How Electrification has Changed Aircraft Testing

Mitch Marks and Doug Lovelace

Presenters

- Mitch Marks
  - BSEE, MSEE – University of Wisconsin – WEMPEC
  - Joined HBM in 2017 (became HBK)
  - Business Development – Electrification
  - Previous experience:
    - Motor manufacturing
    - Controls
    - Traction motor testing

- Doug Lovelace
  - BSME – U.C.
  - Joined Bruel & Kjaer Sound & Vibration in 2005 (became HBK)
  - Business Development Manager – Sound & Vibration
  - Previous experience:
    - Consulting Services - Test Engineer
    - Application Engineer

UNRESTRICTED

HBK
HOTTINGER BRÜEL & KJÆR

Agenda

1. Challenges in testing electrical aircraft propulsion systems
   - Sources of structural excitation
2. Structural concerns with electric and hybrid aircraft
   - What is “Flutter”
   - Closer look at real data
     - Electric Motor Data
     - Modal Data
3. The real reason why we care about flutter
   - Classical Flutter video
   - Whirl Flutter video
4. HBK solutions

UNRESTRICTED

New Propulsion Technology Introduces New Problems

- Many motors
- High voltage
- Inverter driven
  - High frequency electrical signals
  - Higher phase counts and complexity
- Lightweight motors
  - Low inductance
  - Current ripple
- Torque ripple
  - Torsional vibrations from motor and currents
  - Can cause bending moments in propellers

Tilt-lift

DEP Tilt-lift

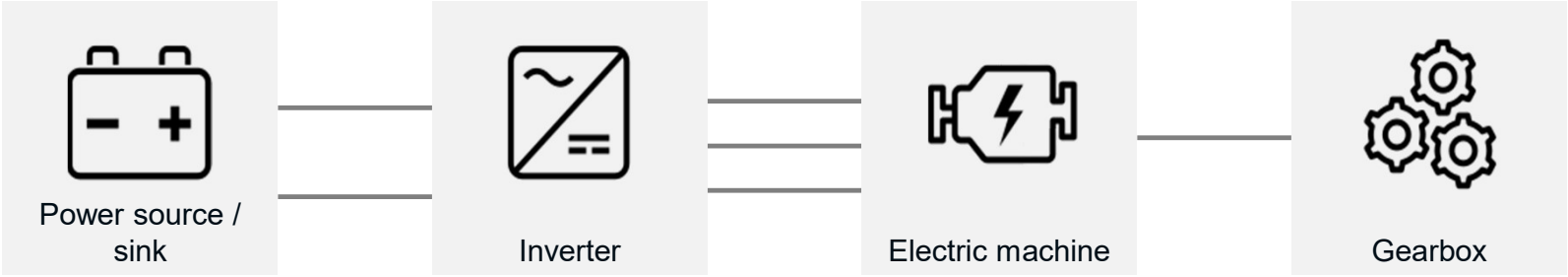
Multirotor

DEP Fixed Wing

HBK
HOTTINGER BRÜEL & KJÆR

UNRESTRICTED

Engineering Trade-offs for Electric Aircraft

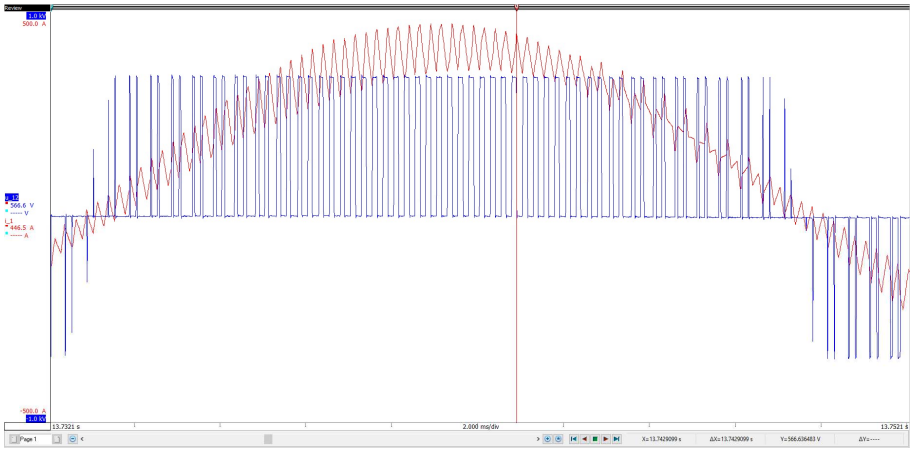


Tradeoff 1		Tradeoff 2
Direct Drive	Vs	Gearbox
Switching Frequency	Vs	Efficiency
Motor Weight	Vs	Torsional Vibrations
Efficiency	Vs	Vibration

