Dangerous Encounters of an Aeronautical Kind

Robert Stengel

January, 2003

- Microbursts
- Wind Rotors
- Wake Vortices
- Clear Air Turbulence

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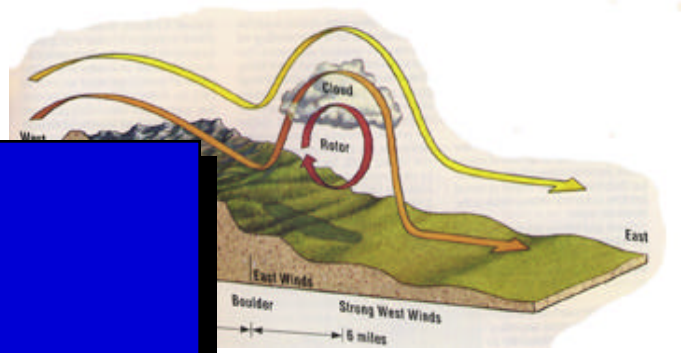
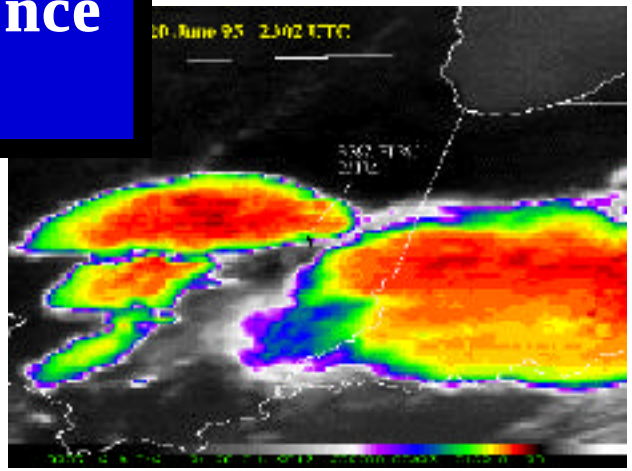
Hazardous Atmospheric Disturbances

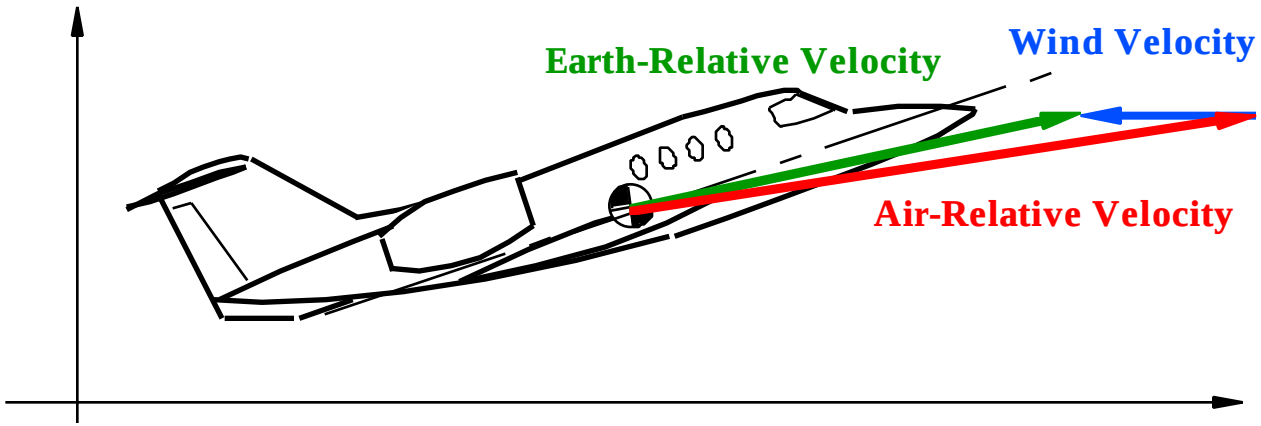


- Microbursts
- Wind Rotors
- Wake Vortices
- Clear Air Turbulence (CAT)

