Swept Pazy Post-Flutter and LCO

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TECHNION
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Aeroelasticity
LAB

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- LCO
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- Response to initial conditions

$S20$ $S10$ $Pazy$

Tested Configurations

Both S10 and S20 models were tested with LE and TE wingtip mass to modify the mode coupling.

In the TE configuration a **hard** flutter mechanism was encountered

In the LE configuration the flutter mechanism was a **hump** flutter mode, like the Pazy.

TE configuration

LE configuration

Post-Flutter

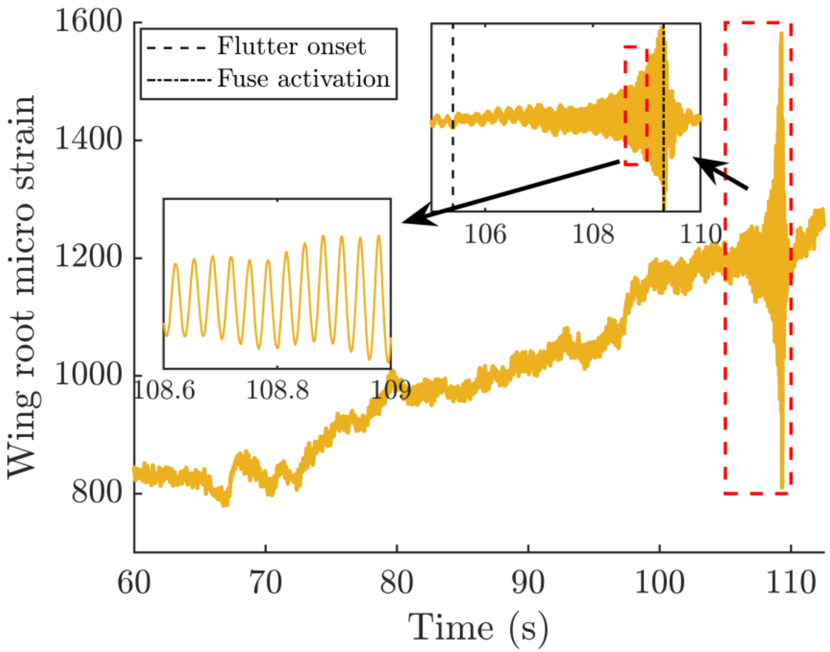
- Over 30 post-flutter events were recorded
- Most post-flutters lasted a few seconds and stopped due to the mechanical fuse activation, preventing LCO.

