D5.7 Workshop / Final Exploitation and Dissemination Report

GA number: 815058
Project acronym: FLIPASED
Project title: FLIGHT PHASE ADAPTIVE AERO-SERVOELASTIC AIRCRAFT DESIGN METHODS

Funding Scheme: H2020 **ID:** MG-3-1-2018
Latest version of Annex I: 1.2 released on 13/12/2022
Start date of project: 01/09/2019 **Duration:** 46 Months

Lead Beneficiary for this deliverable:	TUM
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Last modified: 30.06.203	**Status:**
Due date: 30.06.203	Delivered

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Project website: flipased.eu

Dissemination Level:		
CO	Confidential, only for members of the consortium (including the Commission Services)	
PU	Public	**X**

"This document is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815058."

Table of Contents

1 Introduction

The present deliverable discusses the achieved dissemination and exploitation results and activities within the 46 months duration of the project.

The core objective of WP5 besides everyday project management of the consortium members was to disseminate key findings and outcomes of the project in a structured manner in order to maximise project impact and outreach across key stakeholder groups.

As outlined in the FLiPASED description of work, the dissemination objectives are to:

- Identify the main dissemination target groups and ensure the adequate promotion of the project, its activities and results,
- Prepare materials for the dissemination activities,
- Maximise the dissemination potential of the project outputs to the aerospace community, for the members of parallel H2020, Horizon Europe and Clean Aviation projects,
- Provide a plan for exploitation of the project outputs and support their long-term effects,
- Organise a final workshop for the presentation of the project results and support information to the advisory group.

The dissemination of FLiPASED has been essential throughout the project's life and needed to be carried out with the cooperation of all work packages and all project partners. The aim of this document is to provide the dissemination, communication and exploitation activities as well as the impact of these actions to fulfil the objectives of WP5 described in the FLiPASED GA.

This deliverable will show the achievements of WP5, i.e.:

- The development of all planned dissemination tools,
- The creation of all planned publications (project brochure and newsletters),
- The use of social media to communicate efficiently on the project;
- The complete list of disseminated FLiPASED activities at events such as workshops,

conferences, webinars and internal meetings,

- The cooperation with other H2020 and EU funded projects, and
- The organisation of a final workshop event,

It will also detail the exploitation measures that have been undertaken during the 46 months duration of the project and will present the exploitation plan of the project partners after project end.

2 Dissemination

The dissemination activities were particularly strong within the project on several fronts. These are detailed in the following sections.

2.1 Research Outputs

Several articles were published by the consortium members in peer-reviewed journal publications as well as in conferences. A few notable examples include the joint NASA-FLiPASED workshop at AIAA Scitech 2020, and the IEEE Transaction articles about flutter control design approaches. The research outputs also include the publication of all scientificly relevant flight test data, what can be accessed at https://science-data.hu/dataverse/flipased .

Figure 1 Research Data published on Concorda

2.2 University related Outputs

Members from the TUM team supervised 33 dissertations within the project duration working on the actual problems or closely related to the project itself.

SZTAKI team members also supervised 4 Bsc and Msc topics at the Budapest University of Technology and Economics where they teach and most of the students also worked part time in SZTAKI related to the topics of the project.

Two PhD thesis, by Tamás Baár and Bálint Patartics, were also defended at the Budapest University of Technology and Economics directly related to the project.

2.3 Dissemination within professional network

All project partners were active in disseminating the project results within their professional network. Some noteable examples include:

DLR-SR members briefing the CEO of DLR Anke Kaysser-Pyzalla.

Presenting project results at a NASA/ESA workshop.

Both the project coordinator, DLR and SZTAKI gave updates on Linkedin with posts reaching +30000 views.

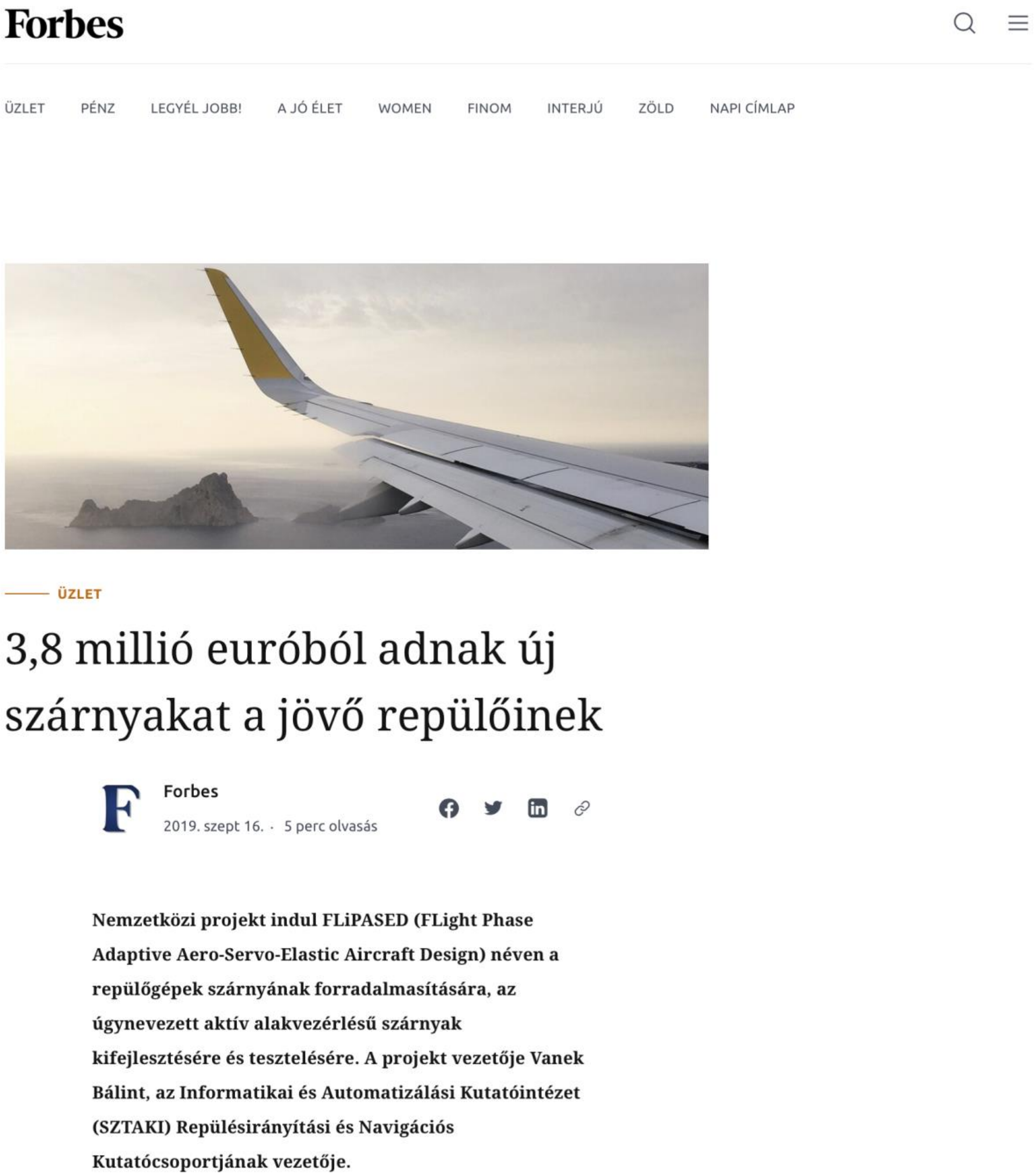
2.4 Dissemination within general public channels

All project partners were active in disseminating the project results within their national general public via their press network. Some noteable examples include:

Press release of the project start followed by 20+ articles in various online media

Forbes article (Hungary)

Süddeitche Zeitung article (Germany)



Forbes

ÜZLET PÉNZ LEGYÉL JOBB! A JÓ ÉLET WOMEN FINOM INTERJÚ ZÖLD NAPI CÍMLAP

ÜZLET

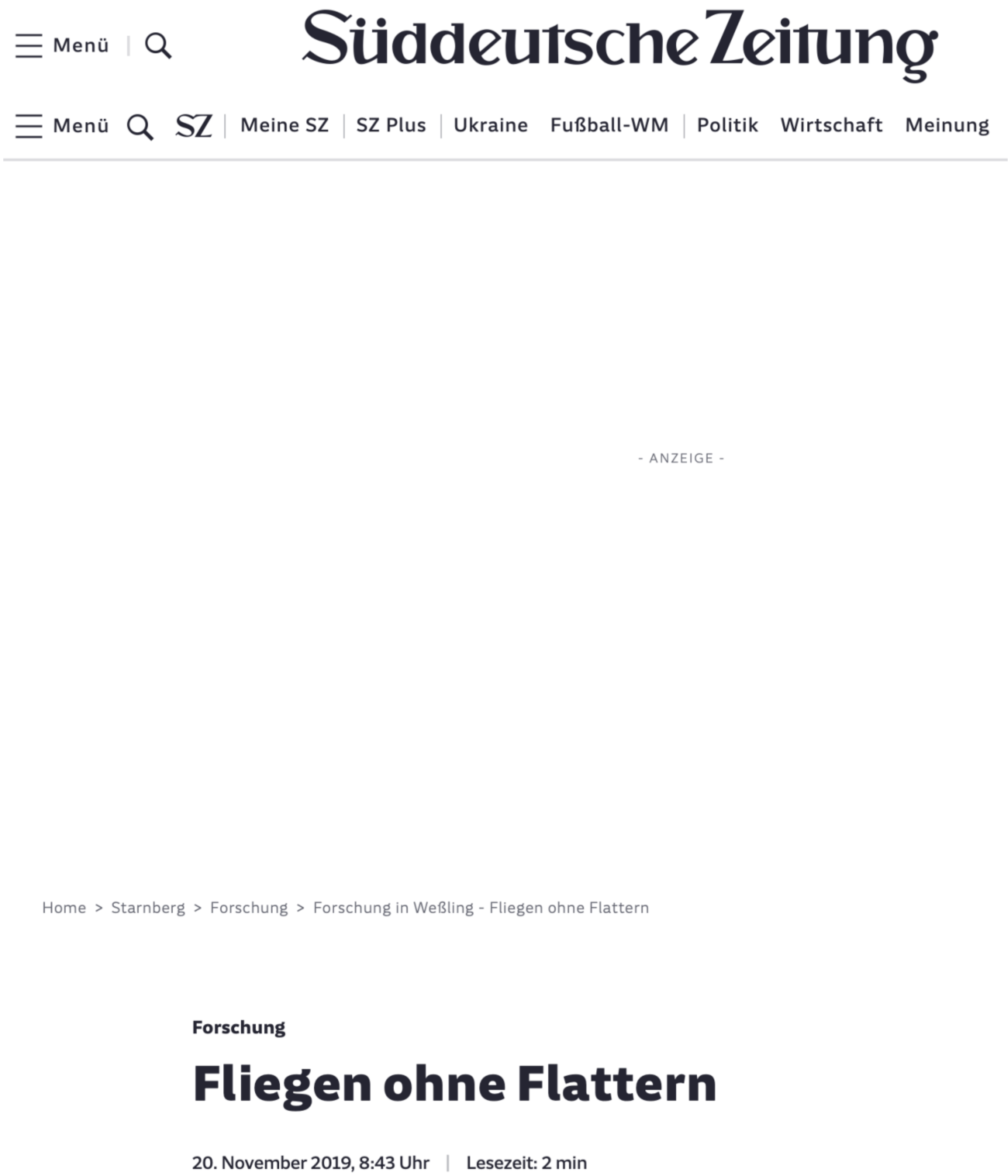
3,8 millió euróból adnak új szárnyakat a jövő repülőinek

Forbes

2019. szept 16. · 5 perc olvasás

Nemzetközi projekt indul FLiPASED (FLight Phase Adaptive Aero-Servo-Elastic Aircraft Design) néven a repülőgépek szárnyának forradalmasítására, az úgynevezett aktív alakvezérlésű szárnyak kifejlesztésére és tesztelésére. A projekt vezetője Vanek Bálint, az Informatikai és Automatizálási Kutatóintézet (SZTAKI) Repülésirányítási és Navigációs Kutatócsoportjának vezetője.

Figure 2 FLiPASED project featuring in Forbes Hungary



Menü | Süddeutsche Zeitung

Menü SZ | Meine SZ | SZ Plus | Ukraine Fußball-WM | Politik Wirtschaft Meinung

- ANZEIGE -

Home > Starnberg > Forschung > Forschung in Weßling - Fliegen ohne Flattern

Forschung

Fliegen ohne Flattern

20. November 2019, 8:43 Uhr | Lesezeit: 2 min

Figure 3 FLiPASED featuring in Süddeutsche Zeitung

Figure 4 Ottobrunn, Germany. 12th July, 2021. Mirko Hornung, Dean at the Technical University of Munich (TUM), Markus Söder (CSU), Prime Minister of Bavaria, and Thomas F. Hofmann, President of the Technical University of Munich (TUM), with T-FLEX in the background

Budapest Science Meetup – online presentation (due to COVID) for general public

Exhibition at Hungarian National Lab event (4 ministers attending)

Hungarian National Television interview

Virtual Aerodays 2020

Inaugration ceremony of the new TUM facility at EDMO airport

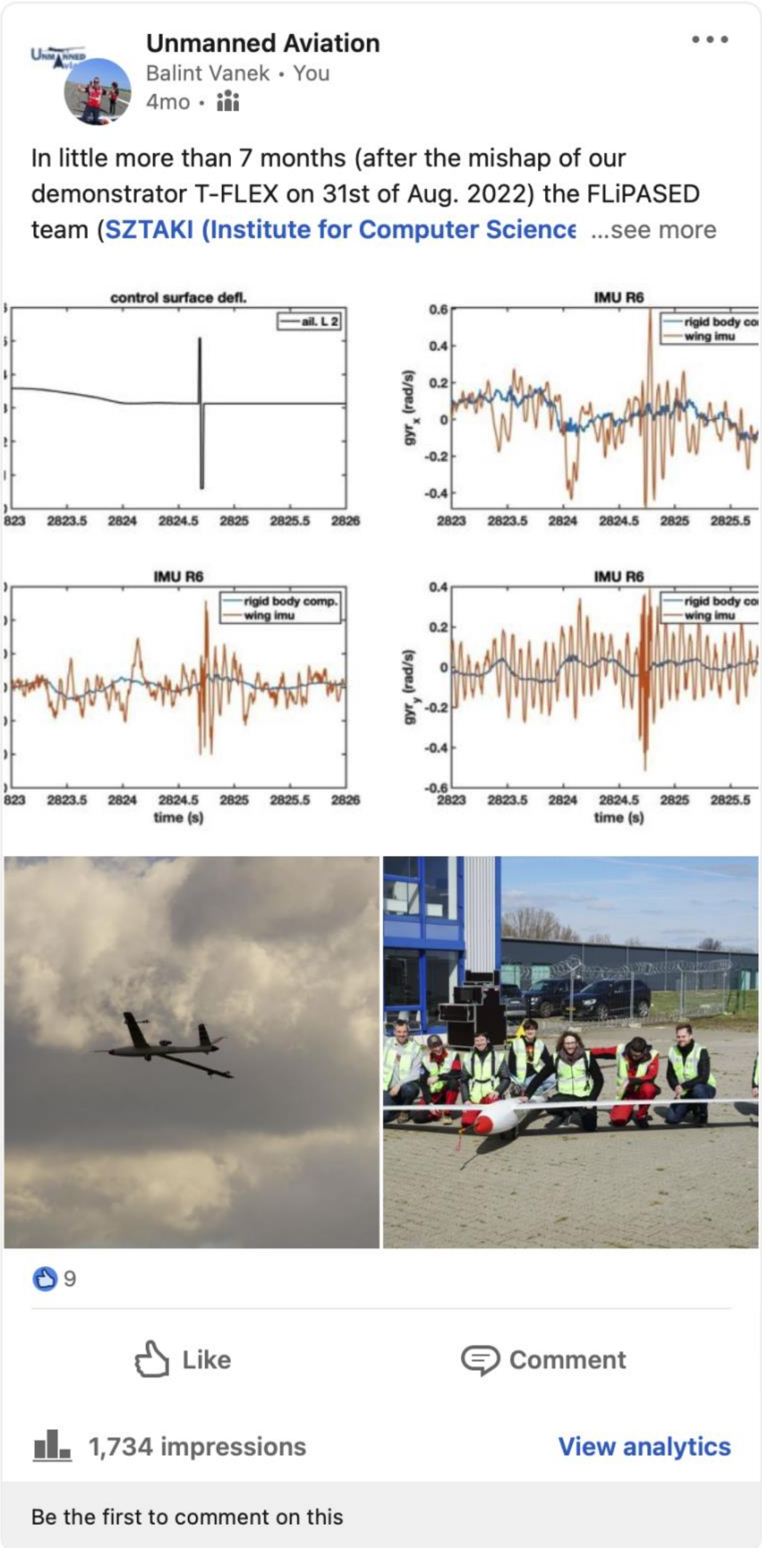


Figure 5 Linkedin post at Unmanned Aviation channel

Balint Vanek reposted this

National Laboratory for Autonomous Syste...
112 followers
10mo •

On October 17, 2022, an AFOSR delegation visited SZTAKI. The visit was organised by the US Embassy in Budapest. The visiting delegation was welcomed by Prof. József Bokor, Scientific Director of SZTAKI and Vice President of ELKH. ARNL researchers also actively participated in the scientific programme.

A delegation from the US Air Force Office of Scientific Research (AFOSR) visited SZTAKI

autonom.nemzetilabor.hu • 1 min read

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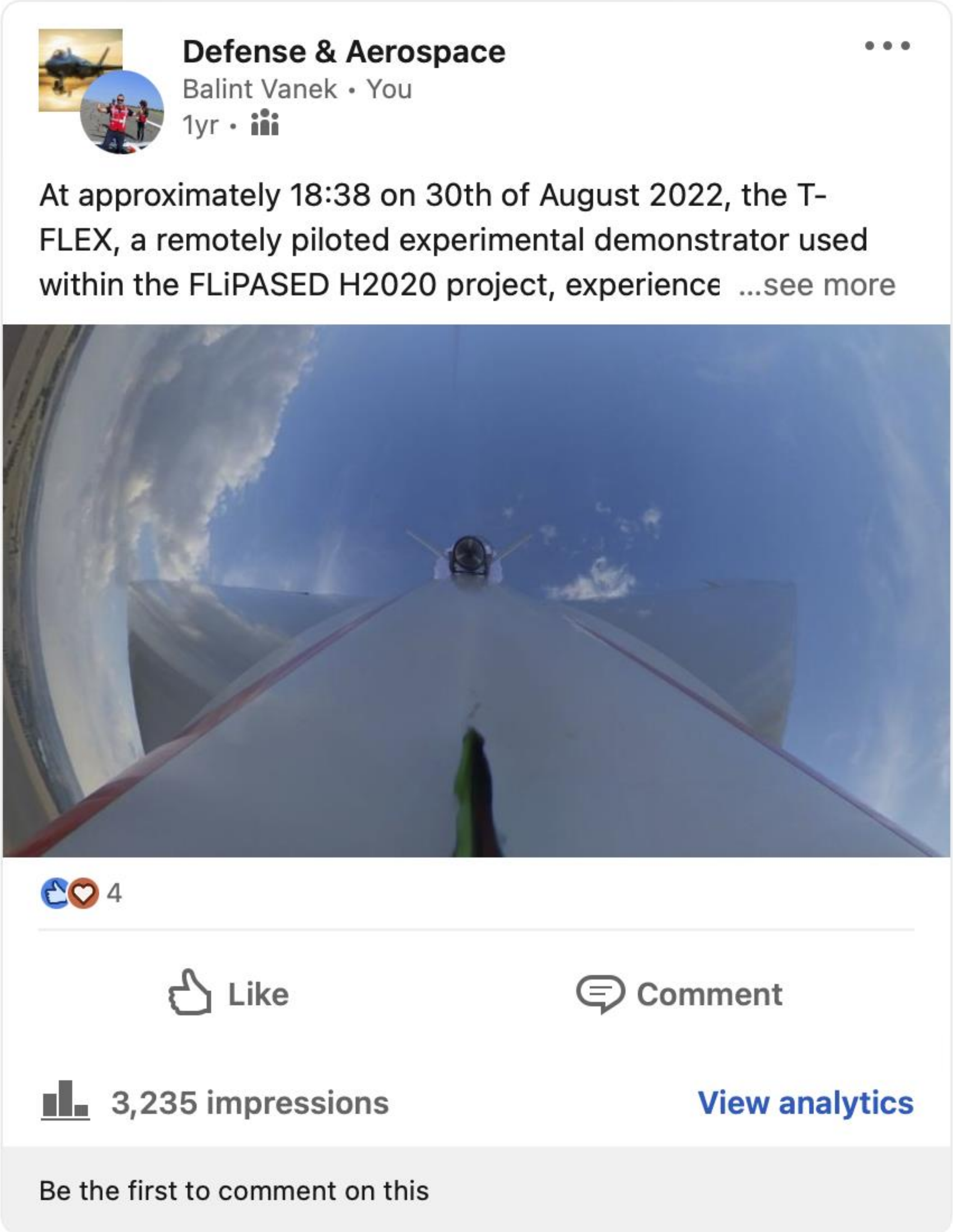
Defense & Aerospace
Balint Vanek • You
1yr •
At approximately 18:38 on 30th of August 2022, the T-FLEX, a remotely piloted experimental demonstrator used within the FLiPASED H2020 project, experience ...see more
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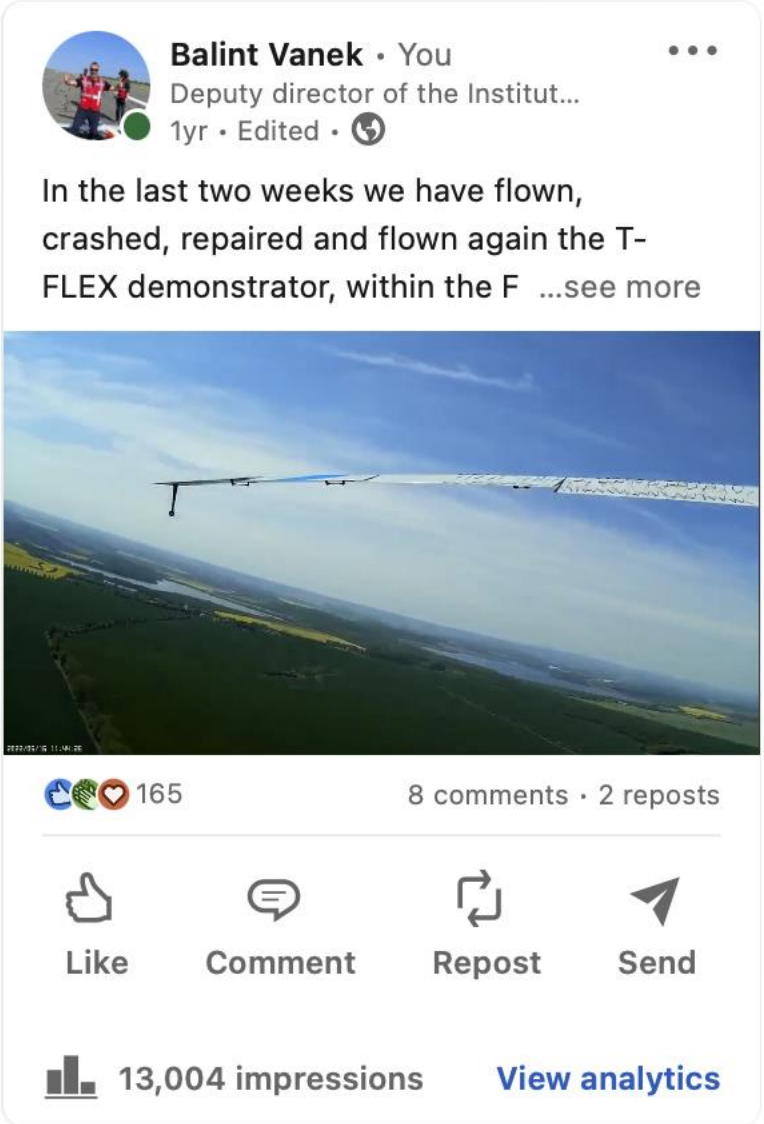
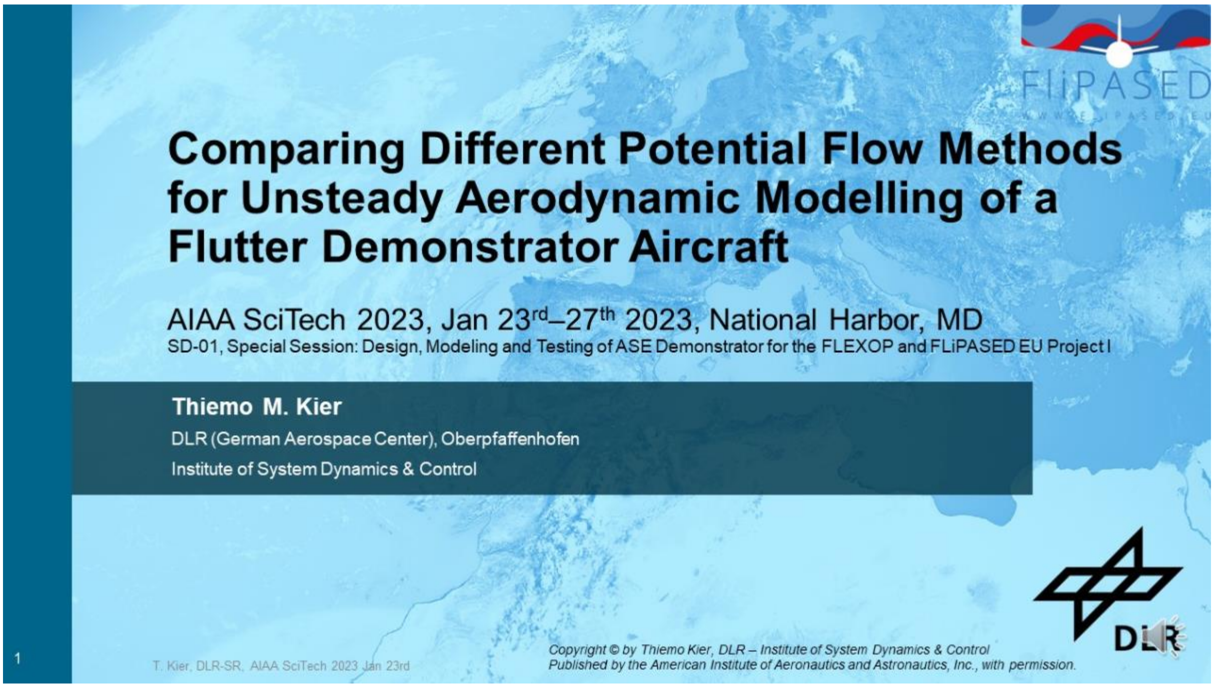


