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Whirl Flutter Testing of ATTILA Tiltrotor Testbed – Initial Results

Stefan van 't Hoff (NLR) | VFS Forum 2024

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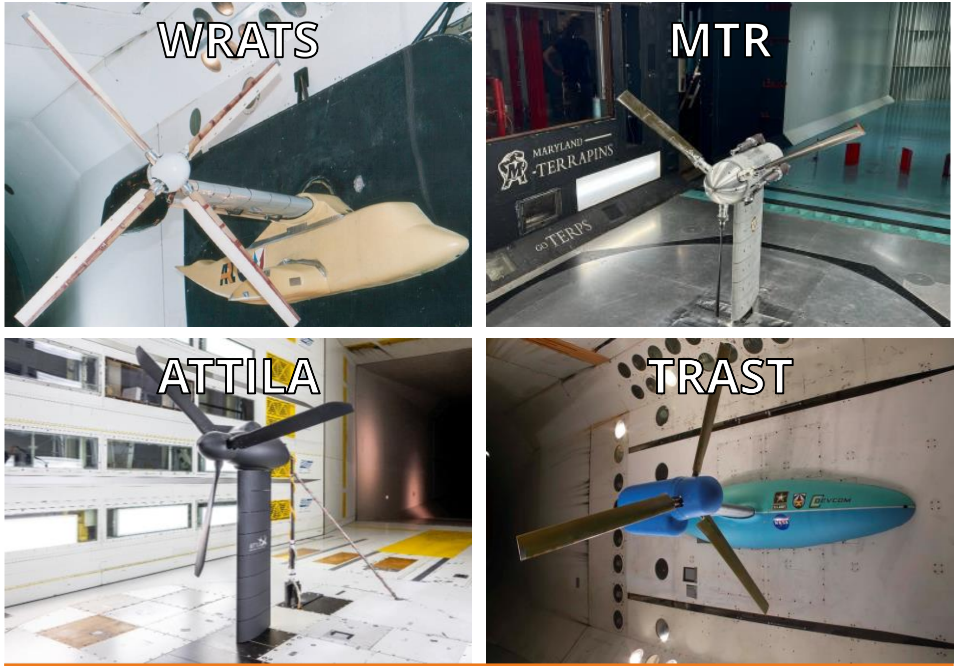
- ATTILA project
- ATTILA testbed
- Wing-pylon dynamics
- Test procedures
- Initial test results
- Conclusions

Tiltrotor whirl flutter

Tiltrotor whirl flutter

- Coupled rotor-wing aeroelastic instability.
- Driver for high-efficiency tiltrotor wing design.
- Research ongoing since the 1980s.
- Numerical prediction remains challenging.



