Static and Dynamic Analysis of an Unconventional Plane: Flying Wings

Sergio Esteban

Department of Mechanical and Aerospace Engineering and Engineering Mechanics

University of Missouri-Rolla

AIAA Region V Student Conference

April 27 & 28, 2000, Wichita, Kansas

Outline

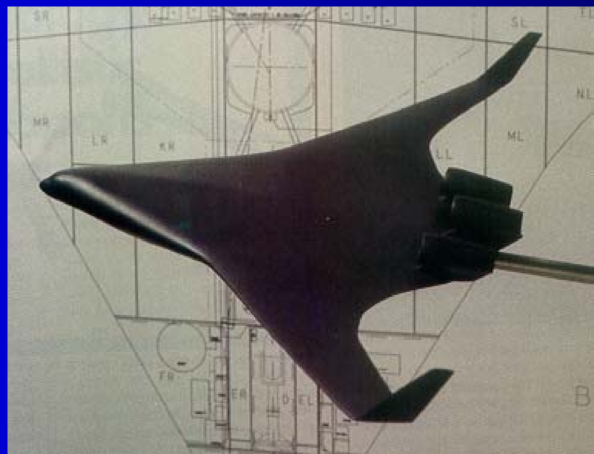
- Introduction
- Motivation
- Analysis
- Results
- Conclusions
- Future Work
- Video
- Questions

Introduction

– **What is a flying wing?**
  - **Tailless airplane where all the surfaces are effectively used for lift.**

– **Why are they a hot prospect?**
  - **Maximizing all lifting surfaces.**
  - **Increase range and decrease the thrust requirements.**
  - **Increase cargo weight.**

– **Present interest:**
  - **Reconnaissance.**
  - **Civil transport.**



Motivation

- Senior design Request to build and fly an unconventional reconnaissance plane.

- Need for prediction of longitudinal and lateral characteristics for unconventional planes.

Challenges

- General literature approximates most stability derivatives with the tail contribution.
- Need for decoupling the derivative coefficients into wing and vertical surfaces contributions.
- Creation of automated code to analyze stability for unconventional planes.

Analysis Approach

Analysis Approach

- **Decoupling stability derivatives.**
  - **Extensive literature research (Smetana & Roskam).**
  - **Wing, fuselage and vertical surfaces contributions.**

- **Determine stability requirements.**

- **Analysis of stability:**
  - **MATLAB automated code (+15000 lines of code).**
  - **Pure flying wings – no winglets.**
  - **Flying wings with winglets.**

- **Determine winglets influence on lateral stability.**

- **Optimize winglets size and location to achieve stability.**

Ala-Voladora MATLAB Code

- Receive input from user.
- Initialize program.
- Iterative process.
- Solve equations of motion.
- Extract data.
- Output results.

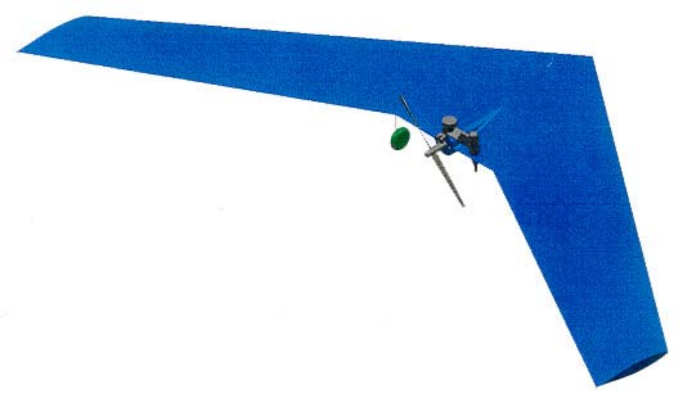
Static Longitudinal Stability Criteria

– **Conditions for static longitudinal stability:**
  - **C_{M_0} must be positive.**
  - **C_{M_α} must be negative.**

