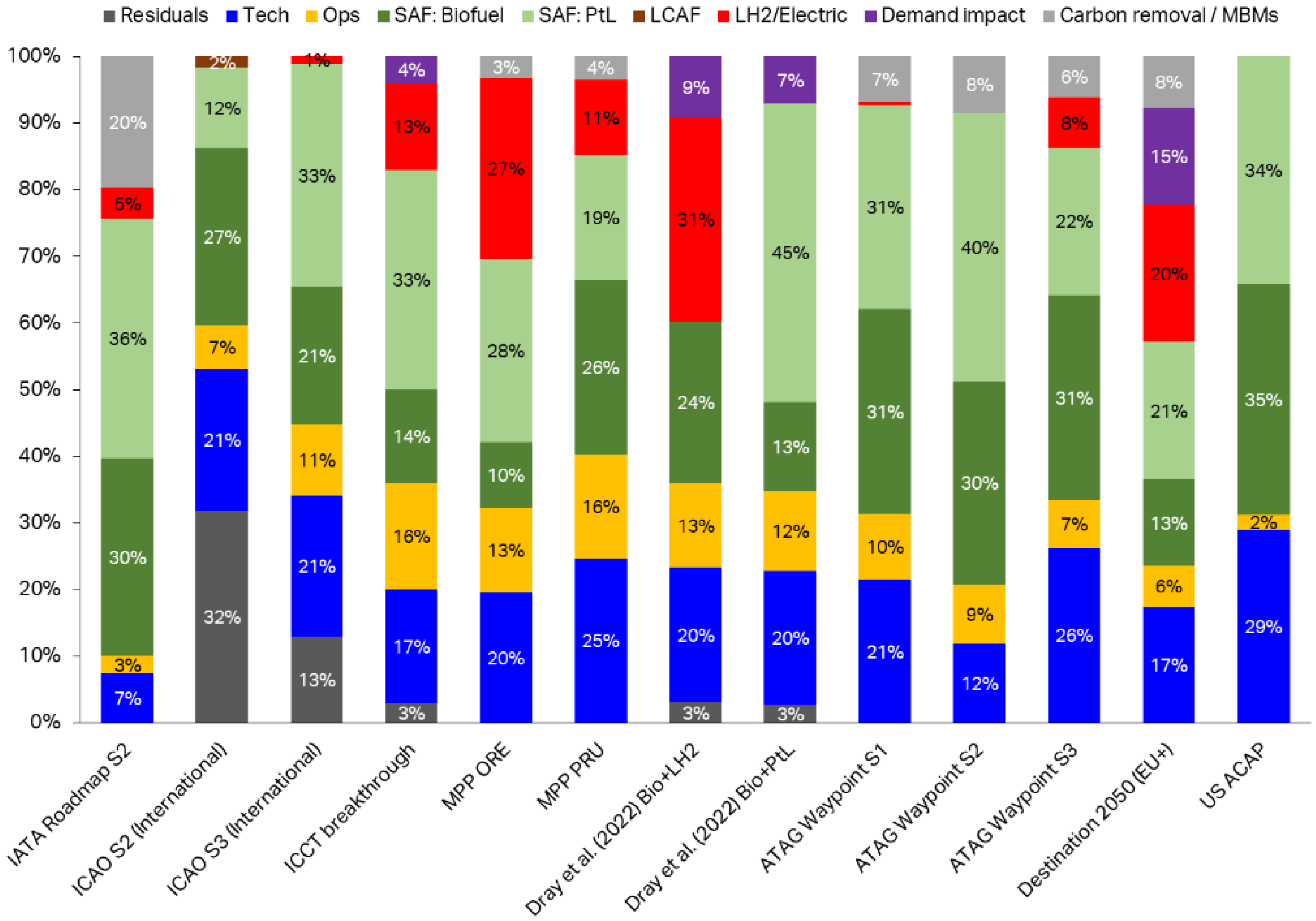
Source: Bergero (2023), *Nature Sust.*



Source: ATAG, 2022

The art of forecasting

Comparing roadmaps for net-zero aviation 2050



Source: IATA, Transition pathways, April 2024

Averages do not tell the whole story

80% of CO_2 from 20% of flights

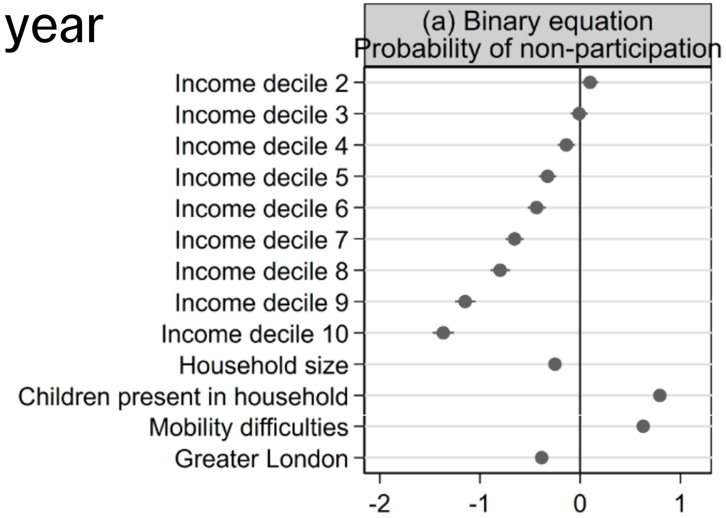
New trade-offs between flying time and climate impact?

Up to 21% fuel savings if redesigned to 50% range.
7% travel increase for refuelling stop.