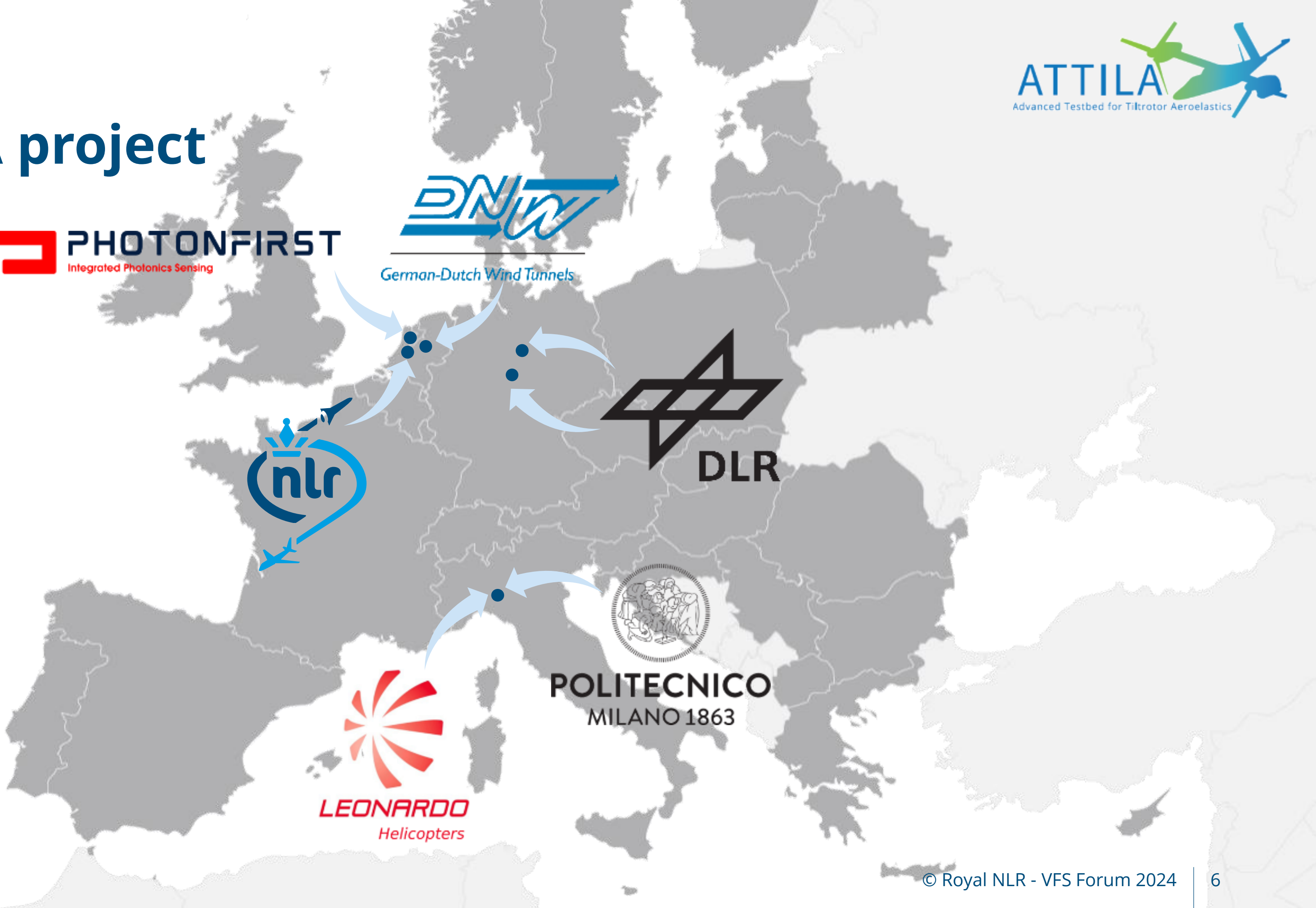
TILTROTOR WHIRL FLUTTER TESTBEDS

ATTILA project

- Wind tunnel testing of powered 1:5 Froude-scale half-wing model of Leonardo NGCTR in DNW LLF.
- Data used for validation of numerical methods that support clearance for high-speed flight testing.

LEONARDO NGCTR

ATTILA project

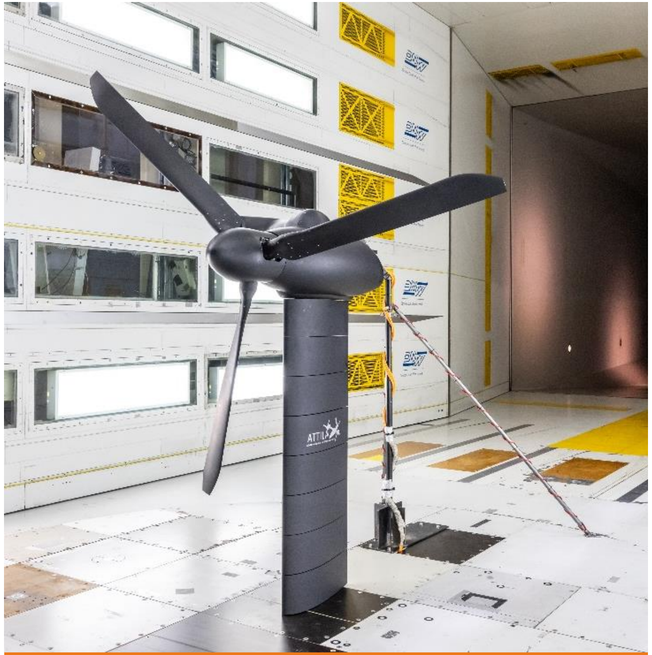


ATTILA testbed

ATTILA testbed

Specifications

- Rotor diameter: 2.5 m (8.2 ft)
- Semi-span: 1.6 m (5.2 ft)
- Gimballed CV rotor
- FO blade strains
- Brushless DC motor in nacelle
- Accelerometers for OMA
- Rotor load balance @ wing tip