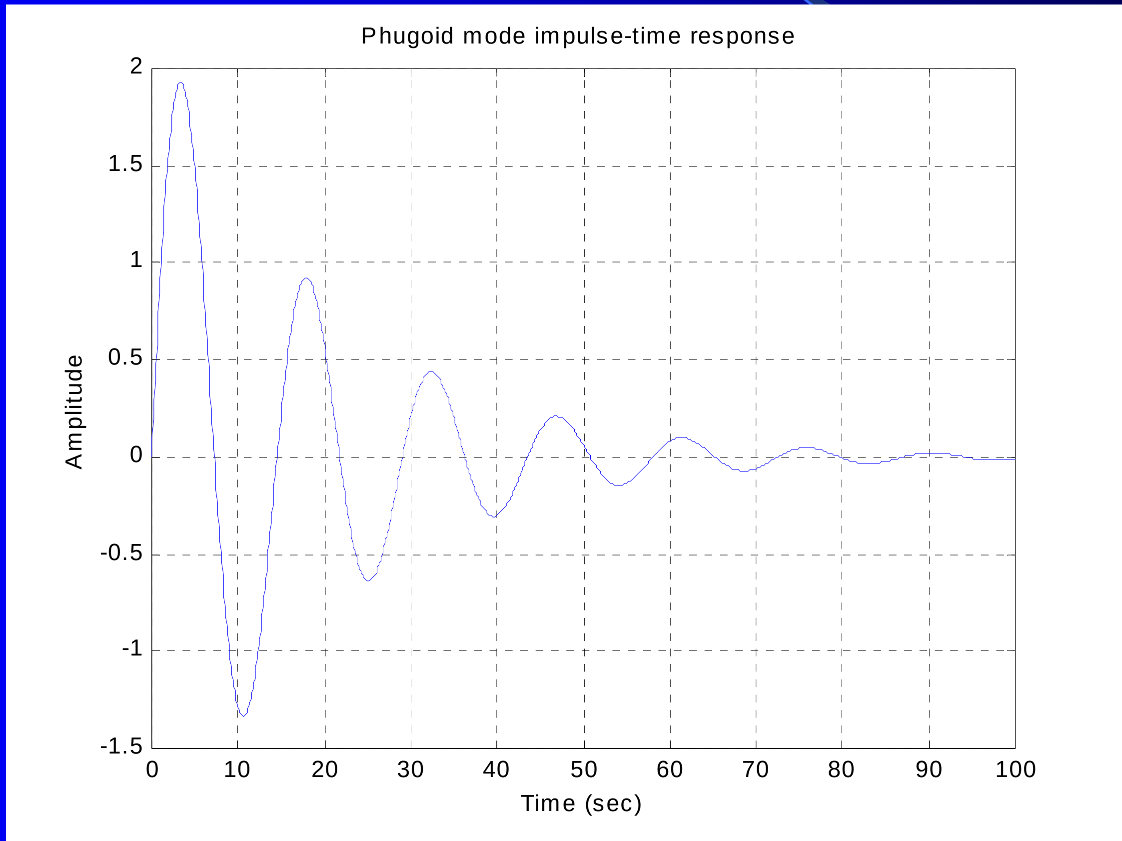
– **To satisfy the above criteria:**
  - **Sweep.**
  - **Symmetric airfoils.**
  - **Geometric twist.**
  - **Reflex airfoils.**