UNRESTRICTED

Excitation Causes Electrical Harmonics

- Inverter PWM output is a square wave
- PWM output introduces harmonics
- Motor acts as filter to remove many of them
- Low inductance machines filter fewer harmonics
- Current ripple is reflected in mechanical torque

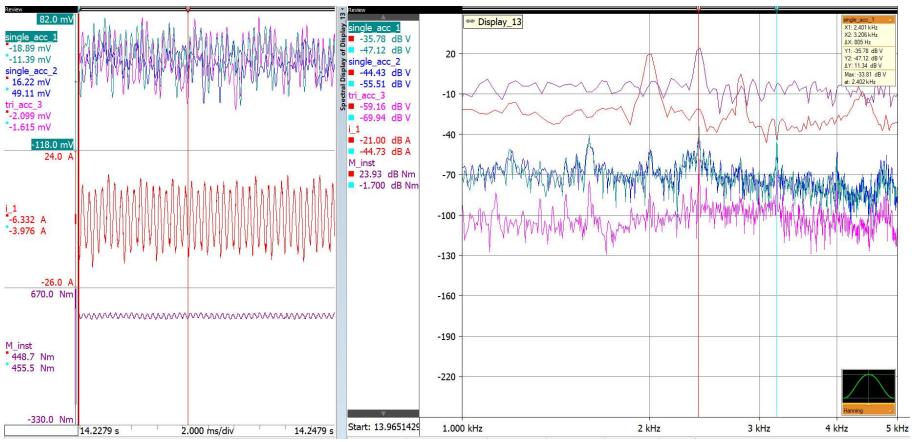


Motor Construction Effects Electrical Harmonics

UNRESTRICTED

Electrical Harmonics Cause Vibrations

- High frequency electrical becomes high frequency torque & vibration
- Magnetics have torsional and radial forces
- Inverters causes torque ripple & vibrations



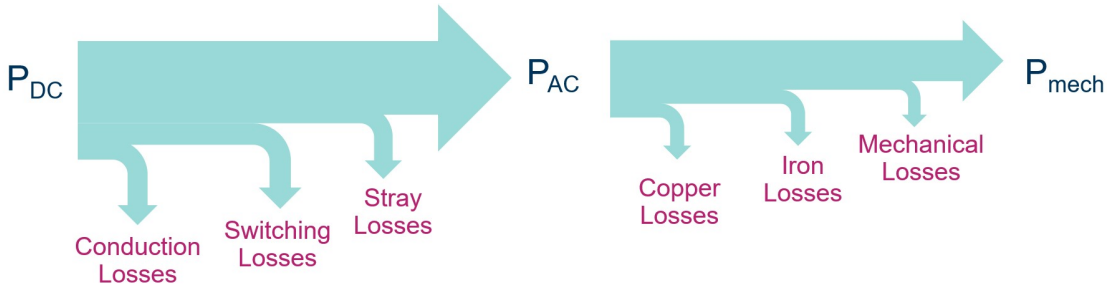
There are Tradeoffs Between Inverter Operation and Mechanical Implications

HBK HOTTINGER BRÜEL & KJÆR

UNRESTRICTED

How to Minimize Electrical Harmonics

- Higher inductance machines add weight
- Line filters (capacitors and inductors) add weight
- Higher switching frequencies add losses
- Active control adds losses