Creemers, AIAA Aviation 2007

50% of UK population fly less than once a year
15% of UK population takes 70% of flights

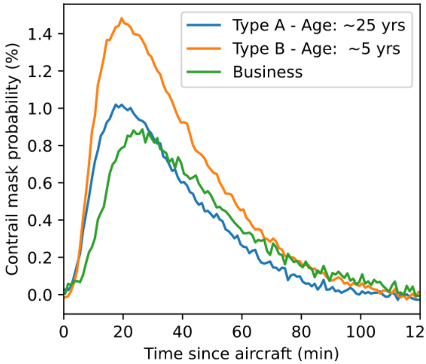
Should demand management be driven solely by cost?



Buechs et al. “Trends in air travel inequality in the UK”, 2021

<5% of flights cause 80% of persistent contrails

How to measure (and cost) actual climate impact?



Gryspeerdt et al. *Env Res. Letters* 2024

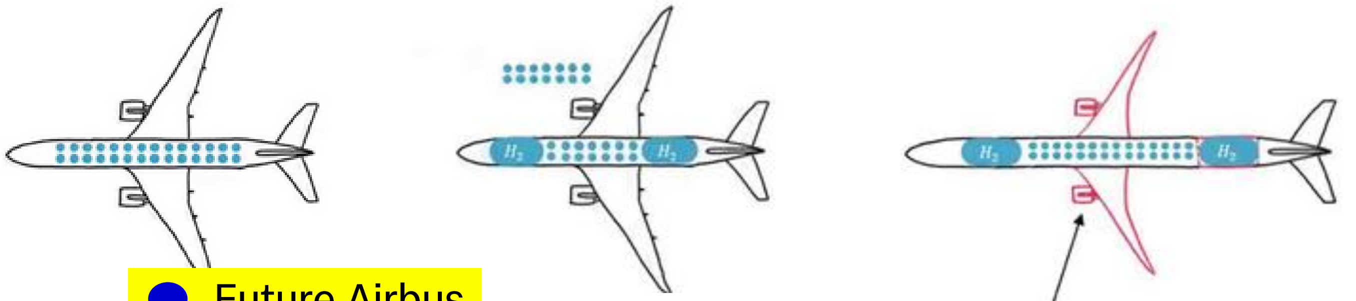
Net-zero needs new fuels AND new aircraft