2.5 AIAA SCITECH Conference final Workshop

The major project dissemination activity was at the 2023 AIAA Scitech conference, where two back-to-back invited sections were held to present various aspects of the project. This highly successful dissemination activity was preceeded by the 2020 AIAA Scitech forum where a joint invited session was organized by the EU FliPASED and the NASA sponsored PAAW project partners.

The slides from the final workshop at Scitech 2023 can be seen below:

Comparing Different Potential Flow Methods for Unsteady Aerodynamic Modelling of a Flutter Demonstrator Aircraft (presented by Thiemo M. Kier, DLR)


FliPASED
Comparing Different Potential Flow Methods for Unsteady Aerodynamic Modelling of a Flutter Demonstrator Aircraft
AIAA SciTech 2023, Jan 23rd–27th 2023, National Harbor, MD
SD-01, Special Session: Design, Modeling and Testing of ASE Demonstrator for the FLEXOP and FLiPASED EU Project I
Thiemo M. Kier
DLR (German Aerospace Center), Oberpfaffenhofen
Institute of System Dynamics & Control
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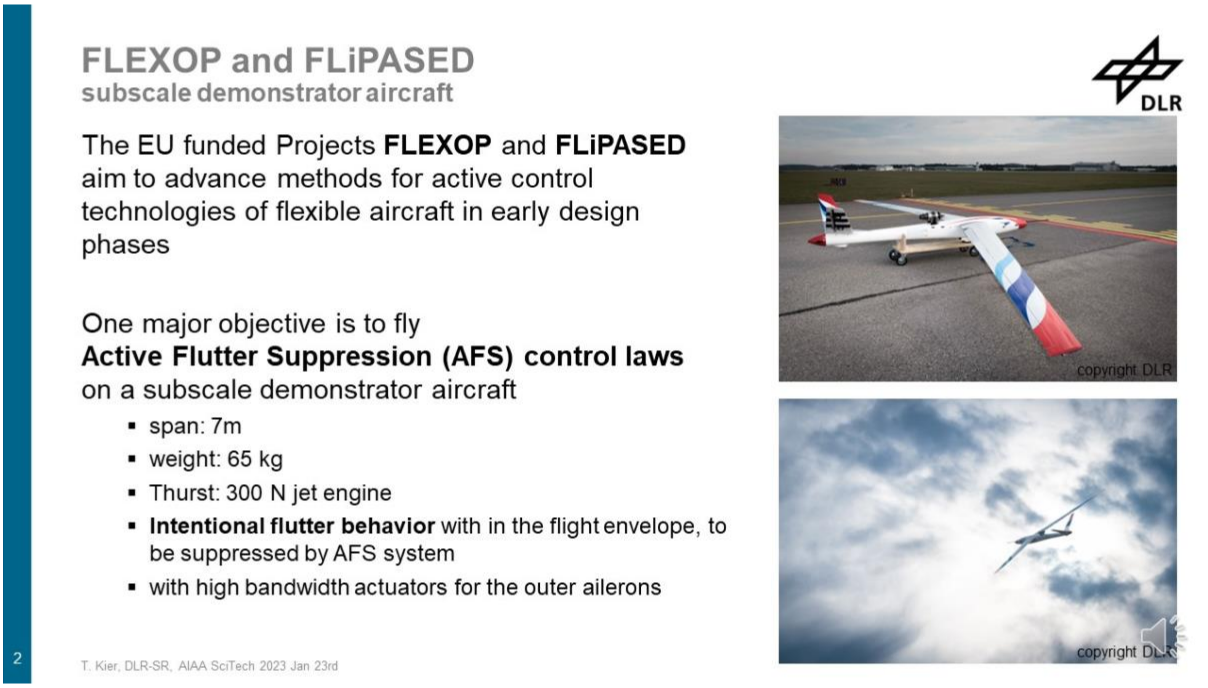
DLR


FLEXOP and FLiPASED
subscale demonstrator aircraft
The EU funded Projects FLEXOP and FLiPASED aim to advance methods for active control technologies of flexible aircraft in early design phases
One major objective is to fly
Active Flutter Suppression (AFS) control laws
on a subscale demonstrator aircraft
▪ span: 7m
▪ weight: 65 kg
▪ Thurst: 300 N jet engine
▪ Intentional flutter behavior with in the flight envelope, to be suppressed by AFS system
▪ with high bandwidth actuators for the outer ailerons
DLR
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Motivation

- Model based **design of Control Laws** for Active Flutter Suppression requires **fast and accurate models**
- The **Doublet Lattice Method** is commonly used for **Flutter analysis**
- standard DLM has a major shortcoming: It does **not account for in-plane forces**
- Therefore, an **enhanced DLM** with complex **directional lift** is employed

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Overview

- Aerodynamic Methods
  - Standard Doublet Lattice Method (DLM)
    cover only forces in z-direction
  - Enhanced Doublet Lattice Method (eDLM)
    accounts for directional lift forces including x-direction
- Aerodynamic Models
  - Wings only
  - Cruciform shaped Fuselage
  - Body Panel Fuselage
- Flutter Results for the subscale demonstrator aircrafts
- Generalized Aerodynamic Forces
  - Fluttermodes
  - In-plane mode
  - Rigid body Fuselage Modes

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Doublet Lattice Method

- Harmonic solution of linearized potential equation at discrete reduced frequencies

$$(1-Ma_\infty^2)\frac{\partial^2\Phi}{\partial x^2}+\frac{\partial^2\Phi}{\partial y^2}+\frac{\partial^2\Phi}{\partial z^2}-\left(2\frac{Ma_\infty}{a_\infty}\right)\frac{\partial^2\Phi}{\partial x\partial t}-\left(\frac{1}{a_\infty^2}\right)\frac{\partial^2\Phi}{\partial t^2}=0 \qquad k=\frac{c_{ref}/2}{U_\infty}\omega$$

- AIC matrix relates normalwash to pressure coefficients

$$\Delta \mathbf{c}_{\mathbf{p}_j}(k)=\mathbf{Q}_{jj}(k)\mathbf{w}_j(k)$$

- Normalwash is determined by pitch angle and heaving motion at each control point

$$\mathrm{w}_j(k)=\left(\mathrm{D^x}_{jk}+\mathrm{i}k\;\mathrm{D^t}_{jk}\right)\;\mathbf{u}_k(k)$$

- Generalized Aerodynamic Forces (GAFs)

$$\boldsymbol{Q}_{hh}=\;\boldsymbol{\Phi}_{gh}{}^{\mathrm{T}}\;\;\mathbf{T}_{kg}{}^{\mathrm{T}}\;\;\mathbf{S}_{kj}\;\;\left[\;\boldsymbol{Q}_{jj}\;\;\left(\mathbf{D^x}_{jk}+\mathrm{i}k\mathbf{D^t}_{jk}\right)+\left(\mathbf{D}\boldsymbol{P}^{\mathbf{x}}{}_{jk}+\mathrm{i}k\mathbf{DP^t}{}_{jk}\right)\right]\;\boldsymbol{T}_{kg}\;\;\boldsymbol{\Phi}_{gh}$$

Modal matrix — *Pressure integration* — *AIC* — *differentiation matrices* — *Motion induced press. matrices* — *Spline matrix*

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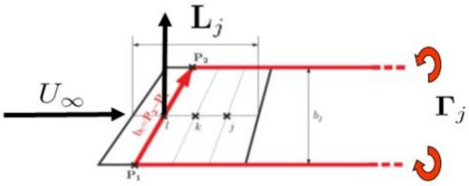
Enhanced Doublet Lattice Method
Kutta Joukowsky Law

Classical Scalar form:



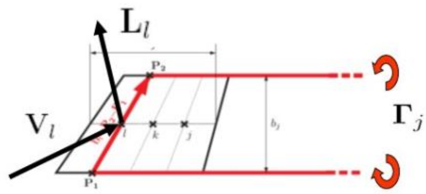
Kutta Joukowsky: $\mathbf{L}_j=\rho U_\infty \Gamma_j \mathbf{b}_j$

DoF: $\mathbf{u}_j=[z]_j\;;\;\mathbf{u}_k=[z\;\;\theta]_k^{\mathrm{T}}\;;\;\mathbf{u}_l=[z]_l$

$$\Delta\mathbf{c}_{\mathbf{p}_j}=\mathbf{Q}_{jj}\mathbf{w}_j$$

$$\Gamma_j=U_\infty\frac{c_j}{2}\Delta c_{p_j}$$

Present Vector form:



$$\mathbf{L}_l=\rho\mathbf{V}_l\times(\mathbf{b}_l\Gamma_j)$$

$\mathbf{u}_j=[z]_j\;;\;\mathbf{u}_k=[x\;\;y\;\;z\;\;\varphi\;\;\theta\;\;\psi]_k^{\mathrm{T}}\;;\;\mathbf{u}_l=[x\;\;y\;\;z]_l^{\mathrm{T}}$

$$\mathbf{L}_l=q_\infty\left(\left[-\mathbf{sk}(\mathbf{b}_l)\right]\mathbf{w}_l\right)\odot\left(c_j\,[1\;\;1\;\;1]^{\mathrm{T}}\Delta c_{p_j}\right)\qquad w_l=\frac{V_l}{U_\infty}$$

Elementwise multiplication (expanded blockwise)

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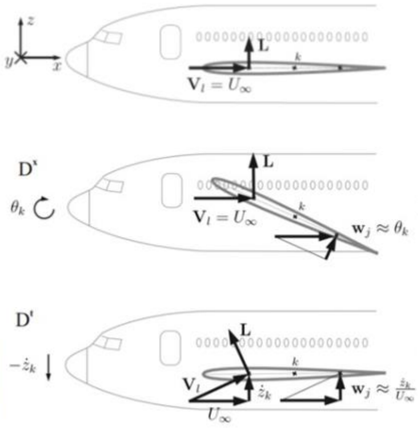
Aerodynamic boundary conditions

DLR

$$\mathbf{w}_l = \mathbf{D^t}_{lk}\left(\frac{c_{ref}/2}{U_\infty}\right)\cdot \dot{\mathbf{u}}_k \qquad \mathbf{w}_j = \mathbf{D^x}_{jk}\cdot\mathbf{u}_k + \mathbf{D^t}_{jk}\left(\frac{c_{ref}/2}{U_\infty}\right)\cdot\dot{\mathbf{u}}_k$$



Torsional deformation:

$$\mathbf{D^x}_{jk} = \begin{bmatrix}0 & 0 & 0 & 0 & 1 & 0\end{bmatrix}$$

Heaving motion:

$$\mathbf{D^t}_{lk} = -\frac{2}{c_{ref}}\begin{bmatrix}1 & 0 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0 & -c_j/4\\ 0 & 0 & 1 & 0 & c_j/4 & 0\end{bmatrix}$$

$$\mathbf{D^t}_{jk} = -\frac{2}{c_{ref}}\begin{bmatrix}\underset{\approx 0}{n_x} & 0 & \underset{\approx 1}{n_z} & 0 & -c_j/4 & 0\end{bmatrix}$$

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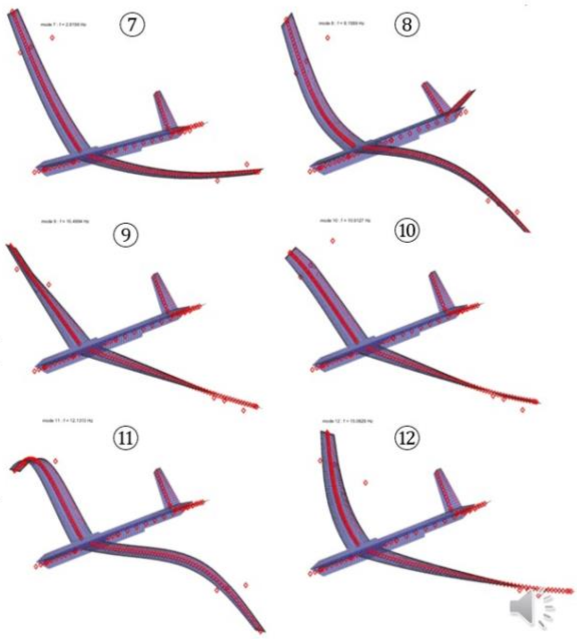
Normal modes of the demonstrator aircraft

- Free-Free Modal Analyis
- First 6 eigenvalues are zero
- Associated Modeshapes are generated geometrically about c.g. in flight dynamics coordinate system (x forward, z down)
- Flexible modes 7–12 are shown:

mode number	description	frequency [Hz]
7	symmetric – 1st wing bending	2.92
8	antisymmetric – 1st wing bending	8.16
9	symmetric – 1st wing torsion	10.50
10	antisymmetric – 1st wing torsion	10.61
11	symmetric – 2nd wing bending	12.13
12	symmetric – 1st wing in-plane bending	15.06



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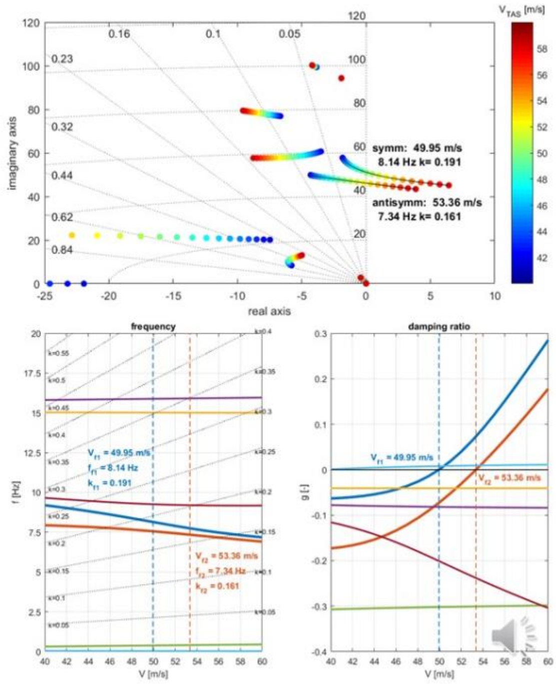
Flutter Analysis

Classical Flutter Methods:

- frequency domain ***p-k*** method
- System matrix ***p*** method requires RFA of the Q_{hh} matrix

Results:

- Eigenvalues in complex plane
- V-f V-g plots: frequencies and damping ratios
- Modal Contribution: which structural modes contribute to the flutter modes



structural mode no.	description of structural mode	modal contribution [%]	
		symmetric flutter mode 1 $V_{f1} = 49.95\,m/s$ $f_{f1} = 8.14\,Hz$	*antisymmetric flutter mode 2* $V_{f2} = 53.36\,m/s$ $f_{f2} = 7.34\,Hz$
7	symmetric – 1st wing bending	**47.1**	1.0
8	antisymmetric – 1st wing bending	0.5	**51.2**
9	symmetric – 1st wing torsion	**34.7**	1.9
10	antisymmetric – 1st wing torsion	1.2	**37.5**
11	symmetric – 2nd wing bending	**12.3**	0.4
12	symmetric – 1st wing in-plane bending	2.2	0.1

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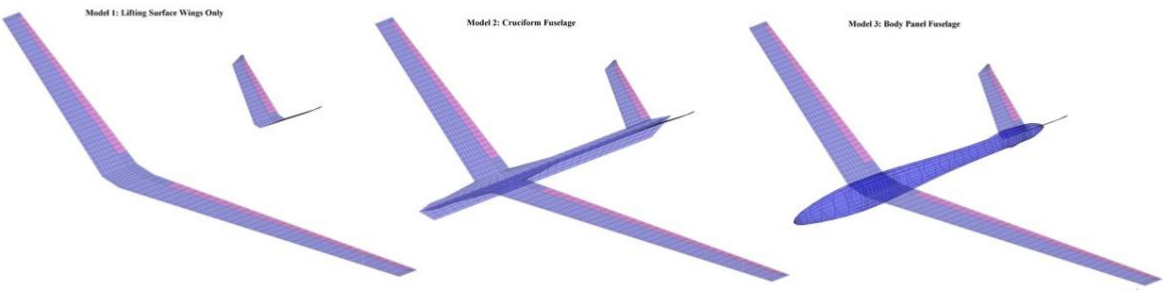
Aerodynamic Models

Three different aerodynamic Models/Grids are employed

- Wings only
- Cruciform Shaped Fuselage
- Body Panel Fuselage



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Flutter Results

- Hardly any influence on flutter results by different **flutter methods, aerodynamic methods** or **aerodynamic grids**
- **Minimal increase** in flutter speed for the **eDLM**

Flutter Mode	Model 1: wings only				Model 2: cruciform fuselage				Model 3: body panels	
	DLM		eDLM		DLM		eDLM		eDLM	
	p	pk	p	pk	p	pk	p	pk	p	pk
symmetric										
V_{f1} [m/s]	48.95	48.90	50.14	50.07	48.79	48.74	50.14	50.07	49.99	49.92
f_{f1} [Hz]	8.30	8.29	8.21	8.22	8.31	8.31	8.21	8.22	8.23	8.23
k_{f1} [-]	0.199	0.199	0.192	0.192	0.200	0.200	0.192	0.192	0.193	0.193
antisymmetric										
V_{f2} [m/s]	53.09	53.10	53.54	53.55	53.10	53.11	53.56	53.57	53.52	53.53
f_{f2} [Hz]	7.42	7.42	7.43	7.43	7.42	7.43	7.43	7.43	7.43	7.43
k_{f2} [-]	0.164	0.164	0.163	0.163	0.164	0.164	0.163	0.163	0.163	0.163