Range and Weight are Tradeoffs with Vibration

UNRESTRICTED

Testing Needs for New Electric Propulsion Methods

VALIDATION FOR FLIGHT AND FUNCTIONALITY

Efficiency measurements for Motors and inverters

Motor/inverter control evaluations

Failure testing

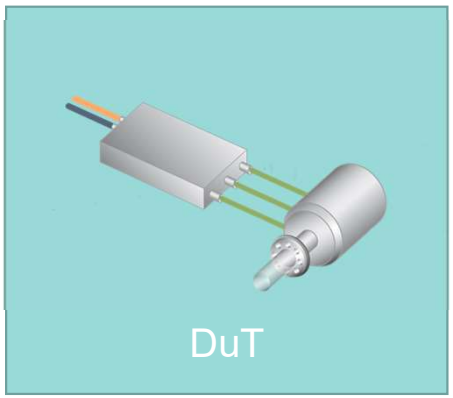
Durability

Electrical system evaluation

Vibration evaluation

https://www.nasa.gov/subject/7564/green-aviation/

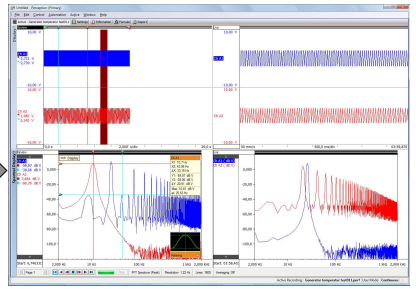
Electric Powertrain and NVH Testing



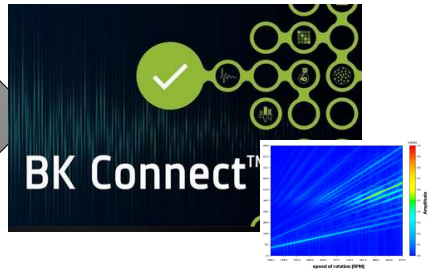
Voltage
Current
AND
Acceleration

ALL
synchronously and
continuously
recorded with eDrive

Time domain and
FFT display
in Perception



PNRF



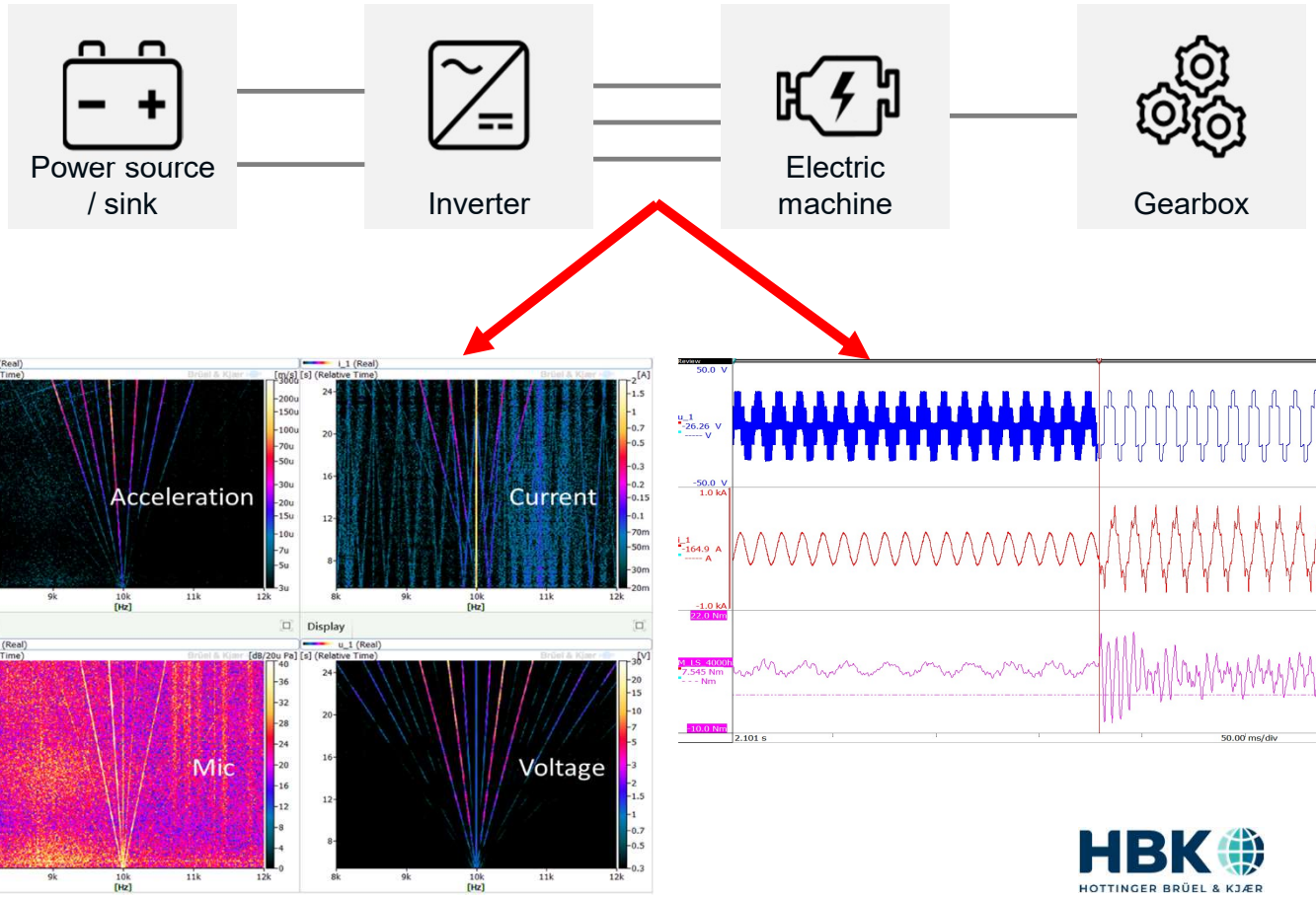
Post process analysis in
BKconnect through new
PNRF import

