Multipropeller Whirl Flutter Stability Study using Component Mode Synthesis Element

Kyle Nelson **Jinwei Shen**
The University of Alabama, Tuscaloosa, Alabama 35401

Carol Wieseman **Josiah Waite**
NASA Langley Research Center, Hampton, Virginia 23681

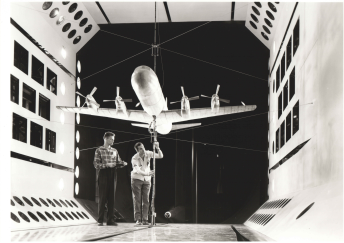
January 25th, 2023

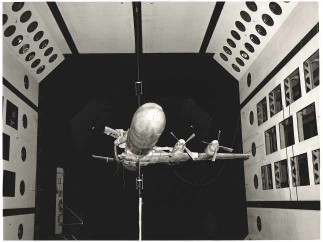
2023 AIAA SciTech Conference

Overview

Whirl Flutter

This aeroelastic instability is caused by the propeller aerodynamics, which drives the airframe/pylon motion to become unstable[1].


2



Electra

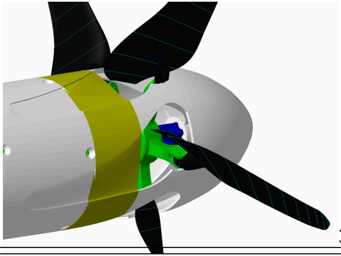
Fatal accidents of the Electra aircraft in the 1960s.
Structural failure that weakened the stiffness in the pylon mount.

[1] E. S. Taylor and K. A. Browne 1938J. Aero Sci. 6, no. 2,43. Vibration isolation of aircraft power plants.
[2] Houbolt,J.C., and ReedIII, W.H., Propeller-Nacelle Whirl Flutter, 1961.

X-57 Maxwell

Parameters

- All Electric
- 14 Propellers
  - 2 Large Outboard
  - 12 Small Inboard
- Thin, Highly Efficient Wings


[3]

Property	Value
Critical Takeoff Speed (kts)	58
Cruise Speed (kts)	150
Nacelle Length (ft)	1.9
Number of Blades	5
Propeller Diameter (ft)	1.9
Aircraft Weight (lbs)	$\approx 3,000$

[3] Litherland, B. L., Patterson, M. D., Derlaga, J. M., and Borer, N. K., "A Method for Designing Conforming Folding Propellers," 17th AIAA Aviation Technology, Integration, and Operations Conference, May 2017.

Multibody Dynamics Analysis: Dymore

Nonlinear Flexible Multibody Dynamics

- Element library includes rigid and deformable bodies and joint elements
- Deformable bodies are modeled as finite elements; beams and shells are geometrically exact
- Aerodynamics calculated using built-in lifting line theory or coupled with external aerodynamics code

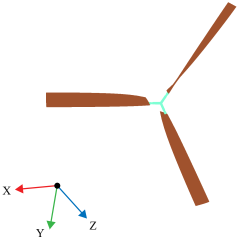
Solution Method

Use of Lagrangian multipliers to model constraints leads to system of differential-algebraic equations solved by robust time marching scheme

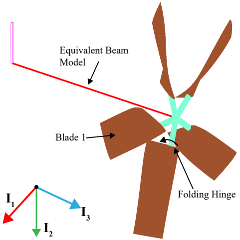
Model Excitation

Whirl flutter: a harmonic deadload is used to excite each individual mode and the transient response is recorded.

