ILRC 2024 CLRC
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22ND COHERENT LASER RADAR CONFERENCE
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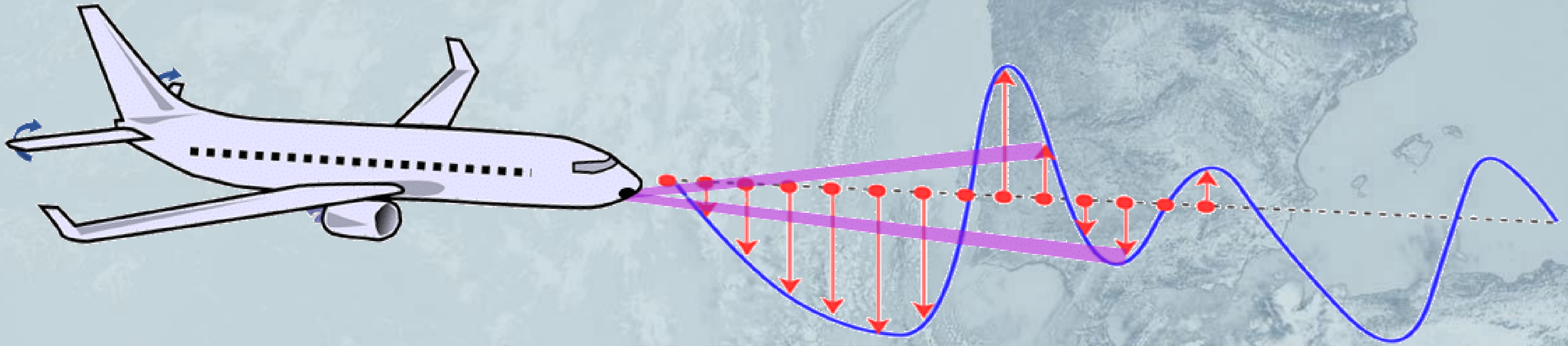
ONERA THE FRENCH AEROSPACE LAB

nlr

Aeronautics lidar revisited – Towards lidar-based gust and turbulence measurement for aircraft load alleviation control



Co-funded by the European Union

CLEAN AVIATION

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Outline

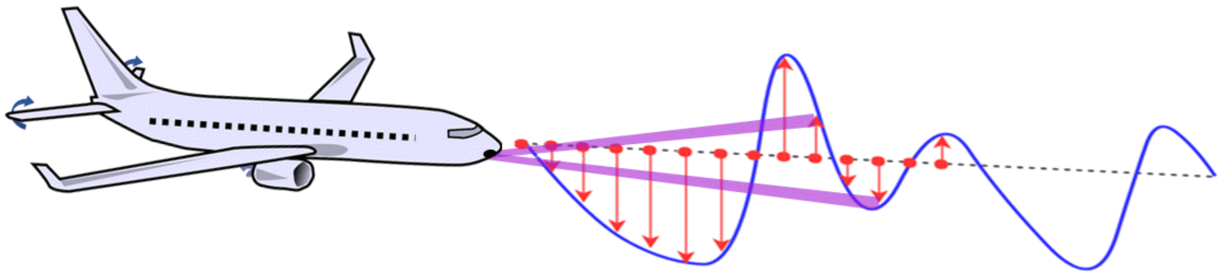
- **Rationale Lidar for gust load alleviation (GLA) control**
- **Our approach**
  - **Lidar technology maturation**
  - **Simulation support**
  - **Validation**
- **Conclusion**

Rationale
Context: **Clear Air Turbulence** and **Aeronautics**

- ! Improve efficiency, safety, comfort !
- Goal: Saving structural mass of aircraft (wing) structure by lowering loads (induced by turb. encounter)
  - turbulence loads are ‚sizing' the design
  - with advanced feed-forward control within turbulence
  - decrease safety factors in aircraft structural design
  - → convince authorities (CAAs) that the approach works
    && → THEN: build lighter structures