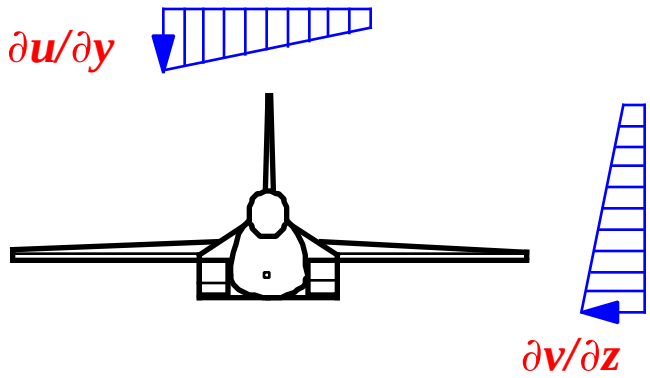


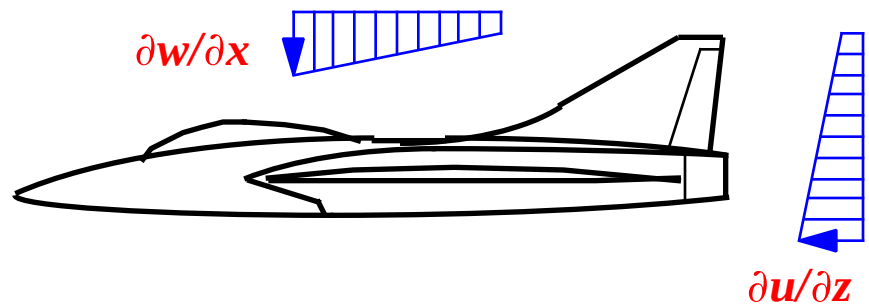
Frames of Reference

- **Inertial Frames**
  - Earth-Relative
  - Wind-Relative (Constant Wind)
- **Non-Inertial Frames**
  - Body-Relative
  - Wind-Relative (Varying Wind)



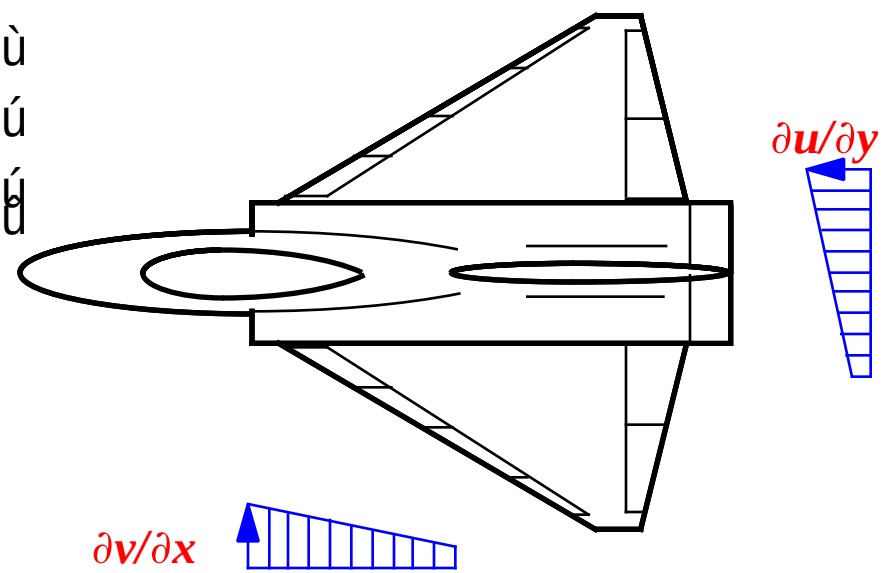
Wind Shear Distributions Related to Configuration