Slow motion of a post-flutter in the TE configuration

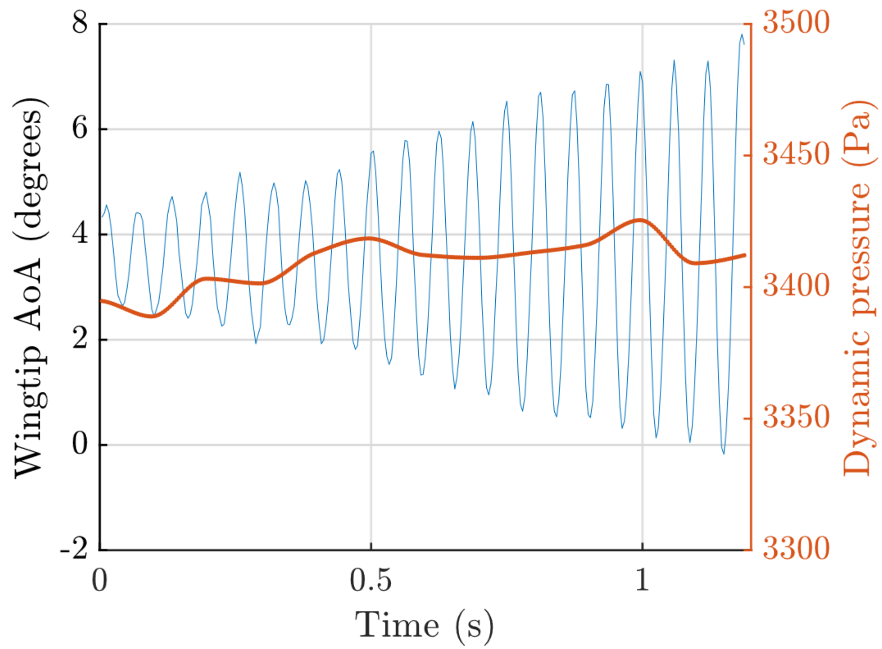
Post-Flutter

During post-flutter strains and displacement data were obtained cleanly

Wing root strains during a representative post-flutter



Wingtip AoA during a post-flutter



Wingtip AoA did not reach the stall region during the post flutters

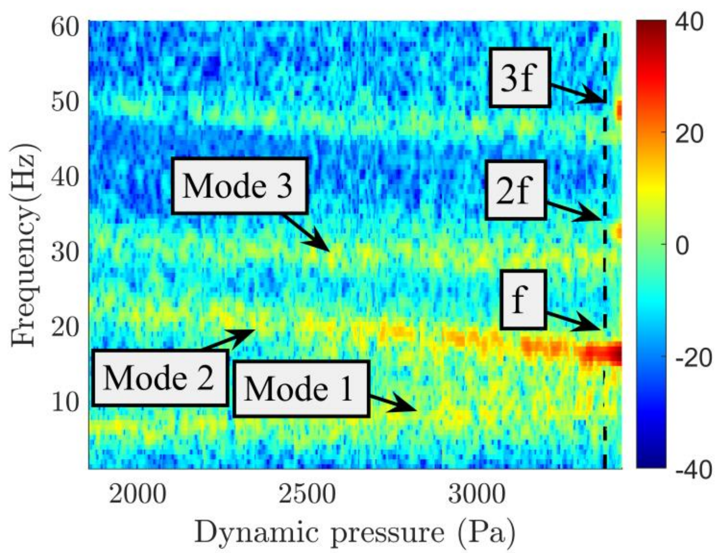
Superharmonic Vibrations

During post-flutter, vibrations in flutter frequency multiples were detected in both configurations, indicating a nonlinear behavior.

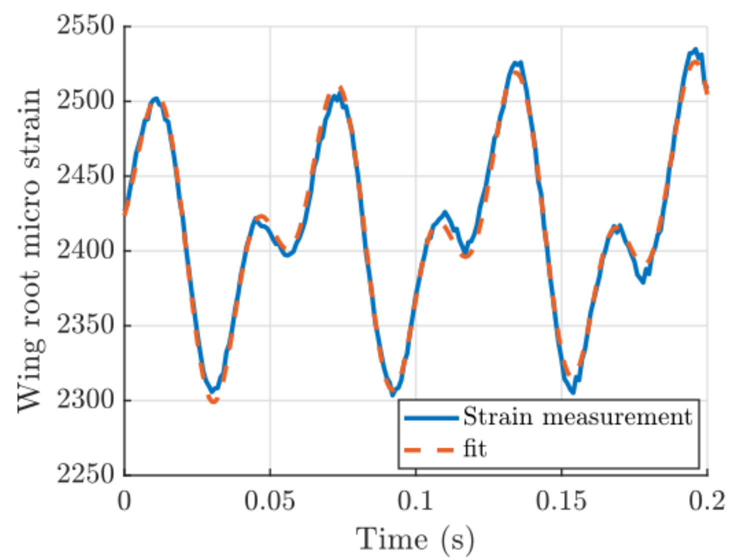
Superharmonic vibrations can increase the damping (structural and aerodynamic).

S10 TE configuration, $\alpha_r = 7°$

Spectrogram



Strains during post-flutter



Strains were fitted to a sinusoidal function of the form $\epsilon = \mathrm{c} + \mathrm{d} \cdot \mathrm{t} + \Sigma_{i=1}^{3} \mathrm{a_i} \sin(2\pi f_i \cdot t + \phi_i)$