All signals can be simultaneously measured for a variety of tests

UNRESTRICTED

Electromechanical Testing Simplifies Testing for Many Needs

- Time aligned data allows system level analysis
  - Frequency domain
  - Time domain
- Streamline validations with one test
  - Efficiency
  - Sound and vibration
  - Control and calibration
- Data can be used by many groups
  - Simulation
  - Structures



UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

Tilt-lift

DEP Tilt-lift

Multirotor

DEP Fixed Wing

UNRESTRICTED

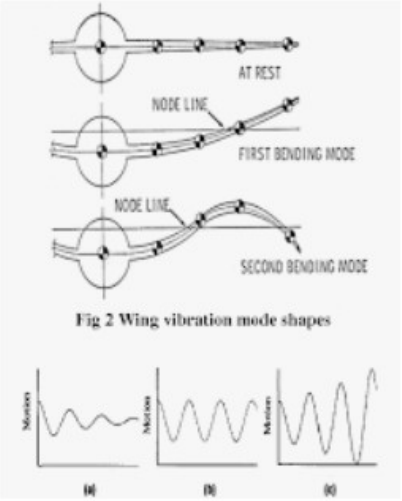
Structural Concerns with Electric and Hybrid Aircraft

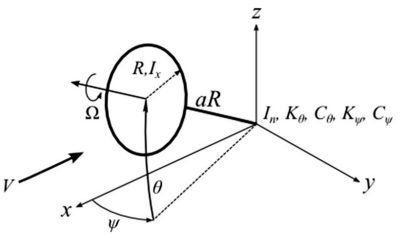
What is Flutter?

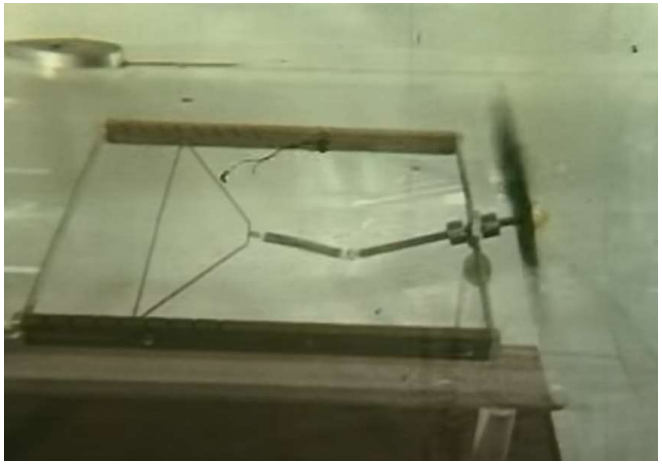
There are two main types of flutter, classical flutter, and whirl flutter. Classical flutter is an instability due to an interaction between aerodynamic, inertial, and elastic forces. Where whirl flutter is a special case involving the stiffness of the supporting nacelle structure and the aerodynamic and inertial effects of a rotating propeller.

Classical flutter is sensitive to the construction of the aircraft, where the response of flutter comes from the oscillation of the wings and various control surfaces. These oscillations can be in the form of bending and/or torsion of fixed surfaces like the wings and fuselage along with torsion and/or rotation of the control surfaces like ailerons, rudder, flaps and elevator.

