

# Control and Stability in Aircraft Conceptual Design

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graphics from  
Joe Chambers



Based on AIAA Paper 93-3968,  
“Control Authority Assessment in Aircraft Conceptual Design,” by  
Jacob Kay, W. H. Mason, W. Durham, and F. Lutze, Virginia Tech  
*and: VPI-Aero-200, November 1993, available on the web as a  
pdf file, see the reference on the class web page.*

 **Aerospace and  
Ocean Engineering**

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## The Problem In Conceptual Design

The Flight Controls Guys

(if they're even there, and worse, they may be EEs!):

*“We need a complete 6 DOF, with an aero math model  
from -90° to + 90° or else forget it”*

The Conceptual Designers:

*“Just Use the Usual Tail Volume Coefficient”*

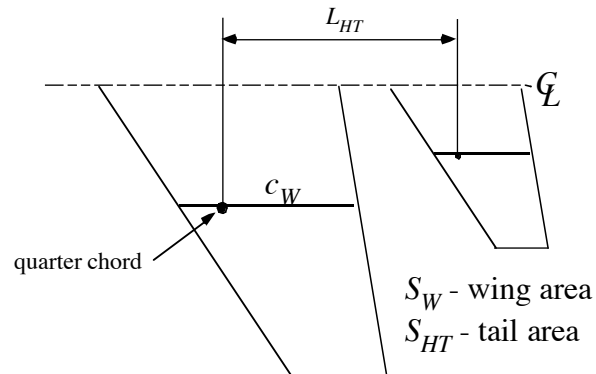
Exaggerated? —Not That Much!

**This class requires a reasonable middle ground  
between these extreme views**

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## What's a Tail Volume Coefficient? (Hopefully a review)

$$c_{HT} = \frac{L_{HT} S_{HT}}{c_w S_W}, \quad c_{VT} = \frac{L_{VT} S_{VT}}{b_W S_W}$$



See Raymer, pages 123-125, typical values:  $c_{HT}$ : 0.5 to 1,  $c_{VT}$ : 0.04 - 0.09

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## What you need to know *and do*

- Control and Stability are distinctly different
- You have to develop a policy for each axis:
  - stable or unstable? Why?
- You have to decide how you want to control the vehicle
  - *including the control system concept design*
- You have to establish the criteria to determine the amount of control needed
- You have to have an assessment plan:
  - How do you know you have adequate control power?

**The story for each design is different,  
there are no universal cookbook answers**

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## To do this you need

- stability derivatives
- control derivatives
- weight and mass properties
  - the *cg* range
  - the moments of inertia
- flight envelope
  - where are the critical conditions?

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## Some Guidance

- FAR Part 25 (commercial) and Part 23 (general aviation)
  - **tell you where and under what conditions you have to demonstrate adequate trim and control**
- MIL STD 1797 (replacing the MIL SPEC 8785)
  - **provides quantitative guidance for handling qualities requirements**
- Some control requirements are performance based
  - **rotation at takeoff (trim for seaplanes)**
- We have some programs to estimate some control and stability derivatives, and a spreadsheet to assess

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## **Typical Conceptual & PD Considerations I**

### ***Equilibrium/Performance Considerations***

#### *Normal Trimmed Flight:*

- Classical 1G trim
- Longitudinal Maneuvering Flight
- Steady Sideslip
- Engine-Out Trim
- Crosswind landing

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## **Typical Conceptual & PD Considerations II**

### ***Dynamic Considerations***

- Takeoff and Landing Rotation
- Time-to-Bank
- Inertia Coupling
  - Pitch Due to Roll and Yaw Due to Loaded Roll
- Coordinated Velocity Axis Roll
- Short Period and CAP Requirements
- High Angle-of-Attack/Departure

