Development of an Open-source Flutter Prediction Framework for the Common Research Model Wing

Brandon Crow, Jethro Nagawkar, and Leifur Leifsson

Department of Aerospace Engineering, Iowa State University, Ames, Iowa

Andrew Thelen

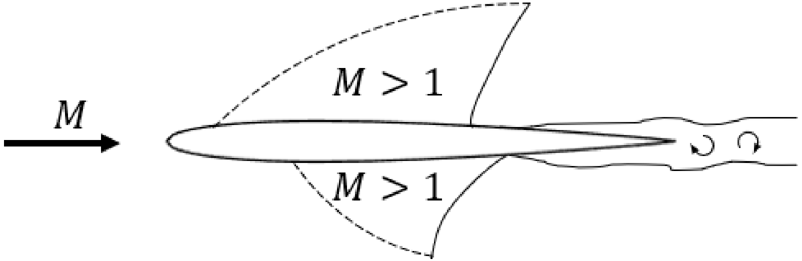
University of Dayton Research Institute, Dayton, Ohio

AIAA SciTech Forum, January 11-15 & 19-21, 2020, Virtual Event

This material is based upon work supported by the Iowa Space Grant Consortium under NASA Award No. NNX16AL88H

Motivation and challenges

- ➢ Flutter prediction is critical for modern transport aircraft



- ➢ Accurate physics-based simulations are needed
- ➢ Systems design requires many evaluations

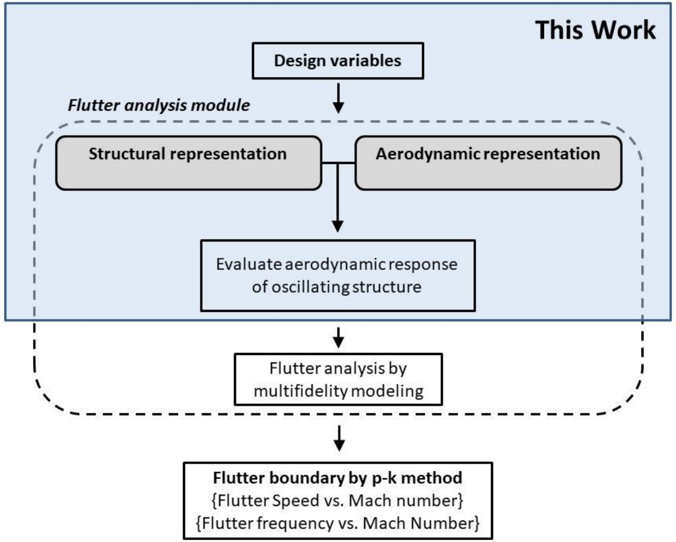
⇒ Fast and accurate models are needed

Objective

Create a fast flutter prediction model for the undeflected common research model (uCRM-13.5) wing

- The uCRM-13.5 is an aeroelastic benchmark case published by the University of Michigan MDO Lab (Brooks et al., 2018)

- The flutter prediction framework by Thelen *et al*. is used, but implemented with open-source software



Structural modeling via MYSTRAN

The structural equations of motion are (Rodden et al., 1979)

$$\boldsymbol{M}\ddot{\boldsymbol{q}} + \boldsymbol{B}\dot{\boldsymbol{q}} + \boldsymbol{K}\boldsymbol{q} = \boldsymbol{f}$$

where $\boldsymbol{M}, \boldsymbol{B}$, and $\boldsymbol{K}$ are the mass, damping, and stiffness matrices, $\boldsymbol{q}$ is displacement and $\boldsymbol{f}$ is force

A modal analysis gives the mode shape matrix, $\boldsymbol{\Phi}$

The generalized structural equations of motion become

$$\boldsymbol{\Phi}^{\mathrm{T}}\boldsymbol{M}\boldsymbol{\Phi}\ddot{\boldsymbol{\eta}} + \boldsymbol{\Phi}^{\mathrm{T}}\boldsymbol{B}\boldsymbol{\Phi}\dot{\boldsymbol{\eta}} + \boldsymbol{\Phi}^{\mathrm{T}}\boldsymbol{K}\boldsymbol{\Phi}\boldsymbol{\eta} = \boldsymbol{\Phi}^{\mathrm{T}}\boldsymbol{f}$$

$$\overline{\boldsymbol{M}}\ddot{\boldsymbol{\eta}} + \overline{\boldsymbol{B}}\dot{\boldsymbol{\eta}} + \overline{\boldsymbol{K}}\boldsymbol{\eta} = \boldsymbol{F}$$