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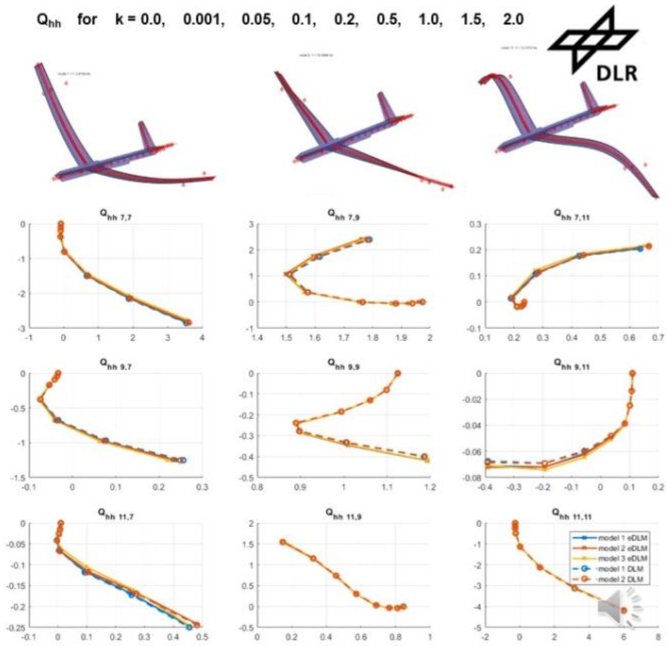
Generalized Aero Forces
symm flutter mode 1 @ k = 0.20

- Modal Participation
  7 : symm 1st bend 47.1 %
  9 : symm 1st torsion 34.7 %
  11: symm 2nd bend 12.3 %

- Almost no difference in aerodynamic transferfunctions, therefore no influence on flutter results



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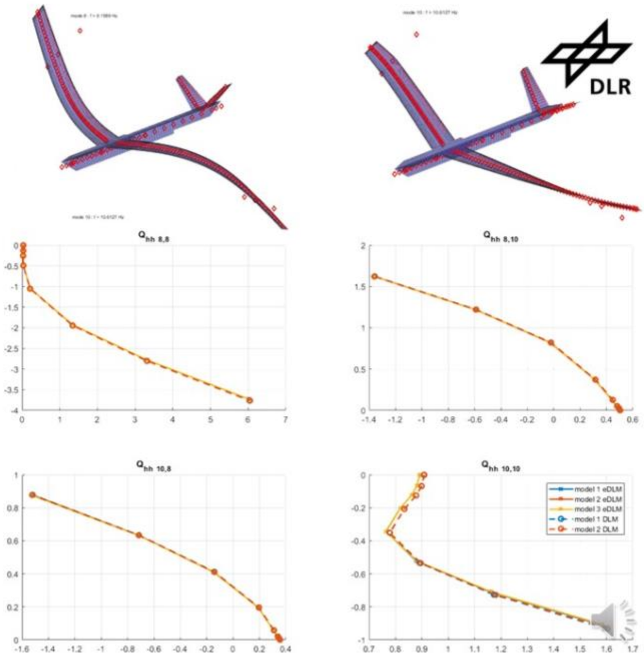
Generalized Aero Forces
antisymm flutter mode 2 @ k = 0.16

- Modal Participation
  8 : antisym 1st bend 51.2 %
  10: antisym 1st torsion 37.5 %
- Almost no difference in aerodynamic transferfunctions, therefore no influence on flutter results



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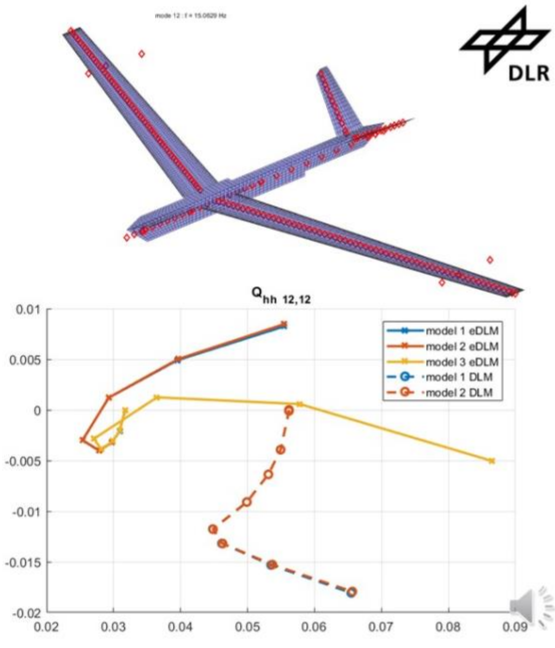
Generalized Aero Forces
in-plane bending mode 12

- Not participating in any flutter mode
- Large differences between standard DLM and enhanced eDLM
- Cruciform fuselage has not influence on this mode
- Body panel fuselage has some impact for higher reduced frequencies k>0.2)



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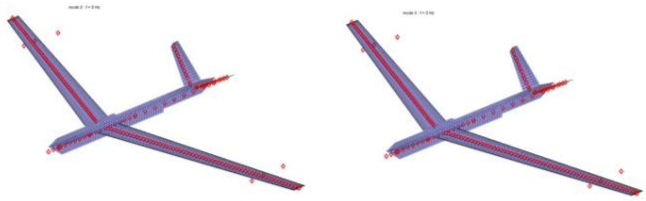
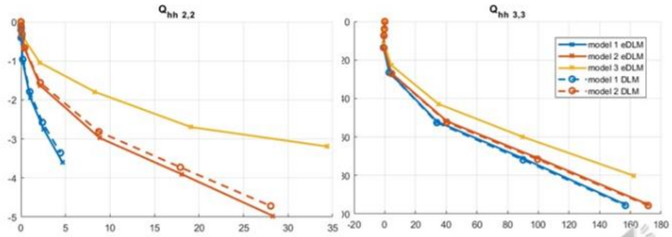
Generalized Aero Forces
fuselage modes

- Rigid Body Sway (2) and heave (3) mode
- Large influence of the fuselage modelling
- No difference between standard DLM and enhanced DLM
- Cruiform shaped fuelage (model 2) seems to underestimate effect compared to body panels (model 3)





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Summary and Conclusions

- A **standard DLM** was compared to an **enhanced eDLM** with directional lift forces
- **No change in flutter** behavior since flutter mechanisms only has out of plane modes
- **Fuselage** modelling has **influence on rigid body modes** (cruciform shape seems to underestimate effect compared to body panels)
- **Large changes for in-plane GAFs** !!!

GVT of the demonstrator showed an **antisymmetric in-plane mode** close to the **1st antisymmetric bending** frequency, which is **not present in the current FE-Model**

Analysis should be repeated with an updated FEM !!!

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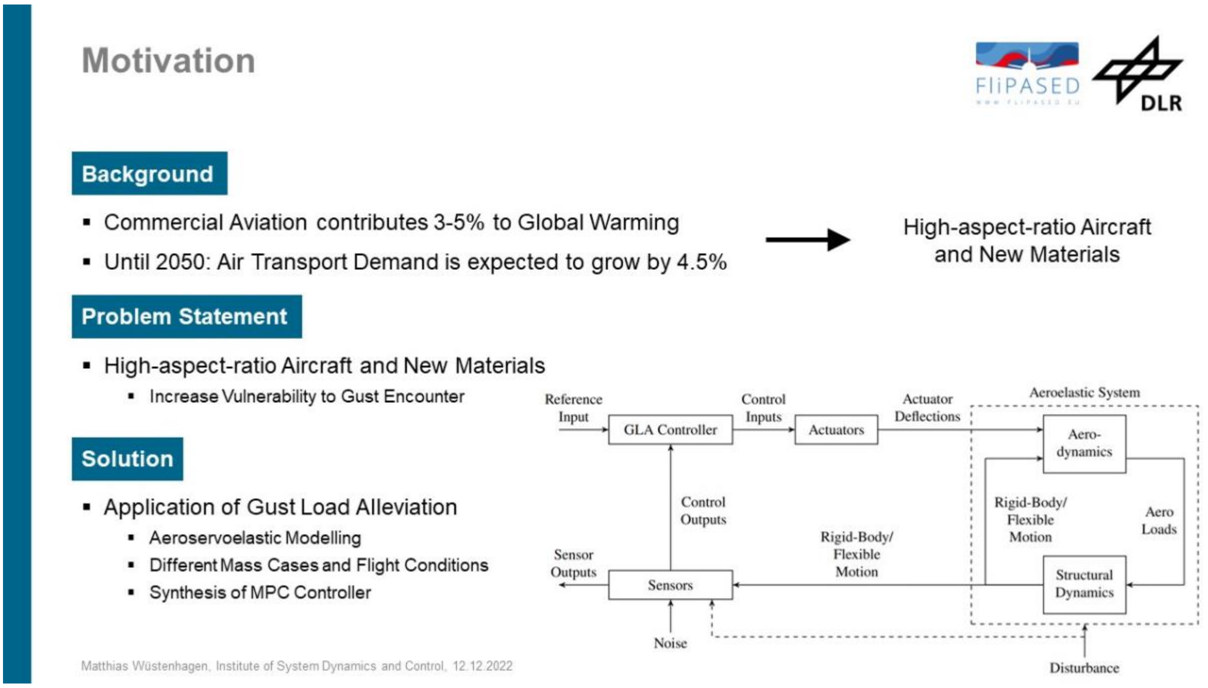
Gust Load Alleviation Control of Aircraft with Varying Mass Distribution (presented by Matthias Wüstenhagen, DLR)



Aeroservoelastic Aircraft Model

Aeroelastic Model

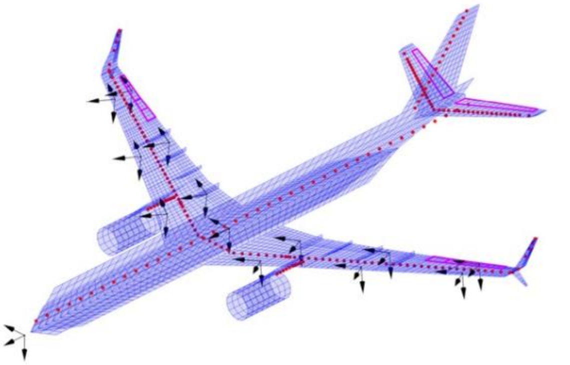
- Structural Dynamics $P_g^{\text{ext}} = P_g^{\text{eng}} + P_g^{\text{aero}}$

$$\begin{bmatrix} m_b(\dot{V}_b + \Omega_b \times V_b - T_{be}(\Theta_b) g_e) \\ J_b \dot{\Omega}_b + \Omega_b \times (J_b \Omega_b) \end{bmatrix} = \Phi_{gb}^T P_g^{\text{ext}}$$

$$M_{ff} \ddot{u}_f + B_{ff} \dot{u}_f + K_{ff} u_f = \Phi_{gf}^T P_g^{\text{ext}}(t)$$

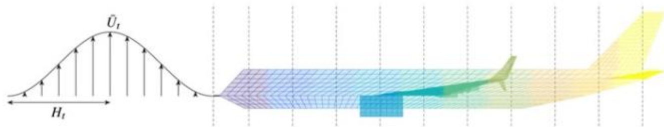
- Aerodynamics

$$\Delta c_{pj}(k) = Q_{jj}(k) w_j(k)$$



Loads Model (Force Summation Method)

$$P_c = T_{cg} \left(P_g^{\text{ext}} - \underbrace{M_{gg} \begin{bmatrix} \Phi_{gb} & \Phi_{gf} \end{bmatrix} \begin{bmatrix} \ddot{u}_b \\ \ddot{u}_f \end{bmatrix}}_{P_g^{\text{iner}}} \right)$$



Matthias Wüstenhagen, Institute of System Dynamics and Control, 12.12.2022

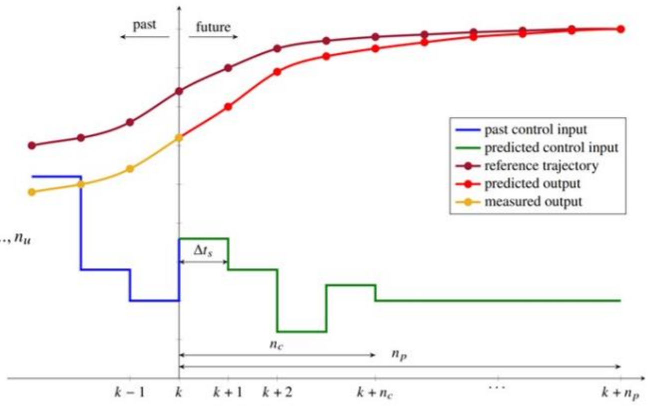
Model Predictive Control

Optimisation Problem

$$J(z_k) = \underbrace{\min_{w_y} \sum_{j=1}^{n_y} \sum_{i=1}^{n_p} \left(w_{y,j} \left(r_j(k+i|k) - y_j(k+i|k) \right) \right)^2}_{J_y(z_k)}$$

$$+ \underbrace{\min_{w_{\Delta u}} \sum_{j=1}^{n_u} \sum_{i=1}^{n_c - 1} \left(w_{\Delta u,j} \left(u_j(k+i|k) - u_j(k+i-1|k) \right) \right)^2}_{J_{\Delta u}(z_k)}$$

$$u_{j,\min} \le u_j(k+i-1|k) \le u_{j,\max}$$
$$\Delta u_{j,\min} \le \Delta u_j(k+i-1|k) \le \Delta u_{j,\max} \qquad i = 1, 2, \ldots, n_p \quad j = 1, 2, \ldots, n_u$$



Prediction Model

$$x(k+1) = A_s x(k) + B_s u(k)$$
$$y(k) = C_s x(k) + D_s u(k)$$

Matthias Wüstenhagen, Institute of System Dynamics and Control, 12.12.2022

Gust Load Alleviation with Model Predictive Control

GLA Controllers

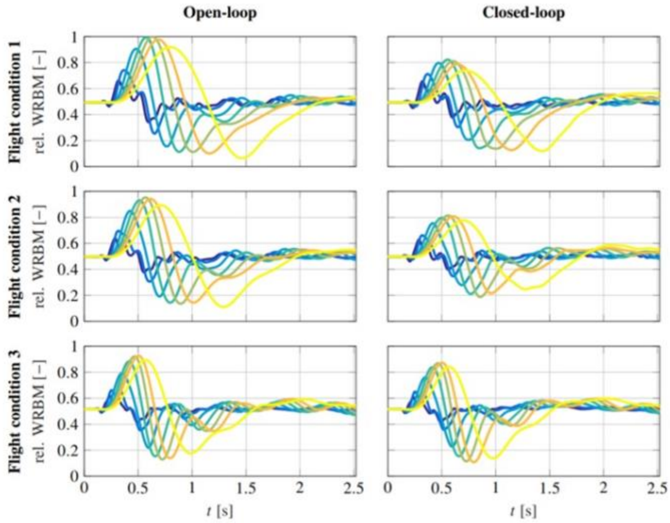
27 GLA Controllers with MPC

- 9 Mass Cases

No.	Definition
1	operating empty mass
2	rear light payload
3	forward light payload
4	rear heavy payload
5	forward heavy payload
6	central heavy payload
7	forward maximum take-off mass
8	rear maximum take-off mass
9	central maximum take-off mass

- 3 Flight Conditions

No.	h [m]	U_∞ [m/s]
1	0	170
2	3000	197
3	8300	264

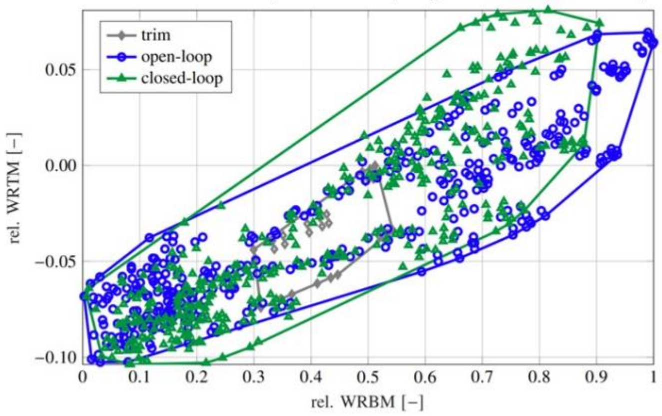


Matthias Wüstenhagen, Institute of System Dynamics and Control, 12.12.2022

Gust Load Alleviation with Model Predictive Control

Analysis of GLA with MPC

- Relative Wing Root Bending Moment vs. Relative Wing Root Torsional Moment
  - Minimum and Maximum Values of 189 Simulations (9 Mass Cases, 3 Flight Conditions, 7 Gust Properties)



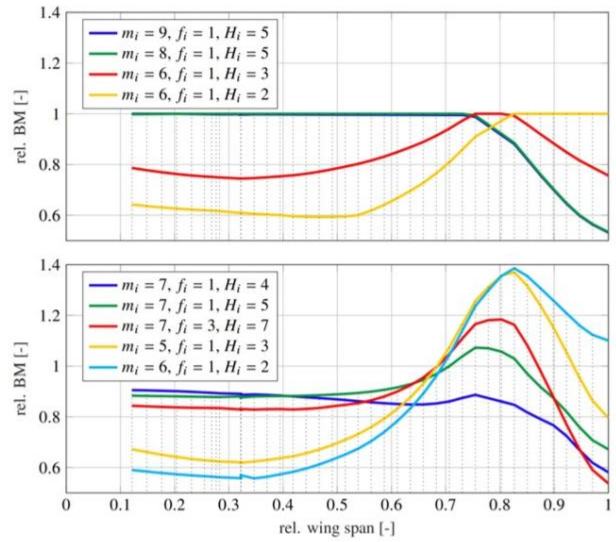
Matthias Wüstenhagen, Institute of

Gust Load Alleviation with Model Predictive Control

Analysis of GLA with MPC

- Relative Bending Moment over Wing Span
  - Open-loop (top): 4 Critical Load Cases
  - Closed-loop (bottom): 5 Critical Load Cases

→ Use more control surfaces along the wing



Conclusion & Outlook

Conclusion

- Aeroservoelastic Model
  - Structural Dynamics
  - Aerodynamics
  - 1-cosine Gust
  - Loads
- 27 GLA Controllers with MPC (9 Mass Cases, 3 Flight Conditions)
  - 10% reduction of WRBM
  - Almost up to 40% increase in Bending Moment at Control Surface Location

Outlook

- Reduction of the Bending Moment over the Wing with GLA
  - Deploy more Control Surfaces distributed over the Wing for GLA
  - Adjust the Weights of the Optimisation
- Methods to use 27 GLA Controllers in unison

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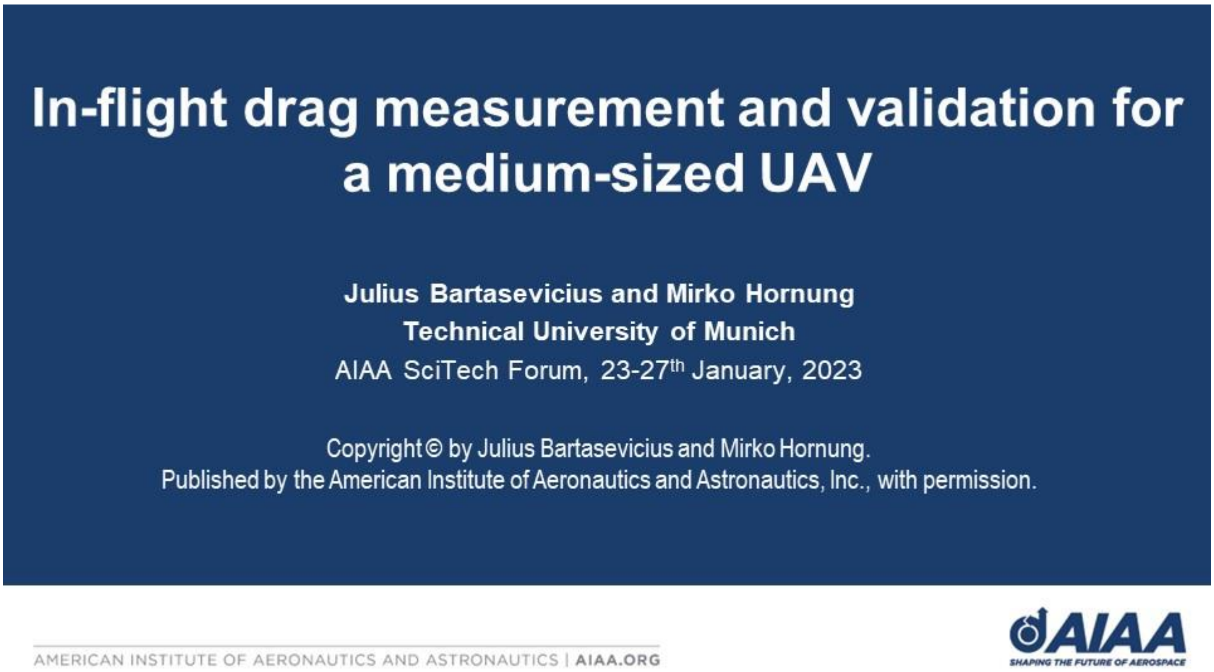
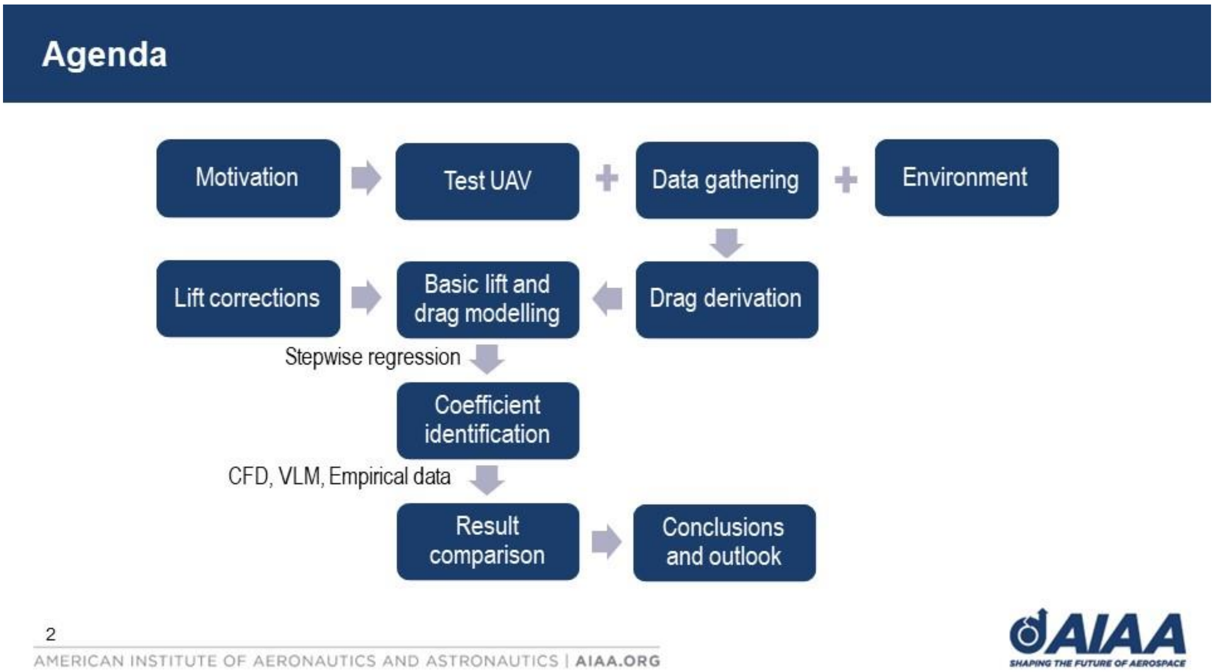
In-flight drag measurement and validation for a medium-sized UAV (presented by Julius Bartasevicius, TUM)





1. Motivation

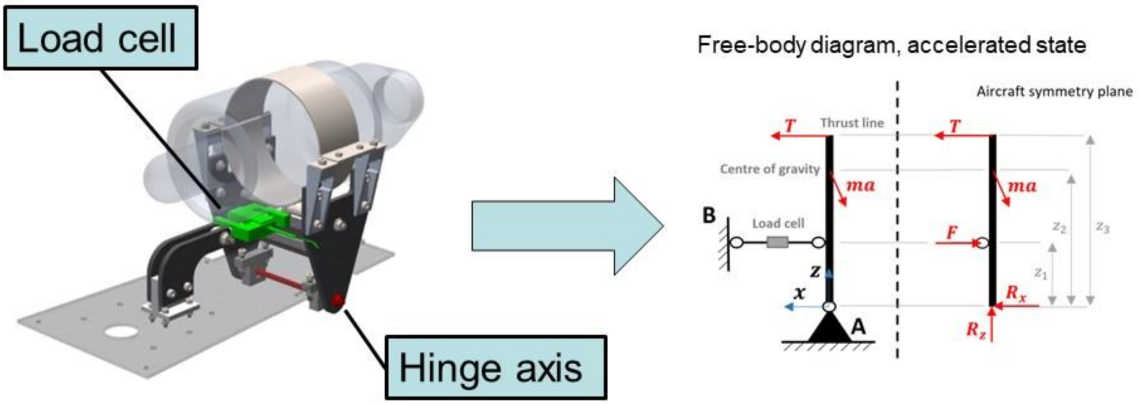
- Design methods are being adapted for the lower Reynolds numbers and new configurations.
- Performance assessment of a manufactured UAV is not being investigated as much.
- What is required to measure the drag of an already flying conventional UAV?