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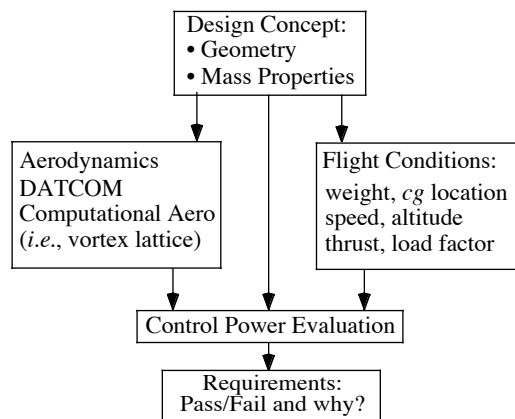
## Typical Conceptual & PD Considerations III

### *Other Considerations:*

- Gust
- Non-linear Aerodynamics
  - High angle of attack
- Aeroelasticity
- Control Allocation for multiple controls
- Special Requirements: weapons separation, stealth, etc.

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## Control Authority Assessment Sequence



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## Some PC Tools

- simple flight condition definitions tool
- a vlm code: JKayVLM
  - longitudinal (& poor lat/dir) S & C derivatives
- three surface & two surf + thrust vector trim code
- a first-cut spreadsheet evaluation of control power.
- **New: Drela's AVL Extended VLM code**

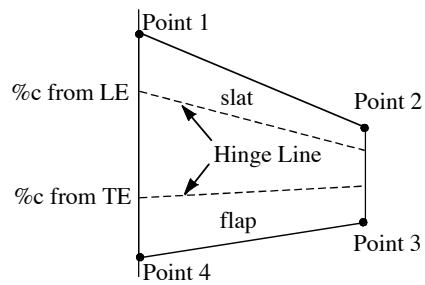
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## JKayVLM the Vortex Lattice Method

- follows Katz and Plotkin: vortex rings
- includes ground effects
- define longitudinal & lateral surface separately
  - lateral is very crude approximation
- define config as a collection of panels, each with a constant % chord LE & TE device
- puts 40-50 rings on each panel
- let code step using finite differences to estimate both stability and control derivatives.

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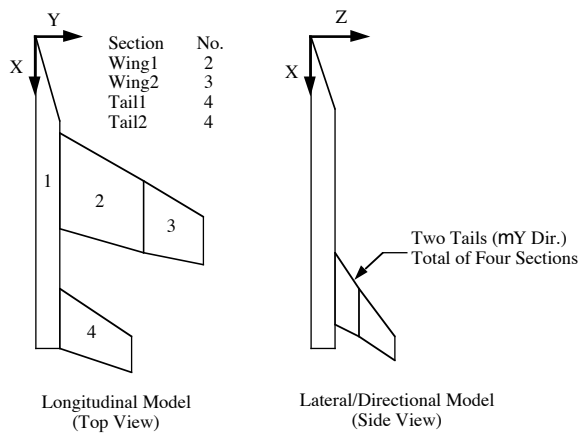
## Single panel:



Note: panel does not have to be in a coordinate plane

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## Combine Panel to Model Plane



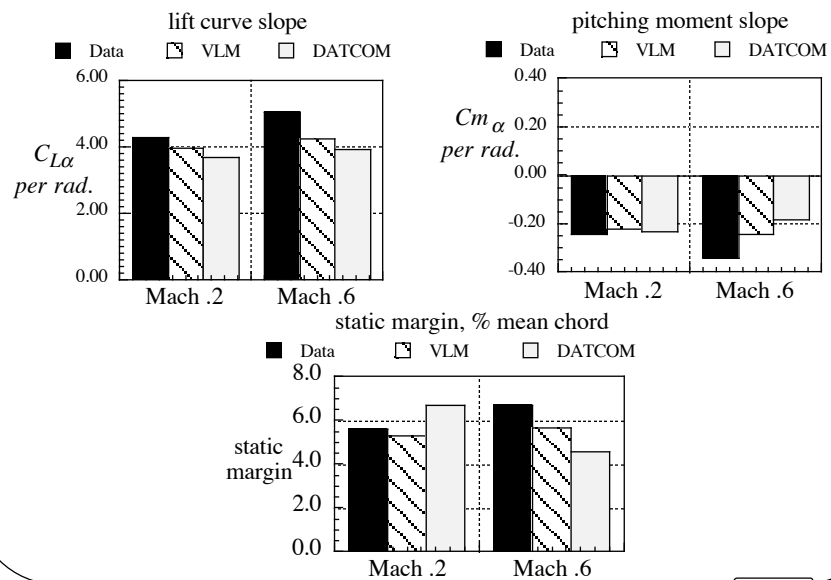
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## JKayVLM Validation

