Influence of asymmetric tip loss on the dynamics of V-tail aircraft

FYP Presentation

Simran Singh Panesar (B516302)

What is the relevance?

What research exists in the field?

How was the study approached?

Key Findings

Conclusions and further work

Purpose

- Aircraft survivability
  - Military and civilian
  - Loss is costly
- Loss of Control (LOC)
  - Leading cause of crashes
  - One every four days (FAA)
- V-Tail
  - Popular alternative to conventional
  - Prone to break ups in the past
- Autonomy and pilot awareness
  - Remotely Piloted Air Systems (RPAS)
  - Fault Tolerant Control (FTC)

Global Hawk RQ-4

Beechcraft Bonanza

[1] https://foxtrotalpha.jalopnik.com/why-the-usafs-massive-10-billion-global-hawk-uav-was-w-1629932000
[2] https://www.ainonline.com/sites/default/files/styles/ain30_fullwidth_large_2x/public/uploads/2019/01/zunum_aero_aircraft_family_wm.jpg?itok=Br0TPef5&timestamp=1546529481

Why V-tail?

Cirrus SF50

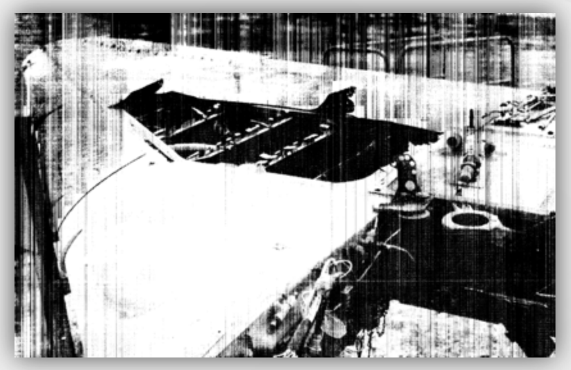
F117 Nighthawk

Salto Libelle

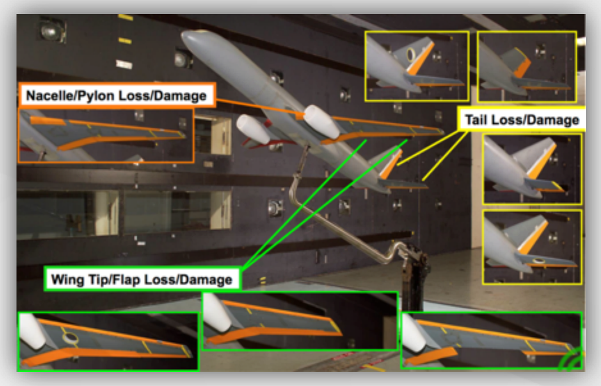
Zunum Aero Family

[1] https://www.aopa.org/-/media/images/aopa-main/news-and-media/publications/pilot-magazine/2018/1801/1801p_bf_budgetbuy/1801p_bf_budgetbuy_16x9.jpg
[2] https://cdn2.img.sputniknews.com/images/102617/90/1026179048.jpg
[3] https://cdn11.bigcommerce.com/s-afq6npz/images/stencil/500x659/products/1710/3310/vtail_5__04068.1391333647.jpg?c=2
[4] https://uncrate.com/p/2014/12/cirrus-vision-sf50.jpg