Whirl flutter is sensitive to the structural damping and the stiffness between the attachment of the motor to the wing. This type of flutter instability becomes more critical when its frequencies align with the structural modes of the aircraft.



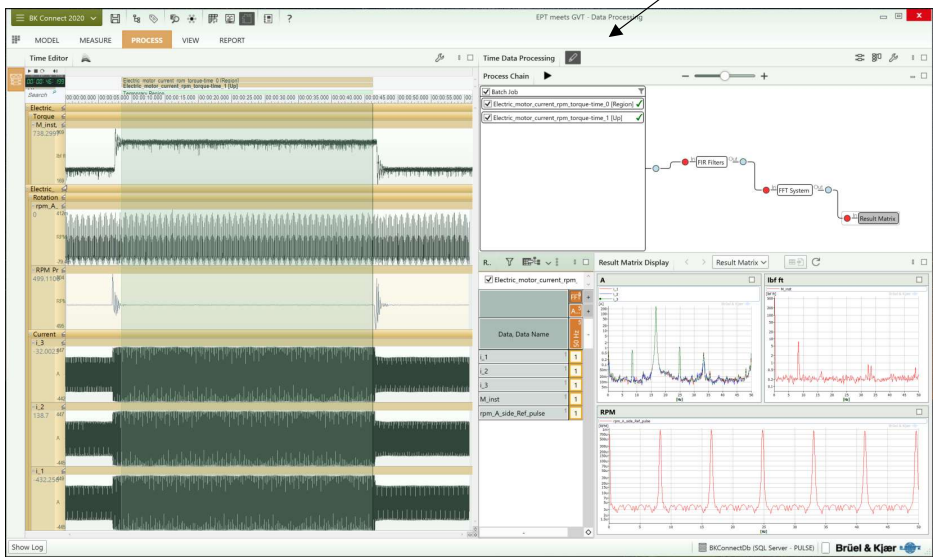




UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

- How this……can cause this



UNRESTRICTED

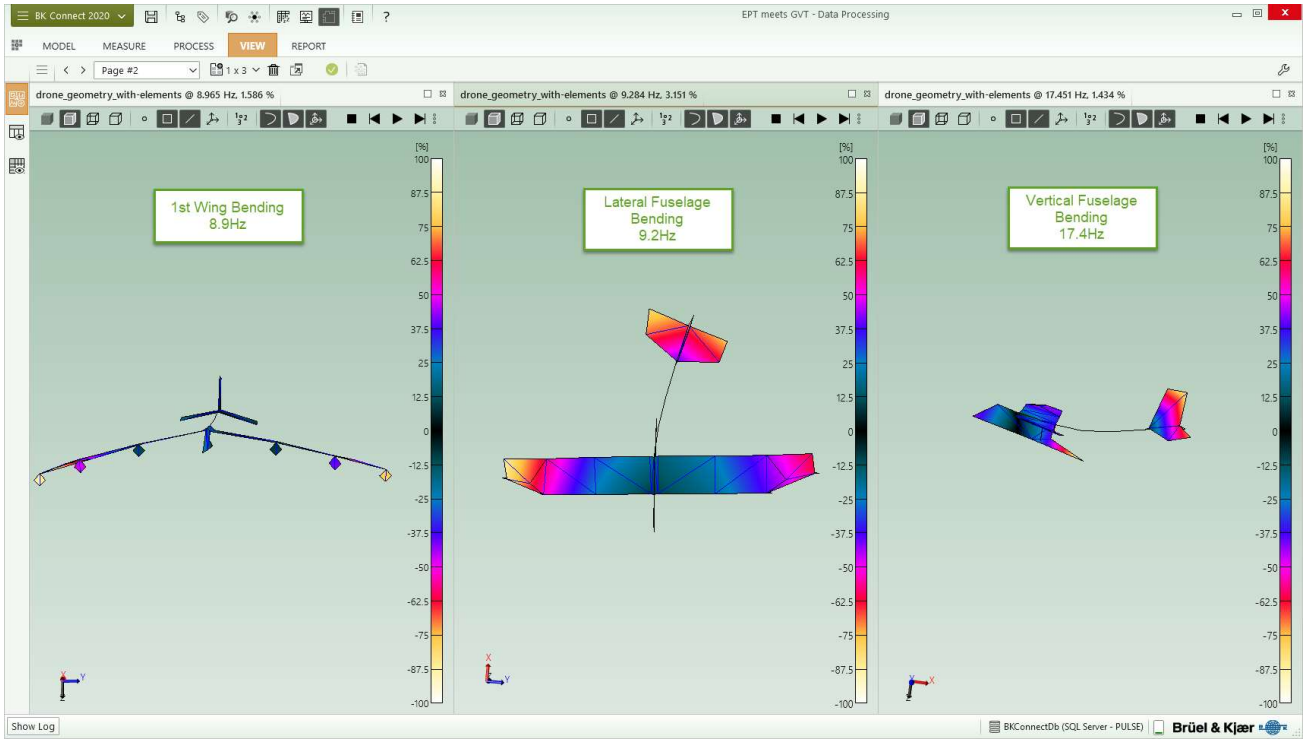
Structural Concerns with Electric and Hybrid Aircraft