2. Test case UAV
Our test case: T-FLEX UAV

Characteristics of T-FLEX UAV	
Wing span	$7.07m$
Wing aspect ratio	19.74
Wing $c/4$ sweep	$18°$
Take-off mass	$65kg$
Maximum thrust	$300N$

2. Test case UAV

Thrust measurement system was built for the T-FLEX UAV



[1] J. Bartasevicius, P. Alexandre, T. Fleig, A. Metzner, and M. Hornung, "Design and testing of an in-flight thrust measurement system for a pylon-mounted miniature jet engine," 2022.

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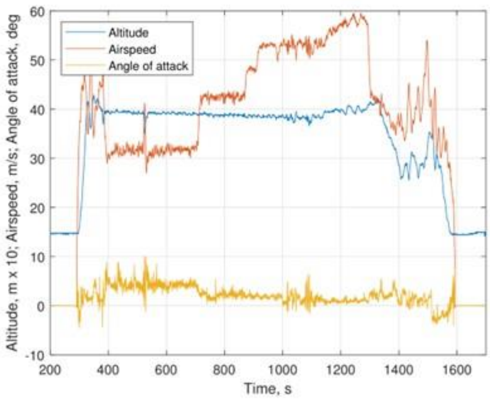
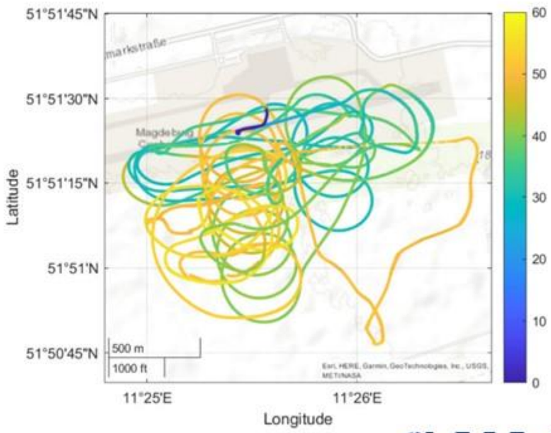
3. Flight test data

Data from complete flight tests was used

- Only smoothing filter was applied.





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3. Flight test data

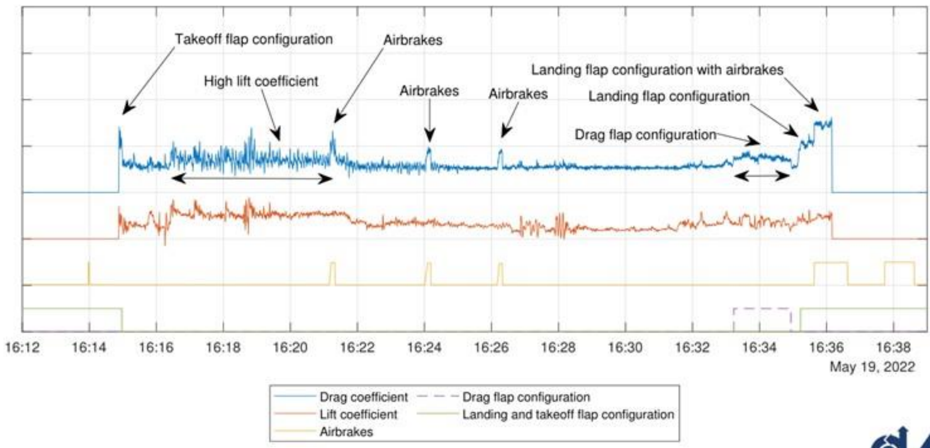
Flight tests were done in high-turbulence environment

Date	Flight number	10-min average wind, m/s	Wind gusts, 10-min window, m/s
09.05.2022	FT10	2.1	3.6
19.05.2022	FT16	3.6	5.1
19.05.2022	FT17	From 1 to 7.1	From 1.5 to 15.4
		Typical cruise speed:	**30 – 35m/s**

3. Flight test data

Global drag coefficient was derived

$$\bar{q}SC_D = \cos\alpha\,(F_T - ma_x) - \sin\alpha\,(ma_z)$$



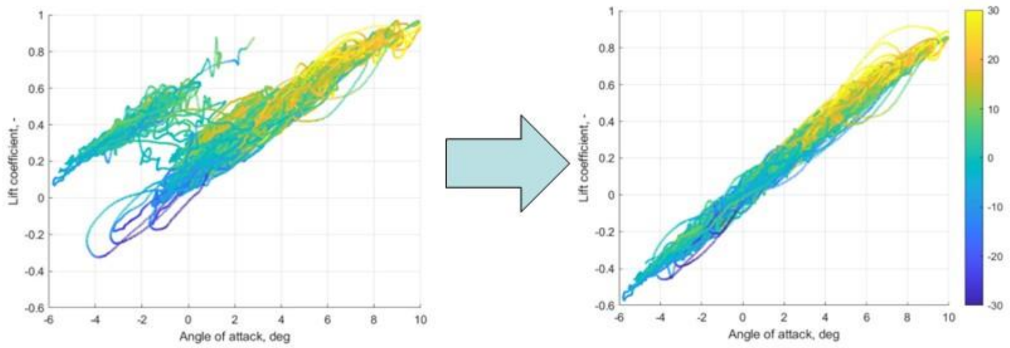
4. Lift and drag modelling: Lift corrections

$$C_L = C_{L0} + C_{L\alpha}\alpha + C_{L\beta^2}\beta^2 + C_{L\delta_{f1}}\delta_{f1} + C_{L\delta_{f1}^2}\delta_{f1}^2 + C_{L\delta_{f2}}\delta_{f2} + C_{L\delta_{f3}}\delta_{f3} + C_{L\delta_{f4}}\delta_{f4}$$

Symbol		Units	Definition
C_L	Lift coefficient	-	-
…	…	…	…
$C_{L\beta^2}$	Lift coefficient due to sideslip	-	-
β	Sideslip angle	deg	-
$C_{L\delta_{fi}}, C_{L\delta_{fi}^2}$	Lift coefficient due to flap deflection	-	-
δ_{fi}	Flap deflection	deg	$\delta_{fiL}+\delta_{fiR}$
δ_{f1}^2	Flap deflection, 2nd term	deg^2	$(\delta_{fiL}+\delta_{fiR})^2$

4. Lift and drag modelling: Lift corrections

$$C_L = C_{L0} + C_{L\alpha}\alpha + C_{L\beta^2}\beta^2 + C_{L\delta_{f1}}\delta_{f1} + C_{L\delta_{f1}^2}\delta_{f1}^2 + C_{L\delta_{f2}}\delta_{f2} + C_{L\delta_{f3}}\delta_{f3} + C_{L\delta_{f4}}\delta_{f4}$$

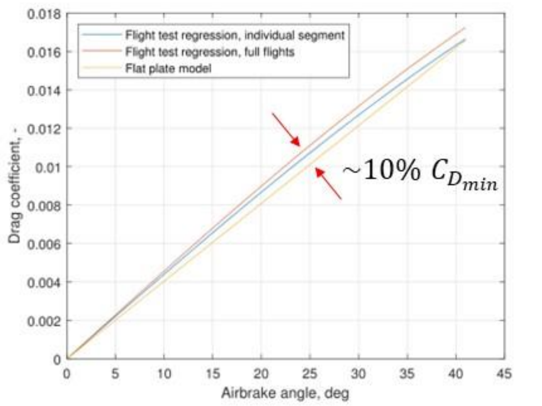


4. Lift and drag modelling:
Drag model

$$C_D = C_{D_0} + C_{D_{C_L}} C_L + C_{D_{C_L^2}} C_L^2 + C_{D_{ab}} \sin\delta_{ab} + C_{D_{lg}}\delta_{lg} + C_{D_{\beta}^2}\beta^2$$
$$+ C_{D_{\delta_{f1}{}^2}}\delta_{f1}{}^2 + C_{D_{\delta_{f23}{}^2}}\left(\delta_{f2}{}^2 + \delta_{f3}{}^2\right) + C_{D_{\delta_{f4}{}^2}}\delta_{f4}{}^2$$

Symbol		Units	Definition
…	…	…	…
$C_{D_{ab}}, C_{D_{lg}}$	Drag coefficient due to airbrake deflection and landing gear	-	-
δ_{ab}	Airbrake deflection	deg	$(\delta_{abL} + \delta_{abR})/2$
$C_{L_{\delta_{fi^2}}}$	Drag coefficient due to flap deflection squared	-	-
δ_{fi^2}	Flap deflection squared	$\deg^2$	$\delta_{fiL}^2 + \delta_{fiR}^2$

5. Drag coefficient identification:
Airbrake drag aligned well with a flat plate model



Deviation to the flat plate model ~10% $C_{D_{min}}$

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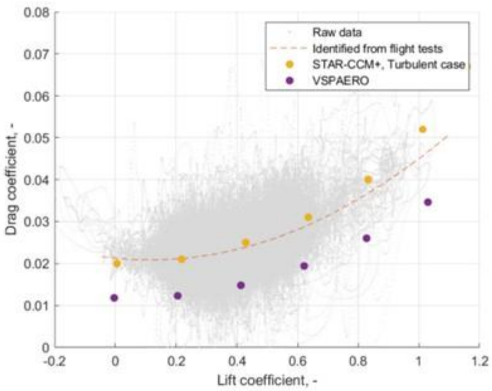
5. Drag coefficient identification:
Induced drag was extracted from full-flight data



$$C_D = C_{D_{min}} + k\left(C_L - C_{L_{minD}}\right)^2$$

	$C_{D_{min}}$	k	e	$C_{L_{minD}}$
STAR-CCM+, fully turbulent	0.0200	0.0344	0.460	0.2576
VSPAERO	0.0117	0.0237	0.666	0.0520
Flight tests	**0.0208**	**0.0308**	**0.513**	**0.1151**

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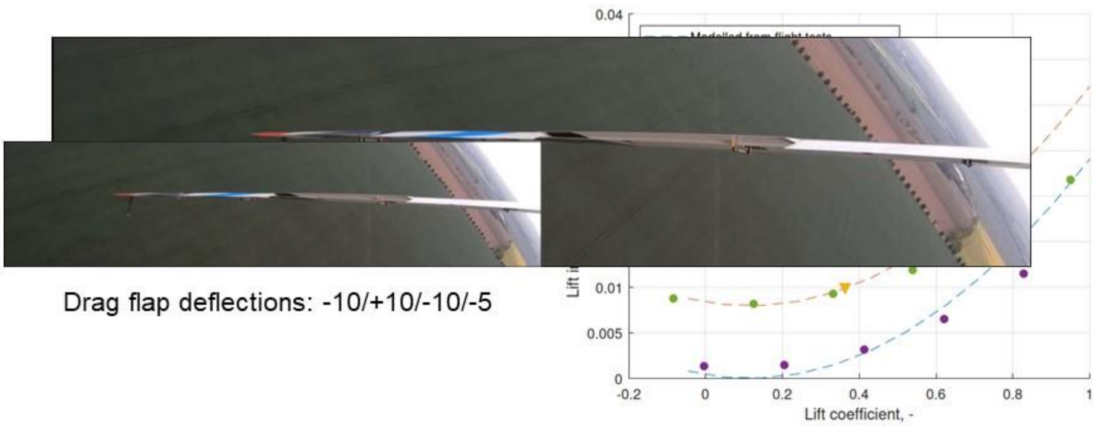
5. Drag coefficient identification:
Drag flap state presented measurable results



Drag flap deflections: -10/+10/-10/-5

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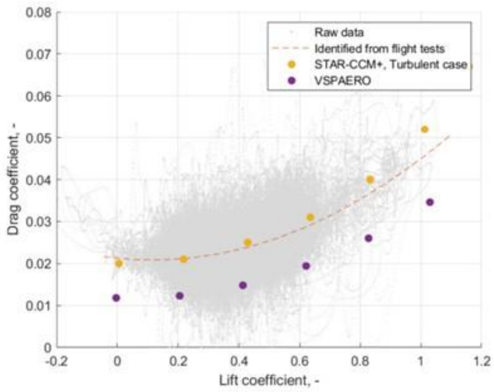
5. Drag coefficient identification:

Drag model residuals are considerably higher than lift



	Lift	Drag
RMSE	0.021	0.00445
R-squared	0.973	0.760

- Potential for improvement:
  - Frequency-based filters
  - Focusing on the data-rich flight segments
  - Flights in calm air

6. Conclusions and outlook

Conclusions:

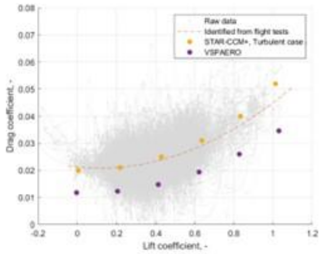
- Initial effort was done to develop methods for extracting drag of a flying UAV by using some basic modelling and stepwise regression.
- Due to environmental conditions, measurement and methodology errors, significant data scatter is present.
- Airbrake and drag flap state drag coefficients matched the available simulation data well.

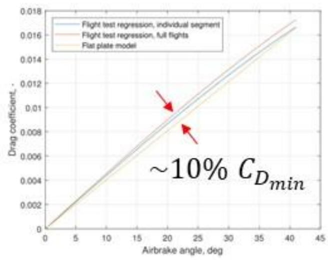
Outlook:

- Additional filters, flight segmentation, calm air flights and advanced system identification methods will be tried next.
- Errors due to various sources (sensor, methodology) will be quantified.

Main take-away

Very simple data analysis methods can already provide usable drag measurement results.





	Lift	Drag
RMSE	0.021	0.00445
R-squared	0.973	0.760

The work presented has been conducted within the framework of projects FLEXOP (grant agreement No. 636307) and FLiPASED (grant agreement No. 815058) funded from the European Union's Horizon 2020 research and innovation program.

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Model Based Automatic Control Design for the T-FLEX Demonstrator Using RCE Environment (presented by Béla Takarics, SZTAKI)

SZTAKI Deutsches Zentrum für Luft- und Raumfahrt DLR ONERA

Model Based Automatic Control Design for the T-FLEX Demonstrator Using RCE Environment

Béla Takarics, Bálint Patartics, Tamás Luspay, Bálint Vanek (SZTAKI)
Charles Poussot-Vassal, Pierre Vuillemin (ONERA)
Matthias Wüstenhagen (DLR)

AIAA SciTech Conference, 23-27 January 2023, National Harbor, USA

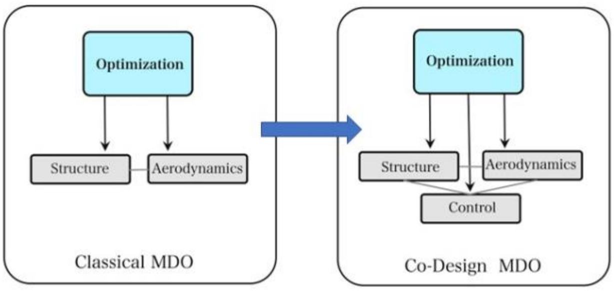
The research leading to these results is part of the FLiPASED project. This project has received funding from the Horizon 2020 research and innovation programme of the European Union under grant agreement No 815058.

Outline

- Motivation
- FLIPASED project
- Demonstrator aircraft
- Implementation environment
- Automatic control oriented modelling
- Automatic control design
- Summary

Motivation

- Control design classically not included into multidisciplinary design optimization (MDO) of aircraft design
- Control comes in a later stage of the design – if it does not "work" – iteration
- Goal: include control into the optimization steps – co-design
- Focus: flexible aircraft



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FLIPASED project

- Flight Phase Adaptive Aero-Servo-Elastic Aircraft Design Methods (FliPASED) – H2020 project
- Partners:
  - *SZTAKI*
  - *TUM*
  - *ONERA*
  - *DLR*
- Goals: Exploit coupling between
  - *aeroelasticity*
  - *gust response*
  - *flight control methods*

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T-Flex demonstrator aircraft

- 7m wingspan, AS 20, 300 N jet engine
- 4 control surfaces on each wing, 4 on the V-tail
- IMU at CG and along the wing
- Symmetric and asymmetric flutter:
  - *@52 m/s, 50.2 rad/s*
  - *@55 m/s, 45.8 rad/s*
- Custom made actuator

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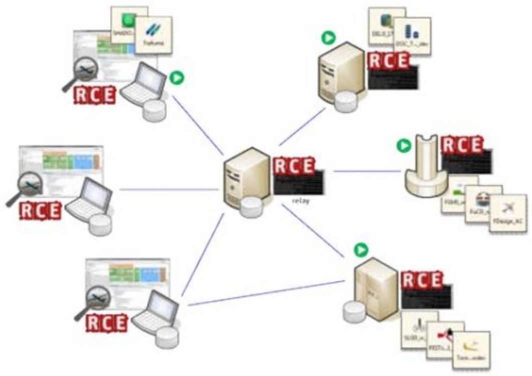
Remote Component Environment (RCE)

- Developed by DLR
- Define and execute workflows
- Beneficial for multidisciplinary applications
- Distributed execution



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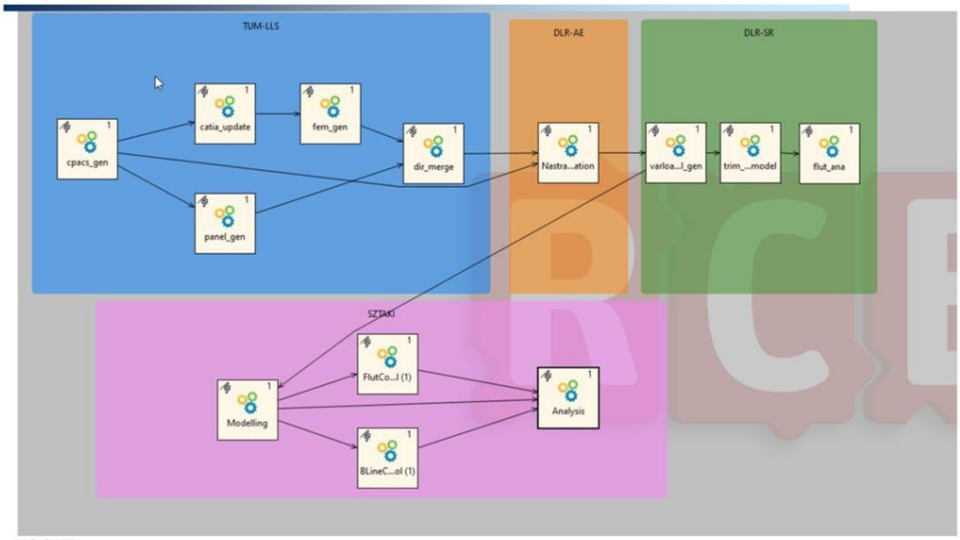
Overall workflow



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Automatic control oriented model development

- Requirements for control oriented model:
  - *Low number of states, numerically well conditioned*
  - *Capture crucial behavior*
    - Rigid body modes
    - Loads
    - Flutter modes
  - *Linear parameter-varying (LPV)*
- Automatic model generation
  - *Structural and aerodynamics change with optimization*
    - Flutter tuning mass
    - Wing sweep angle
    - …
  - *Model generation needs to be robust against these changes*

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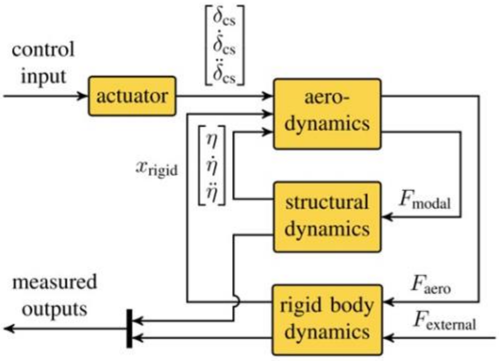
Automatic control oriented model development

- Model properties at starting point:
  - *Nonlinear aeroservoelastic model*
  - *High number of states*
  - *The model structure is fixed*
- Model order reduction:
  - *Bottom-up modeling*
  - *Reduce the subsystems*
  - *Valid for a frequency range of interest*