f_i converged to the flutter frequency and its second and third harmonics

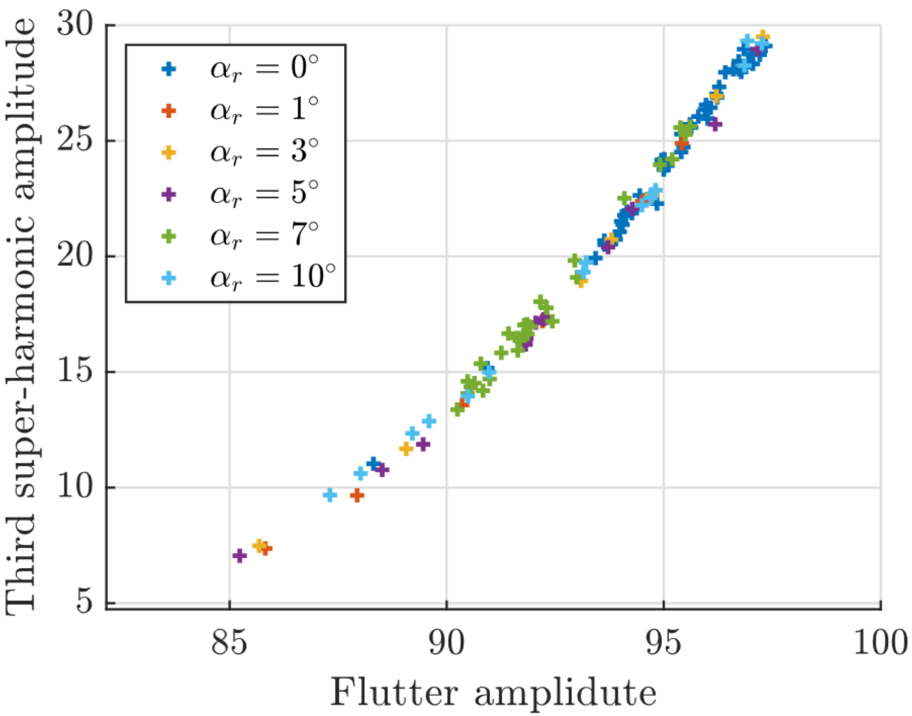
Superharmonic Vibrations

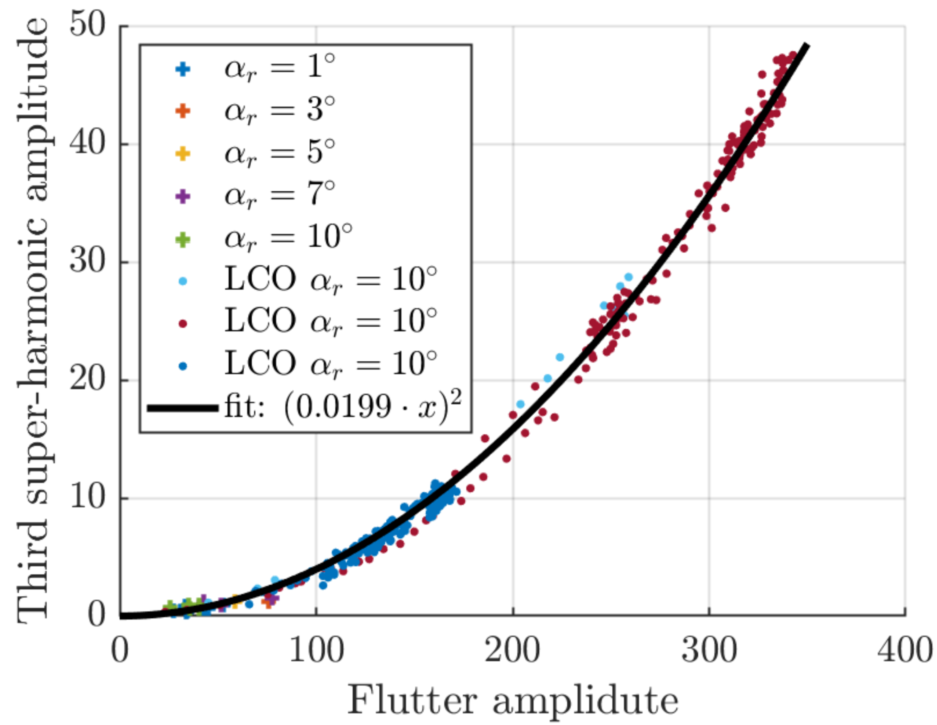
To identify the source of the superharmonic vibrations, wing root strains from each post flutter were segmented into 0.1s windows and fitted to the same sinusoidal function.

This reveals a direct correlation between flutter amplitude and third superharmonic vibration amplitude.

S10 , LE configuration

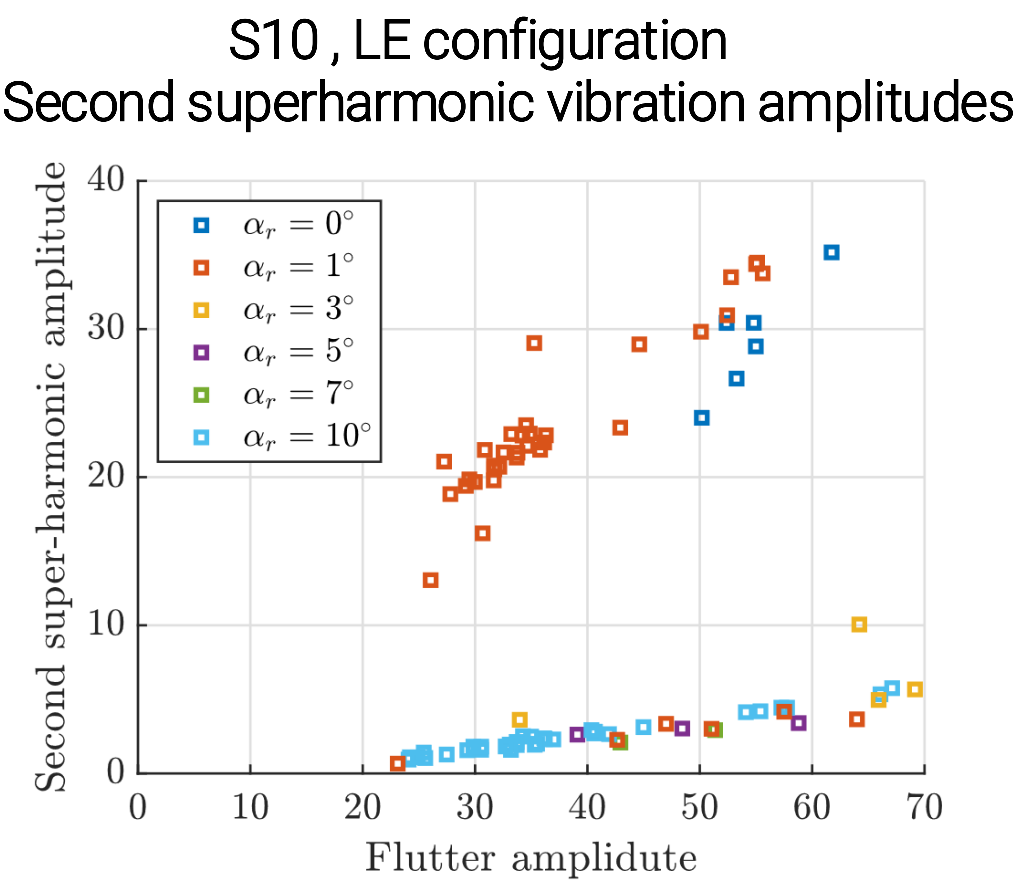
Third superharmonic vibration amplitudes