= Lidar-based Feed-Forward Gust Load Alleviation (GLA)

- Tool: Turbulent gust / wind measurements ahead - retrieved by Doppler wind lidar (DWL)
- Cruise flight levels + system availability requirements:
  → mandatory (UV) Direct-detection Doppler Wind Lidar (independent of aerosol load)
- Other requirements: High spat./temp. resolution,
  close range, small $\sigma_{v_{LOS}}$
- = A challenge…



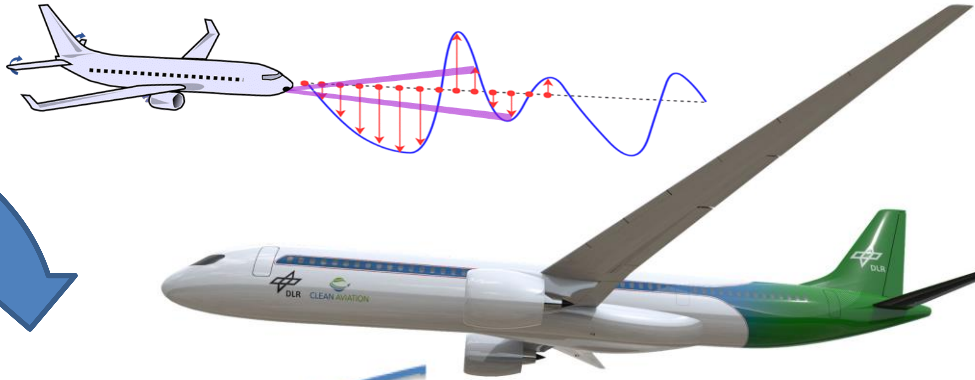
Challenge TRL

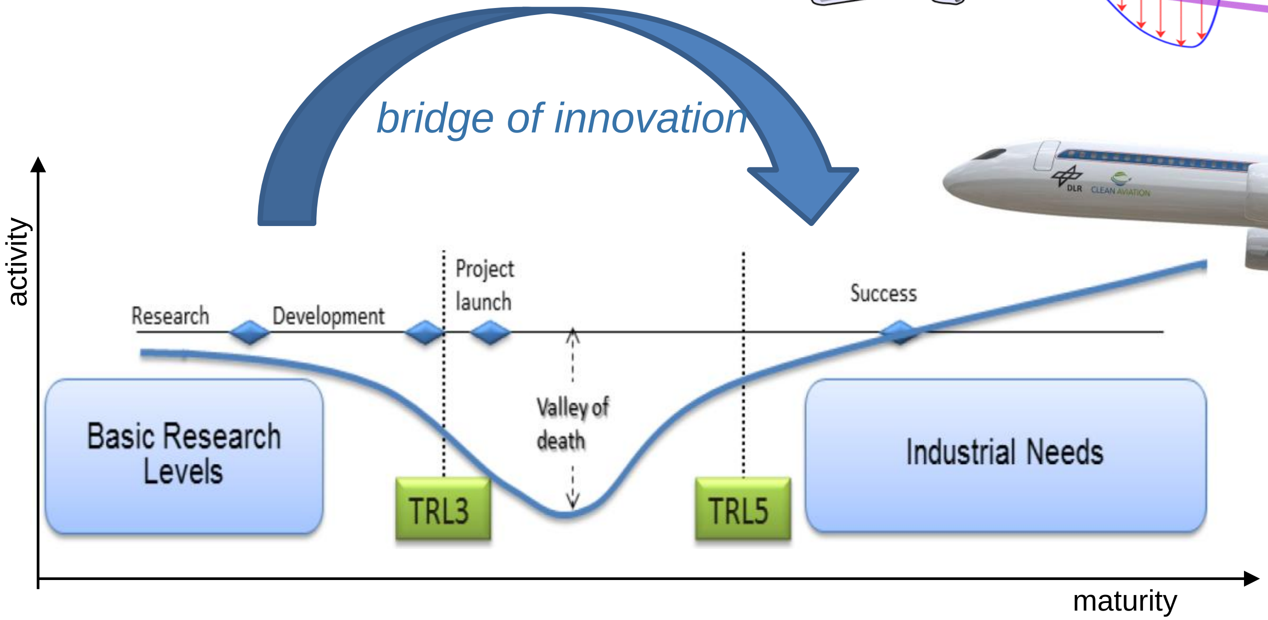
For perspectively industrial use:
***Increase Technology Readiness Level** (TRL), i.e.*
Mature technologies, test, and demonstrate