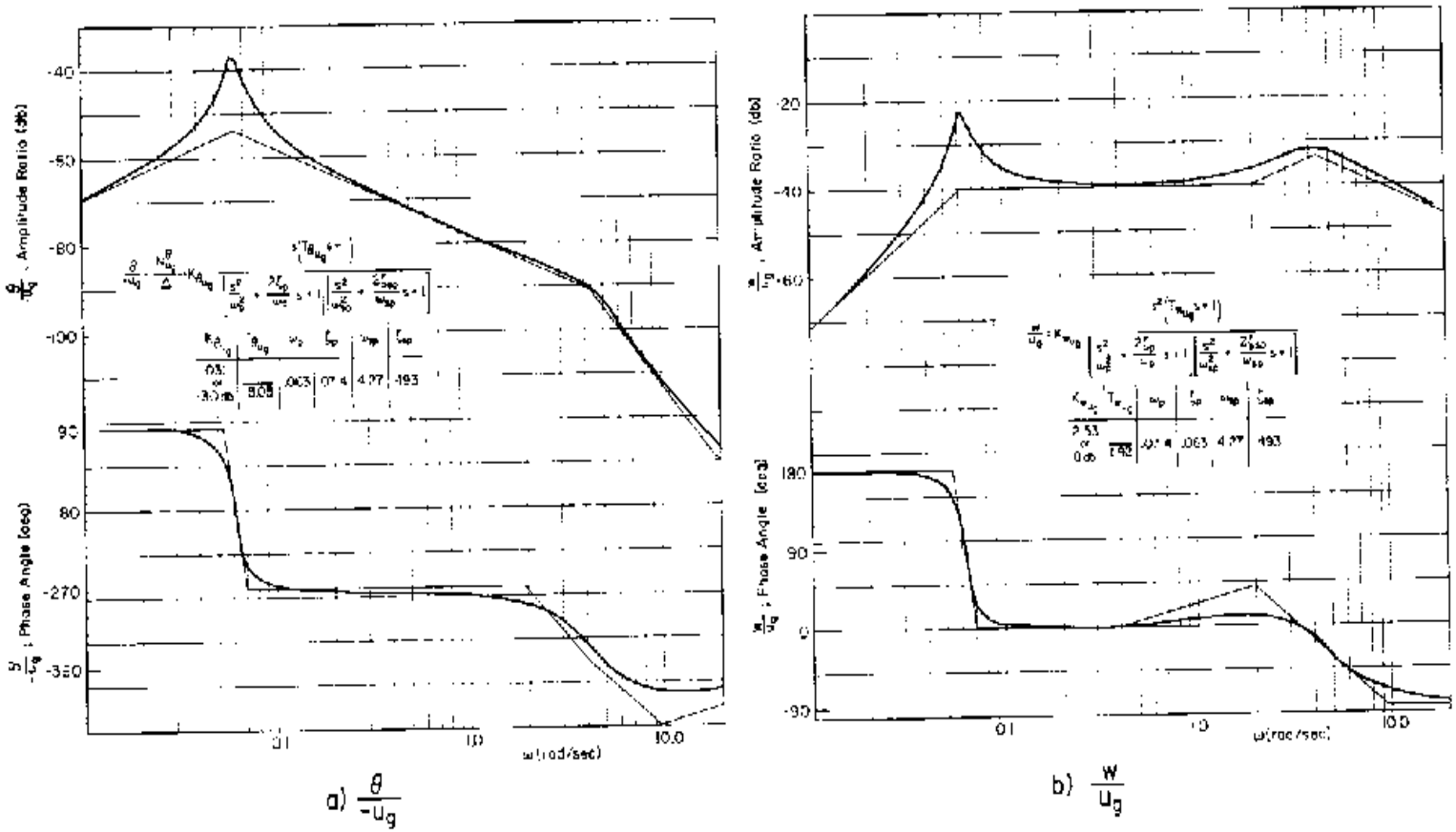
$$\mathbf{W}_E = \begin{bmatrix} \partial w_x / \partial x & \partial w_x / \partial y & \partial w_x / \partial z \\ \partial w_y / \partial x & \partial w_y / \partial y & \partial w_y / \partial z \\ \partial w_z / \partial x & \partial w_z / \partial y & \partial w_z / \partial z \end{bmatrix}$$