The following bar charts show the predictions of JKayVLM with DATCOM and actual values for an F-18 type configuration

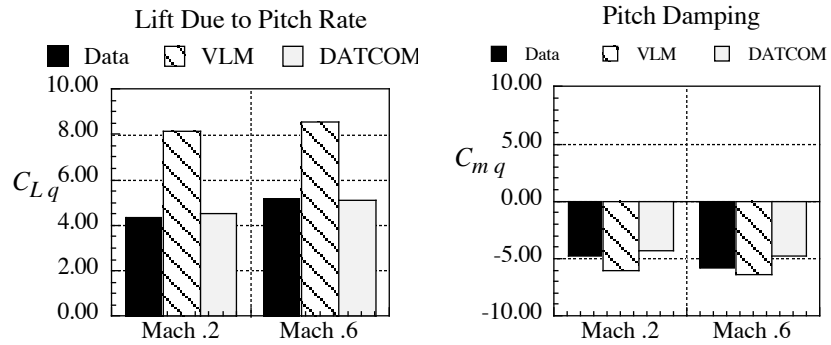
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### VLM Code Accuracy: $\alpha$ Derivatives



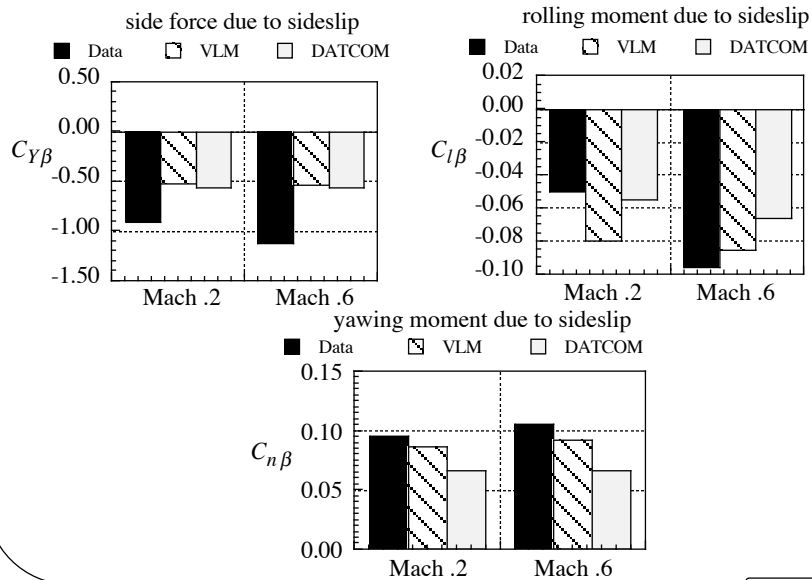
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## VLM Code Accuracy: Pitch Rate Derivatives



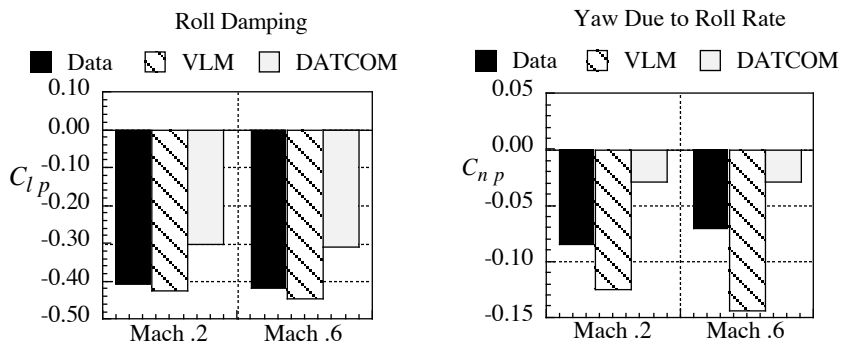
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## VLM Code Accuracy: $\beta$ Derivatives