Structural modeling via MYSTRAN

If generalized forces are linear functions of displacement and dynamic pressure, q, then

$$\boldsymbol{F} = q\boldsymbol{Q}\boldsymbol{\eta}$$

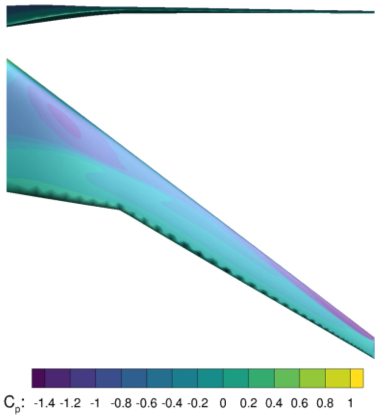
where $\boldsymbol{Q}$ is the generalized aerodynamic influence coefficient (GAIC) matrix. $\boldsymbol{Q}$ is, in general, a function of reduced frequency $k = \frac{\omega\bar{c}}{2V}$

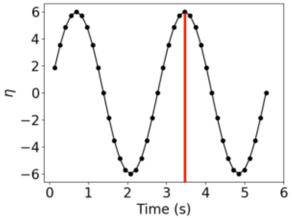
- $\boldsymbol{Q}(k) = \frac{\boldsymbol{F}}{q\boldsymbol{\eta}}$ can be computed from accurate CFD simulations
- $\boldsymbol{Q}(k)$ is used to predict flutter

Aerodynamic modeling via SU2

The aerodynamic modeling begins by picking a reduced frequency (k). Then, for each mode:

1. Harmonic motion is simulated at a frequency $\omega = \frac{2Vk}{\bar{c}}$
2. Pressure forces are extracted
3. Pressure integration can be used to compute the generalized force



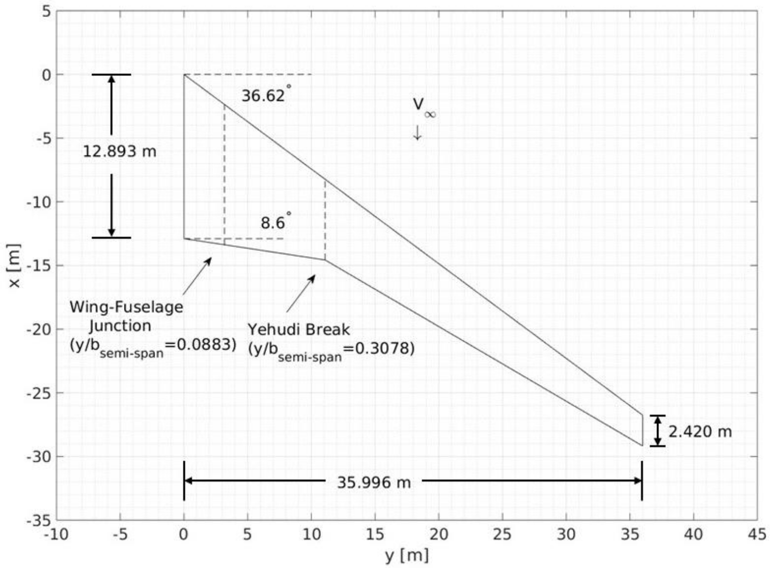


uCRM-13.5 Mode 1
$(k = 0.05)$

uCRM-13.5 wing: case description

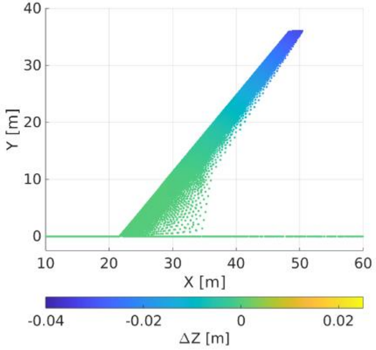
The uCRM-13.5 is a general benchmark case for current and future transport aircraft