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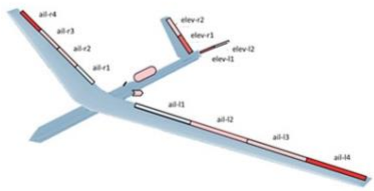
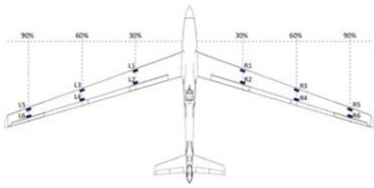
Automatic control oriented model development

- LPV model

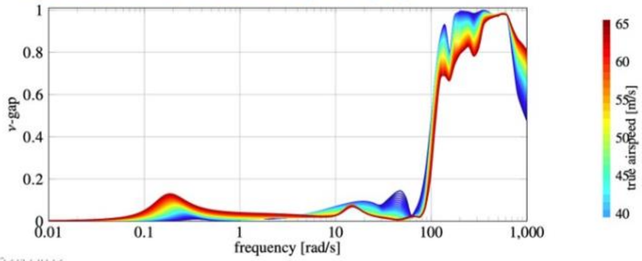
$$\dot{x}(t) = A(\rho(t))x(t) + B(\rho(t))u(t)$$
$$y(t) = C(\rho(t))x(t) + D(\rho(t))u(t)$$

where $\boldsymbol{\rho}$ is the scheduling parameter: airspeed between 40-65 m/s





- Measure of accuracy: $\boldsymbol{\nu}$-gap



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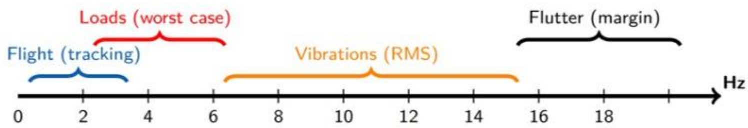
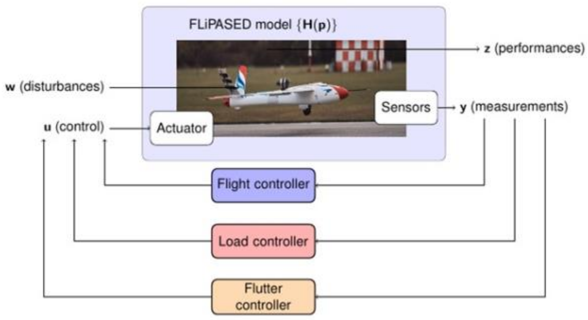
Control design algorithms

- 4 controllers considered
  - *Baseline*
  - *MLA*
  - *GLA*
  - *Flutter*





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Control design algorithms

- Automation aspects
  - *Simpler algorithms than hand tuned controllers*
  - *Lower performance requirements*
  - *Fallback options for cases when no feasible controller can be found*
  - *Low computational time*
  - *Implementation and testing in the RCE environment*

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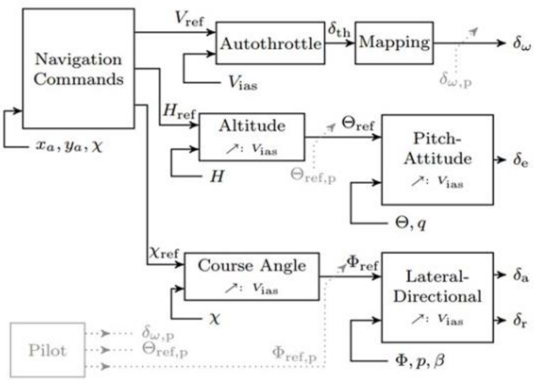
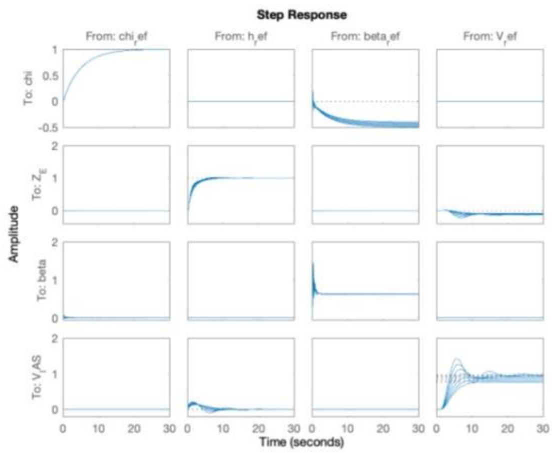
Control design algorithms: Baseline

- Successive loop closure
- Gain scheduled PIDs





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Control design algorithms: MLA

- Takes the reduced, normalized model with loads
- H_∞-based control design
- Inputs/outputs:
  - *Outer ailerons and elevator*
  - *Wing loads, pitch angle, pitch rate, vertical acceleration with reference*
- Performance definitions:
  - *Pilot load factor tracking error*
  - *Attenuation of wing to load transfer peaks*
  - *Stability and roll-off of the controller*

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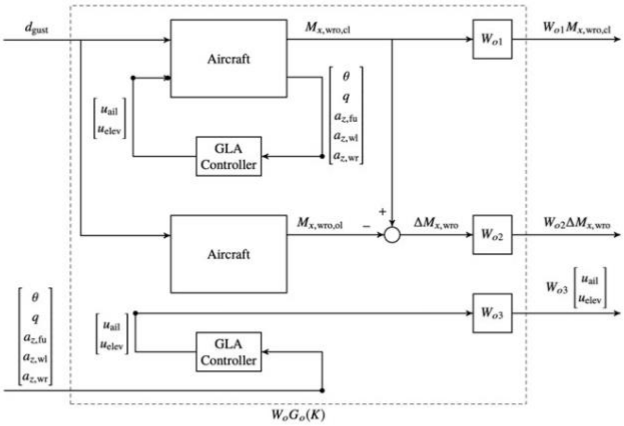
Control design algorithms: GLA

- H_∞-based control design
- Inputs/outputs:
  - *Outer ailerons and elevator*
  - *Wing loads, pitch angle, pitch rate, vertical acceleration in the fuselage and wings*
- Performance definitions:
  - *Closed loop TF from gust to WRBM*
  - *Reduce effects of GLA at low frequencies*
  - *Limit the controller at high frequencies*



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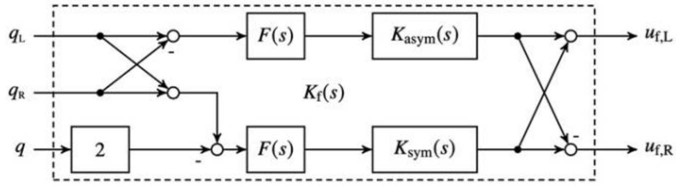
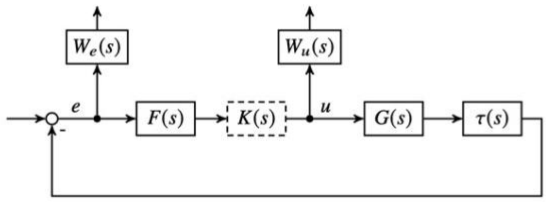
Control design algorithms: Flutter

- Separated symmetrical and asymmetrical flutter controllers
- Inputs/outputs:
  - *Outer ailerons*
  - *Pitch rate at center of gravity and outer IMUs*
- Performance definitions:
  - *Minimize the sensitivity function of the closed-loop – robust stabilization*





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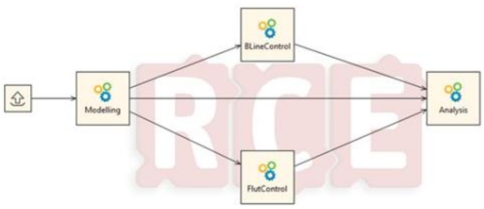
Summary

- Co-design for flexible aircraft
- Implementation for the T-Flex aircraft in RCE environment
- Simplified modelling and control design algorithms for robustness
- Baseline, MLA, GLA and flutter controllers, separated by frequency
- A few A/C parameter changes ran to test the algorithms
- Future steps:
  - *Run more test cases*
  - *Scale-up task*



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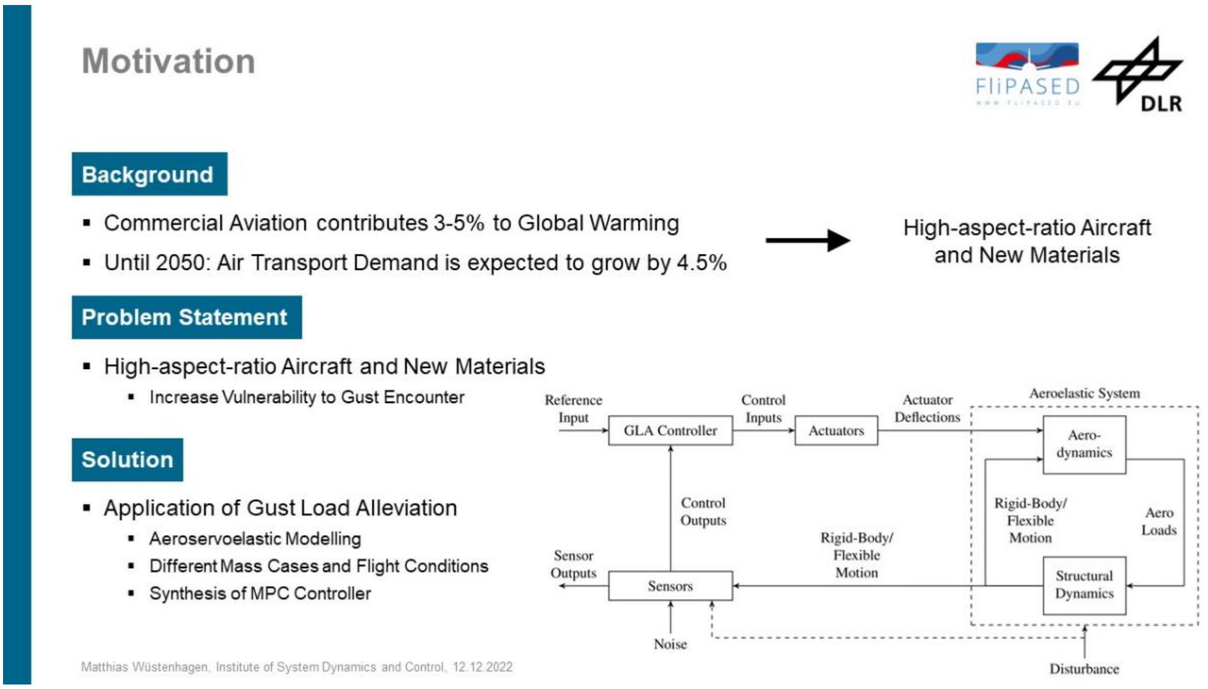
Application and Validation of a Model Updating Approach for Linearized State-Space Models of Flexible Aircrafts Using Multiple Flight Test Data (presented by Özge Süelözgen, DLR)



Aeroservoelastic Aircraft Model

FliPASED DLR

Aeroelastic Model

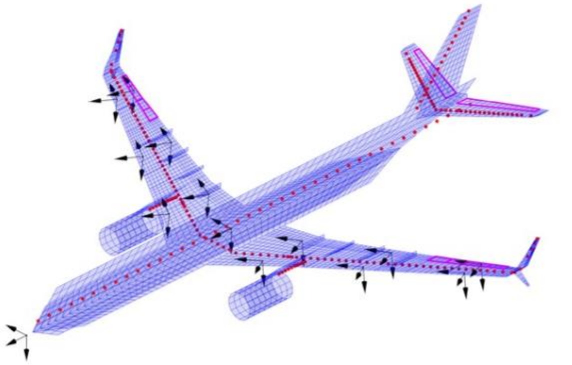
- Structural Dynamics $P_g^{\text{ext}} = P_g^{\text{eng}} + P_g^{\text{aero}}$

$$\begin{bmatrix} m_b(\dot{V}_b + \Omega_b \times V_b - T_{be}(\Theta_b) g_e) \\ J_b \dot{\Omega}_b + \Omega_b \times (J_b \Omega_b) \end{bmatrix} = \Phi_{gb}^T P_g^{\text{ext}}$$

$$M_{ff}\ddot{u}_f + B_{ff}\dot{u}_f + K_{ff}u_f = \Phi_{gf}^T P_g^{\text{ext}}(t)$$

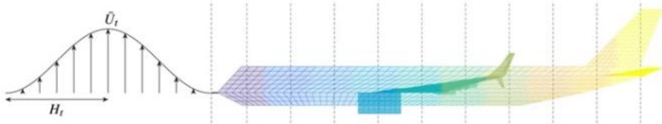
- Aerodynamics

$$\Delta c_{pj}(k) = Q_{jj}(k) w_j(k)$$



Loads Model (Force Summation Method)

$$P_c = T_{cg}\left(P_g^{\text{ext}} - \underbrace{M_{gg}\begin{bmatrix}\Phi_{gb} & \Phi_{gf}\end{bmatrix}\begin{bmatrix}\ddot{u}_b \\ \ddot{u}_f\end{bmatrix}}_{P_g^{\text{iner}}}\right)$$



Matthias Wüstenhagen, Institute of System Dynamics and Control, 12.12.2022

Model Predictive Control

FliPASED DLR

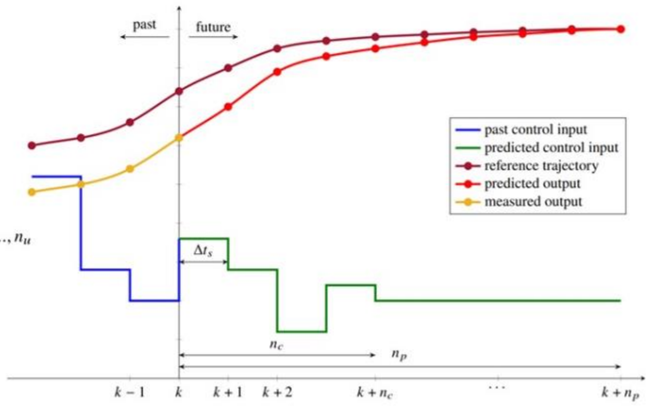
Optimisation Problem

$$J(z_k) = \underbrace{\min_{w_y} \sum_{j=1}^{n_y} \sum_{i=1}^{n_p} \left(w_{y,j}\left(r_j(k+i|k) - y_j(k+i|k)\right)\right)^2}_{J_y(z_k)} + \underbrace{\min_{w_{\Delta u}} \sum_{j=1}^{n_u} \sum_{i=1}^{n_c-1} \left(w_{\Delta u,j}\left(u_j(k+i|k) - u_j(k+i-1|k)\right)\right)^2}_{J_{\Delta u}(z_k)}$$

$$u_{j,\min} \le u_j(k+i-1|k) \le u_{j,\max} \qquad i = 1, 2, \ldots, n_p \quad j = 1, 2, \ldots, n_u$$
$$\Delta u_{j,\min} \le \Delta u_j(k+i-1|k) \le \Delta u_{j,\max}$$

Prediction Model

$$x(k+1) = A_s x(k) + B_s u(k)$$
$$y(k) = C_s x(k) + D_s u(k)$$



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Gust Load Alleviation with Model Predictive Control

GLA Controllers

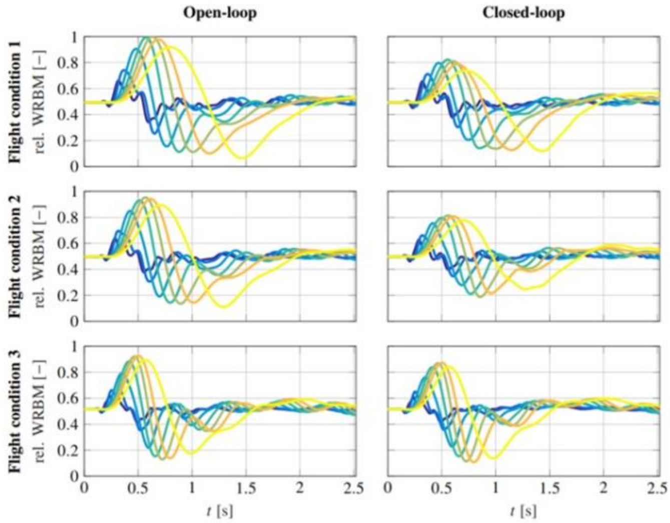
27 GLA Controllers with MPC

- 9 Mass Cases

No.	Definition
1	operating empty mass
2	rear light payload
3	forward light payload
4	rear heavy payload
5	forward heavy payload
6	central heavy payload
7	forward maximum take-off mass
8	rear maximum take-off mass
9	central maximum take-off mass

- 3 Flight Conditions

No.	h [m]	U_∞ [m/s]
1	0	170
2	3000	197
3	8300	264



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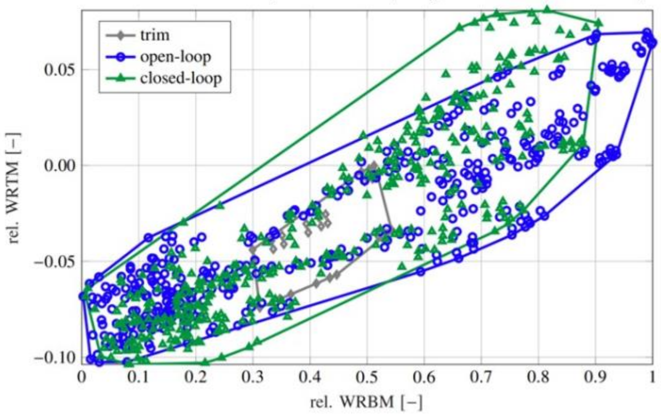
Gust Load Alleviation with Model Predictive Control

Analysis of GLA with MPC

- Relative Wing Root Bending Moment vs. Relative Wing Root Torsional Moment
  - Minimum and Maximum Values of 189 Simulations (9 Mass Cases, 3 Flight Conditions, 7 Gust Properties)



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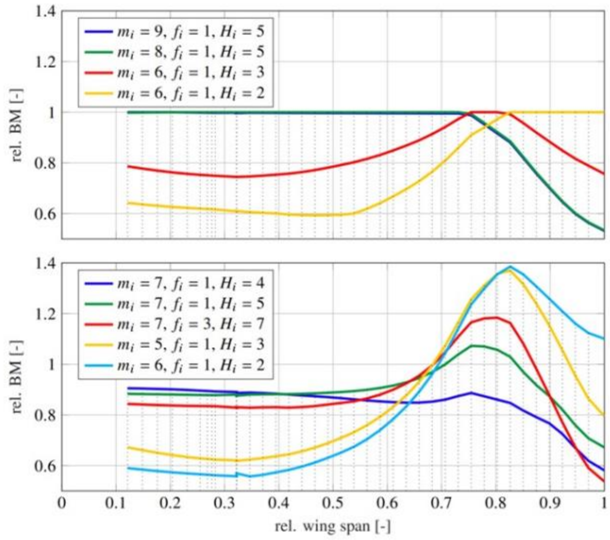
Gust Load Alleviation with Model Predictive Control

Analysis of GLA with MPC

- Relative Bending Moment over Wing Span
  - Open-loop (top): 4 Critical Load Cases
  - Closed-loop (bottom): 5 Critical Load Cases

→ Use more control surfaces along the wing



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Conclusion & Outlook

Conclusion

- Aeroservoelastic Model
  - Structural Dynamics
  - Aerodynamics
  - 1-cosine Gust
  - Loads
- 27 GLA Controllers with MPC (9 Mass Cases, 3 Flight Conditions)
  - 10% reduction of WRBM
  - Almost up to 40% increase in Bending Moment at Control Surface Location

Outlook

- Reduction of the Bending Moment over the Wing with GLA
  - Deploy more Control Surfaces distributed over the Wing for GLA
  - Adjust the Weights of the Optimisation
- Methods to use 27 GLA Controllers in unison

Matthias Wüstenhagen
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Institute of System Dynamics and Control

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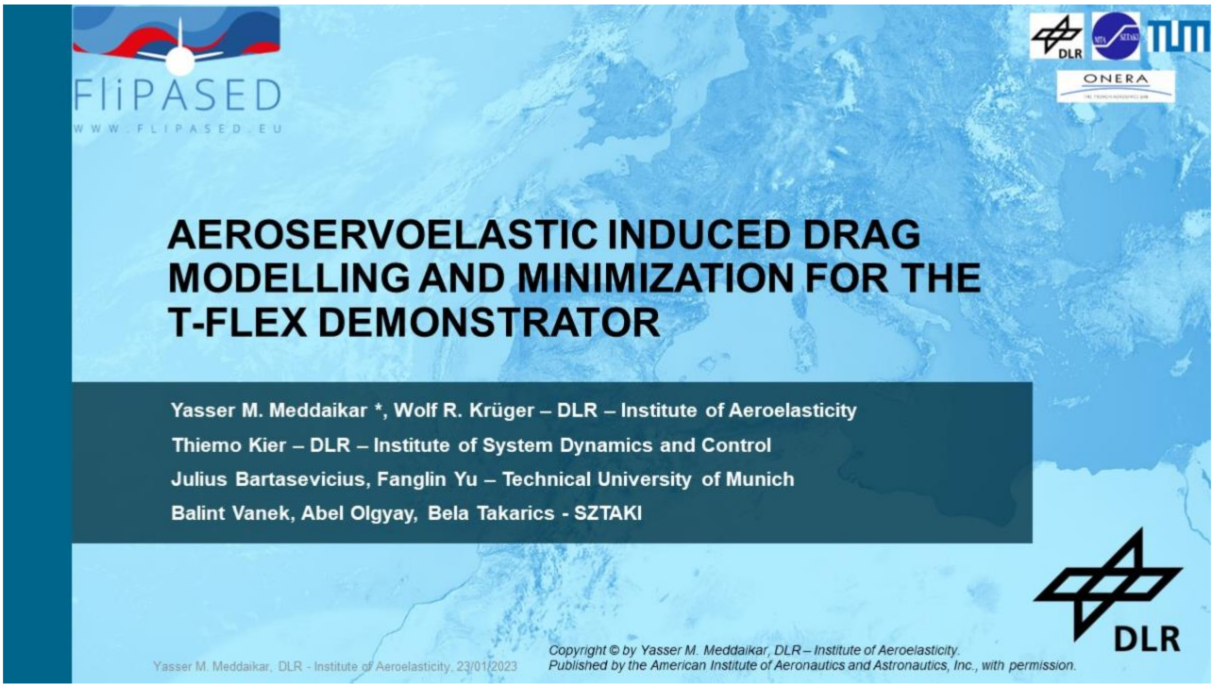
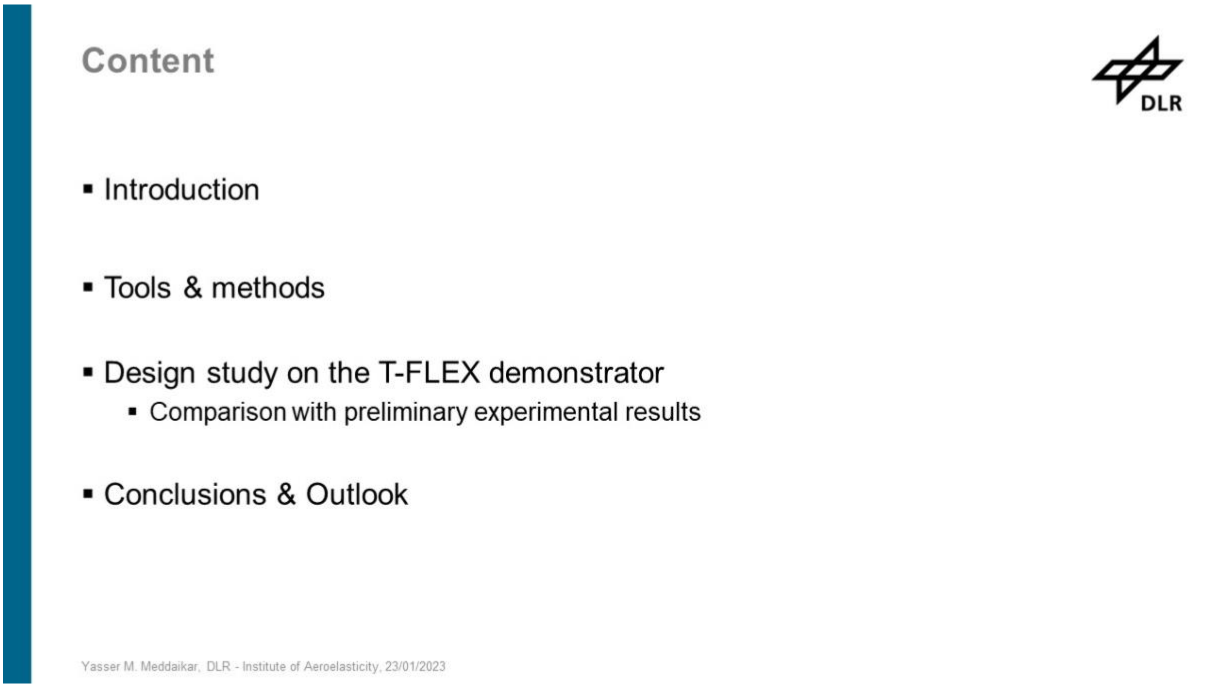
Aeroservoelastic induced drag modelling and minimization for the T-FLEX demonstrator (presented by Yasser M. Meddaikar)