Superharmonic Vibrations

The second superharmonic amplitude also increased with flutter amplitude but also changed with AoA, suggesting it occurs due to aerodynamic nonlinearity.

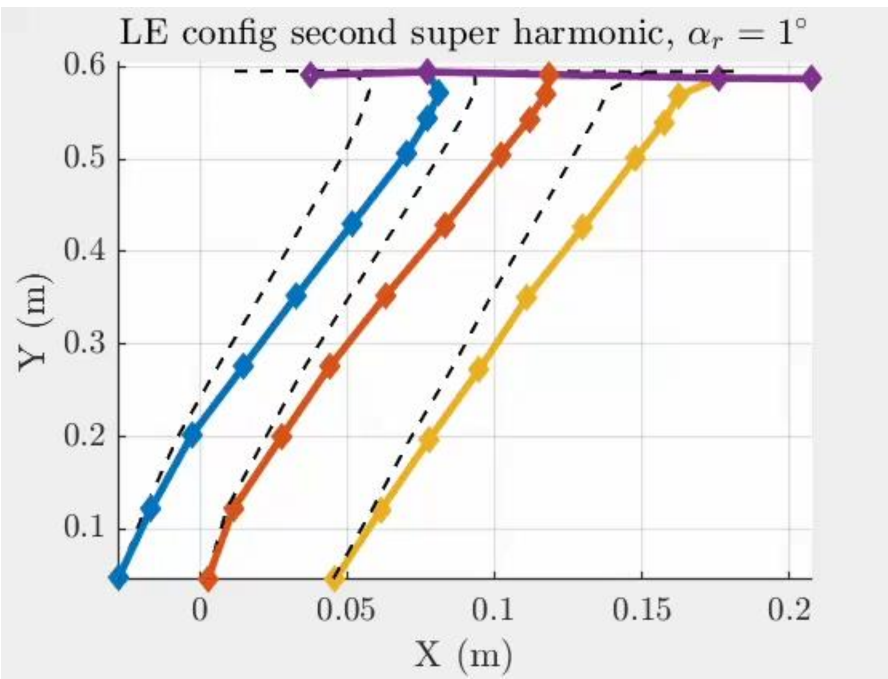


What is the vibration motion in the super harmonic frequencies?