Research:

Many systems developed to more or less robust and reliable TRL3/4 systems

Industrial application:



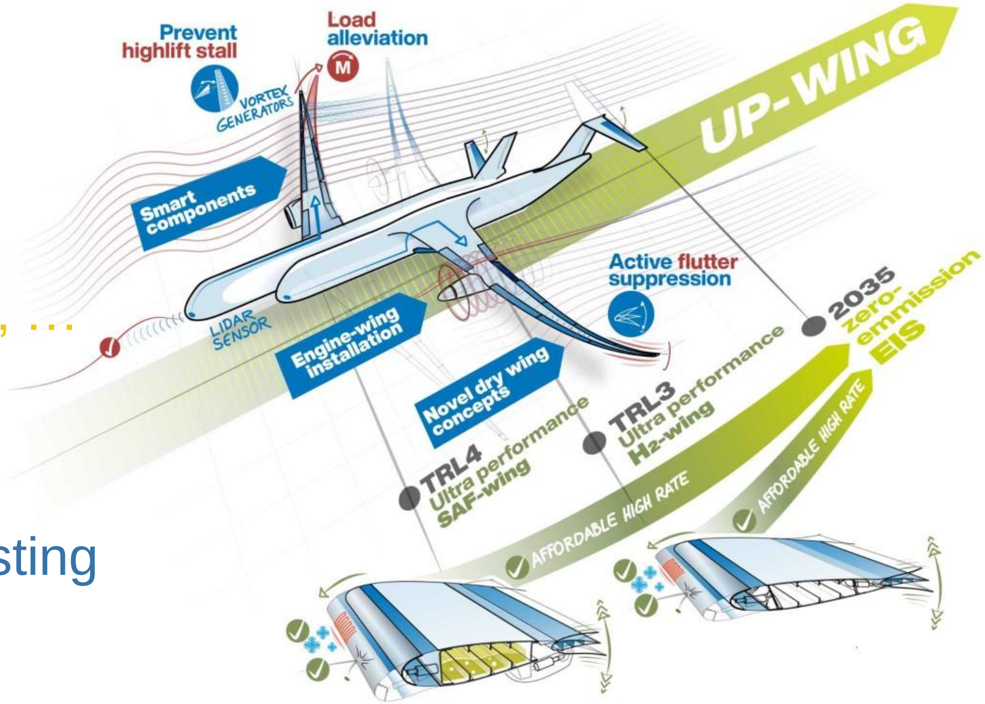


TRL 1 2 3 4 5 6 7 8 9

ONERA‘s & DLR‘s common approach

- Team up! = Combine past & present R&D activities on technologies and demos.
- Common project participation: „UV Lidar“ within Clean Aviation J.U. **UP-Wing**

- Critical technology development/maturation:
  - Laser source, DD-DWL receiver, beam addressing
- Thorough support by simulation and validation:
  - Lidar system simulation, gust load alleviation function, …
- Early testing and demonstration:
  - partial functionality in flight test +
    high altitude ground testing