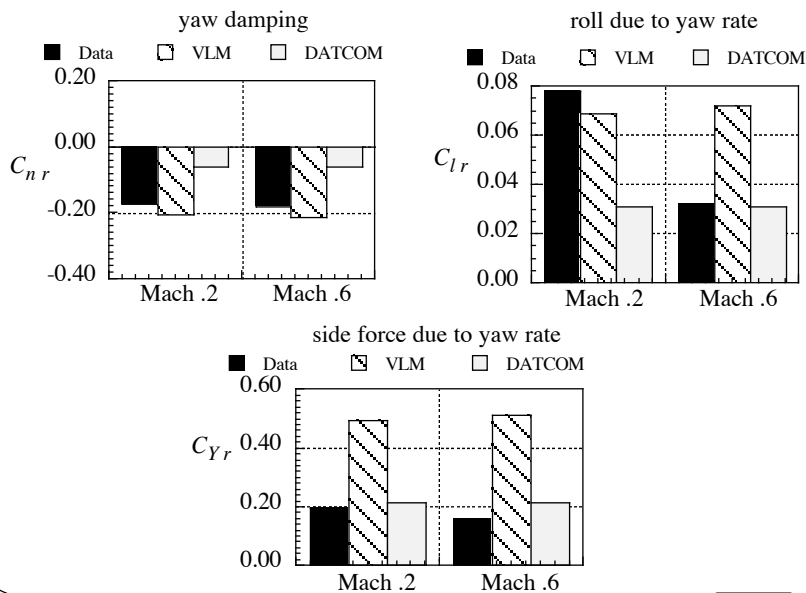
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## VLM Code Accuracy: Roll Rate Derivatives



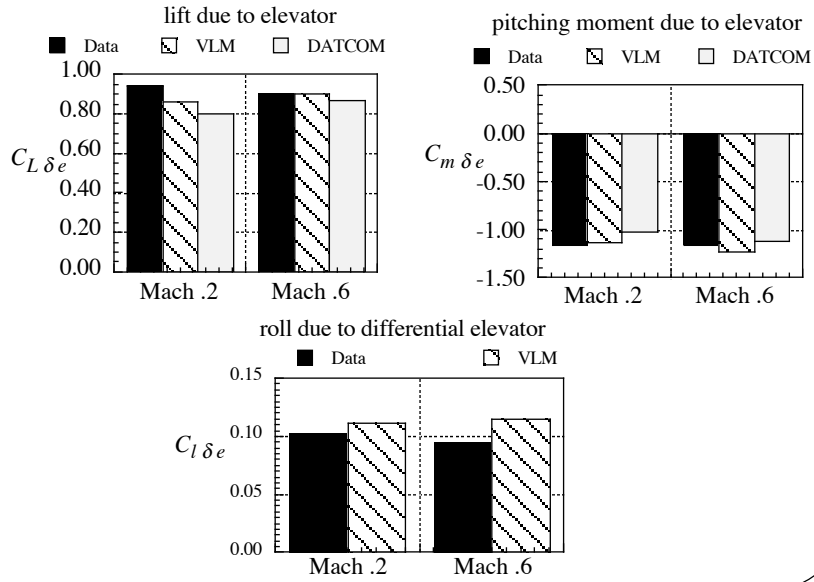
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## VLM Code Accuracy: Yaw Rate Derivatives