Electric propulsion


NASA Maxwell X-57

● Future Boeing

Hydrogen propulsion



● Future Airbus

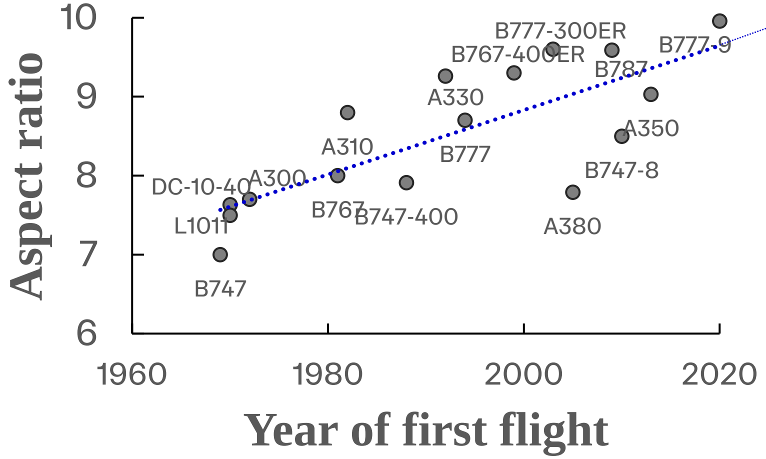
Current (EI=100)

Retrofitted (EI=140)

Redesigned (EI=90)

Source: Miller, *Aviation Impact Accelerator, 2024*

Drop-in SAF



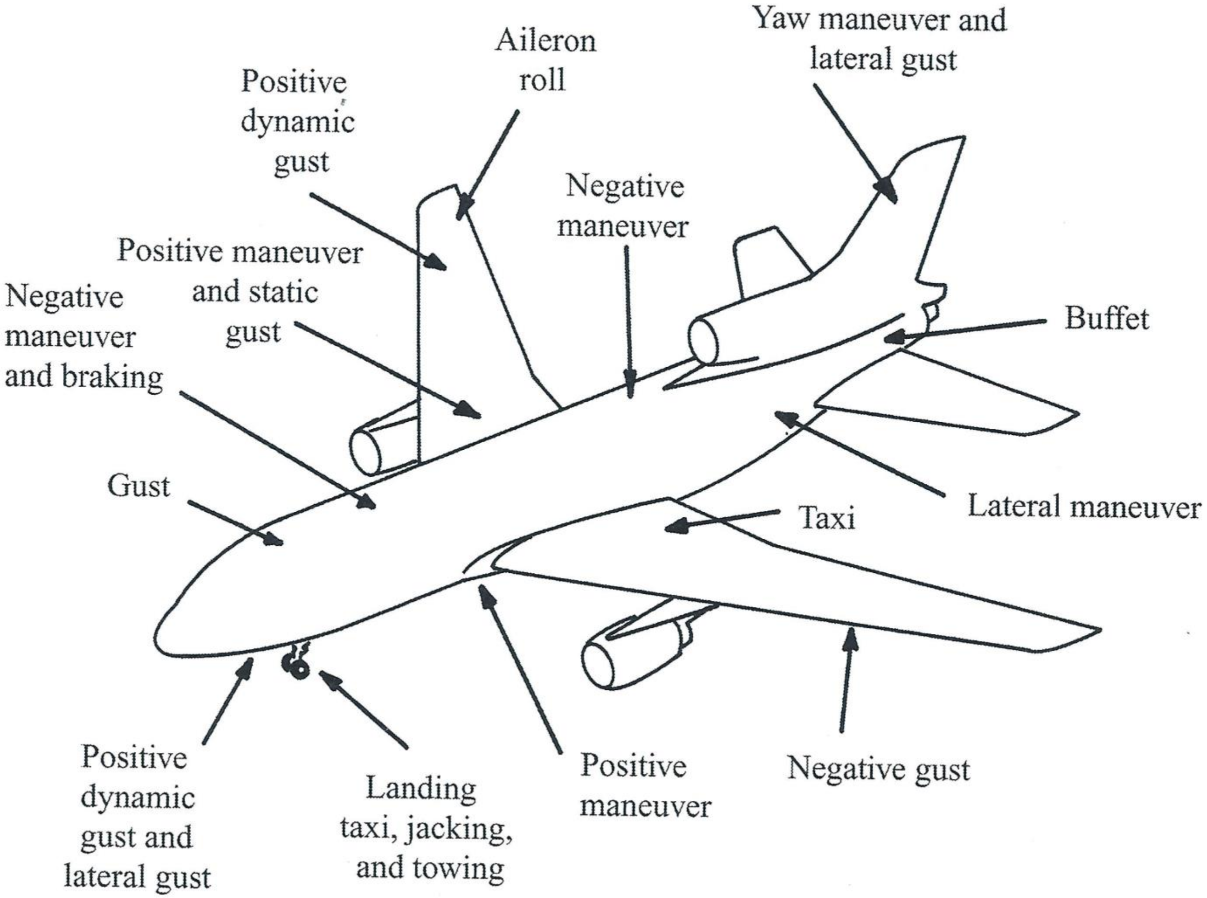

AR ~13 ?