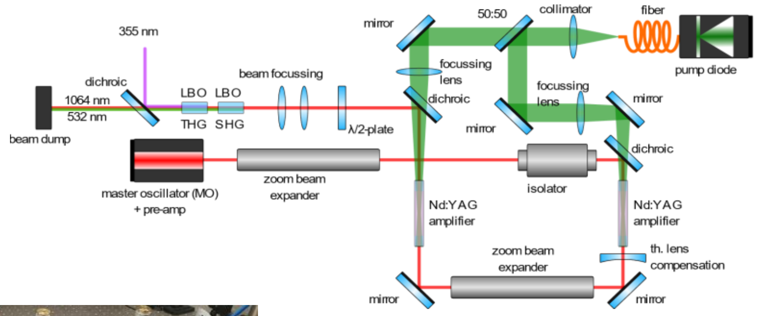


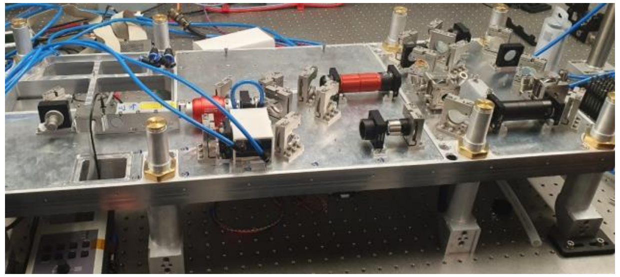
Ultra-Performing Wing

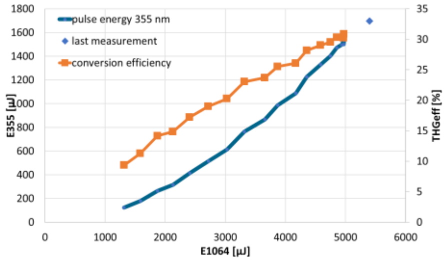
Lidar technology maturation: Complementarity

Laser transmitters

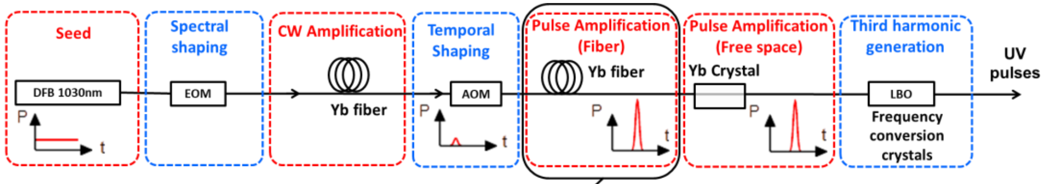
- Compact Nd:YAG DPSS optimized for application
- MOPA architecture (MO, pre-amp, 2x amp, THG)
- 3 kHz PRF, > 5 W @ 355 nm SLM, 10 ns pulses
- Integrated in FP7-DELICAT lidar architecture for test flights on NLR Citation 2

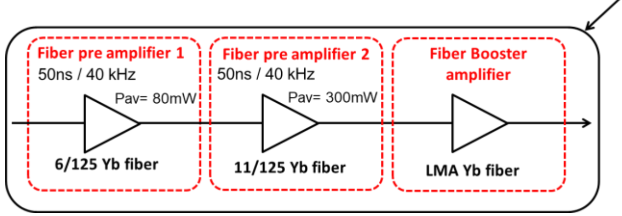




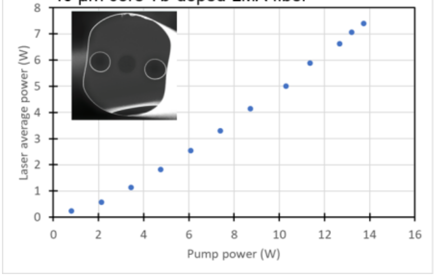


- Compact Yb:YAG DPfiberedSS
- MOPA architecture (cw-MO, spectral&pulse shaping, fibered amps + f-s (amp) + THG)
- 30 kHz PRF, x W @ 343 nm SLM, 25 ns pulses
- under development