$$\mathbf{W}_B = \mathbf{H}_E^B \mathbf{W}_E \mathbf{H}_B^E$$



Pitch Angle and Normal Velocity Frequency Response to Axial Wind

- from *MacRuer, Ashkenas, and Graham*

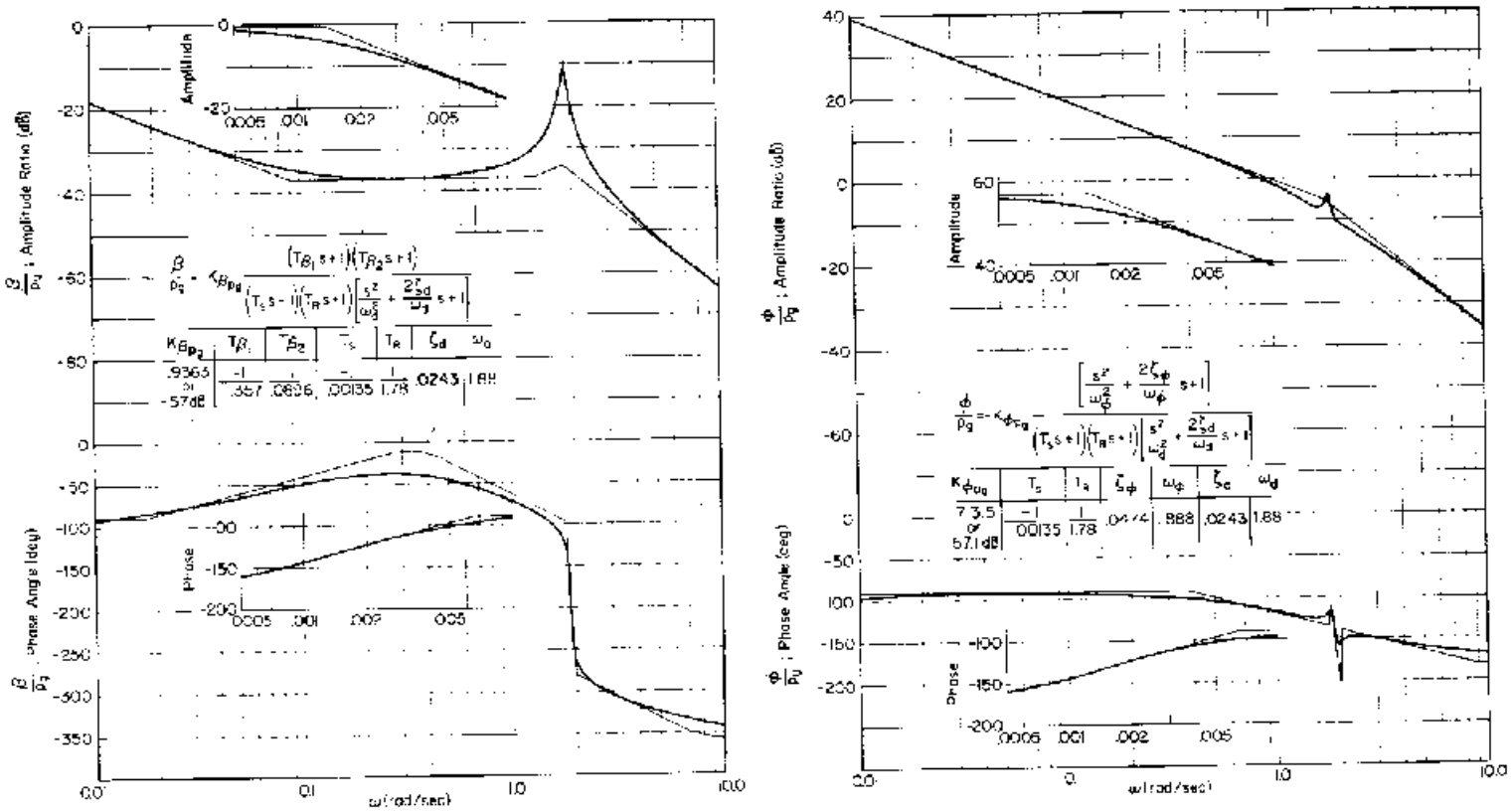


a) $\frac{\theta}{-u_g}$

b) $\frac{w}{u_g}$

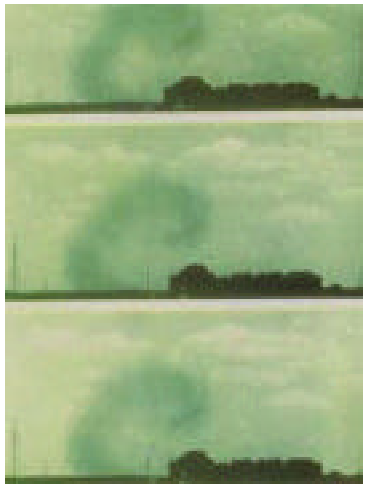
Sideslip and Roll Angle Frequency Response to Vortical Wind