Longitudinal Stability Results

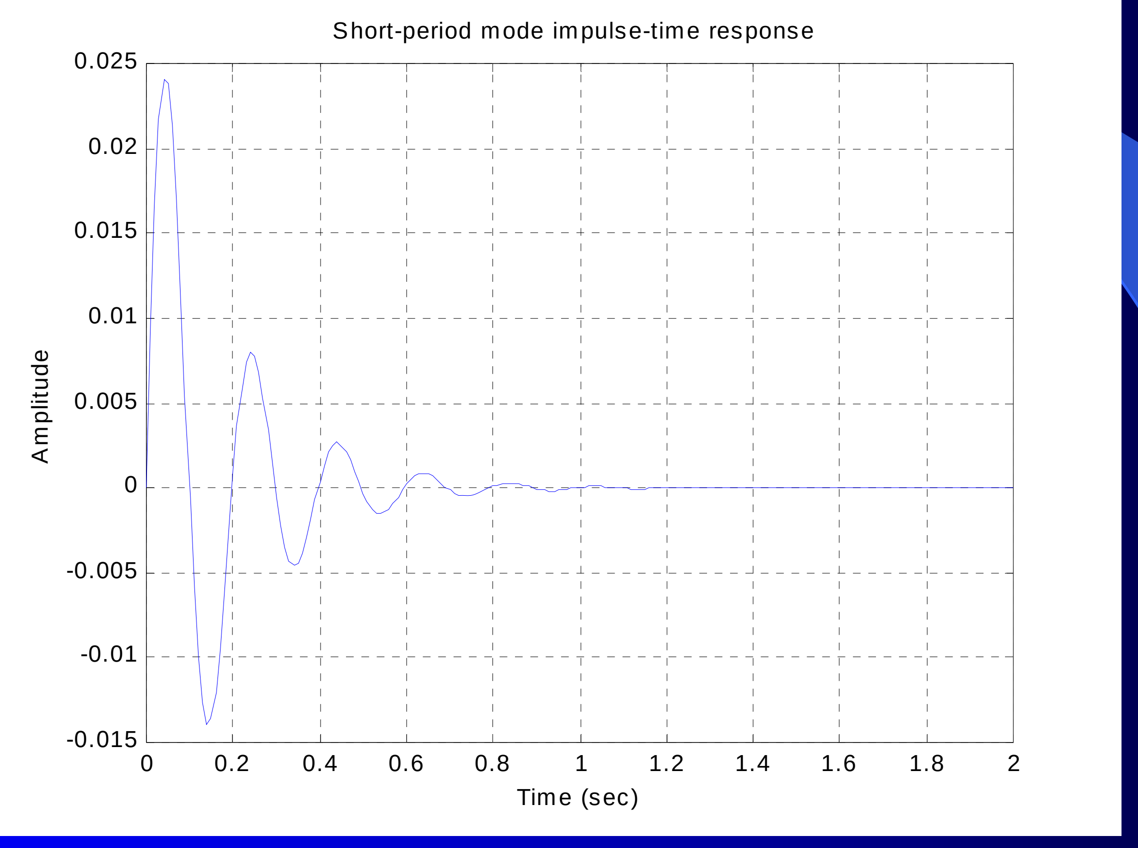
- $C_{M_0} = 0.039$
- $C_{M_\alpha} = -0.00719$ per degree.
- Short period poles = $-5.58 \pm 31.72i$
  - Damping ratio: $\zeta_S = 0.17$
  - Natural frequency: $\varpi_{n_S} = 32.21$
- Phugoid poles = $-0.05 \pm 0.43i$
  - Damping ratio: $\zeta_P = 0.12$
  - Natural frequency: $\varpi_{n_P} = 0.44$



Phugoid Response after an Impulse Perturbation



Short Period Response after an Impulse Perturbation



Suggested Static Lateral Stability Criteria

- Suggested conditions for static lateral stability:
  - C_{l_β} be negative with magnitude half of C_{n_β}.
- Military and civilian flying quality requirements.
  - Four classes.
  - Three flight phase categories.
- Class I, flight phase category A:
  - Minimum Dutch Roll damping ratio of 0.19
  - Minimum Dutch Roll natural frequency 1.0 rad/sec

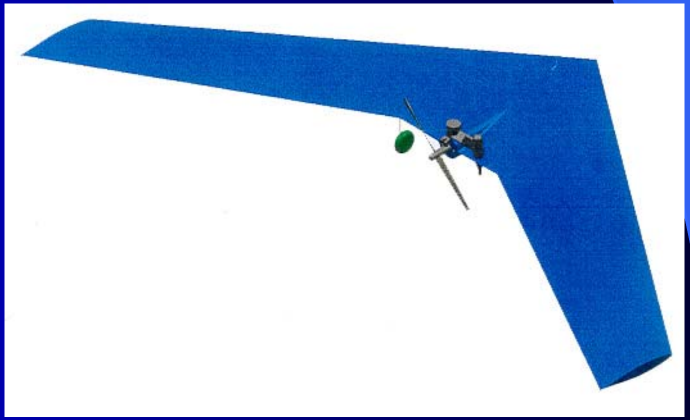
Lateral Results without Winglets

Lateral Stability Results without Winglets

– C_{l_β} = -0.012

– C_{n_β} = -1.26e-4 per degree.