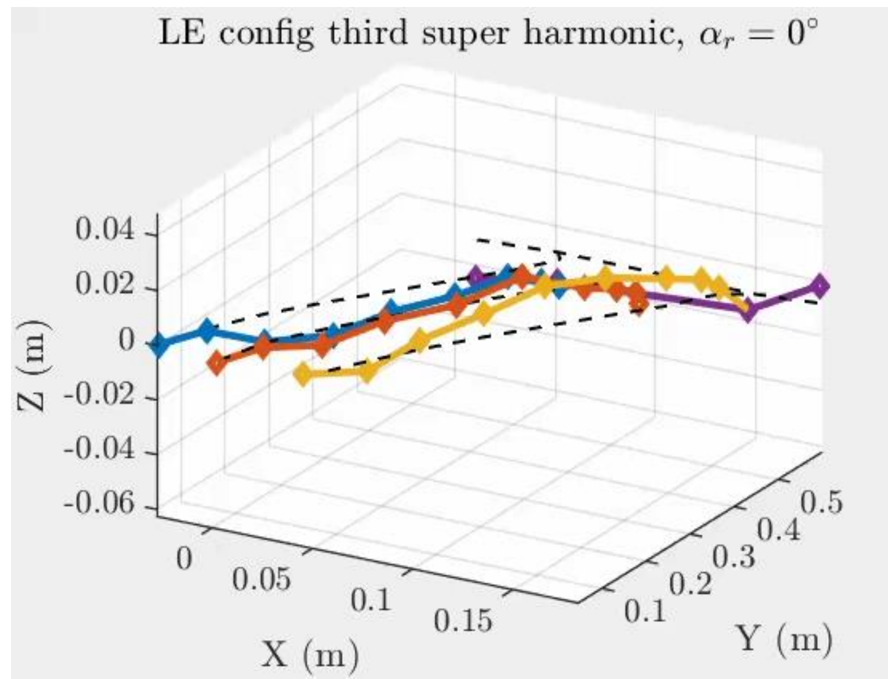
Superharmonic vibrations

The vibrations in the superharmonic frequencies are not in a structural/aerodynamic mode motion. These vibrations were picked up by the motion recovery system in some cases (using Spectral Proper Orthogonal Decomposition).

In the LE configuration, the second superharmonic was in-plane motion, and the third superharmonic was a third bending, first torsion motion.



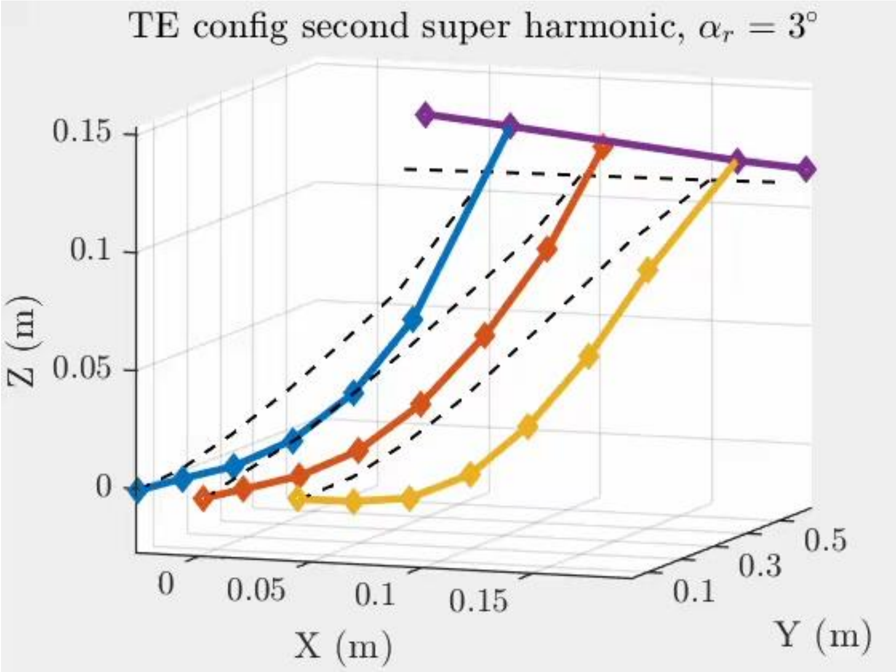
~60 Hz



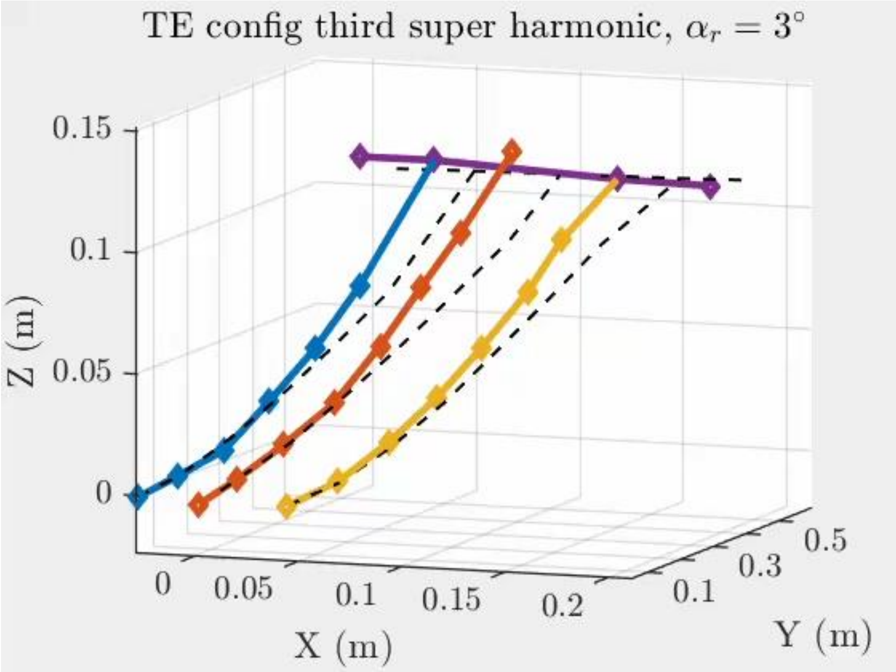
~90 Hz

Superharmonic vibrations

In the TE configuration the second superharmonic was second bending and first torsion, the third SH was not picked up cleanly, but its some combination of IP and torsion