- from *MacRuer, Ashkenas. and Graham*



a) $\frac{\beta}{p_g}$ b) $\frac{\phi}{p_g}$

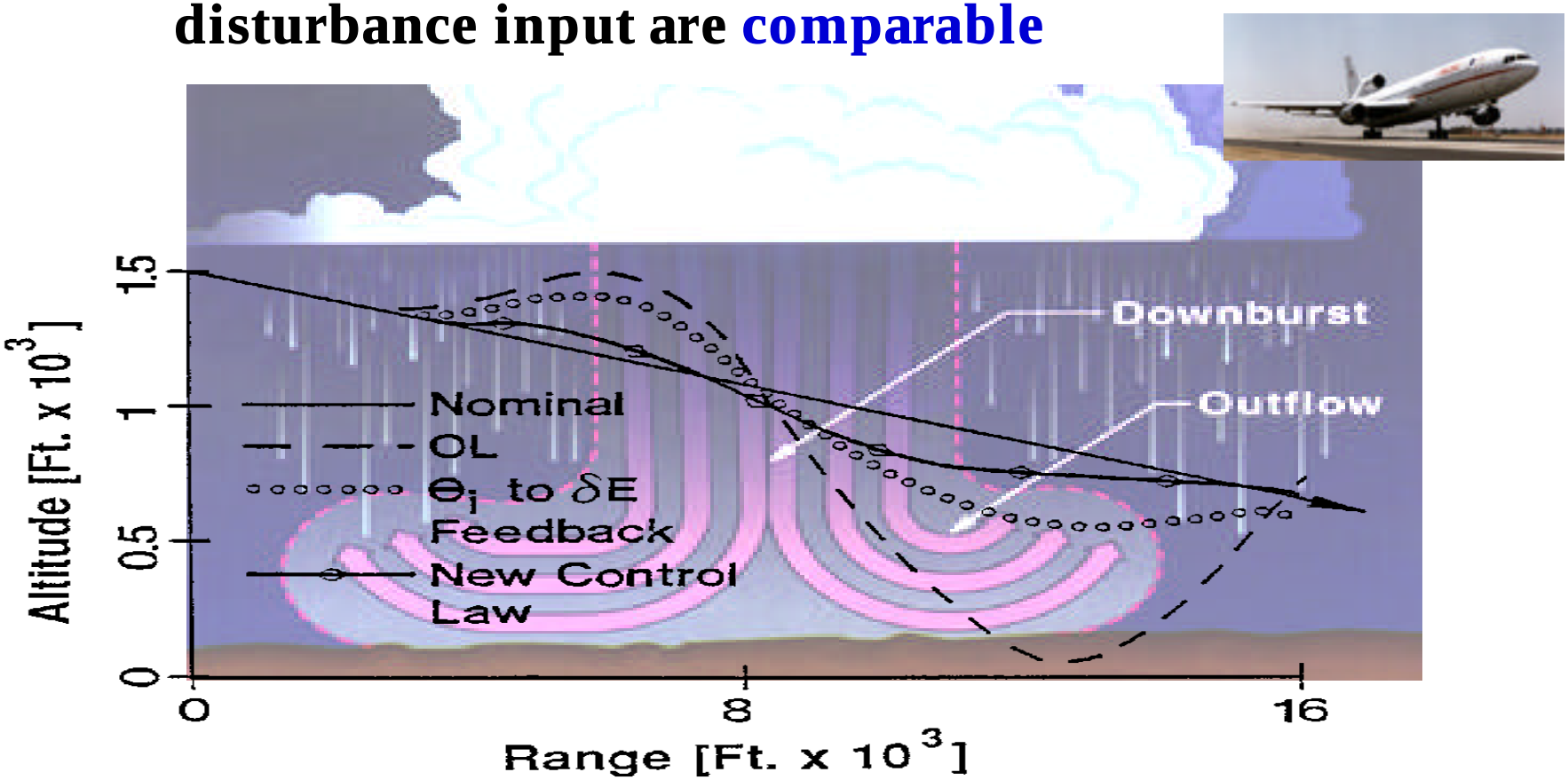
Microbursts

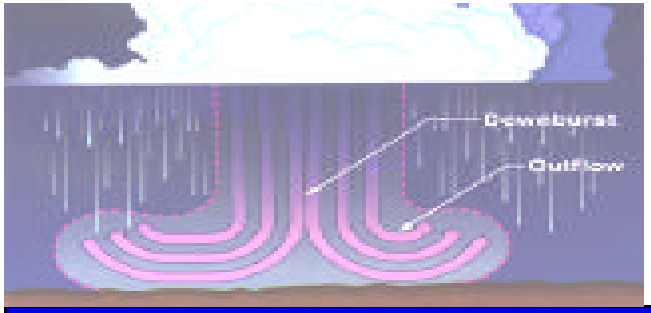


CVR, Delta 191, L-1011
Dallas-Fort Worth
Aug. 2, 1985
137 fatalities, 30 survivors