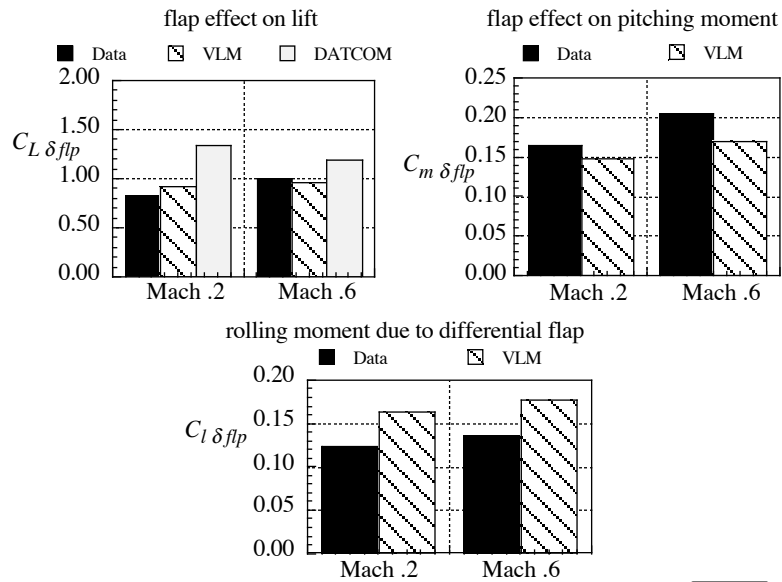
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## VLM Code Accuracy: Elevator Effectiveness



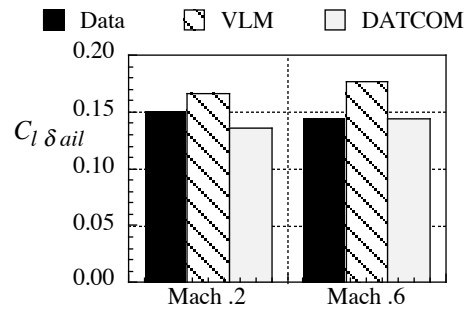
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## VLM Code Accuracy: Flap Effectiveness



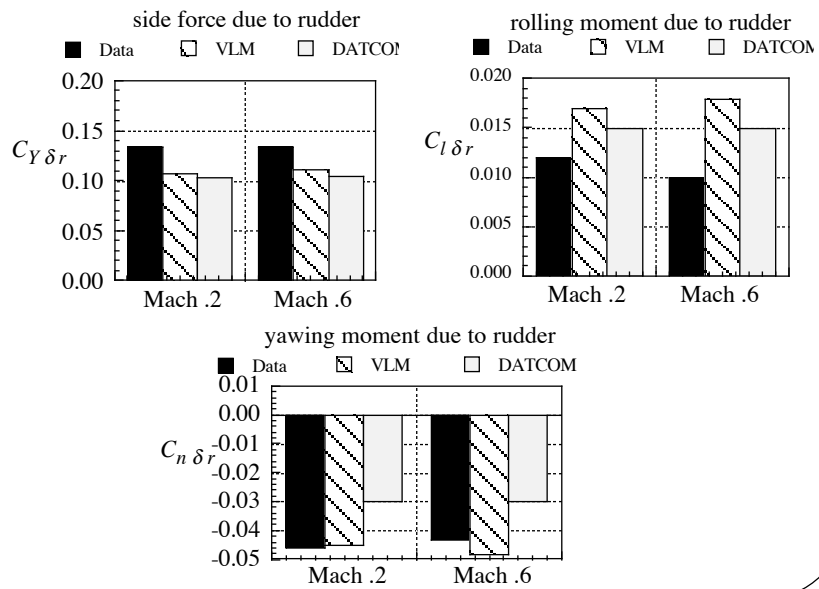
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## VLM Code Accuracy: Aileron Effectiveness



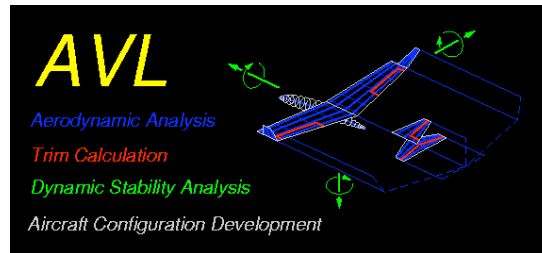
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## VLM Code Accuracy: Rudder Effectiveness