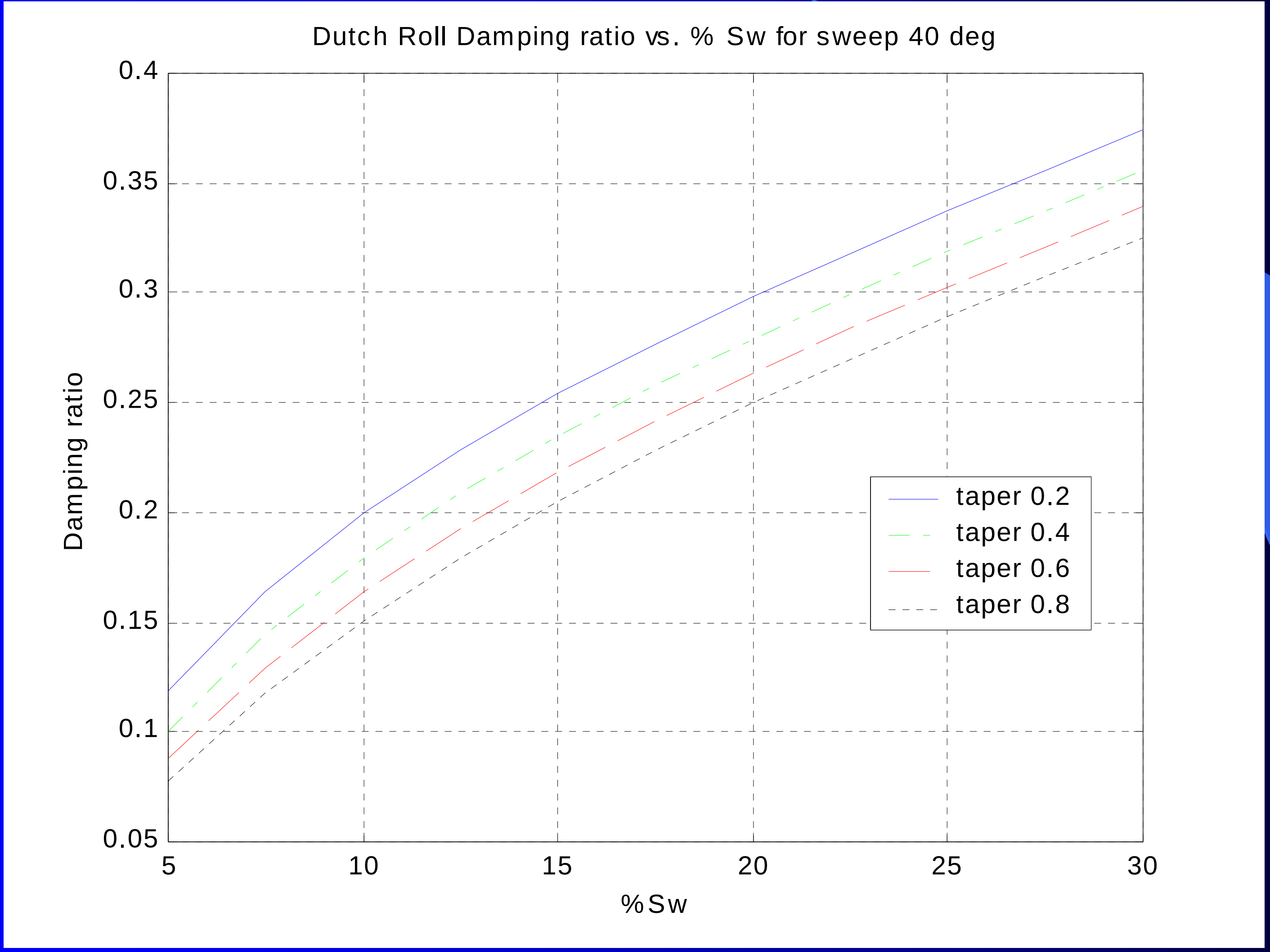
– Dutch Roll poles = 0.07 ± 1.02i
  - Damping ratio: ζ_D = 0.068
  - Natural frequency: ϖ_{n_D} = 1.02 rad/sec