~30 Hz



~45 Hz

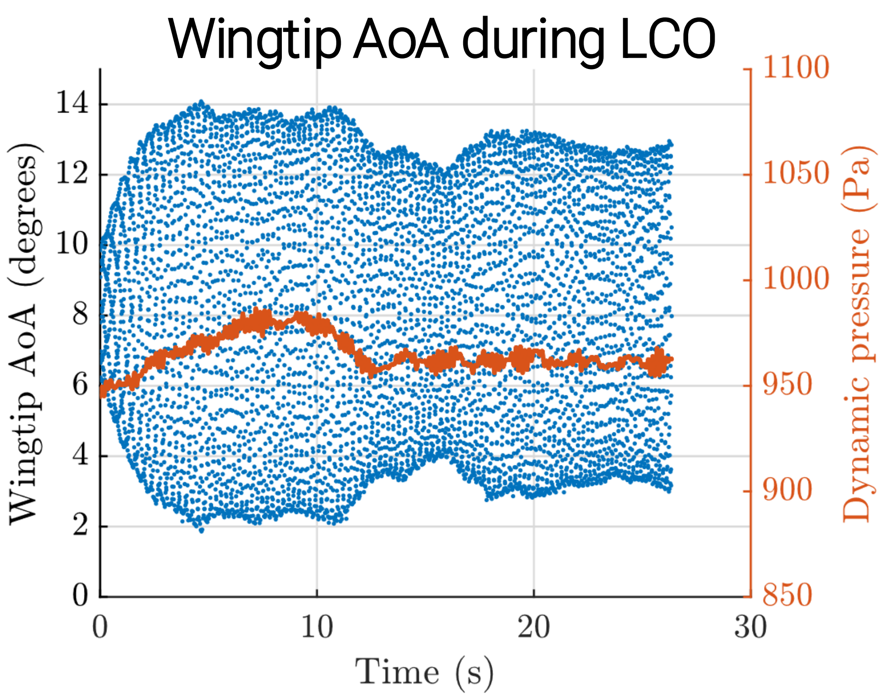
Small Amplitude LCO

LCO tests were preformed in the LE configuration and $\alpha_r = 10°$ with a thicker fuse to enable LCO.

The flutter mechanism was a shallow hump mode which resulted in a low amplitude LCO.

The wingtip AoA oscillated between 3 and 13 degrees at stabilized air speed. Dynamic stall angle at these reduced frequencies (~0.25) is about 20 degrees.

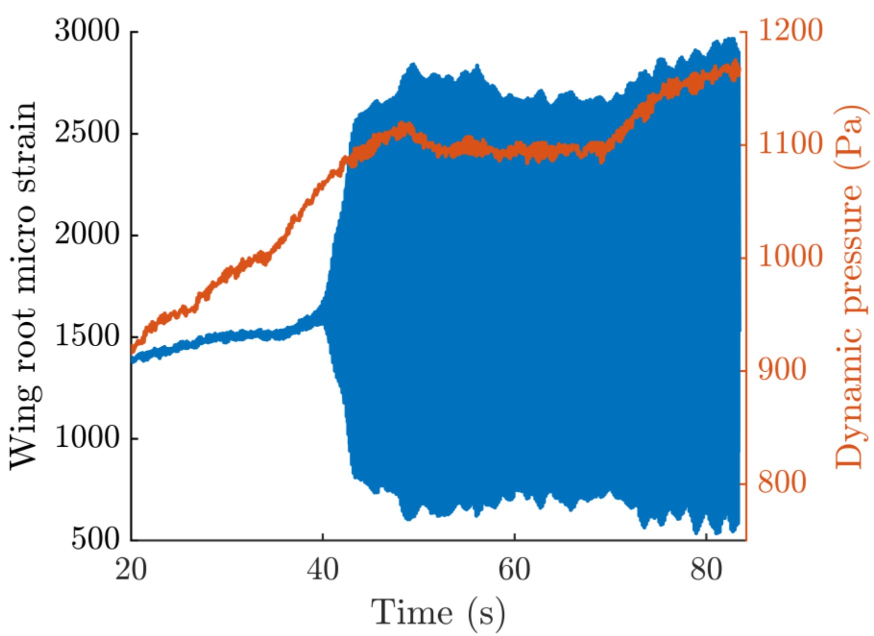
This LCO is suggested to occur due to **nonlinear stiffness and damping**.