Booster fiber amplifier results with 40 µm core Yb-doped LMA fiber



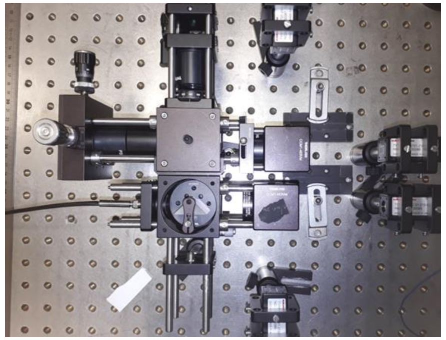
- Further studies

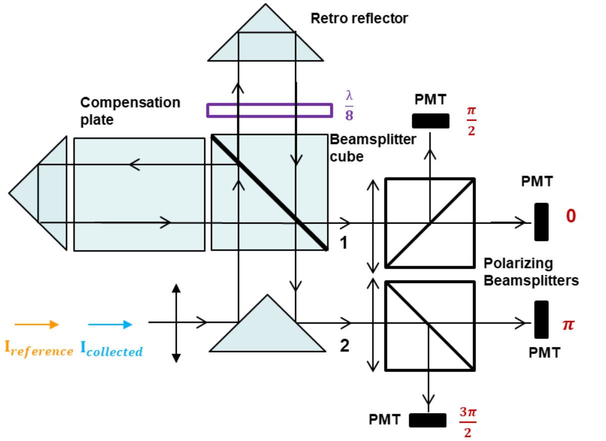
Lidar technology maturation: Complementarity

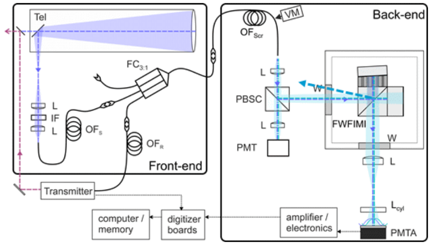
Doppler spectrometric receivers

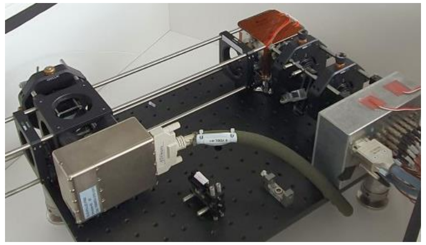
- *Recall Monday CLRC talk Thibault Boulant*
- Quadrature-field-widened Mach-Zehnder receiver
- 4 detectors give phase
- Lab version + monolithic in production

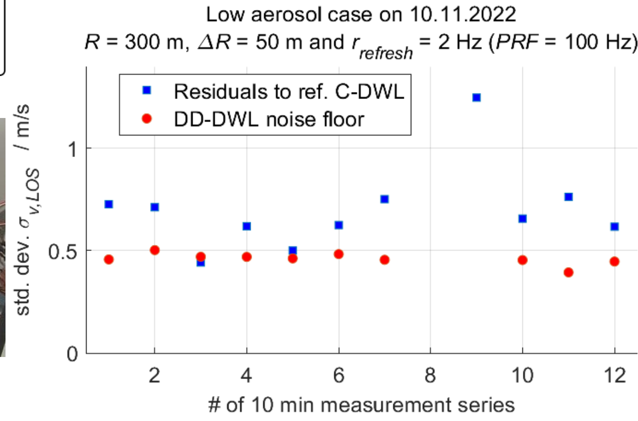
- *Recall Tuesday jCLRC/ILRC talk Philippe Linsmayer*
- Fringe-imaging field-widened Michelson receiver
- (2x) 10-16 detectors (lin. PMT array) image fringe
- 1st generation thoroughly tested on ground and in high altitude, being prepared for flight tests
- 2nd generation / evolution under development