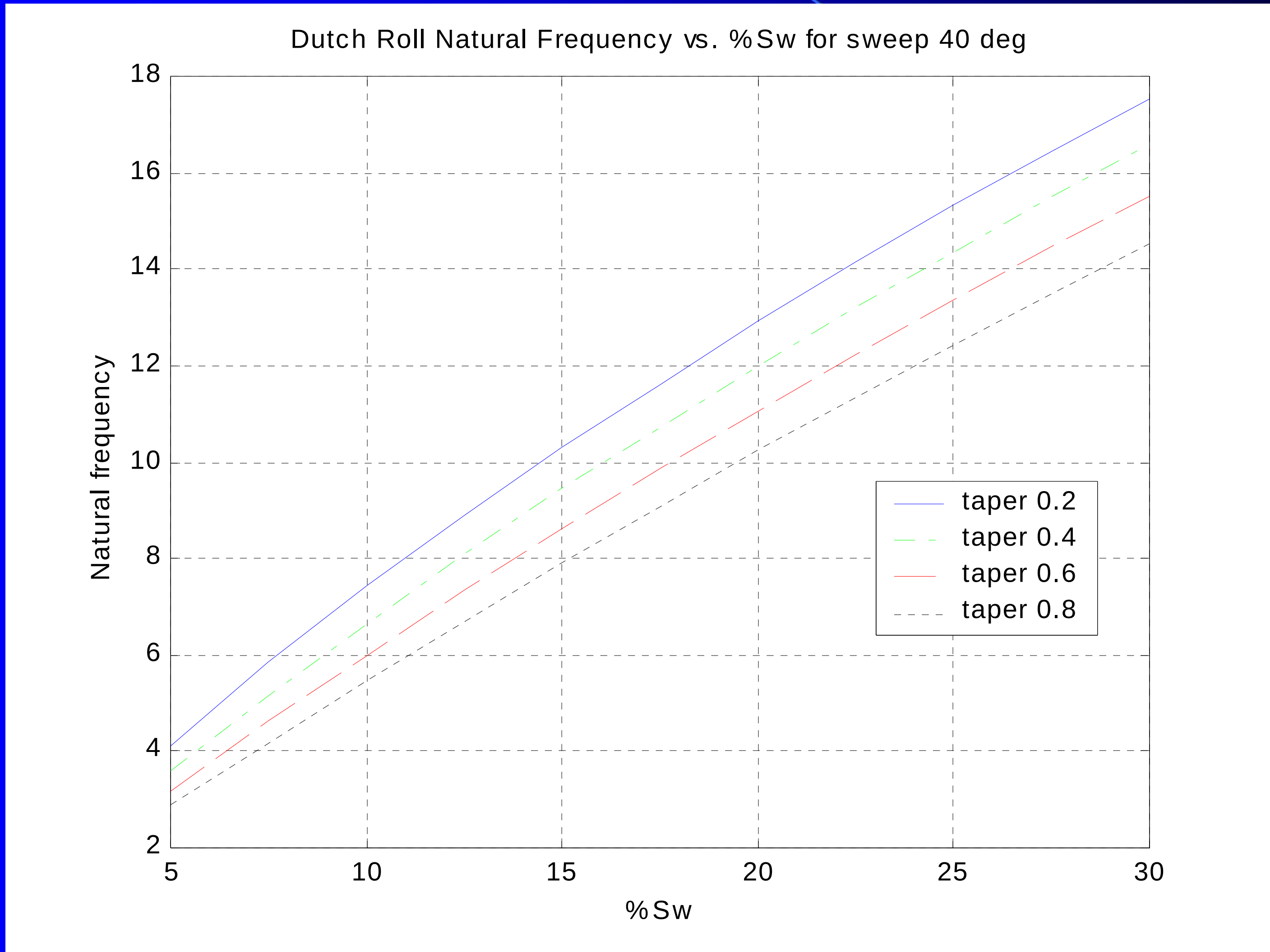
Influence of Winglet Geometry on Damping and Natural Frequency