Airbus X-Wing


AR=19

NASA Boeing X-66

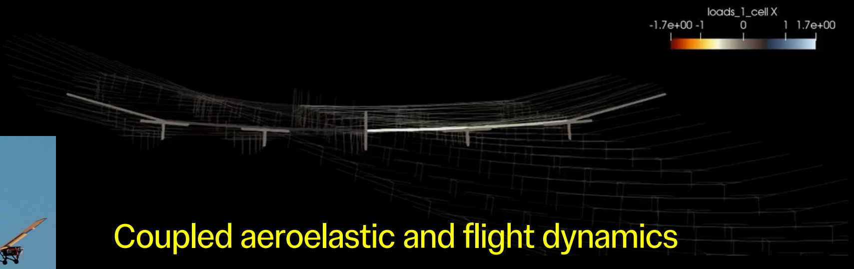
Take off is optional – landing is mandatory



(Raymer, 2006)

Those long wings will find increasingly adverse winds

SHARPy: open-source simulator



Coupled aeroelastic and flight dynamics

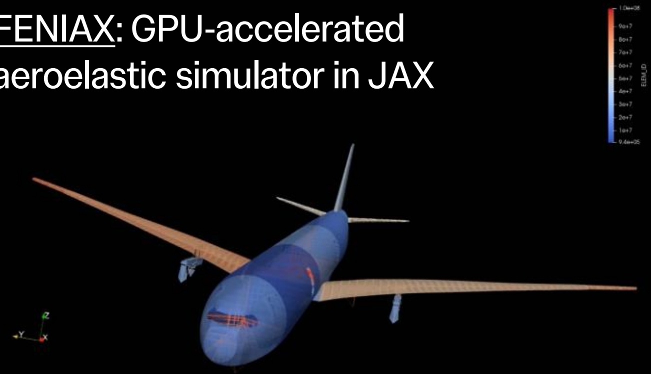
© U. Michigan

Flexible Aircraft Dynamics

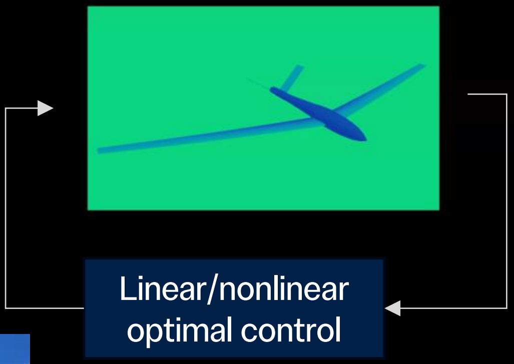
Load alleviation

Aerostructural optimization

FENIAX: GPU-accelerated aeroelastic simulator in JAX



Gust loads on extended wing XFR1

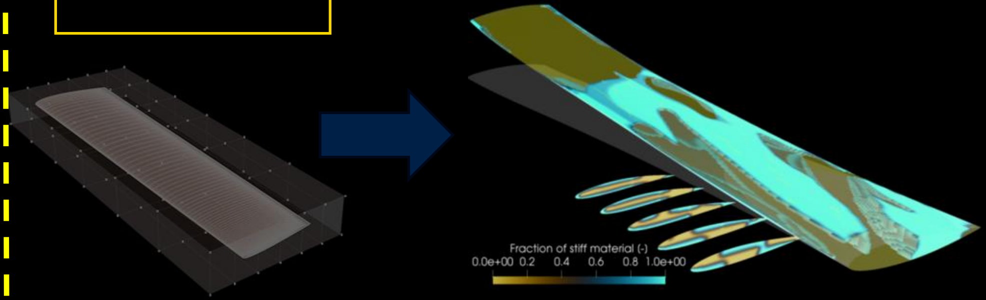