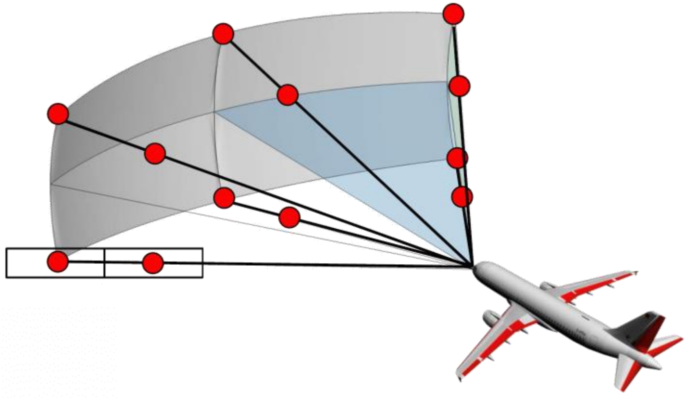


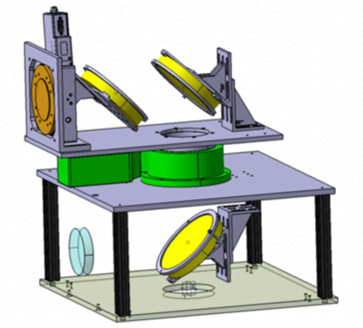
Lidar technology maturation: Common

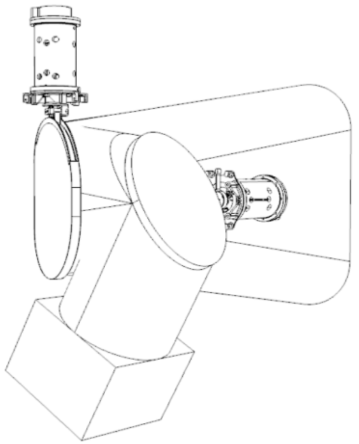
Transmit / receive + directing

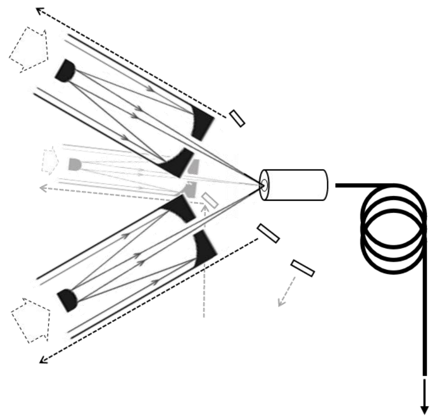
! ahead vert.+ lat. wind LOS projection + aircraft integration !

- Iterative study on requirements on
  - N° of directions, angles, switch/scan speed
    i.a. recall Monday CLRC talk Thibault Boulant
  - Continuous scan - few, discrete directions
  - Monostatic/bistatic, on-/off-axis
  - Technologies –
    S.o.t.A. on mov. mirrors, prisms/wedges, galvo-scanners, MEMs, DOEs, OPAs, …
- Development of demo systems
  - Ground validation
  - Airborne validation









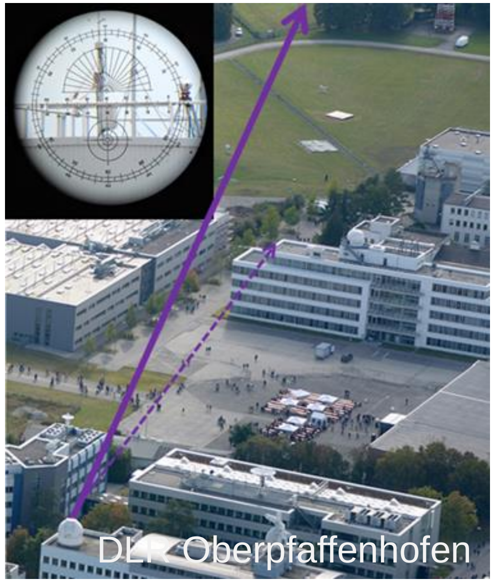
Test and early demonstration: Concurrent & common