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## A Similar Evaluation of AVL Required



<http://raphael.mit.edu/avl/>

- Can't trust that you know how to use the code
- Can't understand code limitations
- Until you do a complete evaluation as shown above for JKayVLM

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## Aircraft Assessment Spreadsheet

For several typical flight situations, a spreadsheet containing 11 different cases has been put together. The spreadsheet actually computes the required control deflection or time required to do the maneuver.

To use it you need to enter:

- the flight conditions and the mass properties, both at **heavily loaded and lightly loaded conditions**, the **full range of  $cg$  locations and the inertias**
- the stability and control derivatives
  - corresponding to the each  $cg$  position

To do the assessment:

- check that the required control deflection is acceptable
- check that the time required meets the requirement

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## EXCEL Spreadsheets, 11 Worksheets:

1. Nose-wheel Lift-off
2. Nose-down Rotation During Landing Rollout
3. Trimmed 1-G Flight
4. Maneuvering Flight (Pull-up)
5. Short Period & Control Anticipation Parameter (CAP)
6. Pitch Due to Roll Inertial Coupling
7. Time-to-Bank Performance
8. Steady Sideslip Flights (Aileron & Rudder Deflections)
9. Engine-out Trim (Aileron & Rudder Deflections)
10. Roll Pullout
11. Initiate & Maintain Coordinated Velocity Axis Roll

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## Just One Simple Example:

```
*****
Trimmed 1-G Flight
*****
```

|         |                                     |             |
|---------|-------------------------------------|-------------|
| Input:  | Weight (lbs)                        | 51900       |
|         | Reference Area (ft <sup>2</sup> )   | 400         |
|         | Speed (ft/s)                        | 400         |
|         | Air Density (slug/ft <sup>3</sup> ) | 0.002376    |
|         | C-m-0                               | 0.0181      |
|         | C-m-delta E (/rad)                  | -1.117      |
|         | C-L-0                               | -0.0685     |
|         | C-L-delta E (/rad)                  | 0.8688      |
|         | C-m / C-L (-Static Margin)          | -0.1        |
|         | C-L-alpha (/rad)                    | 4           |
| Output: | C-L Required for 1-g trim           | 0.6826073   |
|         | Elevator Deflection for Trim (deg)  | -4.53912205 |
|         | AOA Required for 1-g Trim (deg)     | 11.744717   |

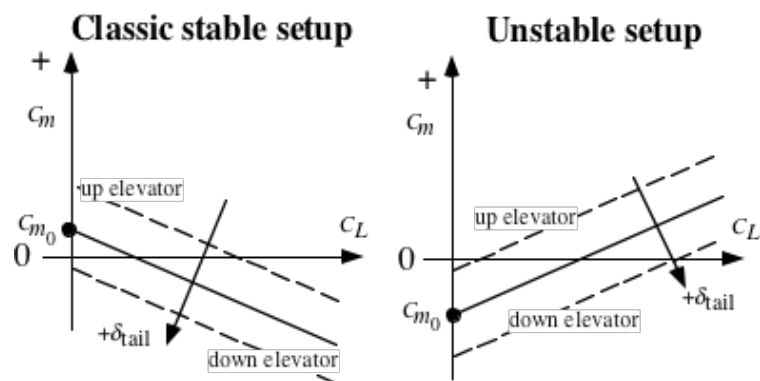
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## Tested Against Existing Airplane

- methodology applied to a known airplane
- results generally good

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## Review: The Pitching Moment Trim Story