Previous Research

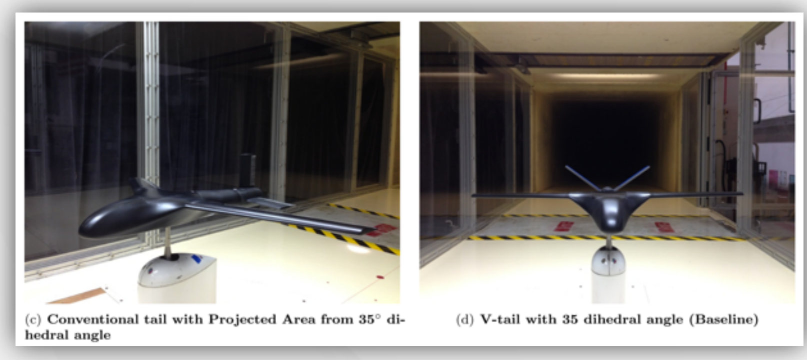


Betzina & Brown – Panel damage on an A-4B



Shah – Asymmetric tip loss to NASA GTM

Irwin/Pickhaver & Render – Hole damage

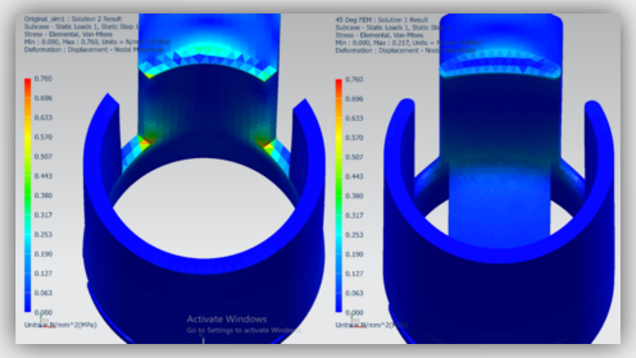


Musa and Mansor – Tail dihedral and sideslip

[1] M.D. Betzina, D.H. Brown, Aerodynamic Characteristics Of An A-4B Aircraft With Simulated And Actual Gunfire Damage To One Wing, 1976.
[2] P.M. Render, T.W. Pickhaver, The Influence of Hole Orientation on the Aerodynamics of Battle Damaged Wings, 2012.
[3] G.H. Shah, M.A. Hill, Flight Dynamics Modeling and Simulation of a Damaged Transport Aircraft, (2012).
[4] Musa et al., Effect of Tail Dihedral Angle on Lateral Directional Stability due to Sideslip Angles, 53rd AIAA Aerosp. Sci. Meet. (2015).

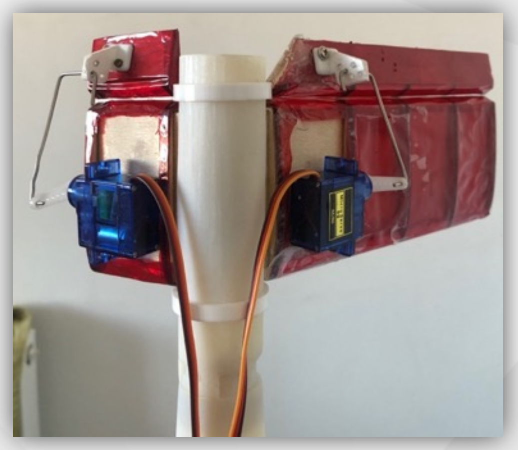
Methodology

- New empennage
  - Model needed to support V-tail configuration
  - 20, 55, 65 and 80 degrees dihedral
- New wing sections
  - NACA 0012 profile
  - 25% tip loss increments up to 75% loss
- Implementation of servos for step input
  - Arduino controlled servos
  - Yaw trimming
- Wind tunnel testing
  - SPPO analysis at each dihedral angle and loss case
  - Locked in roll