Dymore Propeller Model



(a) Dymore Tip Propeller Model



(b) Dymore High-Lift Propeller Model

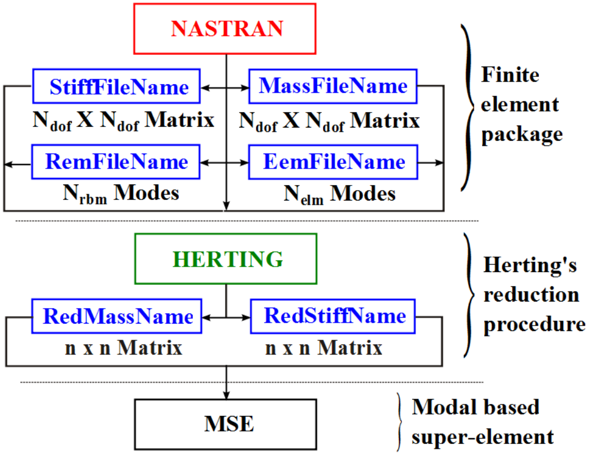
Structure

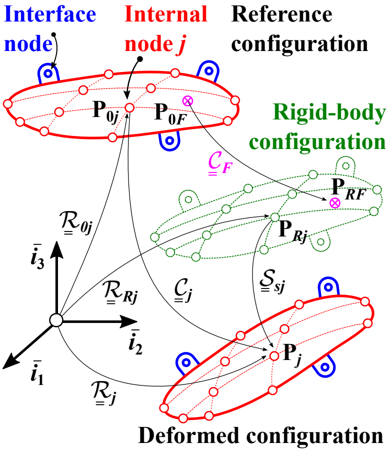
- Beams: blades.
- Rigid bodies: connection to MSE.
- Pitch revolute joint.
- No structural damping is included.

Aerodynamics

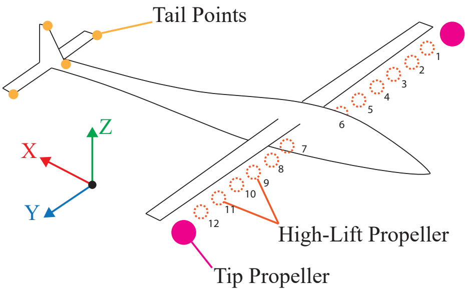
- Lifting line aerodynamics on rotor blades only.
- Uniform inflow model.

Herting Modal Reduction Algorithm





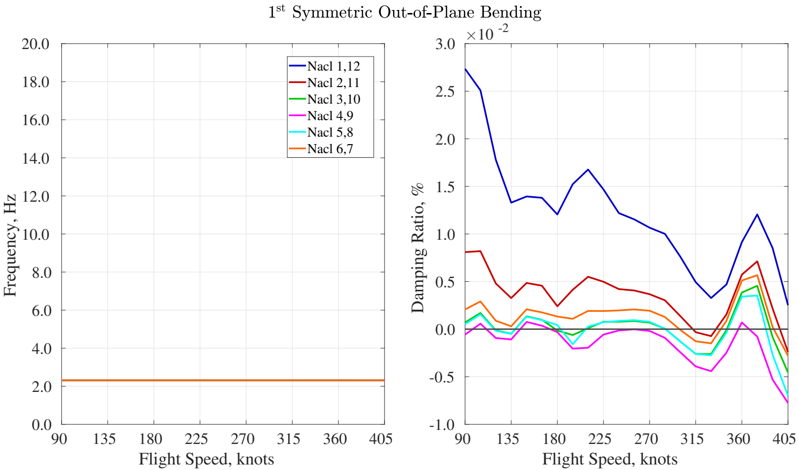
Dymore Model - Modal Super Element Model



- Reduced order modeling techniques provide smaller representations of large complex mechanical systems
- Dymore relies on reduced matrices from the "mode-acceleration method"
- Interface and internal nodes are used with the internal nodes through modal-reduction
- No structural damping is included

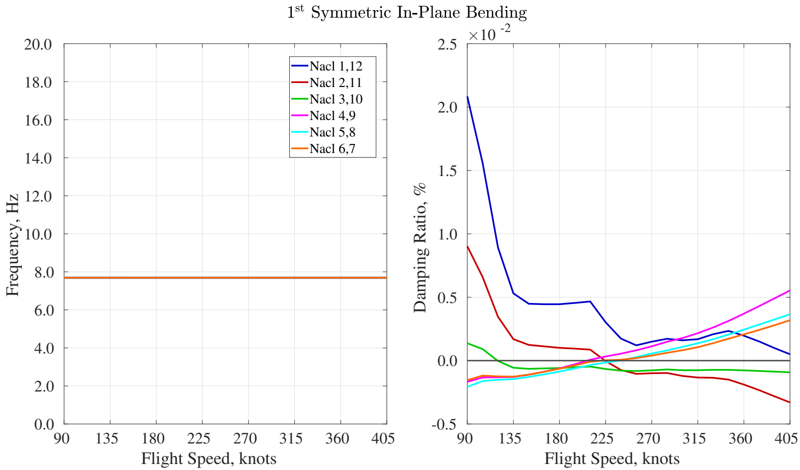
Mode	7	8	9	10	11	12	13	14	15
NASTRAN	3.04	5.67	6.97	9.92	11.44	12.05	13.70	14.16	15.61
MSE	3.05	5.72	7.06	10.01	11.50	12.37	13.96	14.45	16.06