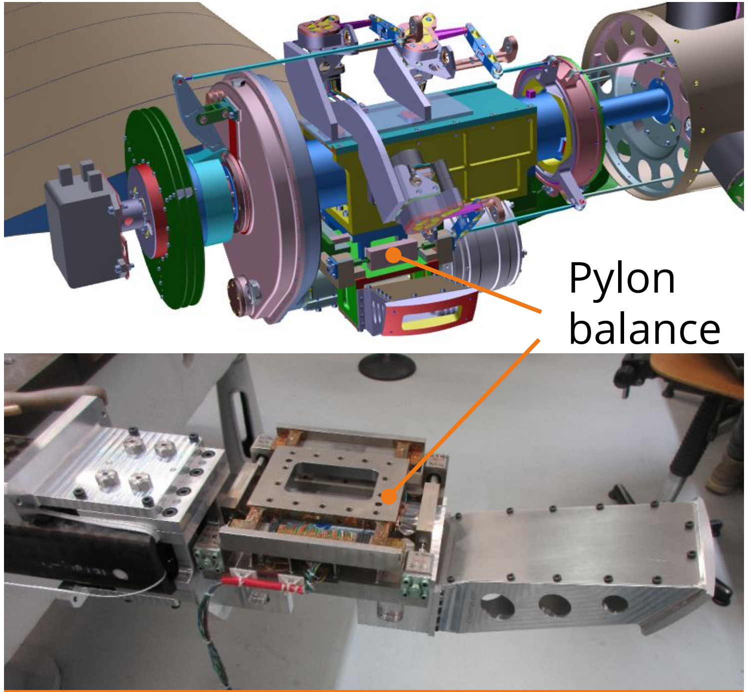


ATTILA TESTBED @ DNW LLF

ATTILA testbed

Load measurements

- Pylon load balance (6 component)
- Torque balance (failed)
- Mast bending (in-plane hub shear)
- Blade & yoke loads
- Wing root bending

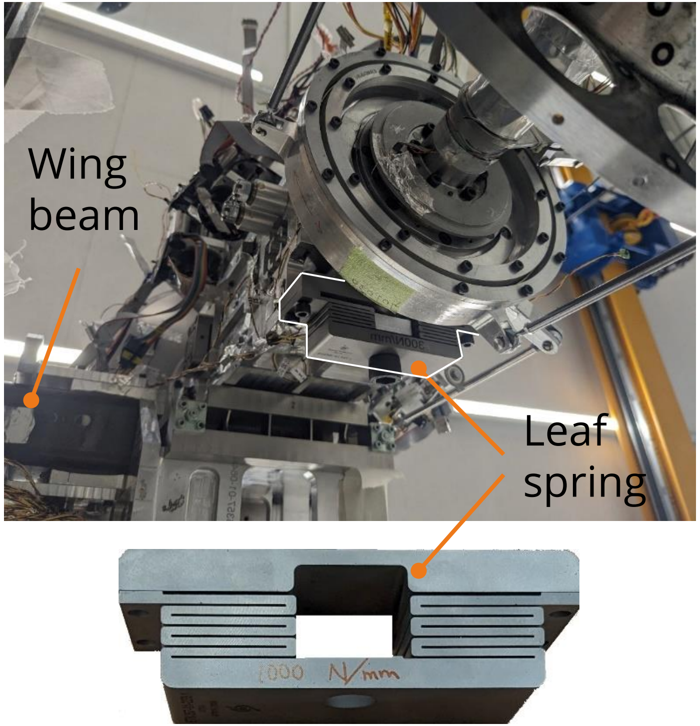


ATTILA PYLON LOAD BALANCE

ATTILA testbed

Mass/stiffness configurations

- Non-structural mass along wing beam (manipulation of span- and chordwise CG).
- Downstop ON/OFF: interchangeable rapid prototype leaf springs (pylon pitch stiffness).