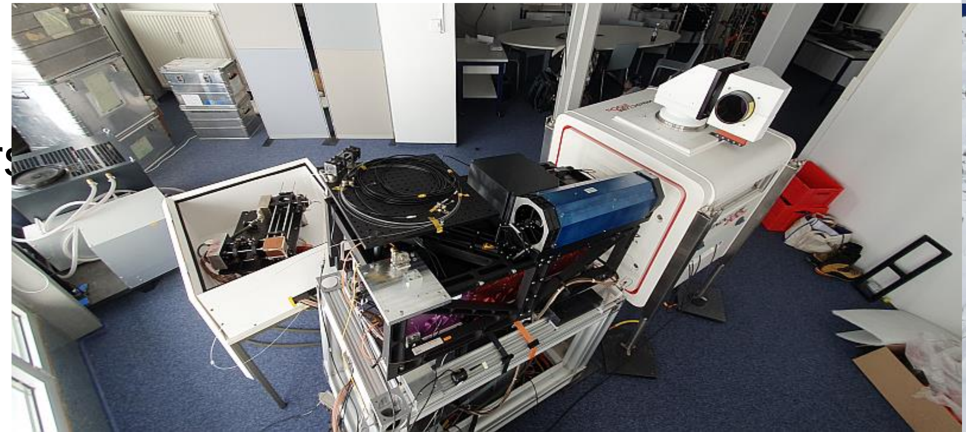
Ground-based: BL and high-altitude demos

- Functional, characterization and sensitivity studies
- Verification of simulations

- Local (PBL): Palaiseau and Oberpfaffenhofen
- High-altitude:
  Environmental Research Station Schneefernerhaus (UFS) at 2650 m a.s.l. (at Mt. Zugspitze)
  Recall Tuesday jCLRC/ILRC talk Philippe Linsmayer

- References: C-DWLs, us anemometers, aerosol: ceilometers, nephelometer, p. size distribution, number





Test and early demonstration : Concurrent & common

Airborne validation of partial and full config.s

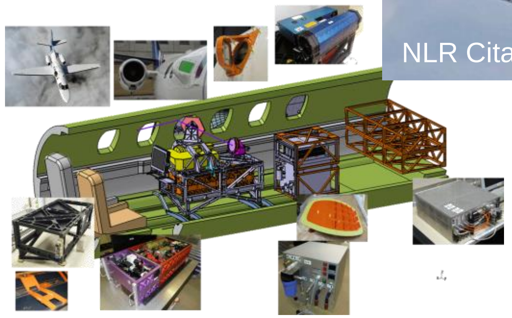
- MOPA-DPSS transmitter + Michelson-single-channel receiver = TRL increase of an important part of the lidar technology

- Means: single-dir. LOS-wind + compare to air data
- Use existing equipment and flight platform including certification EC/FP7 DELICAT installations

- Feasibility study and pre-design for forward-multiple-axes demonstration on DLR‘s F2000 ISTAR (for 202x)