The Insidious Nature of Microburst Encounter

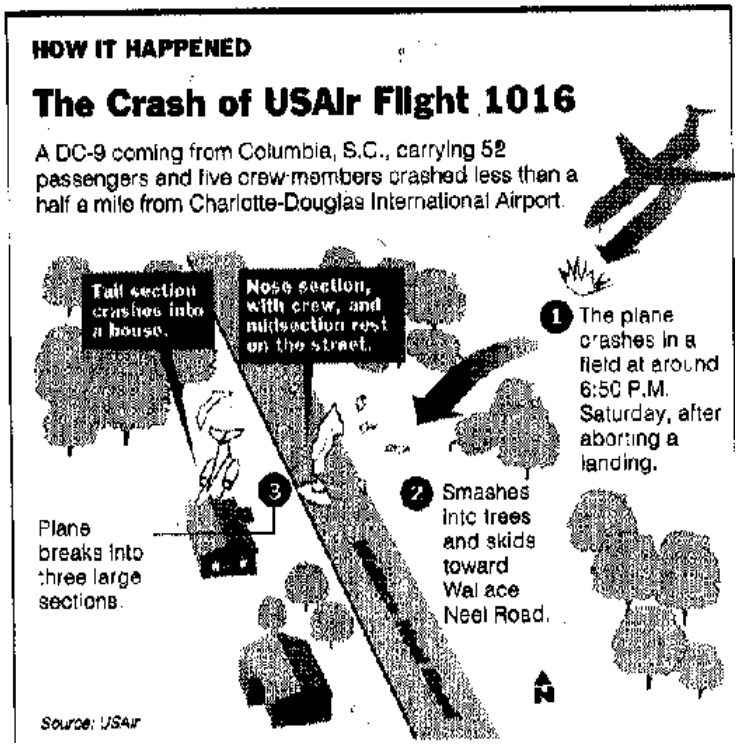
- The period of the phugoid mode and the disturbance input are comparable