High-Lift Propeller Whirl Flutter Sensitivity Study



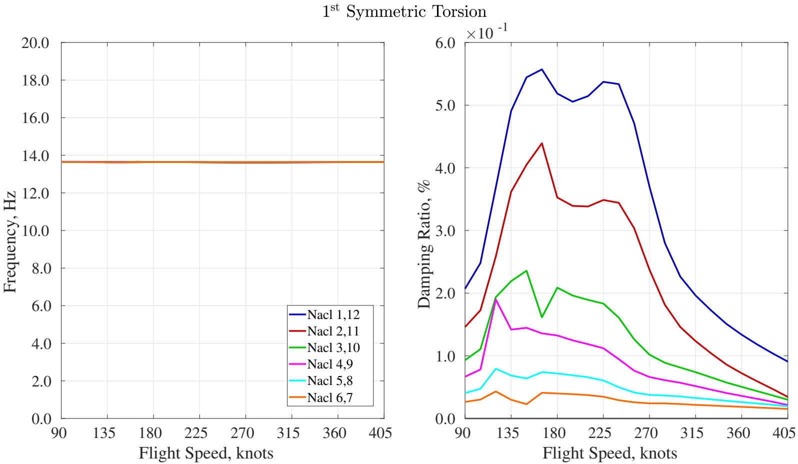
All of the damping is very low. The nacelle pairs at grid 4 and 9 have a consistently unstable response for the velocity range simulated. No structural damping is included.

High-Lift Propeller Whirl Flutter Sensitivity Study



The outboard pairs have the highest damping at low speed. The inboard pairs have a gradual increase in damping with flight speed.

High-Lift Propeller Whirl Flutter Sensitivity Study

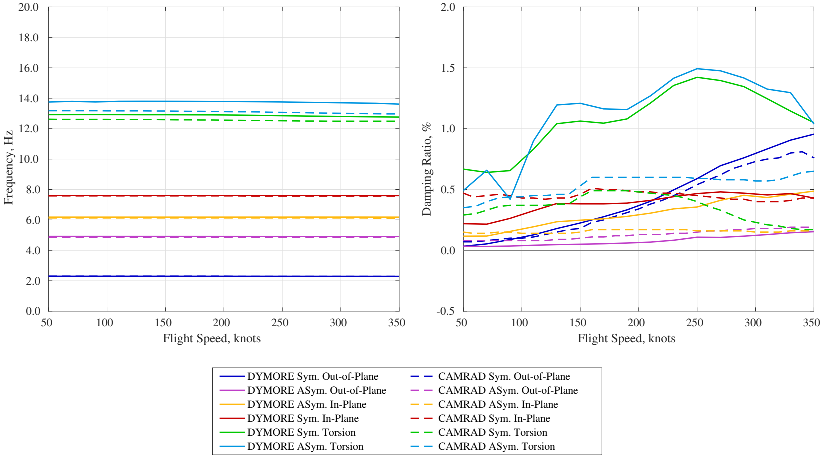


The response to torsional stability is heavily influenced by propeller location. High-lift propellers moving outboard from the fuselage have greater damping.