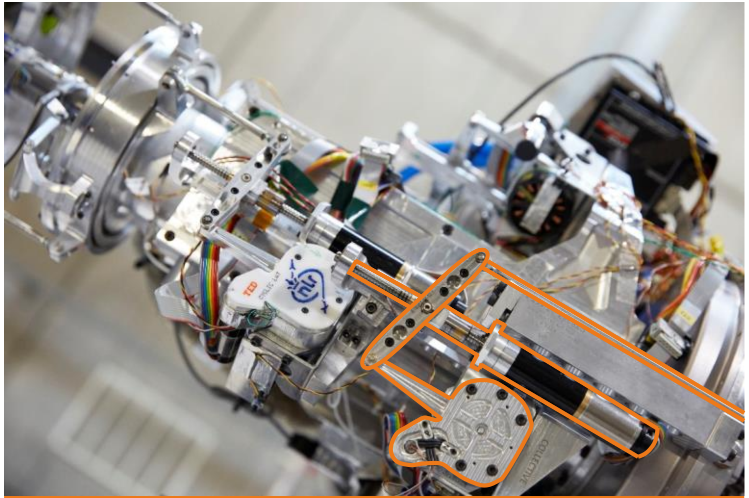


DOWNSTOP ASSEMBLY

ATTILA testbed

Trim-excitation system

- Novel light-weight, electro-mechanical system operating on collective & cyclic blade pitch.
- Three (3) actuators:
  - Trim
  - Excitation amplitude (0-0.5°)
  - Excitation frequency (0-25 Hz)
- S/W: step inputs, sine dwells, linear & exponential sine sweeps, etc.



TRIM-EXCITATION SYSTEM

Wing-pylon dynamics

Ground Vibration Testing (GVT)

- Extensive shaker GVTs of full assembly by DLR.
- Dummy and test rotor blades, gimbal locked and restrained.
- Amplitude-dependent nonlinearity in frequencies and damping, especially in downstop OFF

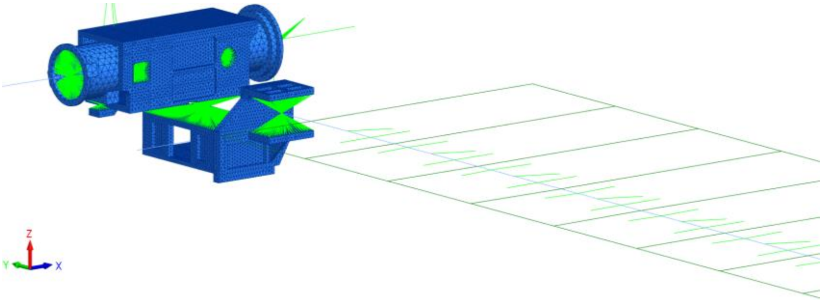
  (higher amplitude > lower damping).

DLR GVT @ DNW LLF

Wing-pylon dynamics

Numerical model correlation

- NASTRAN model:
  - Wing: beam model
  - Pylon: 3D solids
  - Load Balance: 6-DOF springs
- Build-up approach for model tuning: at assembly level downstop spring stiffness tunable