Linear/nonlinear optimal control

Control design and evaluation with model-in-the-loop

© SZTAKI

SU2: coupled adjoint + harmonic balance FSI solver



Simultaneous shape and topology optimization

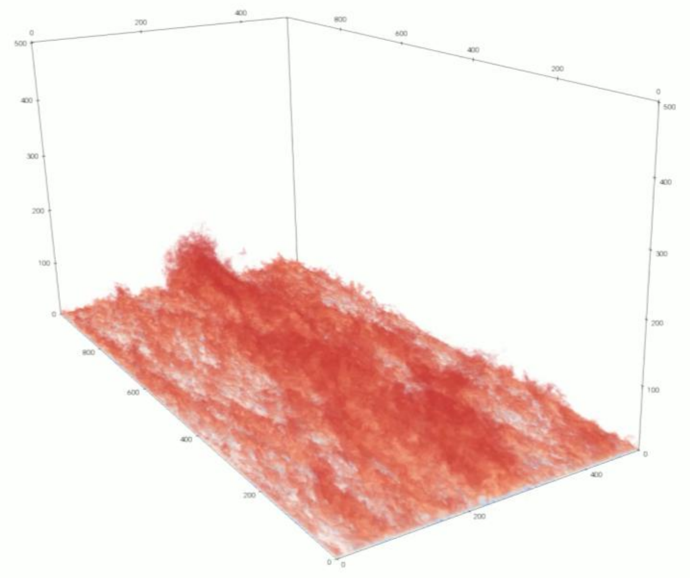
Palacios and Cesnik, *Dynamics of Flexible Aircraft,* Cambridge University Press, 2023

Example 1: Solar-powered aircraft at low altitude

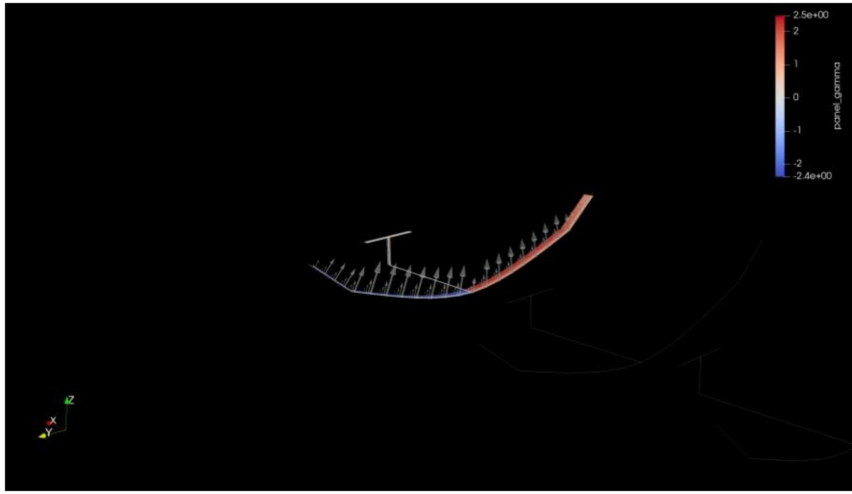
© Airbus

Very light construction for extreme performance at high altitude
Highly susceptible to low-altitude conditions
Lack of regulations (or experience!)