X-57 Mod 4 14 Propeller Simulation

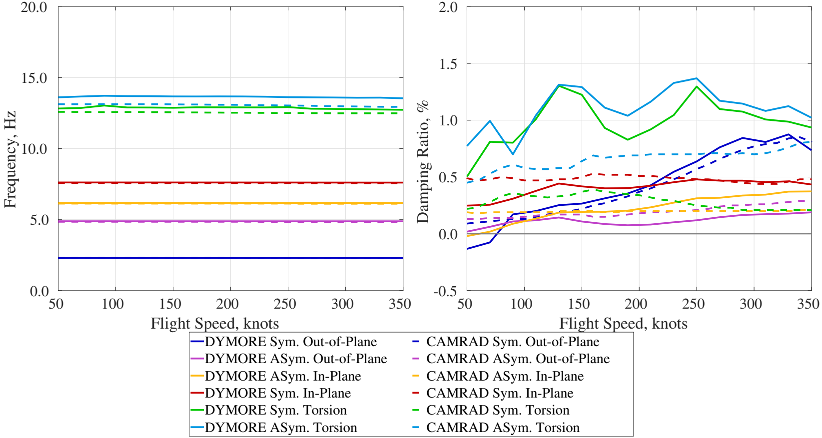
- The Mod 4 X-57 Maxwell model is fully populated with 14 propellers.
- Additional mass is added to the high-lift propeller hub, tip propeller hub, and tip propeller motor location.
  - This added mass is for blade mass, extra mass at the hub, and motor masses taken out of the FEM for us by NASA.
- All cases are run at 8,000 ft.
- The tip propeller is held to 2700 RPM and trimmed to a zero thrust condition.
- Overspeed cases are 10% higher RPM from the operational maximum, high-lift propeller 5940 RPM.
- CAMRAD is using a rigid tip propeller blade.

2700 Tip RPM, 0 HLP RPM



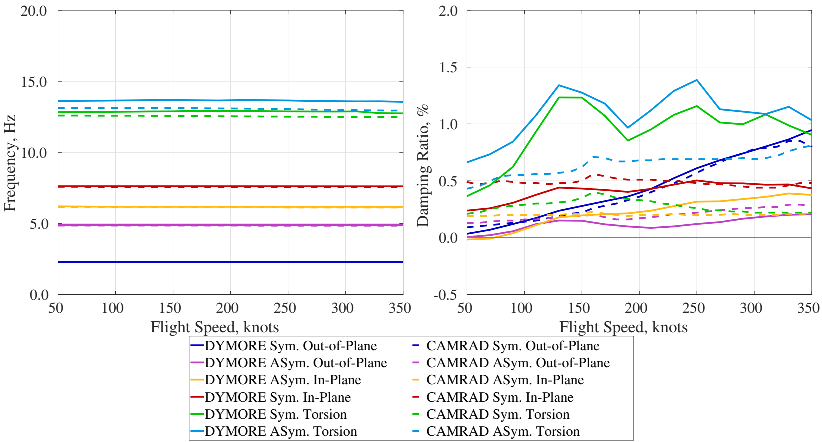
Dymore and CAMRAD have good agreement for the symmetric out of plane bending mode. Dymore estimates greater damping for the antisymmetric modes.

2700 Tip RPM, Scheduled HLP RPM



At low speed, the symmetric out of plane is unstable and the antisymmetric inplane mode is marginally unstable at 50 knots.

2700 Tip RPM, Overspeed HLP RPM



The antisymmetric inplane mode is marginally unstable to 70 knots flight speed.

Summary and Conclusion

- Dymore and CAMRAD are multidynamics codes used to estimate the propeller whirl-flutter stability of the NASA X-57 Maxwell.
- A modal-super-element (MSE) model is used to characterize the mass and stiffness of the NASA X-57 Maxwell in Dymore.
- A parametric study investigated the influence of high-lift propeller pairs on whirl-flutter stability
  - The pair located closest to the wingtips have the greatest contribution, albeit the contribution is small for wing bending.
- The aircraft is simulated with all 14 propellers present and assumes constant tip propeller RPM while varying the high-lift propeller RPM and subjecting the vehicle to increasing flight speeds at constant altitude.
  - Symmetric wing out-of-plane bending is captured well between Dymore and CAMRAD with the high-lift propellers set to zero and overspeed RPM conditions.
  - Dymore predicts marginal low-speed instability with the high-lift propellers in operation.

Acknowledgments

This study is funded by NASA Langley through National Institute of Aerospace:

U.S. Army Combat Capabilities Development Command Army Research Laboratory

Andrew Kreshock

NASA Langley Research Center

Jeffrey Viken and David Piatak

NASA Armstrong Research Center

Keerti Bhamidipati

University of Maryland, College Park

Olivier Bauchau and Matteo Scapolan