- Altitude: 37,000 ft
- $M = 0.85$
- $k = 0.05$

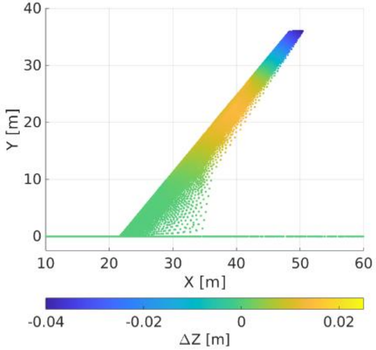


SHAPING THE FUTURE OF AEROSPACE

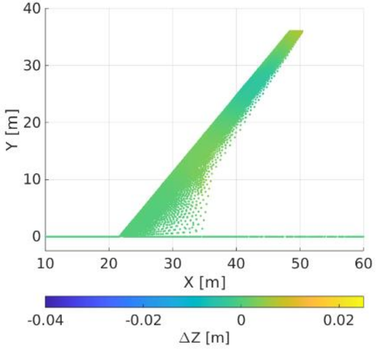
uCRM-13.5: predicted structural modes



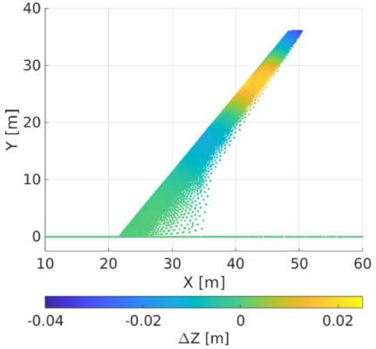
a) Mode 1



b) Mode 2

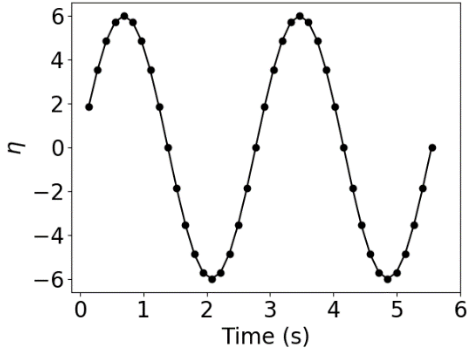


c) Mode 3



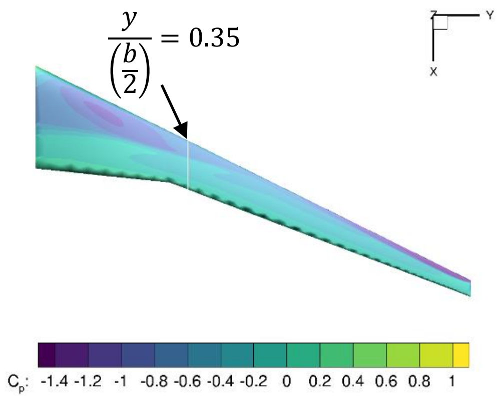
d) Mode 4

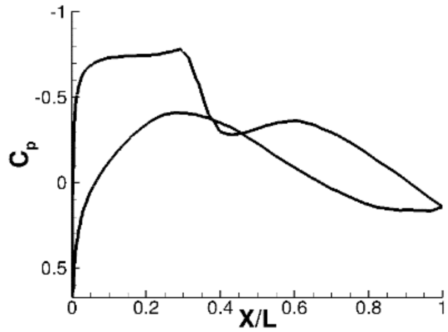
Mode	Predicted Natural Frequency (Hz)
Mode 1	0.505
Mode 2	1.6698
Mode 3	2.773
Mode 4	3.843