Step 1: Models of the Atmospheric Boundary Layer



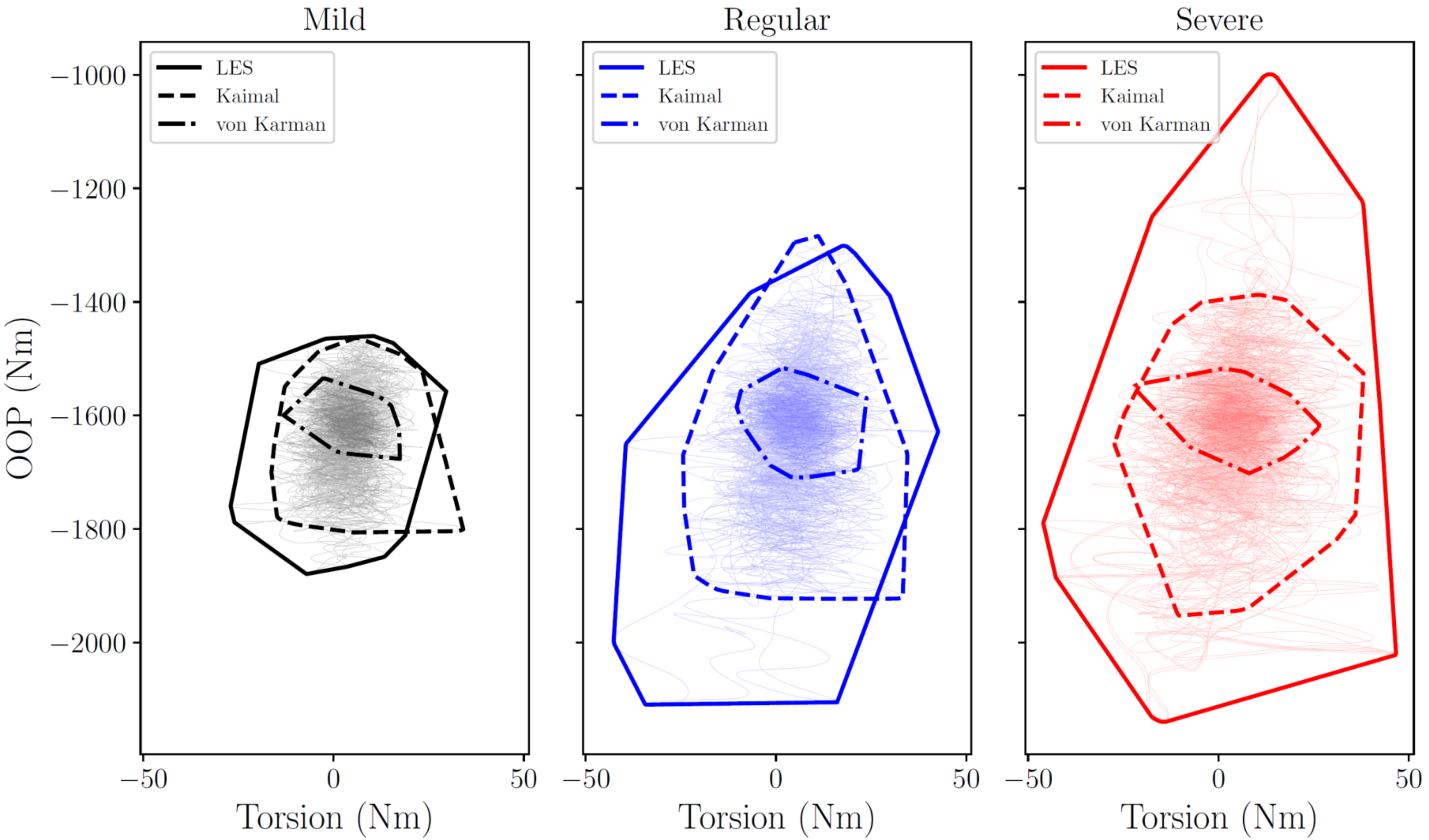
Step 2: Multiple aeroelastic simulations to achieve statistical relevance



Deskos Y., del Carre A., Palacios R., “Assessment of Low-Altitude Atmospheric Turbulence Models for Aircraft Aeroelasticity.” *Journal of Fluids and Structures* 95, May 2020

Example 1: Results

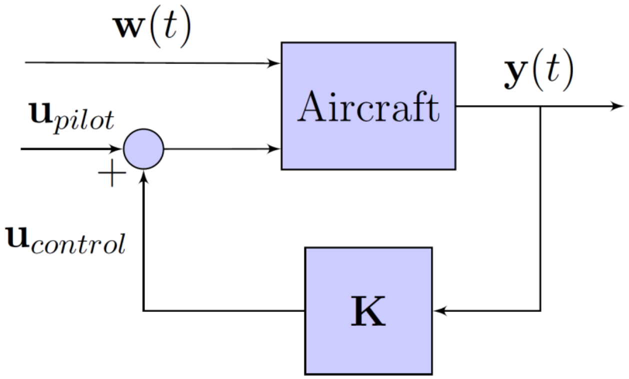
Load diagrams (wing root bending vs. torsional moments)