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Introduction

DLR

FLiPASED - Flight Phase Adaptive Aero-Servo-Elastic Aircraft Design Methods

→ Demonstrate benefits of include active control technologies early-on in the preliminary design stage

- Wing-shape control for performance improvement
- Active flutter suppression
- Loads alleviation

Yasser M. Meddaikar, DLR - Institute of Aeroelasticity, 23/01/2023

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Introduction

FLiPASED - Flight Phase Adaptive Aero-Servo-Elastic Aircraft Design Methods

→ Demonstrate benefits of include active control technologies early-on in the preliminary design stage

- **Wing-shape control for performance improvement**
- Active flutter suppression
- Loads alleviation

- Optimal lift distributions needed for low induced drag
- Changing aircraft mass cause non-optimal lift distributions for changing C_L
- Solution: Active wing-shape control for different C_L

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Introduction
Objectives

- Tools and methods for modelling induced drag
  - Potential flow methods – only induced drag
  - Fast and robust – useable in an automated MDO workflow
  - More focus on the controller aspects, less on aerodynamics

- Apply the tools to make design decisions on a retrofit wing – to maximize demonstratibility of drag reduction
  - Wing choice
  - Control surface layout

Yasser M. Meddaikar, DLR - Institute of Aeroelasticity, 23/01/2023

Content

- Introduction
- **Tools & methods**
- Design study on the T-FLEX demonstrator
  - Comparison with preliminary experimental results
- Conclusions & Outlook

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Tools & methods

Tool	Method	Optimizer
NASTRAN aeroelastic solver	DLM	Kriging-Regression model SciPy *optimize*
VarLoads	VLM	MATLAB *fmincon*
PANUKL	3D panel	Linear-regression MATLAB *fminsearch*
AVL	VLM	NLOPT - *COBYLA*
STAR-CCM+	CFD Euler/RANS	-

Yasser M. Meddaikar, DLR - Institute of Aeroelasticity, 23/01/2023

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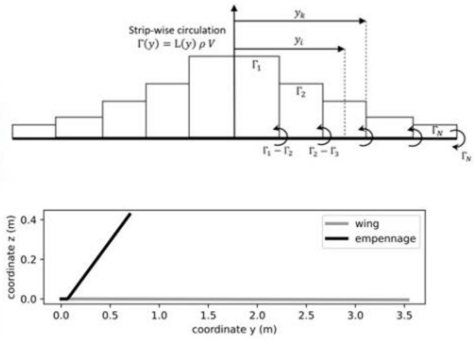

Strip lift → Strip circulation → Strip induced velocity → Strip induced drag

Aerodynamic tool → Strip lift

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Tools & methods

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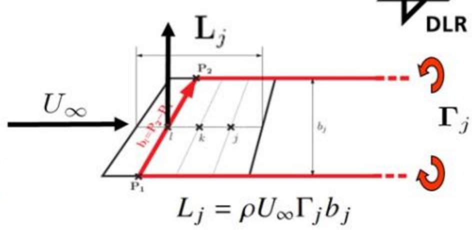

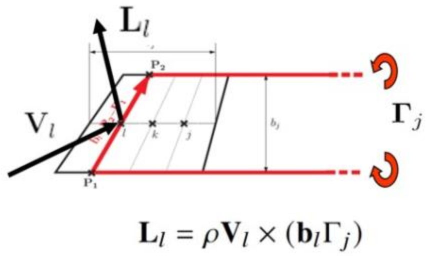

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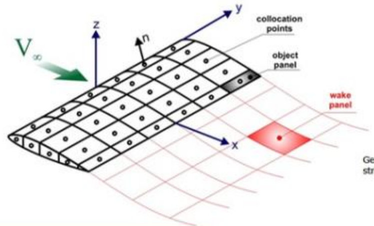
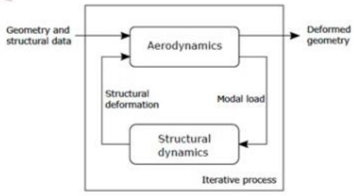
Kier, Thiemo (2022) *An Integrated Flexible Aircraft Model for Optimal Control Surface Scheduling of Manoeuvre Load Alleviation and Wing Shape Control Functions.* International Forum on Aeroelasticity and Structural Dynamics (IFASD) 2022, 13.-17. June 2022, Madrid, Spain.

Tools & methods





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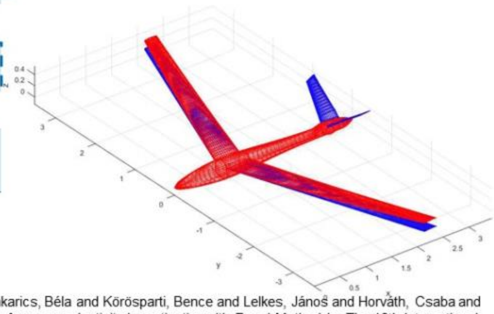
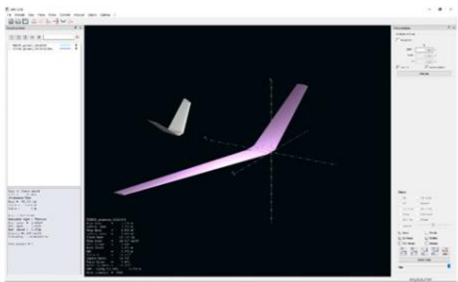


Olgyay, Ábel and Takarics, Béla and Körösparti, Bence and Lelkes, János and Horváth, Csaba and Vanek, Bálint (2022) *Aeroservoelasticity Investigation with Panel Method.* In: The 18th International Conference on Fluid Flow Technologies, August 30-September 2, 2022, Budapest, Hungary.

Yasser M. Meddaikar, DLR - Institute of Aeroelasticity, 23/01/2023

Tools & methods



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Yu, F., Bartasevicius J., & Hornung M. (2022). COMPARING POTENTIAL FLOW SOLVERS FOR AERODYNAMIC CHARACTERISTICS ESTIMATION OF THE T-FLEX UAV. In ICAS - International Council of the Aeronautical Sciences, Stockholm, Sweden .

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STAR-CCM+	CFD Euler/RANS	-

Closely-coupled aeroelastic solution

Loosely-coupled aeroelastic solution

Rigid structure assumption

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Tools & methods

DLR

Tool	Method	Optimizer
NASTRAN aeroelastic solver	DLM	Kriging-Regression model SciPy *optimize*
VarLoads	VLM	MATLAB *fmincon*
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STAR-CCM+	CFD Euler/RANS	-

Far-field Trefftz plane

Near-field pressure integration

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Content

DLR

- Introduction
- Tools & methods
- Design study on the T-FLEX demonstrator
  - Comparison with preliminary experimental results
- Conclusions & Outlook

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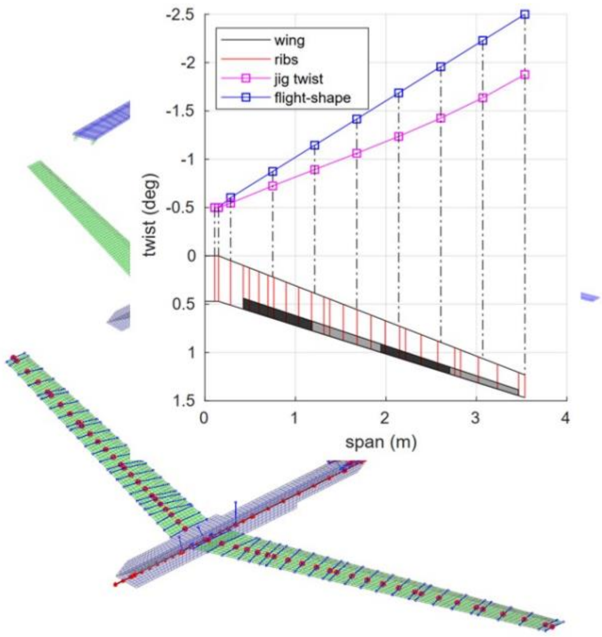
Aircraft model specification

- Span: 7.0m
- Aspect Ratio: 20
- Weight: 65 kg
- Leading edge sweep: 20°
- 4 ailerons per wing + 2 elevators per V-tail half
- Thrust: 300N (Jet-engine)



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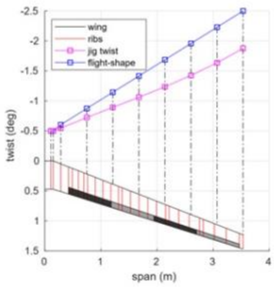
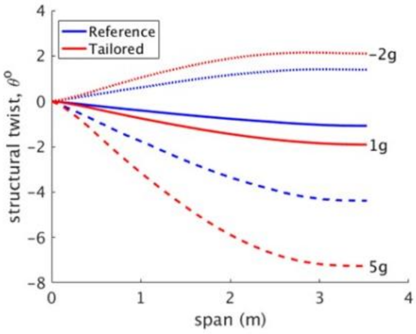
Aircraft model specification

- Two wing pairs were designed during FLEXOP
- Passive load alleviation through composite tailoring
  - "Reference" – conventional balanced laminates
  - "Tailored" – unbalanced → larger bend-twist coupling





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Design study – T-FLEX demonstrator
Optimization problem

DLR

Optimize control surface scheduling for minimum induced drag

Objective function	minimize induced drag (or) thrust
Optimization parameters	aileron deflections ($\delta_{max} < \pm 10°$)
Flight case	Horizontal trim of the flexible aircraft, i.e. trim drag included
Flight speeds	30-60 m/s (varying C_L)

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Design study – T-FLEX demonstrator
1. Wing selection

DLR

- Split each of the 4 control surfaces on wing into 4 → 16 control surfaces

	$20m/s$	$30m/s$	$40m/s$	$45m/s$	$50m/s$	$60m/s$
'reference' (-0) wings	3.6%	2.5%	4.3%	6.7%	9.9%	17.3%
'tailored' (-2) wings	4.8%	4.6%	4.6%	4.9%	5.5%	7.6%

1. At design speed 45m/s, drag reduction potential is less
2. Higher induced drag reduction at off-design speeds
3. 'reference' wing shows higher improvements through wing shape control

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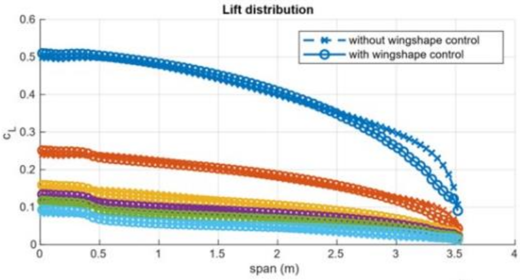
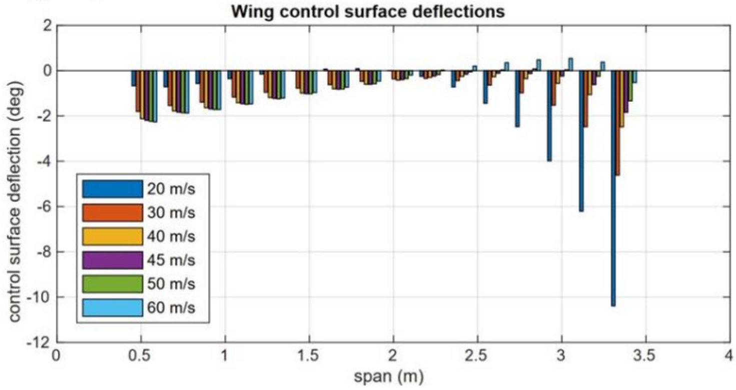


Results for the 'reference' wing

DLR



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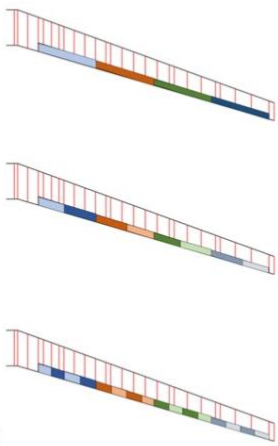
Design study – T-FLEX demonstrator

2. Optimal control surface layout

DLR

- Optimal control surface layout
  - Performance improvement
  - Engineering constraints – existing systems on the wing



	$30m/s$	$40m/s$	$45m/s$	$50m/s$	$60m/s$
4 flaps	1.3%	3.1%	4.9%	7.3%	12.0%
8 flaps	1.9%	3.8%	5.8%	8.1%	13.1%
16 flaps	1.8%	3.9%	6.1%	8.6%	14.0%

1. With increasing number of control surfaces, drag reduction improves
2. Beyond 8 control surfaces on each wing, incremental benefit diminishes

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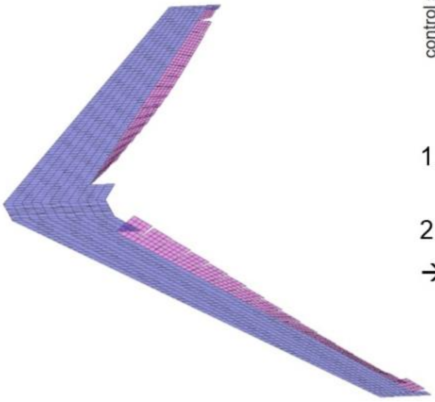
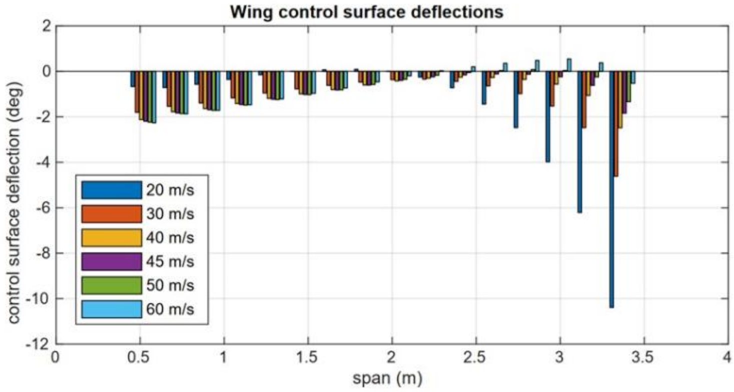
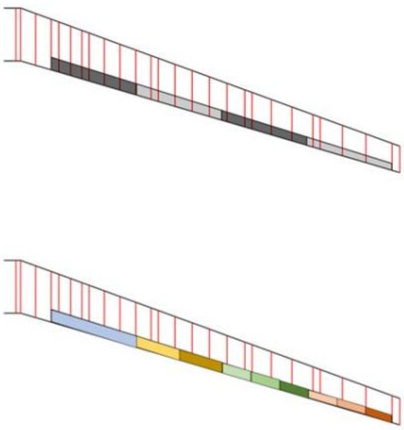
- Optimal control surface allocation at 50m/s 1g trim flight

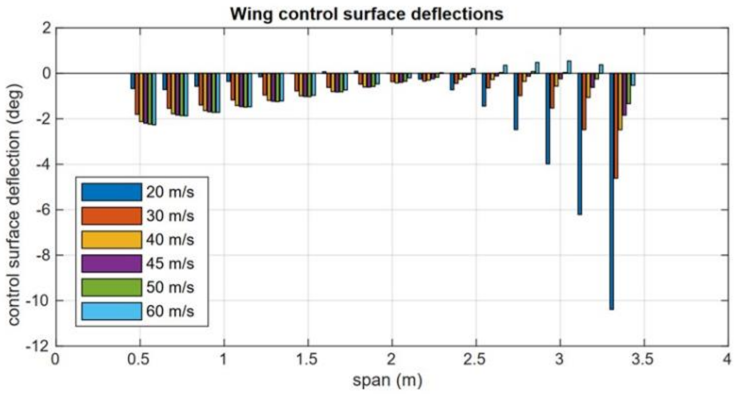




1. Low span-wise gradient in control surface deflection near root and mid-span
2. Largest gradients at wing tip

→ Use smaller control surfaces near the tip





1. Low span-wise gradient in control surface deflection near root and mid-span
2. Largest gradients at wing tip

→ Use smaller control surfaces near the tip

Split control surfaces into 1, 2, 3, 3 – compromise between drag reduction potential vs engineering feasibility (existing hardware)

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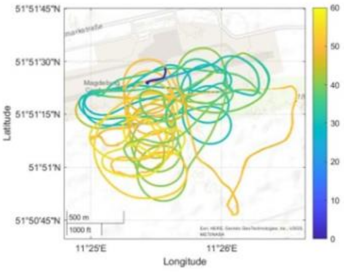
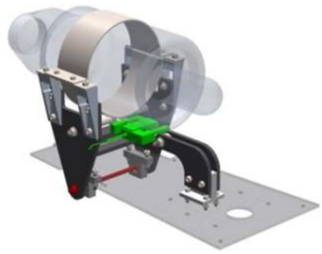
Design study – T-FLEX demonstrator
3. Initial comparison with flight test results

- Flight test campaign – May 2022 – 8 flights – DLR Cochstedt airport





"In-flight drag measurement and validation for a medium-sized UAV" - Julius Bartasevicius et al.