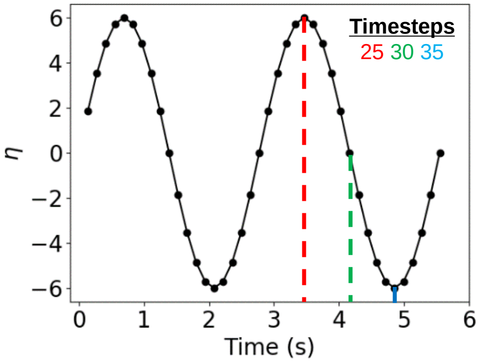
e) Mode scaling function

uCRM-13.5: C_p contours

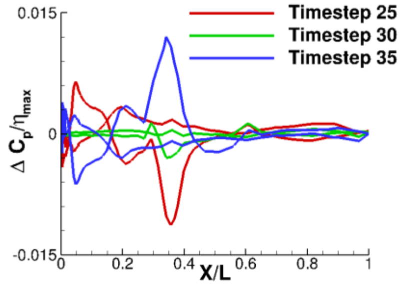




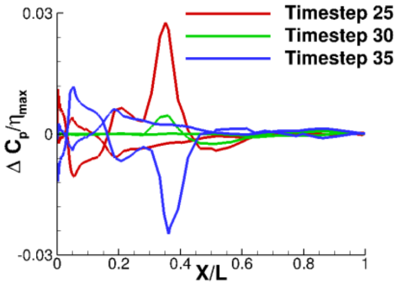
a) Steady State



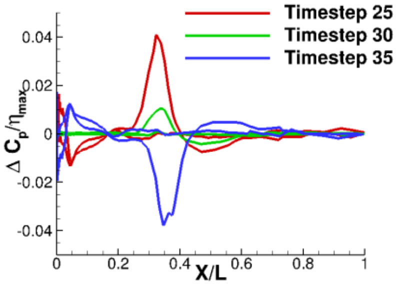
b) Mode Scaling Function



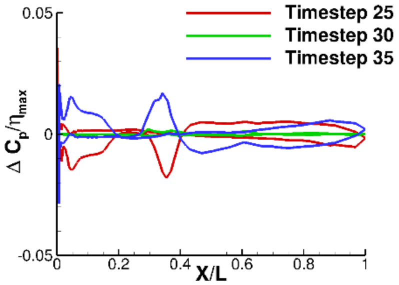
c) Mode 1



d) Mode 2

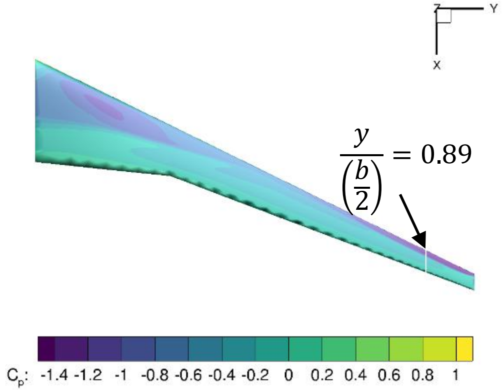


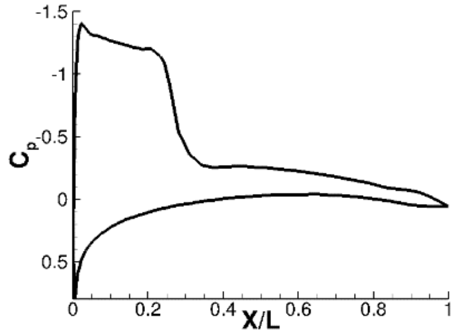
e) Mode 3



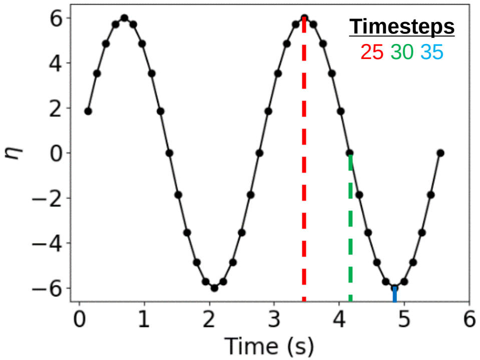
f) Mode 4

uCRM-13.5: C_p contours

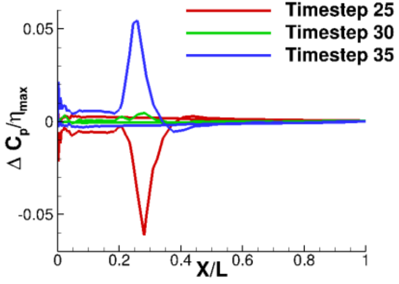




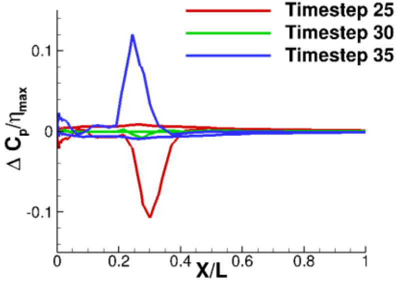
a) Steady State



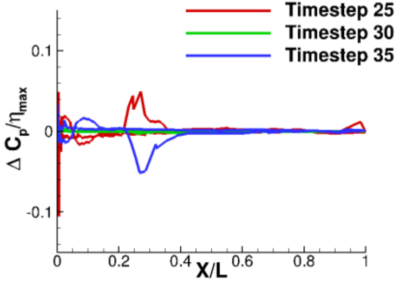
b) Mode Scaling Function



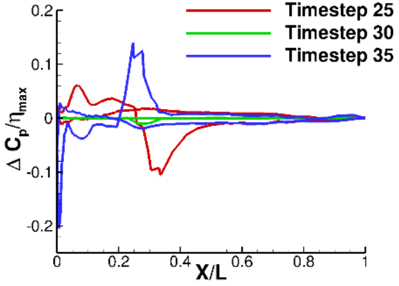
c) Mode 1



d) Mode 2



e) Mode 3



f) Mode 4

Conclusion

- An open-source flutter prediction framework is being created for the uCRM-13.5 wing
- The implementation has been validated so far with the AGARD 445.6 wing
- The results show how the mesh motion simulation is performed by SU2
- Surface pressure at each time step can now be converted to surface forces

Future work

- Implement the remaining portions of the framework
  - Compute generalized forces from pressure data
- Incorporate the present framework with existing codes for the p-k method
- Explore ways to incorporate the flutter module within an optimization framework

Acknowledgements

- This material is based upon work supported by the Iowa Space Grant Consortium under NASA Award No. NNX16AL88H