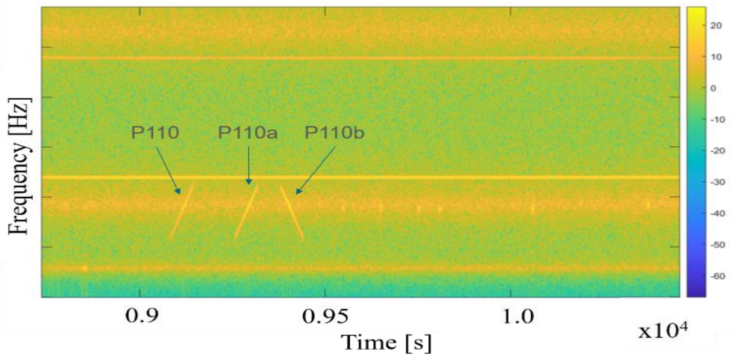
#	Mode	Frequency [-]		MAC [%]	Modal mass [kgm^2]	
		GVT	ΔFEM		GVT	ΔFEM
1	Beam	0.97	+6.2%	99.3	37.8	-3.4%
2	Chord	1.66	0%	98.1	45.8	-5.5%
3	Torsion	3.34	+3.6%	87.6	29.9	-0.7%
4	Yaw	5.13	+12.7%	90.4	16.5	+24.2%

GVT vs NASTRAN WING-PYLON DYNAMICS

Test procedures

Modal identification

- DLR online modal analysis:
  - Wing-pylon accelerometers
  - Multi-algorithm (e.g., SSI, LSCF)
  - Narrow-band sine sweep excitation
  - Bootstrap extrapolation procedure
- Leonardo free-response analysis:
  - Wing root strains
  - Matrix pencil method
  - Dwell excitation

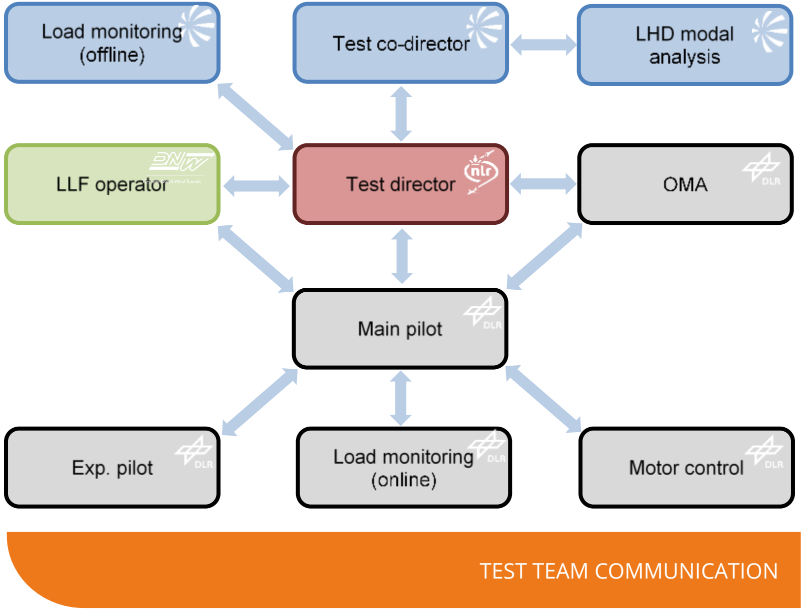


PYLON ACCELEROMETER EXCITATION SPECTROGRAM

Test procedures

Test team organization

- Distributed teams:
  - Piloting & DAQ (DLR container)
  - Online modal analysis (client room)
  - Tunnel operation (control room)
  - Test directors (control room)
- Decision making framework:
  - Resolve conflicting modal est.
  - Ensure success and safety criteria
  - Emergency procedures



Test procedures

Piloting & DAQ

- Main & experimental pilot tasks:
  - Rotor trim
  - Flutter excitation
  - Power supply & motor governor
  - Safety of flight monitoring
  - Emergency procedures (manual)

DLR PILOTING & DAQ CONTAINER

Initial test results

Technical challenges

- Nonlinear structural damping
  - maximum excitation amplitude
- Damping in gimbal degree of freedom
  - trim to non-zero gimbal flap
- High collective excitation loads:
  - cyclic excitation only