- Given target Dutch Roll damping ratio and natural frequency, the following parameters can be used to determine winglet dimensions:
  - Winglet taper ratio.
  - Distance from the Xcg to the vertical tail aerodynamic center.
  - Winglet leading edge sweep.
  - Distance from the vertical tail aerodynamic center to the wing center line.

Dutch Roll Damping Ratio vs. Normalized Surface Area of Winglets



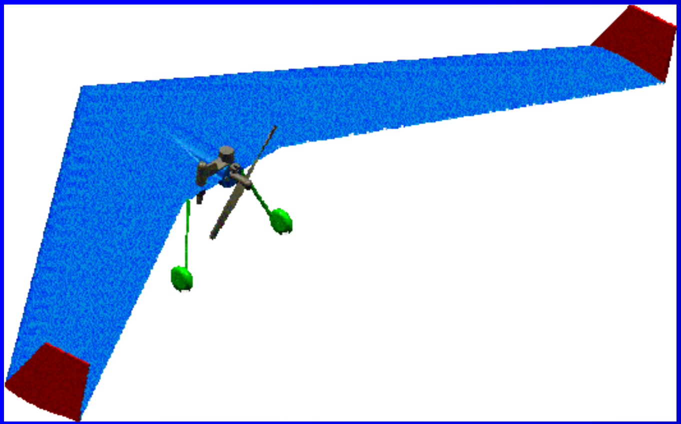
Dutch Roll Natural Frequency vs. Normalized Surface Area of Winglets