FEM analysis for stress concentrations

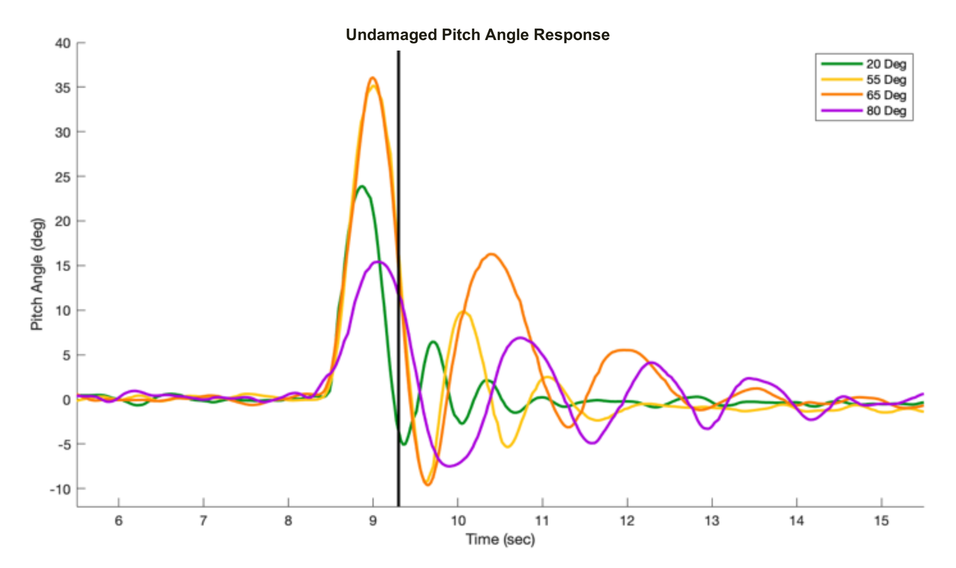
New modular empennage



Final setup

Key Findings – Undamaged Cases

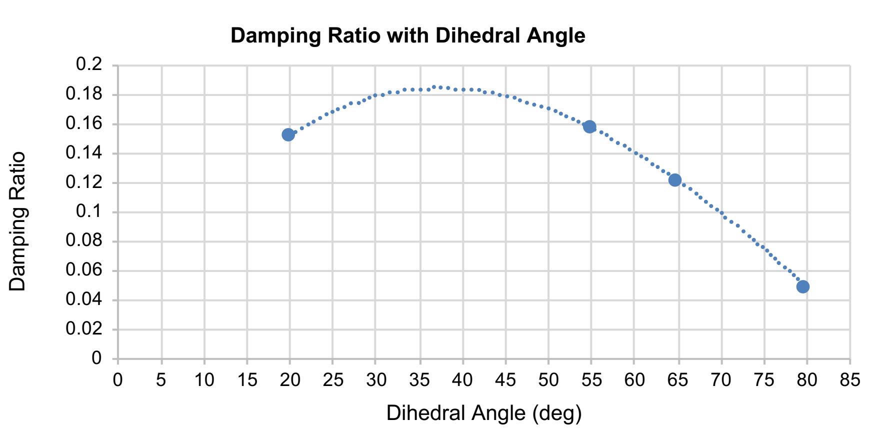
- Longitudinal stability is directly related to the effective horizontal aspect ratio
  - Supported by Zhang and Yu [2]
  - Lower dihedral angles are more responsive
  - Higher dihedral angles are sluggish, but more maneuverable
- 80 degrees achieved level 3 undamaged
  - Any loss would push 65 to level 3
  - 65^{o} defined as upper limit for dihedral

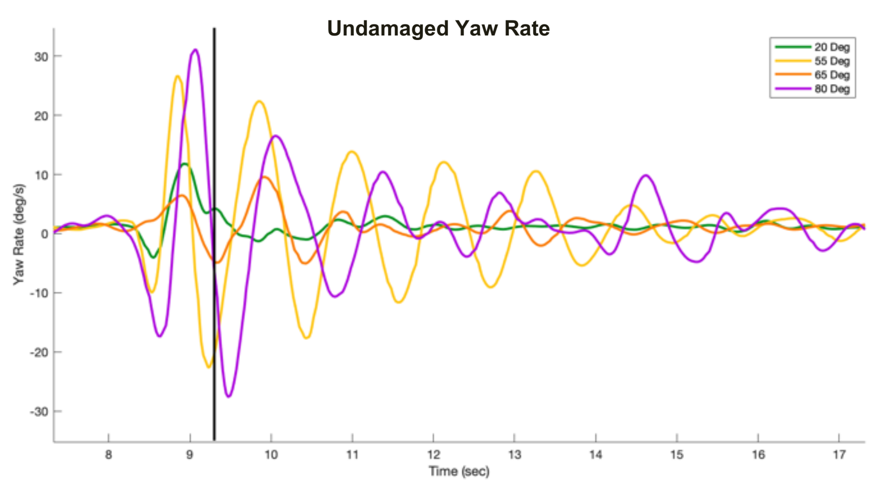


[1] M. V Cook, Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control, Elsevier Science, 2012.
[2] G.Q. Zhang, S.C.M. Yu, A. Chien, Y. Xu, Investigation of the Tail Dihedral Effects on the Aerodynamic Characteristics for the Low Speed Aircraft, Adv. Mech. Eng. 5 (2013)