Session: SD-07, Special Session: Design, Modeling and Testing of ASE Demonstrator for the FLEXOP and FLiPASED EU Project II
January 23, 2023 from 2:00 PM to 3:40 PM

- Load-cell based thrust measurement system

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Design study – T-FLEX demonstrator
3. Initial comparison with flight test results

- Linear model identified split into components
  - Parasite drag, induced drag, airbrake, landing gear, flaps

- Induced drag

$$C_D = 0.0208 + 0.0308\,(C_L - 0.1151)^2 + C_{D\delta_{f1^2}}\delta_{f1^2} + C_{D\delta_{f23^2}}(\delta_{f2^2} + \delta_{f3^2}) + C_{D\delta_{f4^2}}\delta_{f4^2}$$

- Flight legs with *clean* and *high drag* configuration: [-10° / +10° / -10° / -5°]

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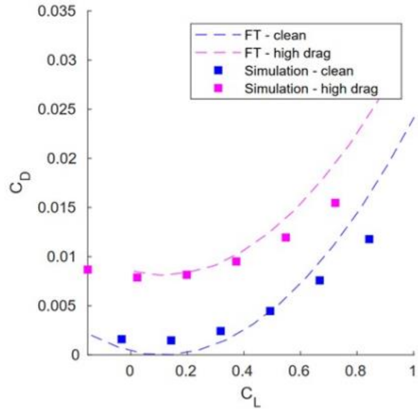
Design study – T-FLEX demonstrator
3. Initial comparison with flight test results

- First check of the modelled tools with flight test results shows good agreement
- Less data available at high C_L points



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Content

- Introduction
- Tools & methods
- Design study on the T-FLEX demonstrator
  - Comparison with preliminary experimental results
- **Conclusions & Outlook**

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Conclusions

- Existing potential flow methods for estimating induced drag (drag due to lift) were studied
  - Quick and robust tools suited to MDO environment
- Optimization problem to determine optimal control surface allocation for minimal drag solved using the different tools
  - Induced drag reduction ~ 3% - 14%
  - Results used to decide on control surface topology for a retrofit of existing wing pairs
- Initial comparison with flight test measurement of drag shows good agreements

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Outlook

- Implement a suitable controller around the drag models – validation in flight tests
- Incorporate the developed controllers in MDO task – re-design of an existing SMR aircraft (DLR-D150)

- Quantify performance gains with/without active wing shape control in the design process + other controller technologies simultaneously

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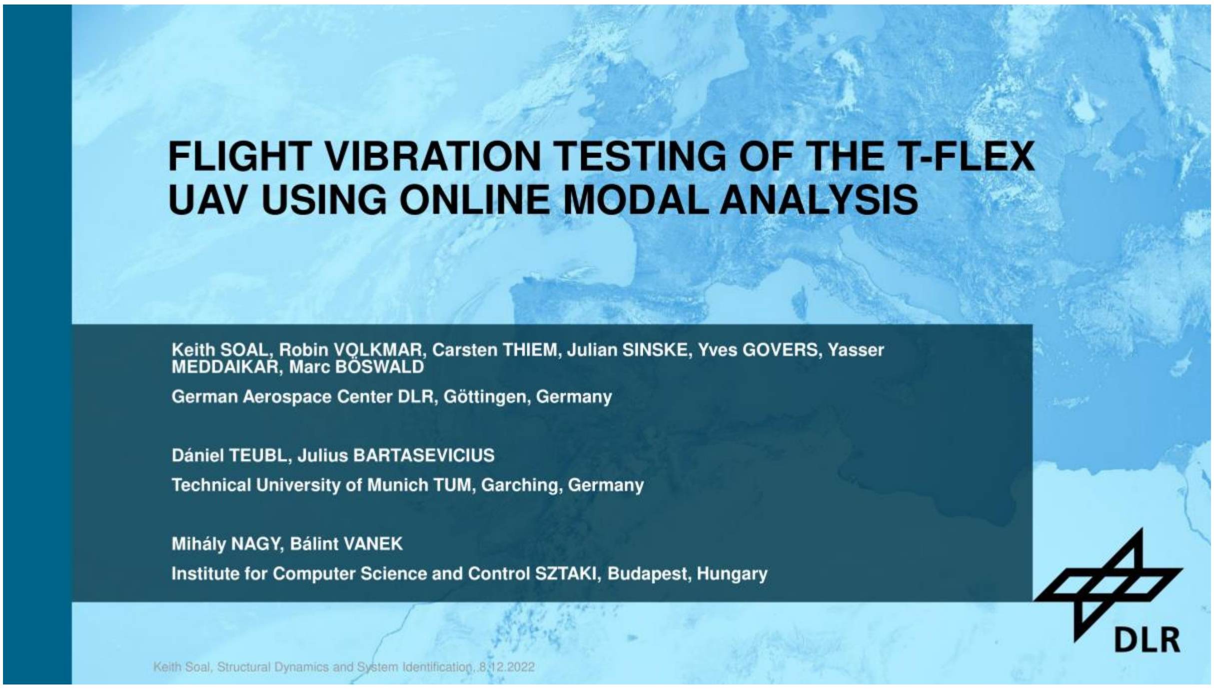
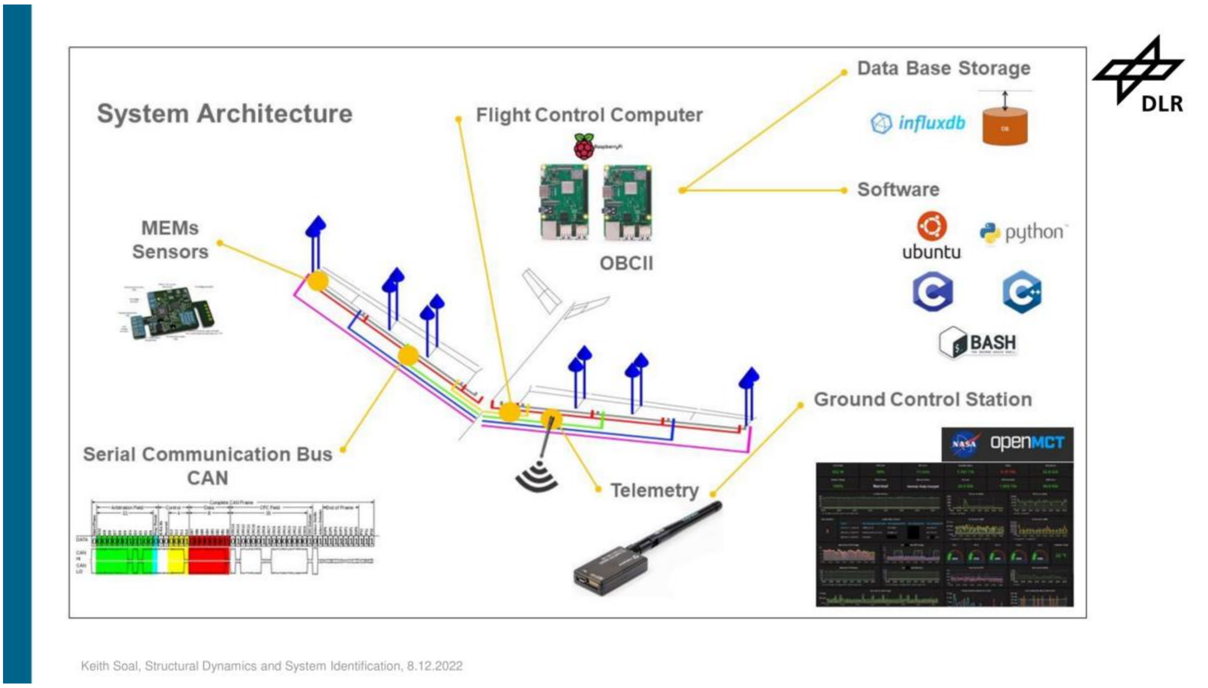
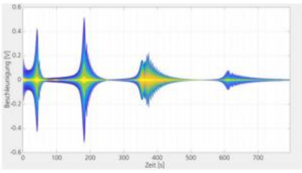
Flight Vibration Testing of the T-FLEX UAV using Online Modal Analysis (presented by Keith Soal, DLR)

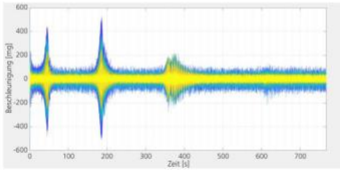



System Architecture
Flight Control Computer
Data Base Storage
influxdb
Software
ubuntu
python
BASH
OBCII
MEMs
Sensors
Ground Control Station
openMCT
Serial Communication Bus
CAN
Telemetry
DLR
Keith Soal, Structural Dynamics and System Identification, 8.12.2022

Challenges

- Operational modal analysis based on MEMs data

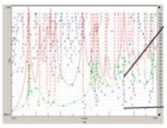
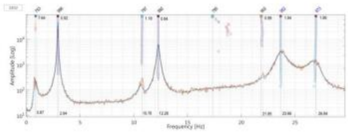


- Computationally expensive tasks on miniaturized hardware

$$H = \frac{1}{\sqrt{j}} \begin{pmatrix} y_0 & y_1 & \cdots & y_{j-1} \\ y_1 & y_2 & \cdots & y_j \\ \cdots & \cdots & \cdots & \cdots \\ y_{i-1} & y_i & \cdots & y_{i+j-2} \\ \hline y_i & y_{i+1} & \cdots & \\ y_{i+1} & y_{i+2} & \cdots & y_{i+j} \\ \cdots & \cdots & \cdots & \cdots \\ y_{2i-1} & y_{2i} & \cdots & y_{2i+j-2} \end{pmatrix} = \frac{Y_p}{Y_f}$$

$$H = \begin{pmatrix} \frac{Y_p}{Y_f} \end{pmatrix} = RQ^T \qquad P_i = U_1 S_1 V_1^T$$

- Challenges of real in flight data for tracking

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DLR Cochstedt Flight Test Facility

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Flight Test Campaign

Table 1 Overview of flight test campaign

Flight No.	Date	Description	Flight No.	Date	Description
FT10	09.05.2022	Augmented mode, pilot training	FT18	23.08.2022	Pilot training, landing imitations
FT11	16.05.2022	Augmented mode, air-data calibration	FT19	23.08.2022	Autopilot mode, pushover-pull-ups
FT12	16.05.2022	Autothrottle	FT20	24.08.2022	Pushover pullup and engine effects
FT13	17.05.2022	Course angle and horse race pattern	FT21	24.08.2022	Rigid body manoeuvres, aborted
FT14	17.05.2022	Course angle and horse race pattern	FT22	29.08.2022	Rigid body manoeuvres, aborted
FT15	18.05.2022	Autothrottle, aborted, log not available	FT23	30.08.2022	Rigid body manoeuvres, crash
FT16	19.05.2022	Autothrottle, constant flight speeds			
FT17	19.05.2022	Rigid body manoeuvres			

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DLR
Torqster
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DLR
UAV Entwurf
FLEXOP

Flight Vibration Test Results

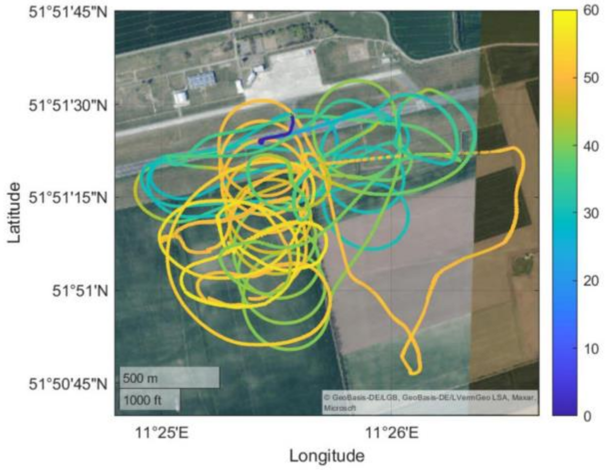

Fig. 7 Flight trajectory of FT16.

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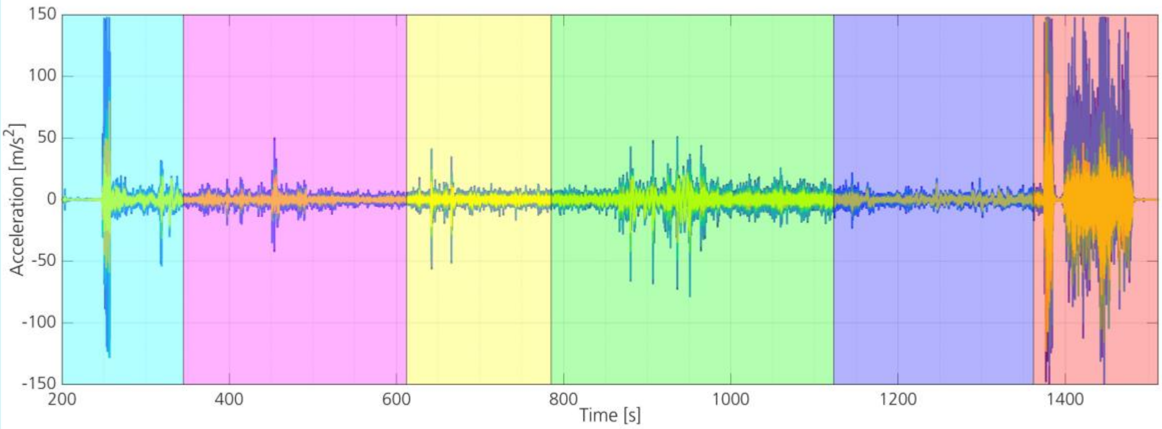
Flight Vibration Test FT16



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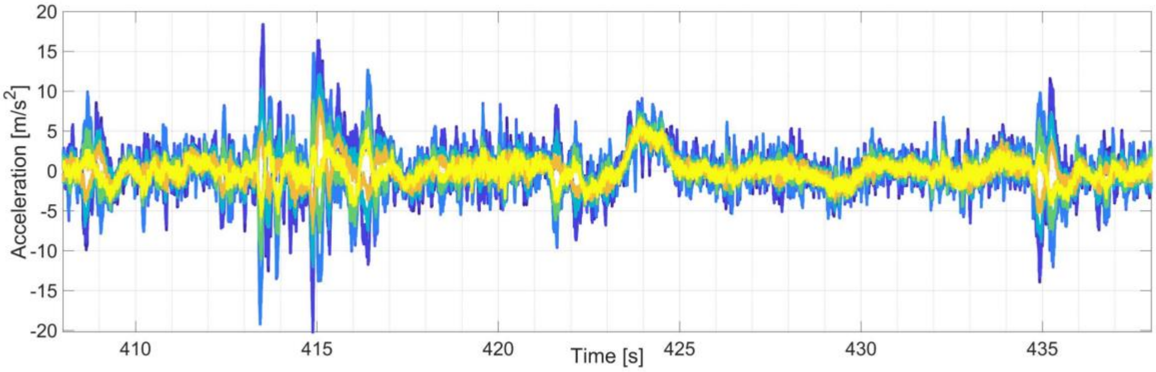
30 Second Data Buffer

DLR



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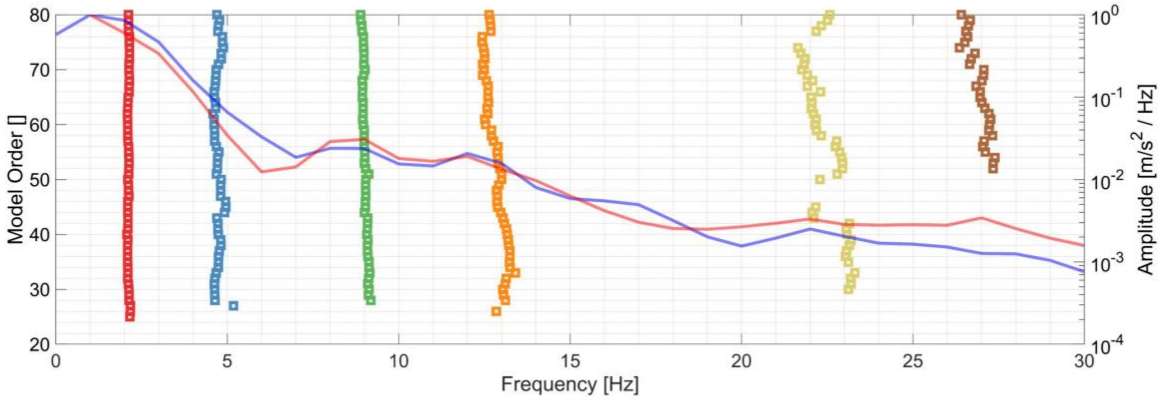
Stabilisation Diagram

DLR



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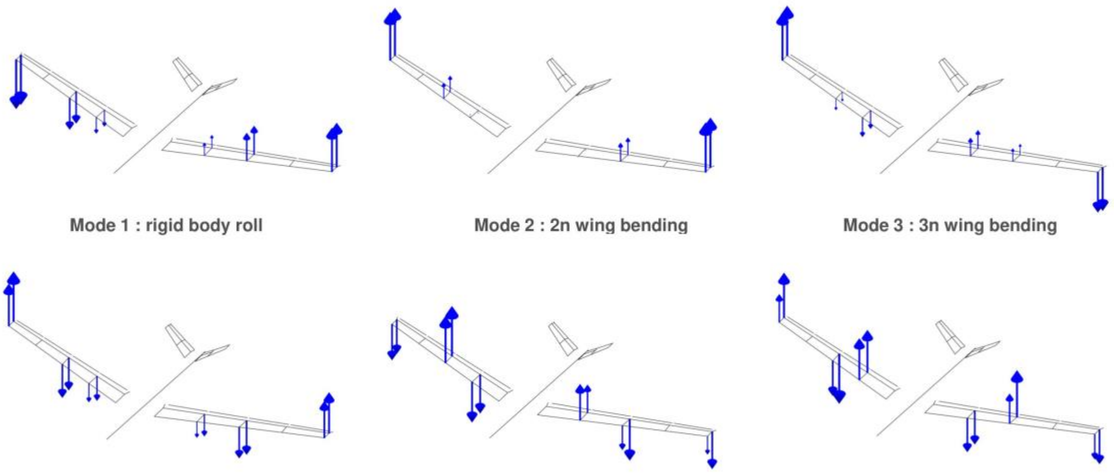
In Flight Mode Shapes



Mode 1 : rigid body roll

Mode 2 : 2n wing bending

Mode 3 : 3n wing bending

Mode 4 : 4n wing bending

Mode 5 : 5n wing bending

Mode 6 : 6n wing bending

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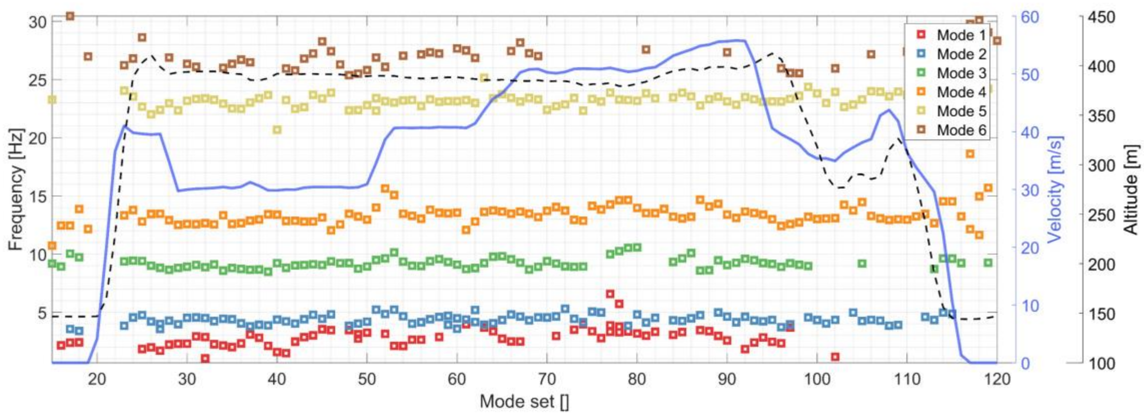
Mode Tracking - Frequency



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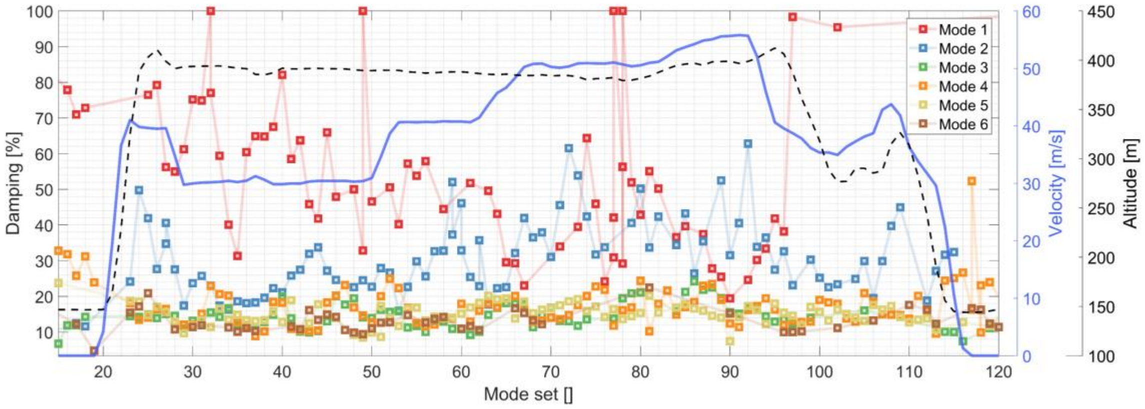
Mode Tracking - Damping



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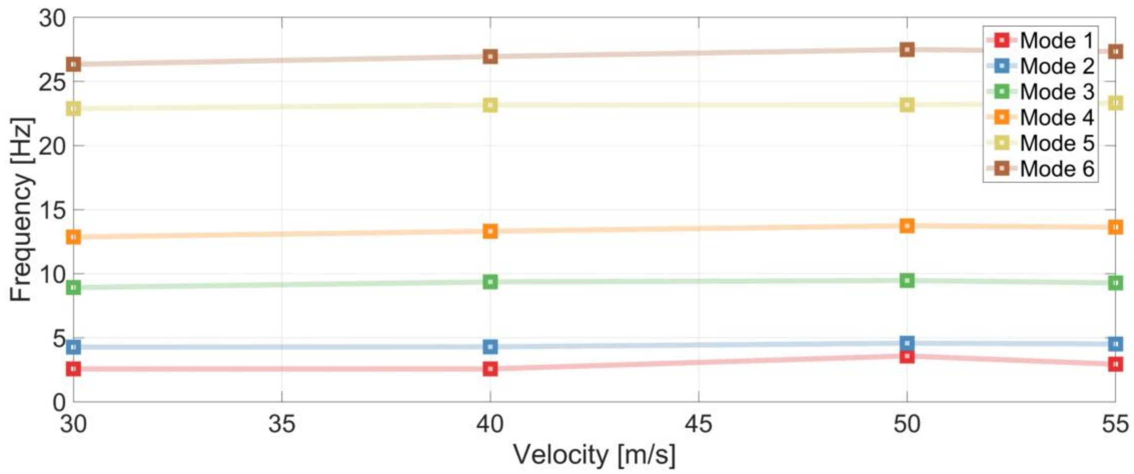
Natural Frequency as a Function of Velocity



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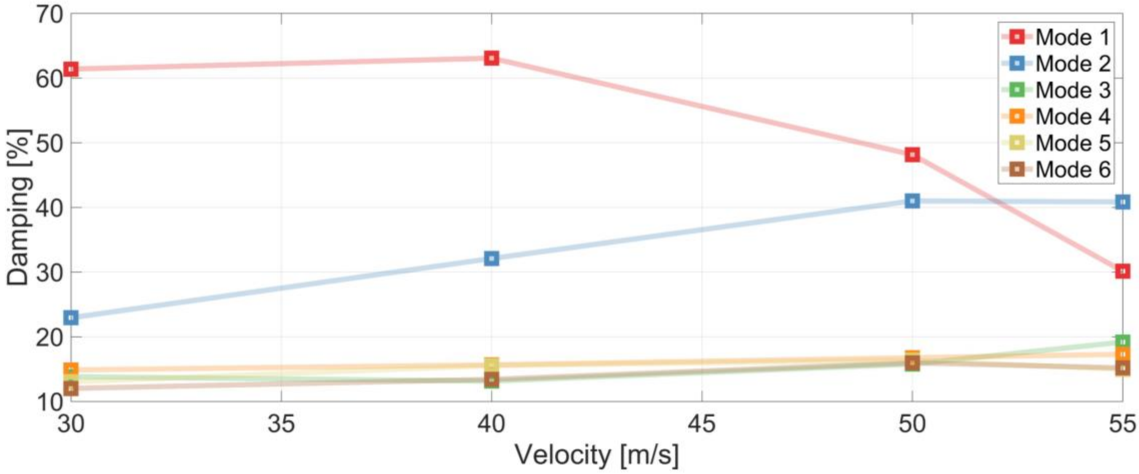
Damping Ratio as a Function of Velocity



Keith Soal, Structural Dynamics and System Identification, 8.12.2022

Conclusion

- Successful flight testing campaign demonstrated the capabilities the system for flutter monitoring based on miniaturized hardware
- System was stable and robust
- On board signal processing, modal analysis and mode tracking produced accurate results and ran in real time
- Telemetry system proved stable with zero disconnects and no package losses
- Six wing bending modes were identified and tracked during the flight campaign
- The six modes showed trends of increasing frequencies and damping ratios for all the elastic modes
- This was in agreement to the non-linear aeroservoelastic model
- The system has therefore been demonstrated as a capable and reliable tool for real time flutter monitoring during flight testing