- Torque Ripple
  - As you can see in the time domain of the torque signal, there is a dynamic signal (torque ripple) riding on top of the static torque
  - As you can see in the frequency domain of the torque, the frequency of the “torque ripple” is ~8.3Hz

UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

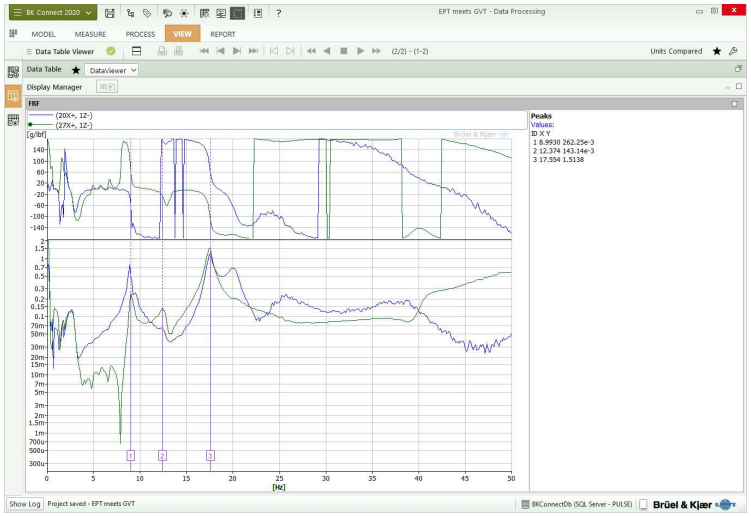
- Various Bending modes of the Drone
  - 1st Wing Bending (8.9Hz)
  - Lateral Fuselage Bending (9.2Hz)
  - Vertical Fuselage Bending (17.4Hz)