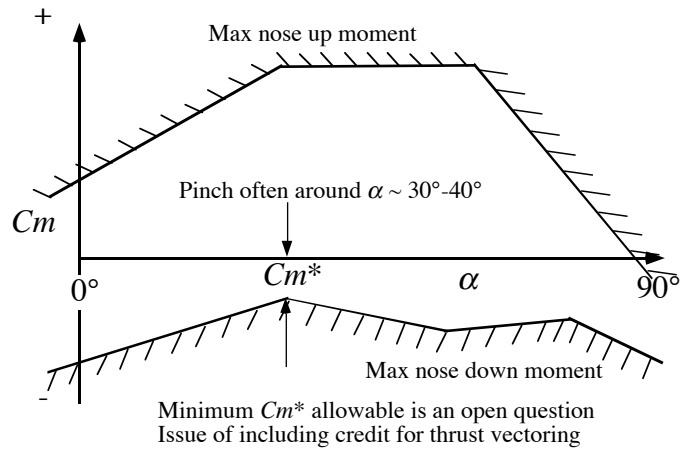


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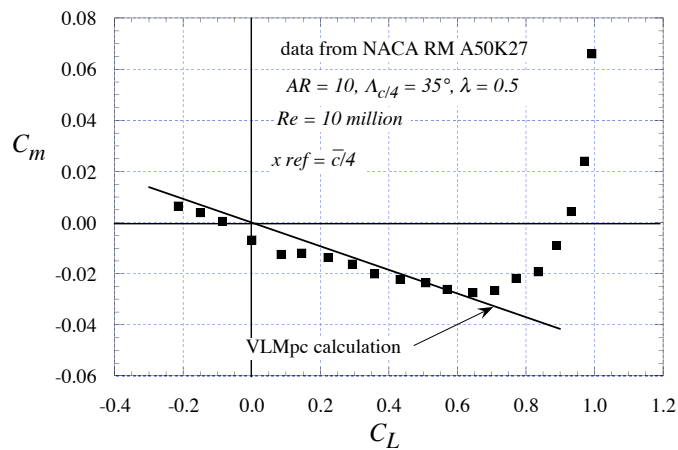
## The Hi- $\alpha$ Story Longitudinal

Typical unstable modern fighter



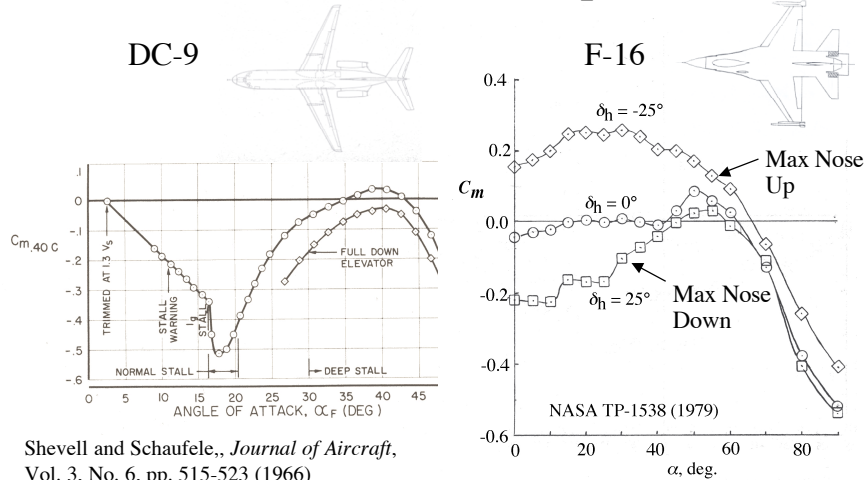
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## Typical Swept Wing $C_m$ Characteristics



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## Real World Pitchup



Shevell and Schauffele., *Journal of Aircraft*,  
Vol. 3, No. 6, pp. 515-523 (1966)