Key Findings – Undamaged Cases

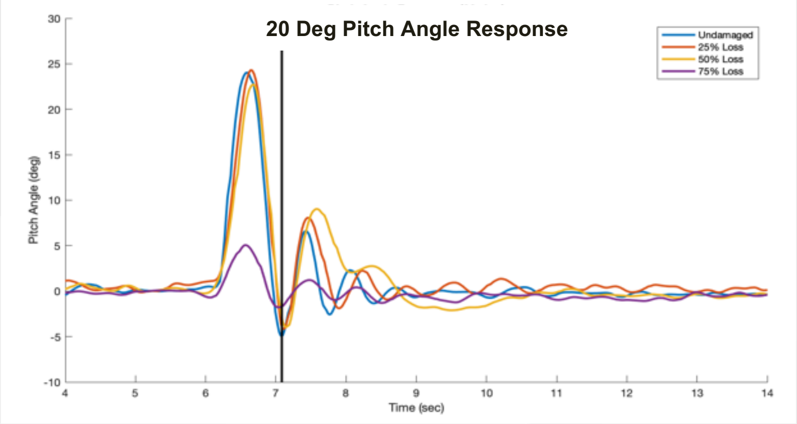
- 38 degrees of dihedral is found as an optimum configuration
  - "Optimum angle between 20 and 45", Zhang & Yu, 2013
- If dihedral angle is too high, aircraft is overly sensitive in yaw
  - 80 degrees reacted strongly to small disturbances
  - Supported by Musa and Mansor

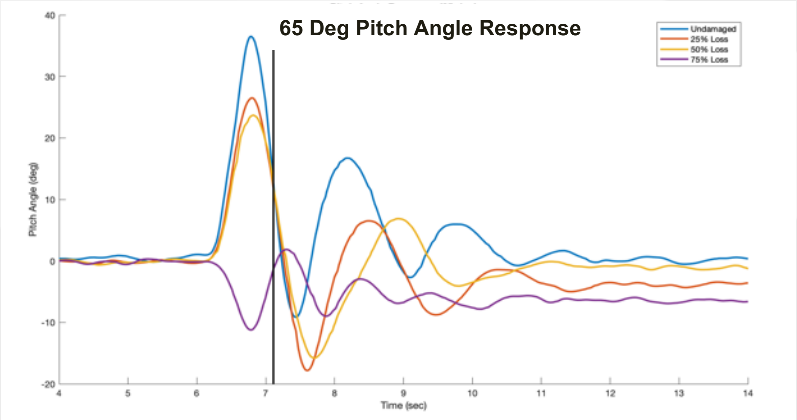




Key Findings – Tip Loss Cases

- 20 degrees dihedral
  - Time to half amplitude more than doubled with 75% loss
  - Level 3 qualities achieved with 75% loss
- 65 degrees dihedral
  - Sluggish in response
  - Reduced to level 3 with 50% loss but never divergent