Deskos Y., del Carre A., Palacios R., “Assessment of Low-Altitude Atmospheric Turbulence Models for Aircraft Aeroelasticity.” *Journal of Fluids and Structures* 95, May 2020

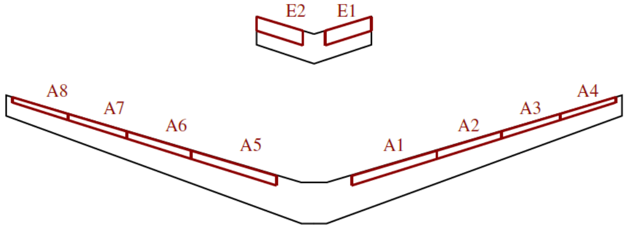
Example 2: Designing load alleviation systems

Active or passive




© University of Michigan


FLEXOP (EU Project)

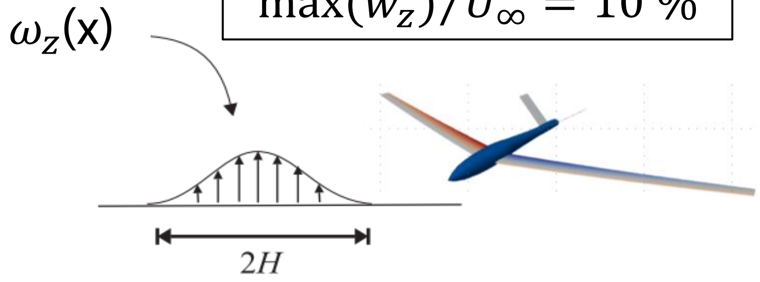


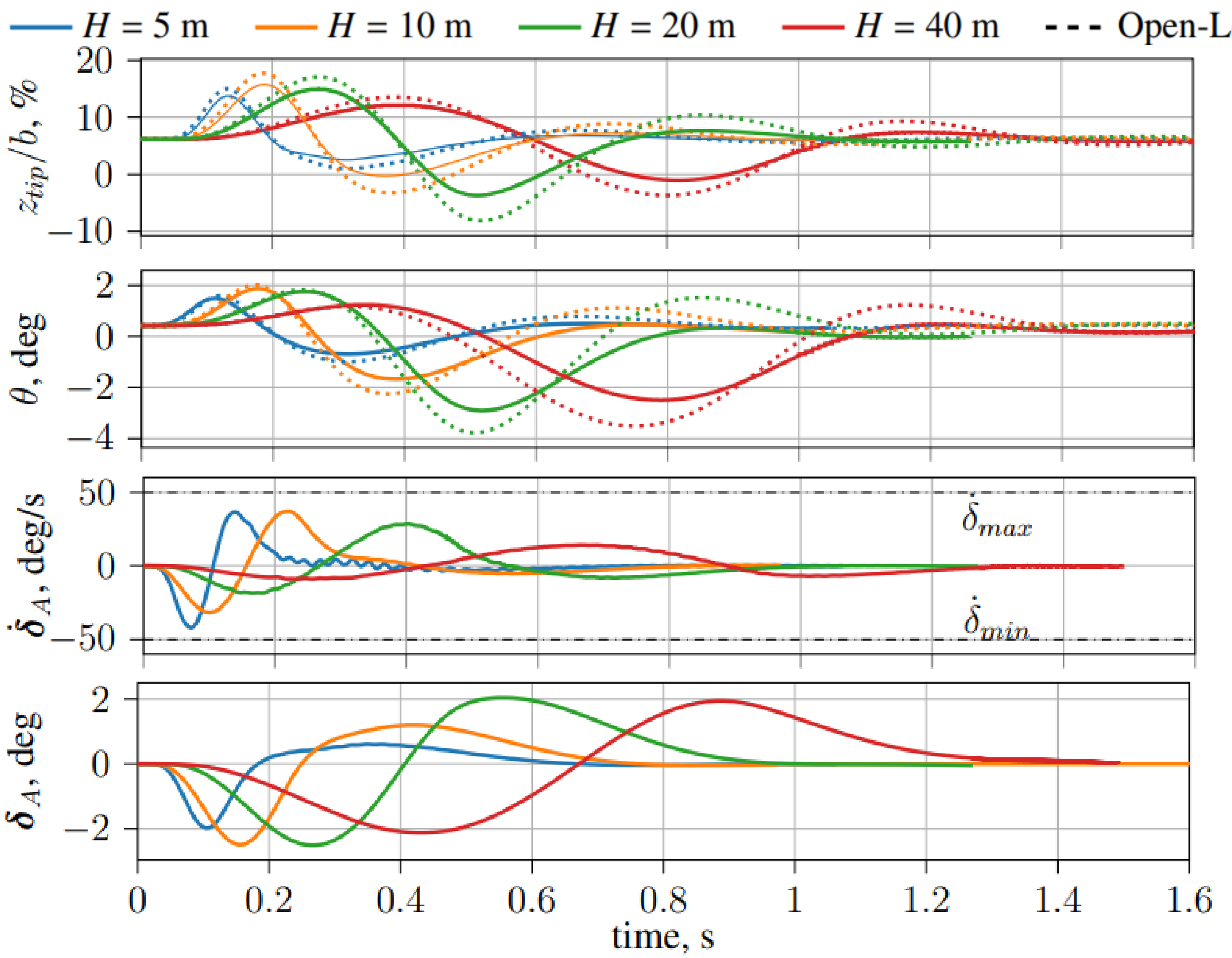
Control surface layout

Example 2: Closed-Loop Gust Load Alleviation on FLEXOP aircraft

Nonlinear simulations in SHARPy with MATLAB & SIMULINK

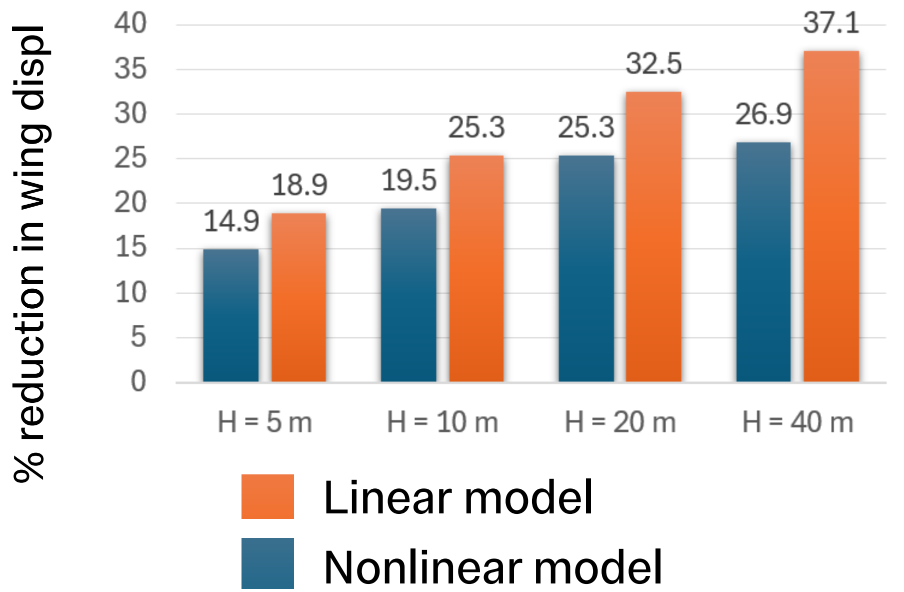
$\max(w_z)/U_\infty = 10\ \%$





Sensors: $\ddot{z}$ at wingtip and IMU at CoG

Load alleviation and wing stabilization for all gust lengths.



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Duessler, *AIAA Scitech 2024*

Some take away messages

Net-zero aviation needs a multi-pronged approach

Atmospheric turbulence will only get worse

… and aircraft will have higher aspect-ratio

We need
- *better forecasting of wind conditions
- *integrated models of aircraft & environment
- *smart wings that adapt to wind conditions

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