AMERICAN INSTITUTE OF
AERONAUTICS AND ASTRONAUTICS

References

Brooks, T.R., Kenway, G.K.W., and Martins, J.R.R.A., “Benchmark Aeroelastic Models for the Study of Transonic Aircraft Wings,” *AIAA Journal,* Vol. 56, No. 7, 2018. pp. 2840-2855. https://doi.org/10.2514/1.j056603

Thelen, A., Leifsson, L., and Beran, P., “Aeroelastic Flutter Prediction using Multi-fidelity Modeling of the Aerodynamic Influence Coefficients,” AIAA SciTech Forum, San Diego, CA, January 2019

Rodden, W., Harder, R., and Bellinger, E., “Aeroelastic Addition to NASTRAN,” *NASA Contractor Report 3094,* 1979

References

Haimes, R., Galbraith, M.C., Allmaras, S.R., Dannenhoffer, J.F. III, Marcum, D.L., and Karman, S., "Computational Aircraft Prototype Synthesis (CAPS)," Tech. Rep. AFRL-RQ-WP-TR-2019-0214, Air Force Research Laboratory, Wright-Patterson AFB, November 2019

Haimes, R., and Dannenhoffer, J., "The Engineering Sketch Pad: A Solid-modeling, Feature-based, Web-enabled System for Building Parametric Geometry," *21st AIAA Computational Fluid Dynamics Conference,* San Diego, CA, June 24-27, 2013

References

Case, B., “MYSTRAN – General Purpose Finite Element Structural Analysis Computer Program,” 2020. URL https://www.mystran.com/.

Economon, T.D., Palacios, F., Copeland, S.R., Lukaczyk, T.W., and Alonso, J.J., “SU2: An Open-source Suite for Multiphysics Simulation and Design,” *AIAA Journal,* Vol. 54, No. 3, 2015, pp. 828-846. https://doi.org/10.2514/1.J053813