Keith Soal, Structural Dynamics and System Identification, 8.12.2022

Outlook

DLR

- Deploying the system on the flutter critical wing set will provide the ultimate test of the result accuracy in predicting the flight envelope – planned for 2023
- Finally, the integration of the system with the onboard flight control system for active flutter control will be the next step in the research and development

Keith Soal, Structural Dynamics and System Identification, 8.12.2022

2.6 List of Publications

Authors / Speaker	Partner	Title	Conference / Journal	state	Place	DOI
Matthias Wüstenhagen ; Özge Süelözgen ; Lukas Ackermann; Julius Bartaševicius	DLR, TUM	Validation and Update of an Aeroservoelastic Model based on Flight Test Data	AeroConf 2021 (IEEE)	published	Big Sky, MT, USA	10.1109/aero50100.2021.9438354
Balint Patartics, Gyorgy Liptak, Tamas Luspay, Peter Seiler, Bela Takarics and Balint Vanek	SZTAKI	Application of Structured Robust Synthesis for Flexible Aircraft Flutter Suppression	IEEE Transaction on Control System Technology Journal:	published	USA	10.1109/tcst.2021.3066096
Béla Takarics and Balint Vanek	SZTAKI	Robust Control Design for the FLEXOP Demonstrator Aircraft via Tensor Product Models	Asian Journal on Control	published	Australia	10.1002/asjc.2547
Peter Bauer, Lysandros Anastasopoulos, Franz-Michael Sendner, Mirko Hornung, Balint Vanek	SZTAKI, TU	Identification and Modeling of the Airbrake of an Experimental Unmanned Aircraft	JOURNAL OF INTELLIGENT & ROBOTIC SYSTEMS	published	Netherlands	10.1007/s10846-020-01204-1
Réka Dóra Mocsányi, Béla Takarics, Aditya Kotikalpudi, Bálint Vanek	SZTAKI	Grid-Based and Polytopic Linear Parameter-Varying Modeling of Aeroelastic Aircraft with Parametric Control Surface Design	Fluids	published	Switzerland	10.3390/fluids5020047

Réka Dóra Mocsányi, Béla Takarics, Bálint Vanek	SZTAKI	Grid and Polytopic LPV Modeling of Aeroelastic Aircraft for Co-design	IFAC PapersOnline	published	Germany	10.1016/j.ifacol.2020.12.1600
Thiemo M. Kier	DLR	An Integral Flexible Aircraft Model for Optimal Control Surface Scheduling of Manoeuvre Load Alleviation and Wing Shape Control Functions	AIAA SciTech 2022 Category: Dynamics	published	Germany	
Matthias Wüstenhagen	DLR	Synthesis of a Multiple-Model Adaptive Gust Load Alleviation Controller for a Flexible Flutter Demonstrator	AIAA SciTech 2022 Category: Dynamics	published	San Diego, CA	10.2514/6.2022-0440
Balint Patartics, Yagiz Kumtepe, Bela Takarics, Balint Vanek	SZTAKI	On the necessity of flexible modelling in fault detection and isolation for flexible aircraft	Modeling, Estimation and Control Conference (MECC) 2021	published	Austin, Texas, USA	10.1016/j.ifacol.2021.11.247
Tamás Baár, Tamás Luspay,	SZTAKI	Robust Minimum Gain Lemma	Conference on Decesion and Control (CDC) 2021.	published	Austin, TX, USA	10.1109/cdc45484.2021.9683413
Özge Süelözgen	DLR	A Novel Updating Algorithm for Linearized State-Space Models of an Unmanned Flexible	SciTech 2022 (AIAA)	published	San Diego, CA (USA)	10.2514/6.2022-0725

		Aircraft Using Flight Test				
Julius Bartasevicius, Pedro A. Fleig, Annina Metzner and Mirko Hornung	TUM	Design and testing of an in-flight thrust measurement system for a pylon-mounted miniature jet engine	AIAA SCITECH 2022 Forum Category : Flight Testing	published	San Diego, CA (USA)	10.2514/6.2022-1827
Julius Bartasevicius, Sebastian J. Koeberle, Daniel Teubl, Christian Roessler, Mirko Hornung	TUM	Flight Testing of 65kg FLEXOP Subscale Demonstrator	ICAS	published	Germany	
Janos Bezsilla, Bela Takarics, Balint Vanek, Jian Guo	SZTAKI	Parameter Uncertainty Analysis in Precise Pointing Control of Flexible Spacecraft	IFAC MATHMOD 2022	published	Vienna, Austria	10.1016/j.ifacol.2022.09.102
Tamás Baár, Tamás Luspay	SZTAKI	Robust Decoupling of Uncertain Subsystems	International Journal of Robust and Nonlinear Control	published	USA	10.1002/rnc.6141
Yasser M Meddaikar, Wolf R Krüger, Thiemo M Kier, Julius Bartasevicius, Fanglin Yu, Balint Vanek, Abel Olgyay, Béla Takarics	DLR-AE TUM SZTAKI	Aeroservoelastic induced drag modelling and minimization for the T-FLEX demonstrator	AIAA Scitech 2023 Forum	Published	National Harbor, MD, USA	10.2514/6.2023-0176
Keith Soal, Robin Volkmar, Carsten Thiem, Julian Sinske, Yasser M Meddaikar, Yves Govers, Marc Böswald, Daniel Teubl, Julius Bartasevicius, Mihaly Nagy, Balint Vanek	DLR-AE TUM SZTAKI	Flight Vibration Testing of the T-FLEX UAV using Online Modal Analysis	AIAA Scitech 2023 Forum	Published	National Harbor, MD, USA	10.2514/6.2023-0373

Keith Ian Soal, Mihaly Nagy, Daniel Teubl, Robin Volkmar, Carsten Thiem, Muhammad Yasser Meddaikar, B Vanek, Yves Govers, Marc Böswald	DLR-AE SZTAKI TUM	Hardware-in-the-loop testing of a miniaturized real time flutter monitoring system for UAVs	ISMA 2022 - International Conference on Noise and Vibration Engineering	Published	Leuven, Belgium	
Fanglin Yu; Julius Bartasevicius; Mirko Hornung	TUM	COMPARING POTENTIAL FLOW SOLVERS FOR AERODYNAMIC CHARACTERISTICS ESTIMATION OF THE T-FLEX UAV	ICAS PROCEEDINGS 33th Congress of the International Council of the Aeronautical Sciences	published	Stockholm	10.6084/m9.figshare.21656960
Réka Dóra Mocsányi, Béla Takarics, Bálint Vanek	SZTAKI	Control-oriented Aircraft Modelling and Analysis Framework for Educational Purposes	2021 IFAC Workshop on Aerospace Control Education	published	Germany	10.1016/j.ifacol.2021.11.005
Bence Zsombor Hadlaczky, Noémi Friedman, Béla Takarics, Balint Vanek	SZTAKI	Wing shape estimation with Extended Kalman filtering and KalmanNet neural network of a flexible wing aircraft	Proceedings of The 5th Annual Learning for Dynamics and Control Conference	published	Philadelphia, PA, USA	
Béla Takarics, Bálint Patartics, Tamás Luspay, Balint Vanek, Charles Poussot-Vassal, Pierre Vuillemin and Matthias Wuestenhagen	SZTAKI ONERA DLR	Model Based Automatic Control Design for the T-FLEX Demonstrator Using RCE Environment	AIAA SCITECH 2023 Forum	published	National Harbor, MD, USA	10.2514/6.2023-0175
B Patartics, P Seiler, B Takarics, B Vanek	SZTAKI	Worst Case Uncertainty Construction via Multifrequency Gain Maximization With	IEEE Transactions on Control Systems Technology	published	USA	10.1109/tcst.2022.3173044

		Application to Flutter Control				
B Patartics, P Seiler, J Carrasco, B Vanek	SZTAKI	Construction of a Destabilizing Nonlinearity for Discrete-Time Uncertain Lurye Systems	IEEE Control Systems Letters	published	USA	10.1109/lcsys.2022.3171707
B Hadlaczky, N Friedman, B Takarics, B Vanek	SZTAKI	Comparison of EKF and Neural Network based wing shape estimation of a flexible wing demonstrator	19th International Forum on Aeroelasticity and Structural Dynamics (IFASD 2022)	published	Madrid, Spain	
Ábel OLGYAY, Béla TAKARICS, Bence KÖRÖSPARTI, János LELKES, Csaba HORVÁTH, Bálint VANEK	SZTAKI	Aeroservoelasticity Investigation with Panel Method	The 18th International Conference on Fluid Flow Technologies	published	Budapest, Hungary	
Bálint Patartics, Bálint Vanek	SZTAKI	Advantages of flexible aircraft model based FDI	IFAC-PapersOnLine	published	Germany	10.1016/j.ifacol.2022.07.194
Julius Bartasevicius, Mirko Hornung	TUM	In-flight drag measurement and validation for a medium-sized UAV	AIAA SCITECH 2023 Forum	published	National Harbor, MD, USA	10.2514/6.2023-0372
Julius Bartasevicius, Mirko Hornung	TUM	Flight Testing for Flutter – Operational Design and Lessons Learned	SFTE International Symposium 2023	accepted	USA	
Matthias Wüstenhagen	DLR	Gust Load Alleviation Control of Aircraft with Varying Mass Distribution	AIAA SCITECH 2023 Forum	published	National Harbor, MD, USA	10.2514/6.2023-0371

Thiemo M. Kier	DLR	Comparing Different Potential Flow Methods for Unsteady Aerodynamic Modelling of a Flutter Demonstrator Aircraft	AIAA SCITECH 2023 Forum	published	National Harbor, MD, USA	10.2514/6.2023-0177
Özge Süelözgen	DLR	Application and Validation of a Model Updating Approach for Linearized State-Space Models of Flexible Aircrafts Using Multiple Flight Test Data	AIAA SCITECH 2023 Forum	published	National Harbor, MD, USA	10.2514/6.2023-0374
Matthias Wüstenhagen	DLR	Model Selection for a Multiple-Model Adaptive Gust Load Alleviation Controller	International Forum on Aeroelasticity 2022	published	Madrid, Spain	
Özge Süelözgen, Gertjan Looye	DLR	Application and Validation of a New Updating Algorithm for Linearized State-Space Models of Flexible Aircrafts Using Flight Test Data	International Forum on Aeroelasticity 2022	published	Madrid, Spain	
S. Olasz-Szabó, T. Baár, T.Luspay	SZTAKI	Decoupled parameter identification for a flexible aircraft	EURO GNC 2022	published	Berlin, Germany	

2.7 List of Thesises and Dissertations

Author	Partner	Title
Ákos László Radványi	SZTAKI	Feasibility Study of an Aeroelastic Pseudo-Satellite
Balázs Vidor Huszár	SZTAKI	Flexible airplane’s induced drag modelling with panel methods and its reduction with active wing shape deformation

Milán Barczi	SZTAKI	Surrogate Drag Modeling for a Flexible Wing Passenger Aircraft using Panel Methods
Zsombor Wermeser	SZTAKI	Multidisciplinary Design Optimization of Flexible Aircraft with Flutter Suppression Control
Gribkov Aleksandr	SZTAKI	Application of Grid-based and TP-based Control for Active Flutter Suppression of Flexible Aircraft
Johanna Kärner	TUM	Aerodynamic and Structural Configuration Potential for FLEXOP UAV
Annina Metzner	TUM	Calibration and Testing of an In-Flight Thrust Measurement System for UAV Applications
Kenneth Yhen Hong Leow	TUM	Software Development and Laboratory Testing of an Electro-Mechanical Actuator Control and Monitoring Unit
Elias Simon Peter	TUM	Nonlinear Static Aeroelastic Analysis of T-FLEX UAV
Olivia Aschermann	TUM	Observer-based capture of dynamic behaviour change on a UAV flight control surface
Mohamed El Hedi Letaief	TUM	Fault detection algorithm development for UAV actuators
Daniel Harlander	TUM	Design, manufacturing and testing of an Instrumented Wing Glove for in-flight UAV applications
Mehdi Hammami	TUM	Development of Flight Test Data Analysis and Planning Tools
Guthörl Matthias Frank	TUM	Independent power consumption measurement device developement for the FLEXOP demonstartor
Marius Haag	TUM	Comparison of low and high order aerodynamic modelling of an UAV
Sebastian Lang	TUM	Analysis and Structural redesign of the FLEXOP demonstrator main landinggear
Fernando Puelles	TUM	Development of Flight Test Data Analysis Tools
Chen Xiaohui	TUM	Retrofitting actuators on the T-FLEX demonstartor with enxhanced actuator monitoring system
Olga Balaska	TUM	Drag influence on TFLEX UAV from airbrakes and landing gear
SAI KIRAN EDIGA	TUM	Implementation of Structural Sizing in the MultiDisciplinary Design Toolchain
Huang Ching-Ting	TUM	Loads Analysis of T-FLEX UAV
Yi Zhan	TUM	Implementation of a conceptual design toolchain for D150 configuration
Chang Xu	TUM	Drag Reduction with Active Wing Shape Control
Yuchen Chou	TUM	Embedded Software development for the Actuator Control and Monitoring Unit

Sebastian Lang	TUM	Analysis and Structural redesign of the FLEXOP demonstrator main landinggear
Bastian Scheufele	TUM	Design, Implementation and Flight Testing of a Subscale Dynamic Demonstrator.
Marius Weber	TUM	Development and Implementation of a Framework for Telemetry Data Visualization and UAV Guidance.
Joschua Gosda	TUM	Effects of reference signal shaping in UAV servos
Victor Magalhaes	TUM	Software development for the ACMU system
Pedro Alexandre Tonet Fleig	TUM	Improvement and Further Design of a Thrust Measurement System for In-Flight Applications on an Unmanned aerial Vehicle
Bastian Scheufele	TUM	DEVELOPMENT, FLIGHT-TESTING AND EVALUATION OF A SUBSCALE DYNAMIC DEMONSTRATOR TO REPRODUCE THE STALL BEHAVIOR OF A SWEPT WING RESEARCH UAV.
Lawan Nuri Sharif	TUM	Retrofit Design of an UAV wing for active drag control
German Nogues Armengol	TUM	Drag Modelling of FLEXOP Demonstrator with CFD
Martin Löwenhauser	TUM	Drag optimization by means of control surface deflections for T-FLEX demonstrator
Marius Weber	TUM	Application of Orthogonal Multi-Sine Inputs for Flight Testing of UAVs.
Simon Schelle	TUM	Investigation and Implementation of Airspeed Calibration Methods based on UAV Flight Test Data
Sergio Augustin Gallego	TUM	Aerodynamic study of wing manufacturing defects for a UAV
Arturo Gutierrez Munoz	TUM	Numerical analysis and setup-up of components for wind-tunnel configuration of UAV air-brakes
PhD : Tamás Baár	**SZTAKI**	**Optimal Decoupling of Dynamic Systems: a Convex Approach with Aerospace Applications**
PhD : Bálint Patartics	**SZTAKI**	**Uncertain systems: analysis and synthesis with application to flutter suppression control**

2.8 Dissemination and communication activities

Type of dissemination and communication activities	Number
Organisation of a Conference	0
Organisation of a workshop	2
Press release	1
Non-scientific and non-peer reviewed publications (popularised publications)	1
Exhibition	2
Flyers training	0
Social media	2
Web-site	1
Communication campaign (e.g radio, TV)	0
Participation to a conference	7
Participation to a workshop	0
Participation to an event other than a conference or workshop	0
Video/film	5
Brokerage event	0
Pitch event	0
Trade fair	0
Participation in activities organised jointly with other H2020 project(s)	0
Other	0

Type of audience reached In the context of all dissemination & communication activities ('multiple choices' is possible)	Estimated Number of persons reached
[Scientific Community (higher education, Research)]	1000
[Industry]	200
[Civil Society]	
[General Public]	1000
[Policy makers]	2
[Medias]	
[Investors]	
[Customers]	
[Other]	

Workshop: Flight test data processing workshop (We organized it, students took part)

Two exhibitions:

- https://www.stmwk.bayern.de/allgemein/meldung/6843/bayern-gruendet-europaweit-beachtetes-aerospace-flight-test-center.html
- 12.07.21 opening of the new faculty building with minister President Markus Söder, we displayed FLIPASED

popularised publications: on Homepage about Flight tests in May 23

Videos: Flight test data + one cuted press release editing right now

Homepage with project description

Conferences:

- AIAA Scitech 2023
- SFTE international Symposium 2023
- ICAS 33rd Congress of the International Council of the Aeronautical Society
- AIAA Scitech 2022

→ 4 different conferences but 6 publications

(Media Team TUM at Flight tests, don't know if there was a press release)

3 Exploitation Activities

This section sums up the major outputs of the deliverable including information on the “next steps”: HOW the concrete results from the project done will be used, WHEN and BY WHOM.

3.1 SZTAKI

As a result of the FLIPASED project, SZTAKI is working on an industrial project proposal with Embraer on flexible a/c control technologies. Moreover, there is a submitted proposal to ESA on flexible satellite control in a consortium in which the modelling techniques/tools and control design are closely related to FLIPASED.

SZTAKI, together with TUM also presented results to Dassault aviation, who indicated interest in directly using the project results within their Clean Aviation research project.

There is another submitted proposal to ESA on reuseable launcher system identification and state estimation in a consortium where the modelling and estimation techniques are closely related to FLIPASED.

Furthermore, SZTAKI won a project about flexible pseudo satellite control at ELKH (HU) where the avionics components and estimation techniques are reused from the project.

The institute won a project at US Air Force Office of Scientific research related to active wingshape control and the related big data modelling developed in FLiPASED. The project was highlighted in the annual report of SZTAKI towards the Government. Here the flexible aircraft active control theory was emphasized, especially related to sustainable aviation.

3.2 DLR-SR

In the FLIPASED project, DLR applied the method of “blending” for design of flutter control laws (i.e., application to unstable systems) and tested them in flight. This approach will be extended and matured in several succeeding projects also involving industry partners.

The tools and experiences gained during the FLIPASED flight test campaigns will be utilized in upcoming projects where experiments will be conducted. This includes modelling approaches for simulation models, controller synthesis models, as well as Hardware- and Software-in-the loop simulations for test clearance for experiments to ensure safety.

The flight test data gathered during the FLIPASED project enabled to mature simulation model updating methods, where previously only synthesized test data was available. The model updating methods will be used in subsequent project where test data will be produced, e.g. from windtunnel experiments. In particular EU projects like Clean Aviation UPWing, where a transonic windtunnel experiment with a gust generator is setup these methods will be most valuable.

The project FLIPASED was presented to the CEO of DLR Anke Kaysser-Pyzalla in July 2021. The importance of active control theory was emphasized in particular the relevance of the active flutter suppression which is to be demonstrated in a flight test with the scaled demonstrator.

3.3 Onera

During the FLIPASED project, ONERA lead the Ground Vibration Test (GVT) activities, along with the DLR Institue of Aeroelasticity, to characterize the structural dynamic behavior of the aircraft. Although being a relatively conventional aircraft, this GVT allowed to unveil several difficulties specific to drone demonstrators fitted with fast control surfaces. It must be highlighted that this aircraft as very active control surfaces, which actuate in a much broader frequency range. This requires a renewed vision of the GVT preparation (active / passive configurations), and results interpretation. In fact, with such designs, there are more and more ways to mis-interpret the GVT data, potentially leading to either an improper Finite Element Model update or flutter computations. The experience of this GVT will be of great use to define new GVT protocols for such aircraft, to ease the modal identification and therefore certification of new aircraft, in either CS-VLA, CS-23 or CS-25 certification categories.

Also, this project allowed to adapt flutter prediction software that where initially designed for wind tunnel models, to full aircraft flutter computations. These tools allow to compute the flutter behavior of aircraft, despite the lack of a finite element model. In fact, these tools only need the results obtained from a GVT and a simplified panel model for the flutter computations. This kind of flutter assessment strategy is particularly interesting for the certification of light aircraft or drones as the companies leading these developments often lack specialists able to obtain a completely correlated numerical model or their aircraft. Thanks to the developments performed during the FLIPASED project, these tools are currently being used in several national (MAKJESTIC, ALFA, HAPARACCHI) and EU funded (CONCERTO) projects.

3.4 TUM

Due to the work in FLIPASED TUM gained substantial experience in aeroelastic wing design. The expertise, models and tool chains provided a basis for further research projects initiated in this field. Within the national aerospace research programme LuFo, TUM was able to succeed in the project ProFla, which address aeroleastic optimization tool chains as well as the adaptation of Open Source software solutions for flutter prediction of general aviation aircraft. The models developed in FLIPASED, and the workflow of the toolchain can be used to be integrated in the chairs own aircraft design tool ADEBO expanding its capabilities.

Besides aeroelastic wing design TUM was responsible for building and operating the demonstrator to gain in flight data for validation. The FLIPASED flight tests had to be conducted on an operating commercial airport. During the project the certification rules for UAV had changed and thus TUM had to go through the certification process for another airport as it was not possible to fly at the original anymore. Thus, TUM gained substantial experience in certification being one of the first to go through this process applying the new rules. Already existing procedures, operations and related background information from the FLEXOP project were refined and compiled in five main documents, as described below.

- The UAV Flight Operations Manual
- FLIPASED Flight Manual
- FLIPASED Flight Test Programme
- Flight Test Cards
- FLIPASED Emergency Cases and Procedures

TUM will use those documents and the knowledge gained for actual and follow on projects with flight demonstrators involved. Especially the UAV Flight Operations Manual is the new standard to safely and efficiently conduct test, research and training flights of unmanned vehicles within the Institute of Aircraft Design of the Technical University of Munich. Its main purposes are:

- to define the standard operations before, during and after a flight,
- to increase the safety and efficiency of a test or research flight and
- to be a method for making the transfer of knowledge from generation to generation easier

The exploitation of the gathered ground and flight test data also helped to provide a more efficient data retrieval and analysis process to be used in other demonstrator projects, thus enhancing the speed for validation of numerical models and integrated tool chains.

Flight test data from FLIPASED are being published for the use of the community. This will provide other researchers with the unique opportunity for the utilization of real test data for further model validation and improvement.

4 Conclusion

The FliPASED team spent significant effort in disseminating the project results both to the general public as well as to the professional aerospace research and development community.

Several lists of relevant documents, publications and other key references are presented within the deliverable.

The key exploitation results and short-term targets are also discussed within the document.

The numbers, even though many of them are estimates, show significant outreach and showcase a highly successful project reaching target audience.