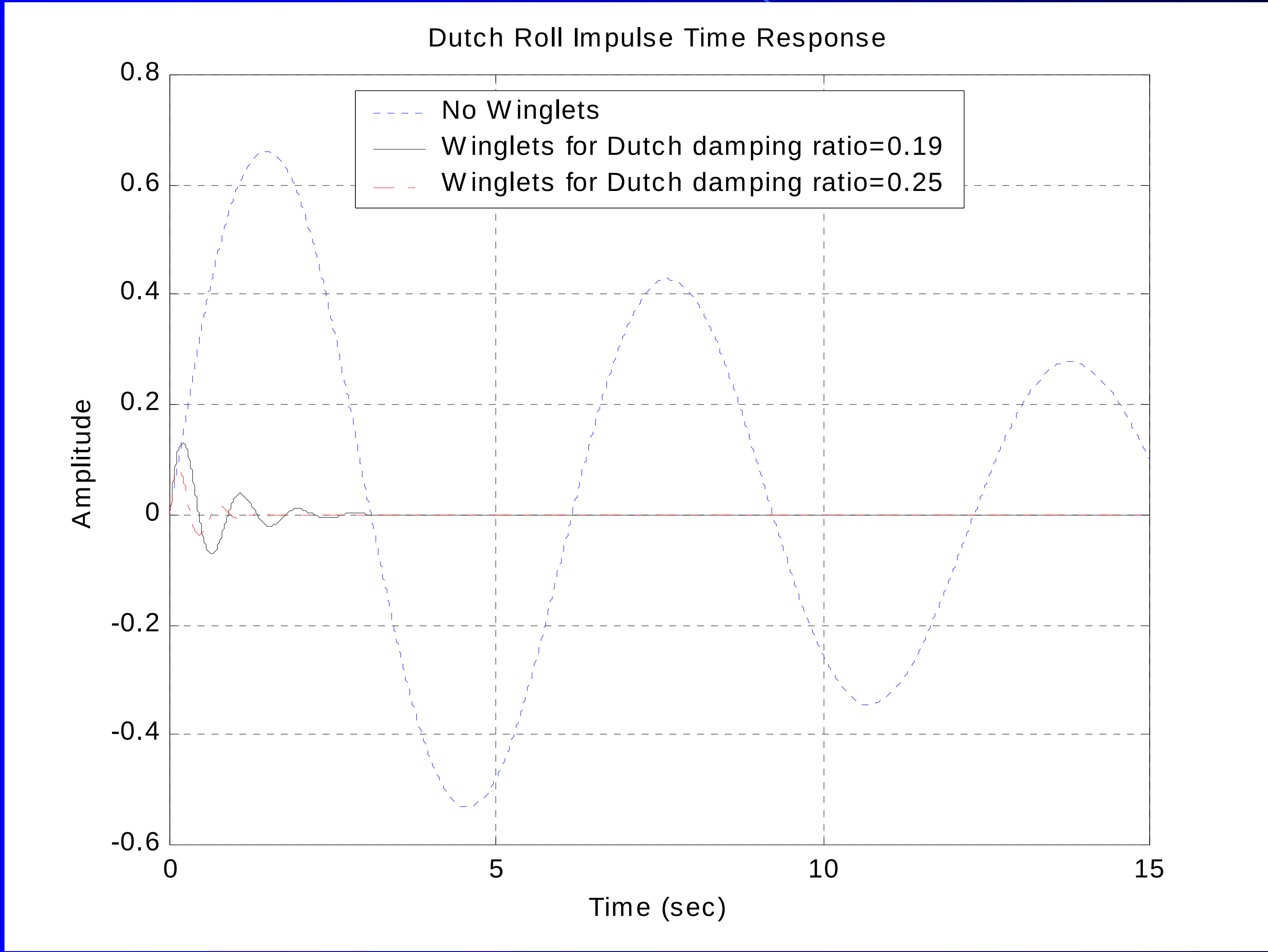
Lateral Results with Winglets

Lateral Stability Results for Flying Wing with Winglets

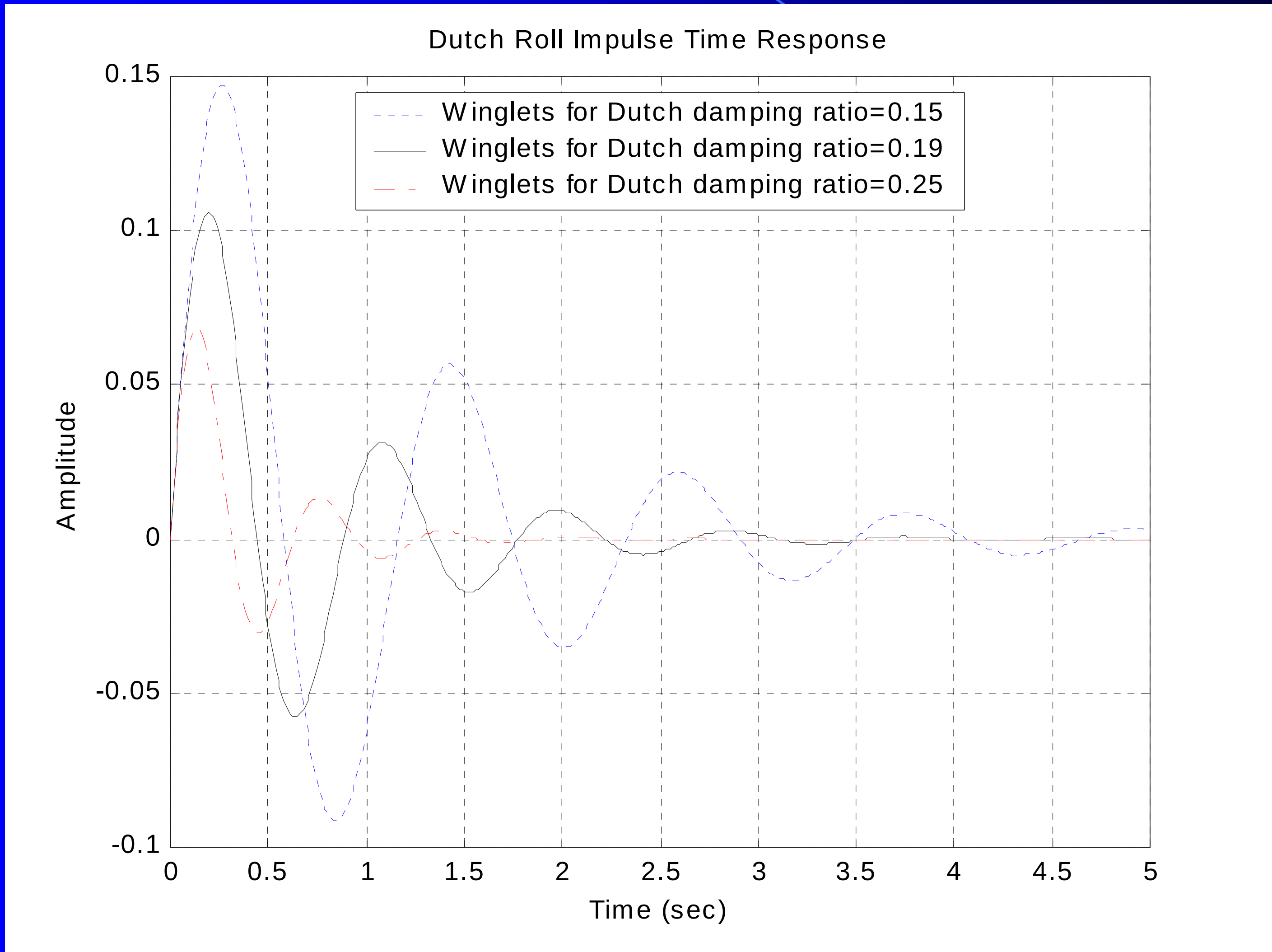
- C_{l_β} = -0.026
- C_{n_β} = 0.049 per degree.
- Dutch Roll poles = -1.37 ± 7.09i
  - Damping ratio: ζ_D = 0.19
  - Natural frequency: ϖ_{n_D} = 7.22 rad/sec



Dutch Roll Response With and Without Winglets



Dutch Roll Response for Several Winglets



Conclusions

Conclusions

- **Dynamic and static longitudinal stability achieved without winglets, however to achieve lateral stability winglets were required.**
- **Longitudinal stability can be achieved by:**
  - **Proper location of center of gravity.**
  - **Proper wing geometry**
- **Lateral stability can be achieved by:**
  - **Proper winglet sizing (l_v, λ_v, S_v & z_v).**
- **Dutch Roll lateral stability can be achieved without augmentation of flight controls.**

Final Conclusion

The present stability analysis was implemented on an actual flying wing:

- **Flew successfully on April 1999.**
- **Highly maneuverable.**
- **Numerous acrobatic maneuvers:**
  - **Barrel rolls.**
  - **Hammer heads.**
  - **Loops.**

Future Work

– **Refinement of the code, and use of Visual C++ to develop a Windows based environment.**

– **Use it as a tool for stability analysis of unconventional designs.**

Video

Questions?

Important Derivative Definitions

- **Longitudinal Stability**
  - **$C_{L_{\text{å}}}$ - change in lift coefficient with angle of attack.**
  - **$C_{M_{\text{å}}}$ - change in pitching coefficient with angle of attack.**
  - **C_{L_q} - change in lift with varying pitching velocity**
  - **C_{M_q} - change in pitching moment with varying pitching velocity.**

- **Lateral Stability**
  - **C_{l_β} - change in rolling moment due to a sideslip angle variation.**
  - **C_{n_β} - change in yawing moment due to a sideslip angle variation.**