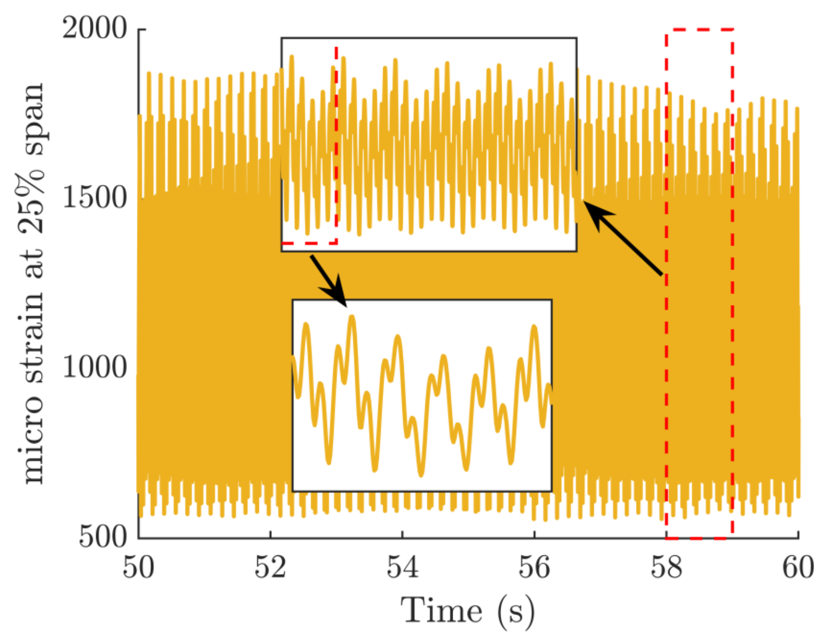


Large Amplitude LCO

Another LCO test was preformed with fixed weights, mounted closer to the LE, resulting in a harder hump flutter mechanism.

- A wingtip AoA measurement was not taken. Strain measurements showed 5 times greater amplitude relative to the small LCO, suggesting wingtip AoA reached about 30 degrees, making this a **stall driven LCO**.
- A dynamic pressure increase caused a further amplitude increase.
- Additional frequencies are observed