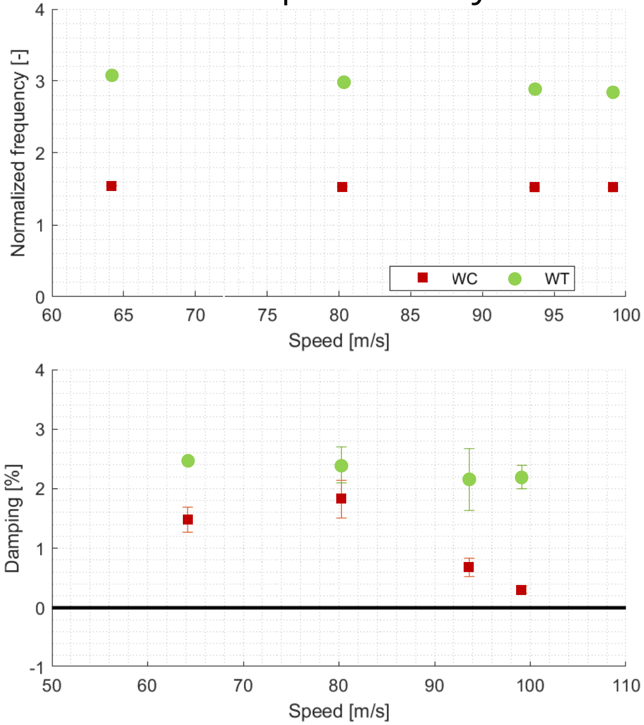
BLADE PITCH ENCODER ASSEMBLY

Initial test results

Preliminary flutter results

- Power OFF, downstop ON, conversion mode NR (102%)
- Wing chord (WC) mode instability at ~100 KT.
- Wing torsion (WT) remains stable; **contrary to prediction!**
- Error bars: 1σ considering repeated dwells and time windows variations