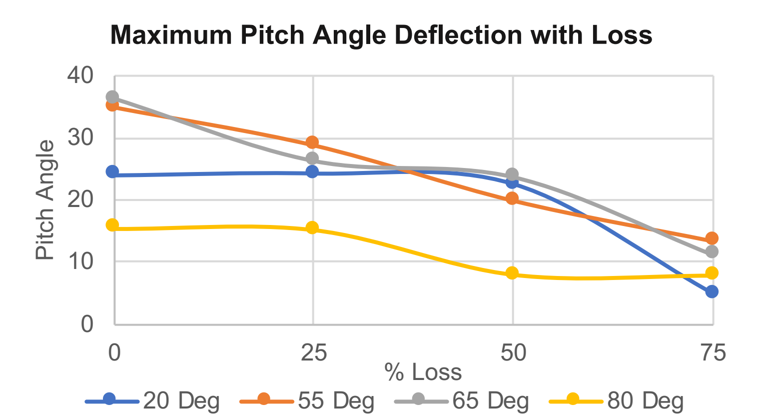


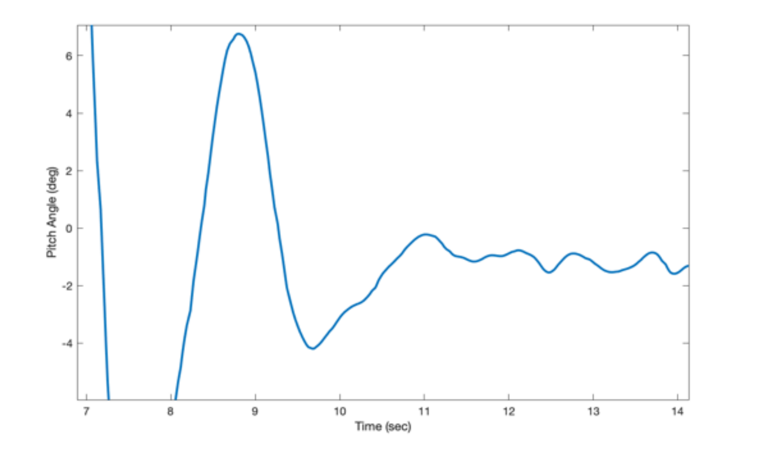


Key Findings – Tip Loss Cases

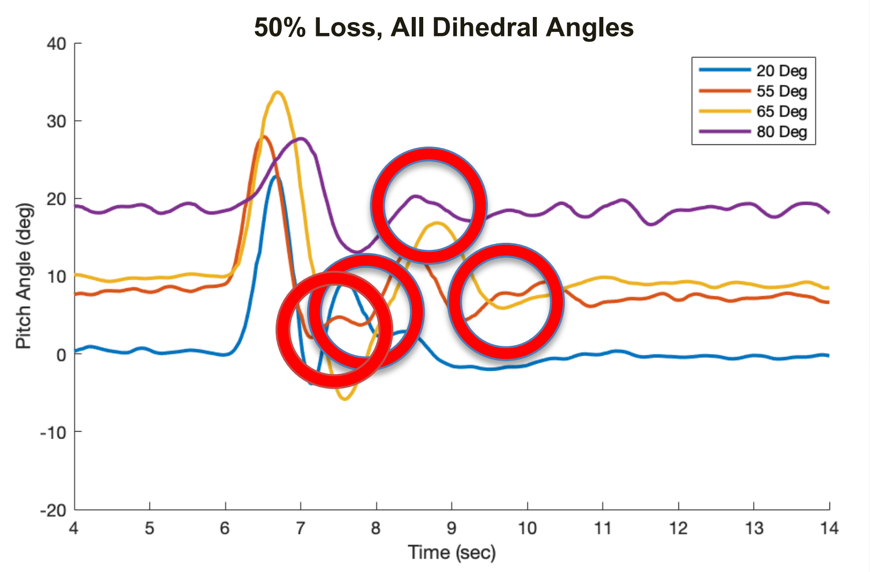
- Ruddervator effectiveness is maintained at higher dihedral angles
  - 20 degrees was most resilient up to 50% loss
  - 80 degrees showed the smallest overall reduction from undamaged (48.8%)