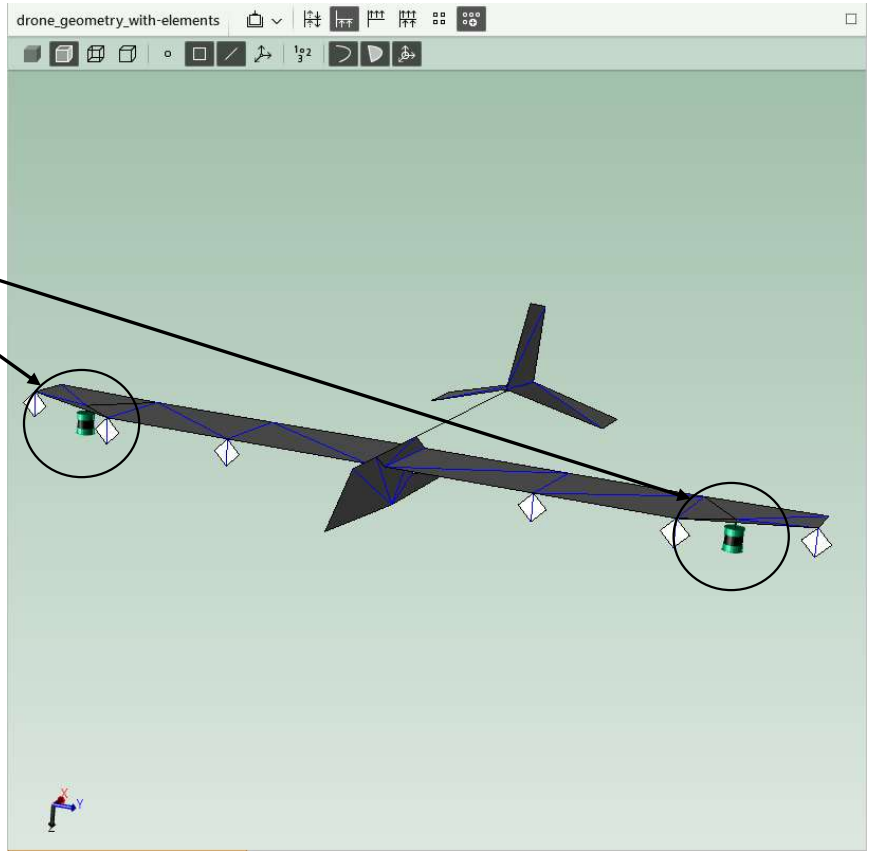


UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

- Drone GVT
  - Drone GVT was done with two electro-mechanical shakers where Random Excitation was used to excite the modes of interest

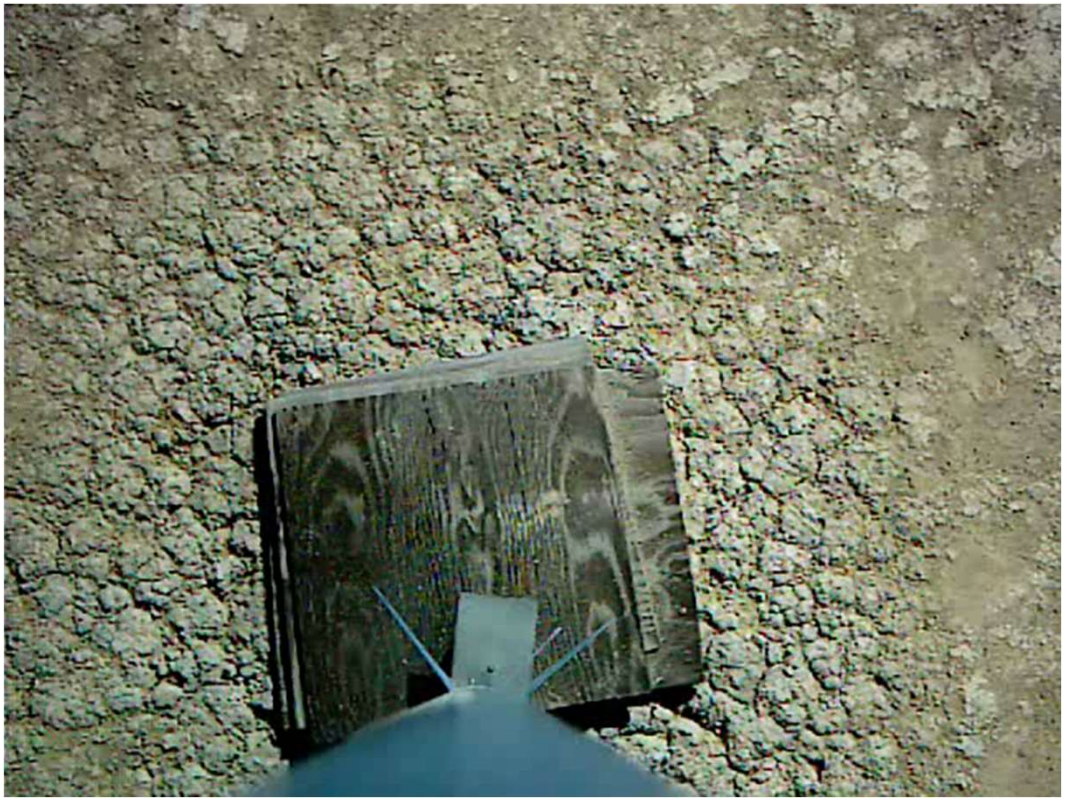




UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

- Flutter
  - Classical Flutter Video



UNRESTRICTED

Structural Concerns with Electric and Hybrid Aircraft

- Flutter
  - Whirl Flutter Video

UNRESTRICTED

Thank You

Mitch Marks
Business Development
Electrification
HBK
mitchell.marks@hbkworld.com

Doug Lovelace
Business Development
Sound & Vibration
HBK
doug.lovelace@hbkworld.com

www.hbkworld.com | © HBK – Hottinger, Brüel & Kjær | All rights reserved