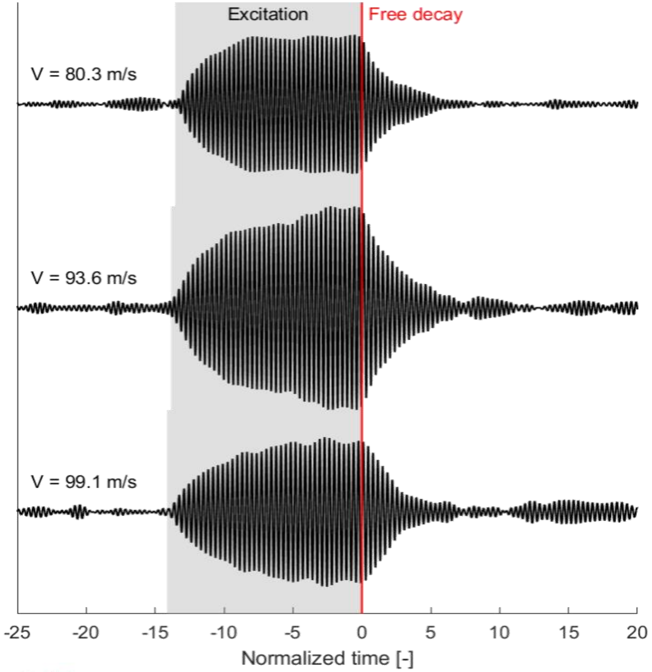
Free response analysis



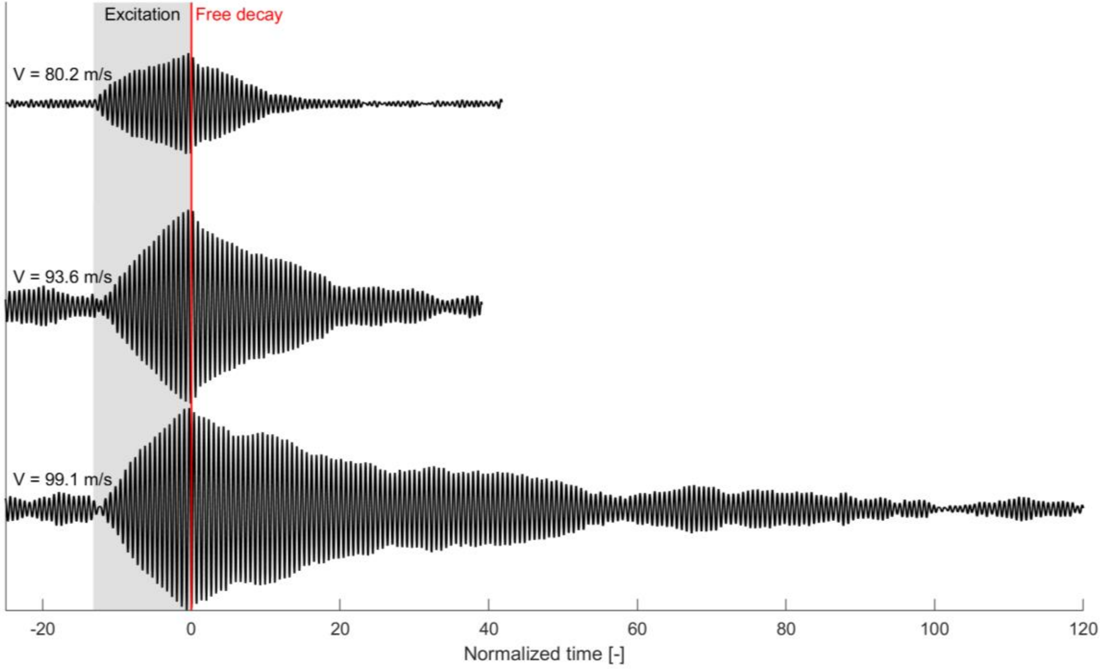
P-OFF, DS-ON, 102%NR

Initial test results

Wing root torsion / WT excitation



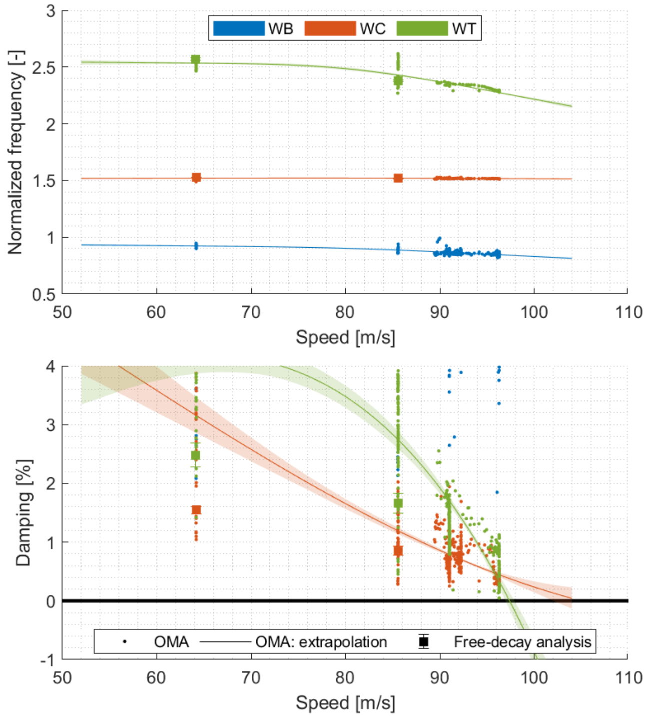
Wing root chord bending / WC excitation



Initial test results

Preliminary flutter results

- Power OFF, downstop **OFF**, conversion mode NR (102%)
- WC mode damping unaffected; WT instability <100 KT
- DLR OMA: dotted markers with solid bootstrap extrapolation (solid lines with 1σ uncertainty bands)
- Excitation amplitude effects comparison identification methods.



P-OFF, DS-OFF, 102%NR

Conclusions

- Further data analysis required, particularly regarding amplitude-dependence and gimbal friction (see upcoming ERF paper).
- Current key take-aways:
  - Combined modal identification using sine sweep OMA and sine dwell free decay analysis proved efficient and robust.
  - Amplitude dependence necessitated maximum allowable excitation; to be correlated with shaker GVTs.
  - Friction/damping in gimbal DOF has substantial impact on whirl flutter stability.

Conclusions

- Current key take-aways:
  - Downstop spring assembly shows significant impact on torsion mode stability.
  - Torsion mode stability not well predicted: further analysis required to identify key deficiencies in modelling and/or experiment.
  - Novel trim-excitation system on cyclic swashplate proved flexible and effective in exciting all fundamental wing-pylon modes.

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