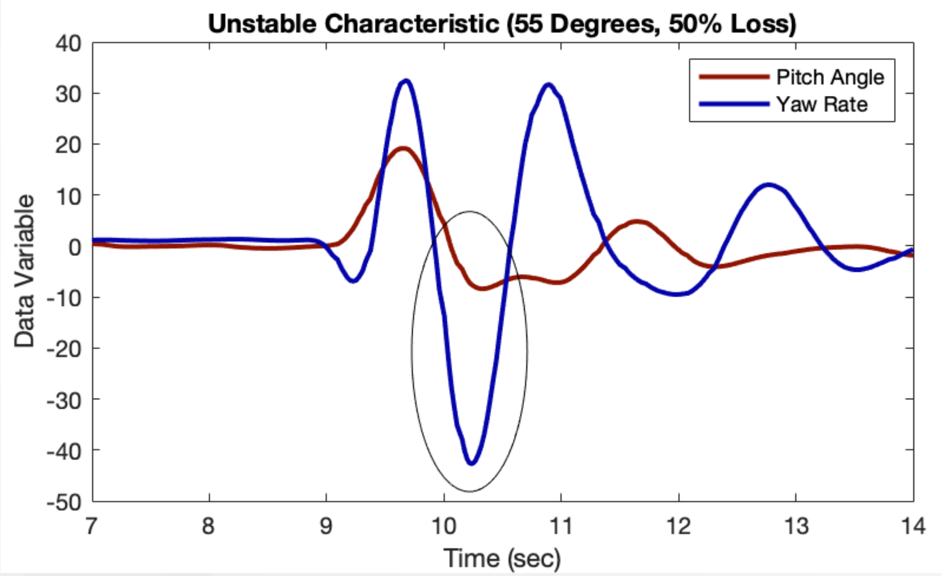
- Unstable characteristic observed
  - All 50% loss cases showed a tendency to counter-pitch when damping
  - Of most interest due to coupling





Key Findings – Unstable 50% Characteristic

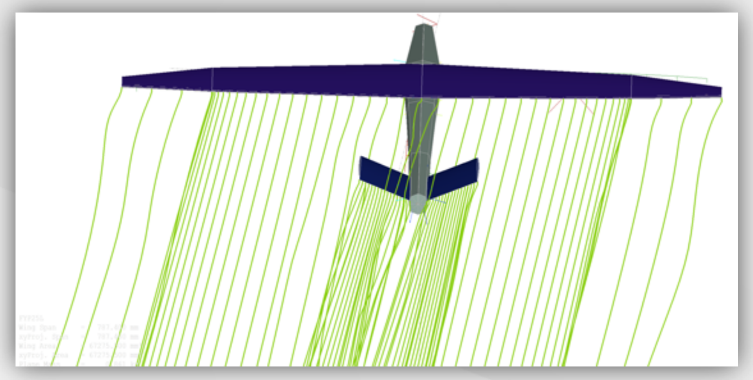




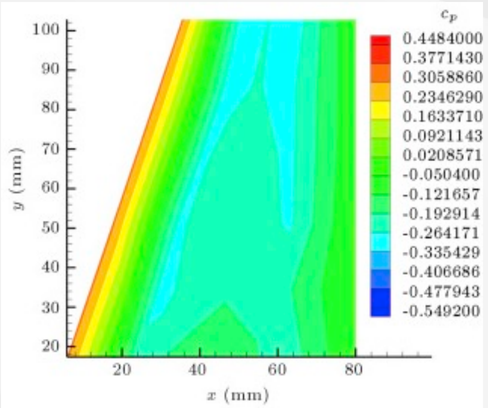
- All 50% loss cases showed a tendency to counter-pitch
- Affected ability to calculate damping ratios
- Coupling was correlated to a change in yaw rate

Key Findings – Unstable 50% Characteristic

- Consequences
  - PIO induced
  - Roll increment would increase pilot workload
  - Prone to tailspin



- Potential Explanations
  - Though roll was locked, the aircraft rocked
  - Fuselage sidewash and wing downwash interaction (Musa & Mansor / Zhang and Yu)
  - Asymmetric mass loss, therefore COG shifts laterally
  - 50% span location is high pressure (Moradi et al.)



(b) Tail pressure distribution, α=5°

Conclusions

- Dihedral angles between 38 and 65 degrees provide a more maneuverable aircraft even with loss

- Nose always pitches up and yaws towards the damaged side

- No cases were divergent

- 50% unstable characteristic needs to investigated further as occurs at all angles

Further Work

- Repeat the experiment to ensure characteristic is aircraft agnostic
- Perform tests with roll unlocked
- Perform CFD or flow visualisation to understand vortex interaction
- Develop FTC system

Thank You