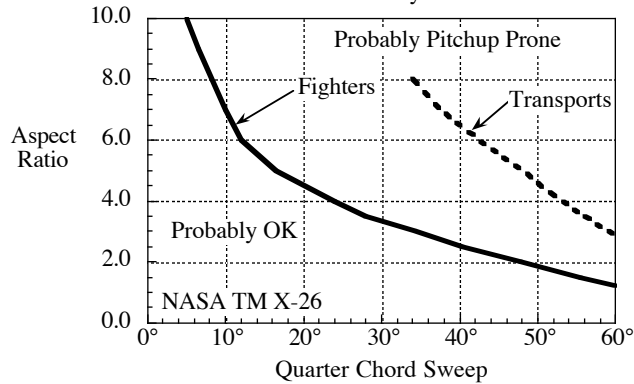
W. H. Mason, "Stability and Control in Computational Simulations for Conceptual and Preliminary Design of Aircraft: the past, today, and future?," NASA/CP-2004-213028/PT1, April 2004, pp. 309-340

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## Design Chart to Avoid Pitchup: A starting point

*Pitching moment characteristics as separation occurs must be controllable. Requires careful aero design.  
Horizontal tail location is critical*

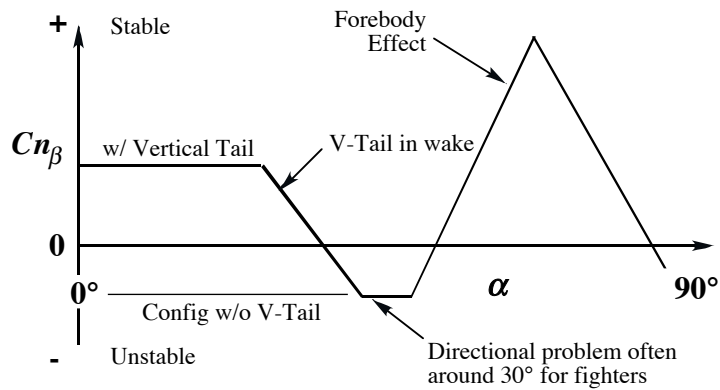
historical trends from early wind tunnel data



Note: DATCOM has a more detailed chart

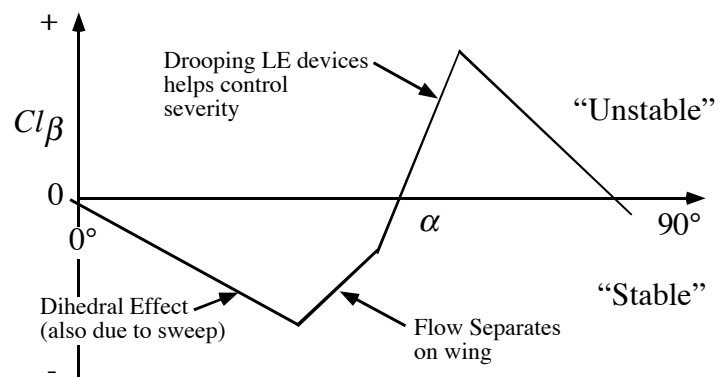
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## The Hi- $\alpha$ Story Directional



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## The Hi- $\alpha$ Story Lateral



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## Comment on Thrust Vectoring

- Thrust vectoring mainly provides moments at high thrust
  - a problem if you don't want lots of thrust!
- Thrust vectoring moment is near constant with speed
- Ratio of aero to propulsive moments
  - propulsion dominates at low  $q$
  - aero dominates at high  $q$

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## Special Issues for Supersonic Flight and Related Planforms

- *Pitchup*
  - See Alex Benoliel's Thesis for a survey and estimation method
- *Aerodynamic Center Shift*
  - See Paul Crisafulli's Thesis. One chapter addresses *ac* shift

Both available at Mason's web site under:

Thesis/Dissertation Titles and Placement.

[http://www.aoe.vt.edu/aoe/faculty/Mason\\_f/MRthesis.html](http://www.aoe.vt.edu/aoe/faculty/Mason_f/MRthesis.html)

Alex's Thesis is also under "design related reports" on our web site

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## Conclusion

- We've outlined the issues, typical criteria and procedures
- We've established some useful tools.
- Each project is different in the details
- Each individual controls person has to develop the detailed approach for their particular design