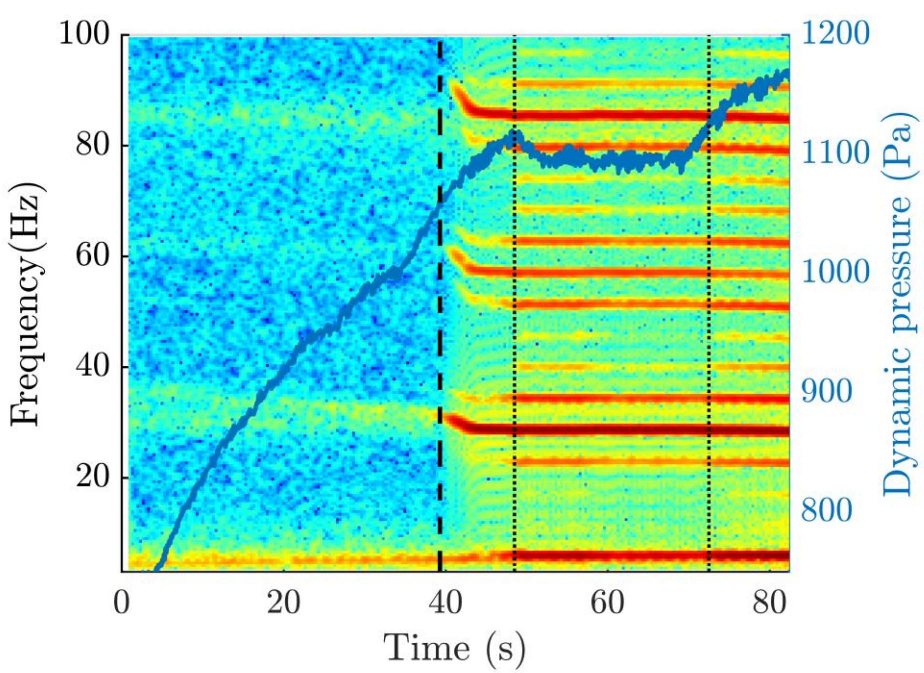


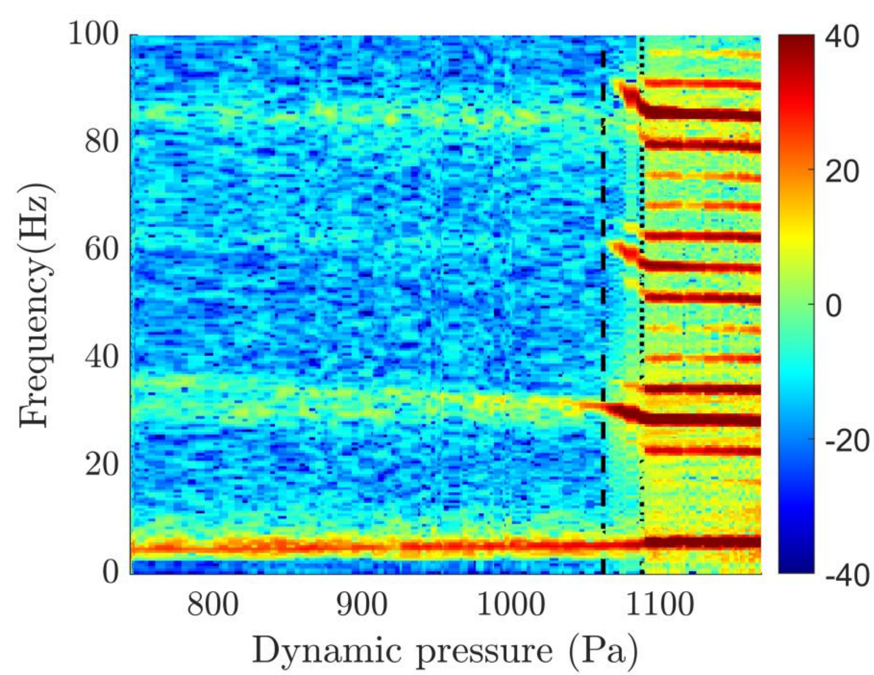


Large Amplitude LCO

Spectrograms show that from a certain dynamic pressure, subharmonics frequencies emerge.

- Flutter onset is marked with a dashed line.
- Subharmonic frequencies “onset” marked with a dotted line
- The subharmonics are in $\frac{f}{5}$ jumps, an uncommon behavior which might help understand underlaying physical mechanism .





Summary

- During post-flutter the wing vibrates in superharmonic frequencies. These vibrations increase with flutter amplitude.
- The superharmonic vibration motions are not in a structural\aerodynamic mode.
- A small amplitude LCO, below dynamic stall might occur due to the superharmonic vibrations.
- During a larger amplitude, stall driven LCO, subharmonic vibrations emerge.

- These results share some similarities to the work of Patil, Hodges and Cesnik – Limit-cycle oscillations in high-aspect-ratio wings
- Future work: analyze the aerodynamic damping of the super harmonics using UVLM.

Questions?

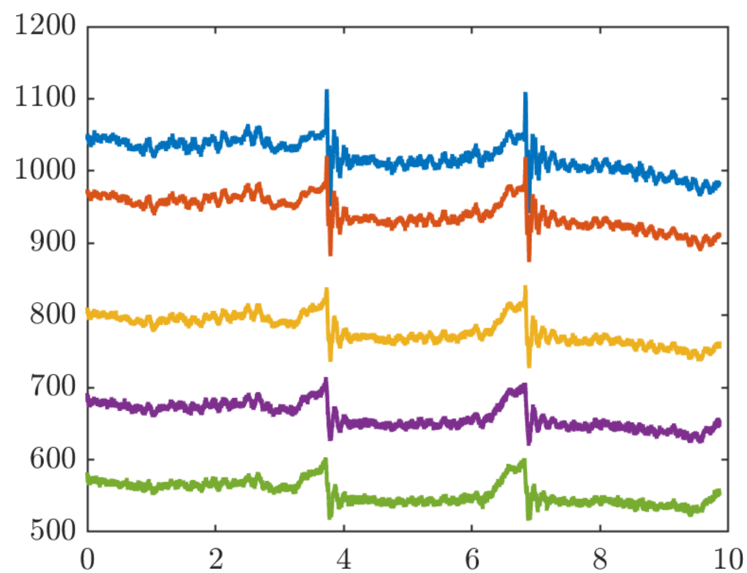
Straight Pazy Update

- To gather additional damping and LCO data the Pazy underwent additional wind tunnel tests.
- During the first LCO test, the wingtip rod decided wind tunnel testing was not exciting enough, so he went for a flight test, never to be seen again..
- A prosthesis rod was made

Response to Initial Conditions

- The S10 model response to initial conditions was measured at different AoAs and airspeeds.
- A loose wire was attached to the wingtip, pulled and released at stabilized airspeed and AoA.

Strains along the LE, $\boldsymbol{\alpha_r = 5^\circ}$, $\boldsymbol{v = 40\ m/s}$



Data

The S10 data is available at https://doi.org/10.5281/zenodo.16912762

The S20 data is available at https://doi.org/10.5281/zenodo.16354529

S20 NASTRAN models are available, S10 models will be uploaded soon.