- Possibly further/other test aircraft on various config. demos in C.A. phase2

NLR CitationII PH-LAB

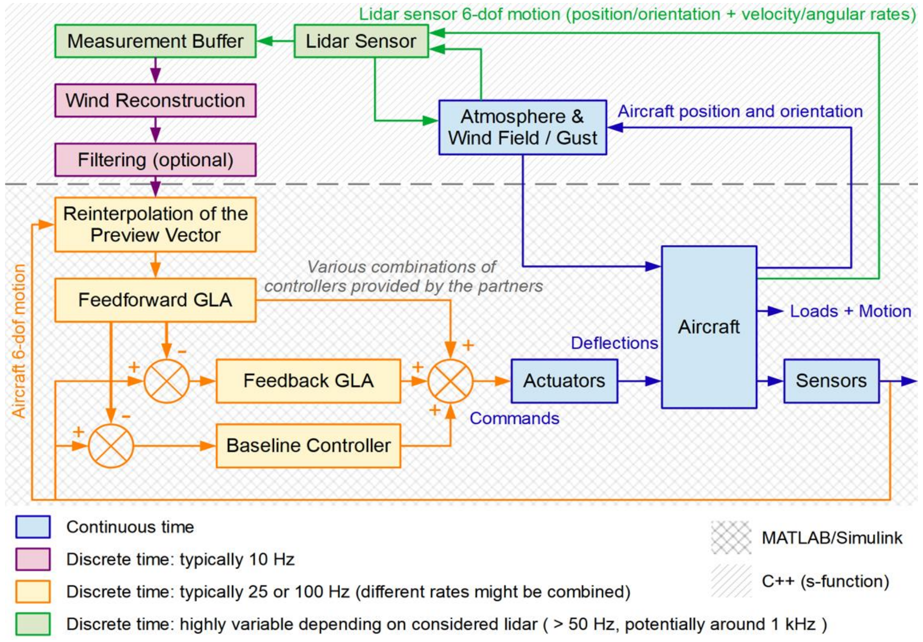


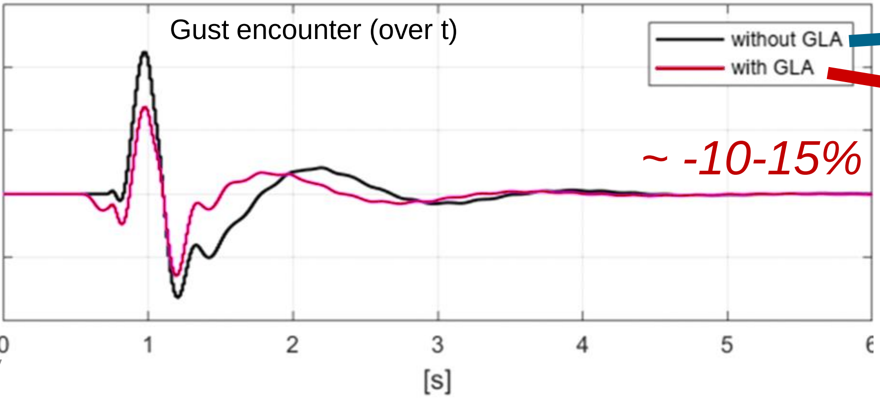
DLR team at Braunschweig

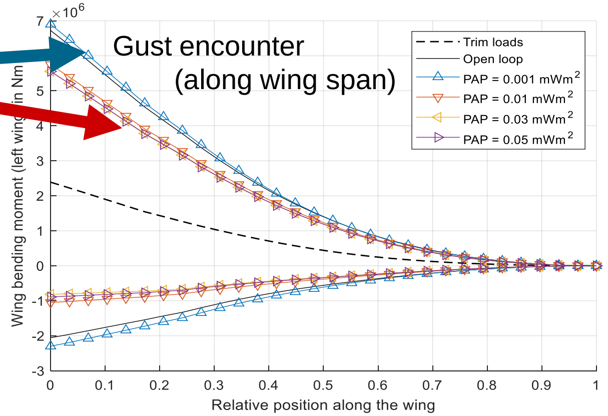
Simulation support: Concurrent, common & combined

- Lidar performance simulation: Simplified + E2E
- Turbulent wind data
- Wind reconstruction algorithm
- Flight controller
- Aircraft aero-servo-elastic models
- Loads analysis: yield GLA capability

Full lidar-GLA simulator







Summary

- Two aeronautics lidar groups teaming up for European R&D project (2023-2026++)
- Know-how, experience and lessons-learnt from many airborne wind lidar projects

- Approach: Foremost raise TRL, identify&adopt path to industrialization

- Many thanks to the team!

DLR: Paula Cutipa, Matteo Faccioni,
Philippe Linsmayer, Adithya Pankan, Nicolas Fezans,
Daniel Kiehn, Oliver Kleinert, Oliver Kliebisch,
Raoul Lorbeer, Johann Thurn
ONERA: Thibault Boulant, Laurent Lombard,
Tomline Michel, Pierre Pichon, Jonathan Pouillaude,
Matthieu Valla
NLR: Harald de Haan, Robert de Muynck, Robert Tump

ONERA, NLR, DLR teams in Palaiseau

… and at Amsterdam

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