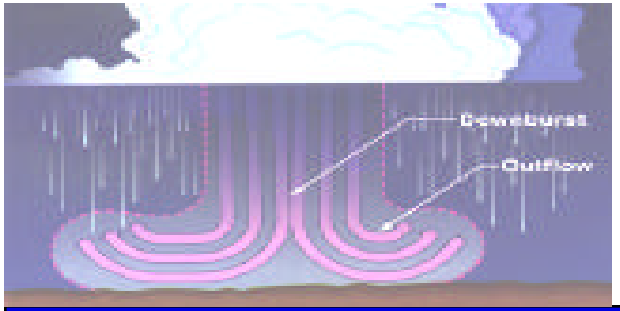


Importance of Proper Response to Microburst Encounter

FAA Windshear Training Aid, 1987

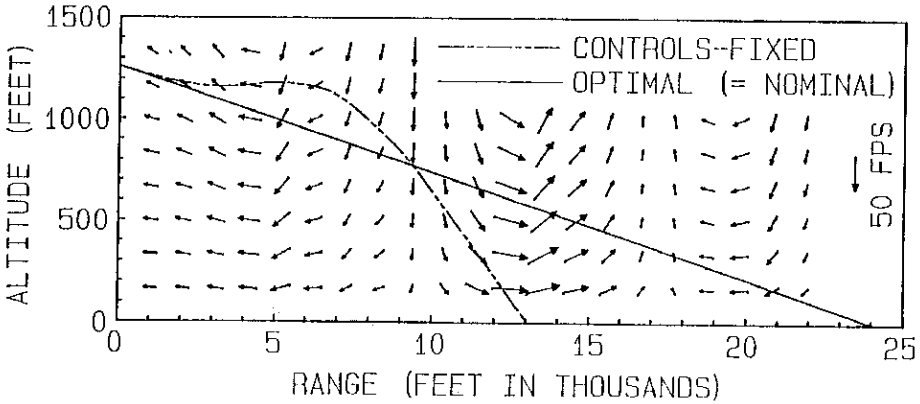


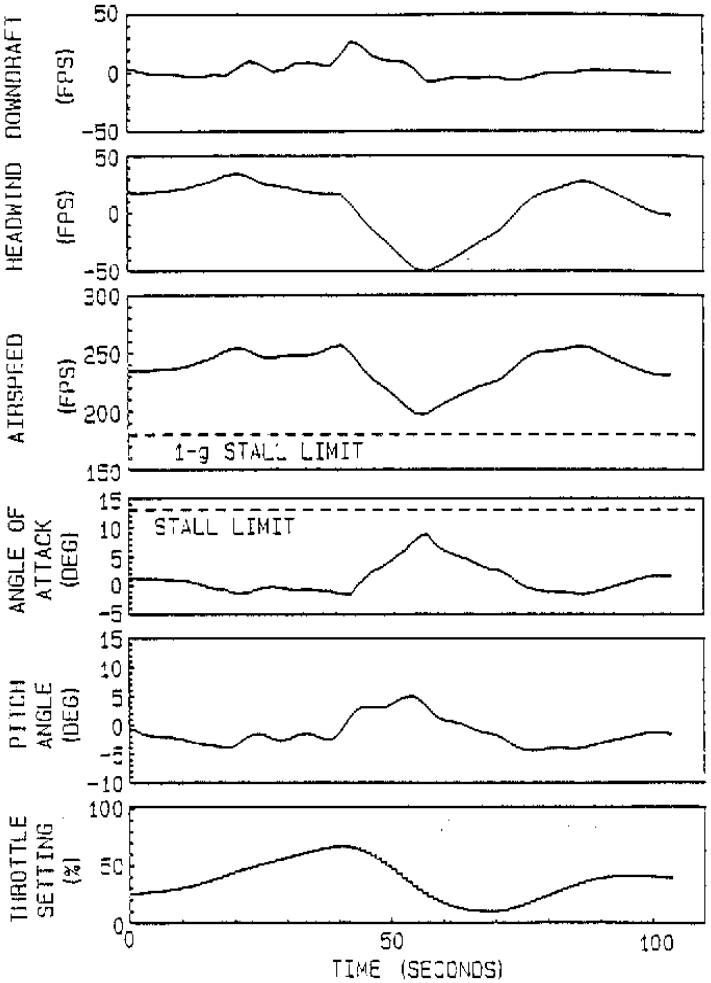
- It was a stormy evening July 2, 1994 as **USAir Flight 1016** approached the Charlotte airport. A windshear alert was issued as 1016 began it's descent down the glideslope. The DC-9 encountered an incredible 61-kt windshear; the crew executed a missed approach. As the aircraft rotated for go-around, it turned slightly to the right. The plane continued to descend, striking trees and telephone poles before impacting the ground.
- The crew's go-around procedure was begun correctly -- the aircraft's nose rotated up -- but the power was not advanced. That, together with the increasing tailwind, caused the aircraft to stall. The crew lowered the nose to avoid the stall, but the descent rate increased, causing ground impact.

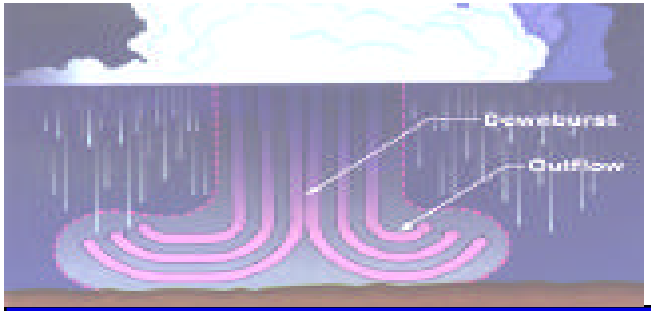


Optimal Flight Path Through Worst JAWS Profile

- **Graduate Research of *Mark Psiaki***
- **Joint Aviation Weather Study (JAWS) measurements of microbursts (1983)**
- **Negligible deviation from intended path using available controllability**

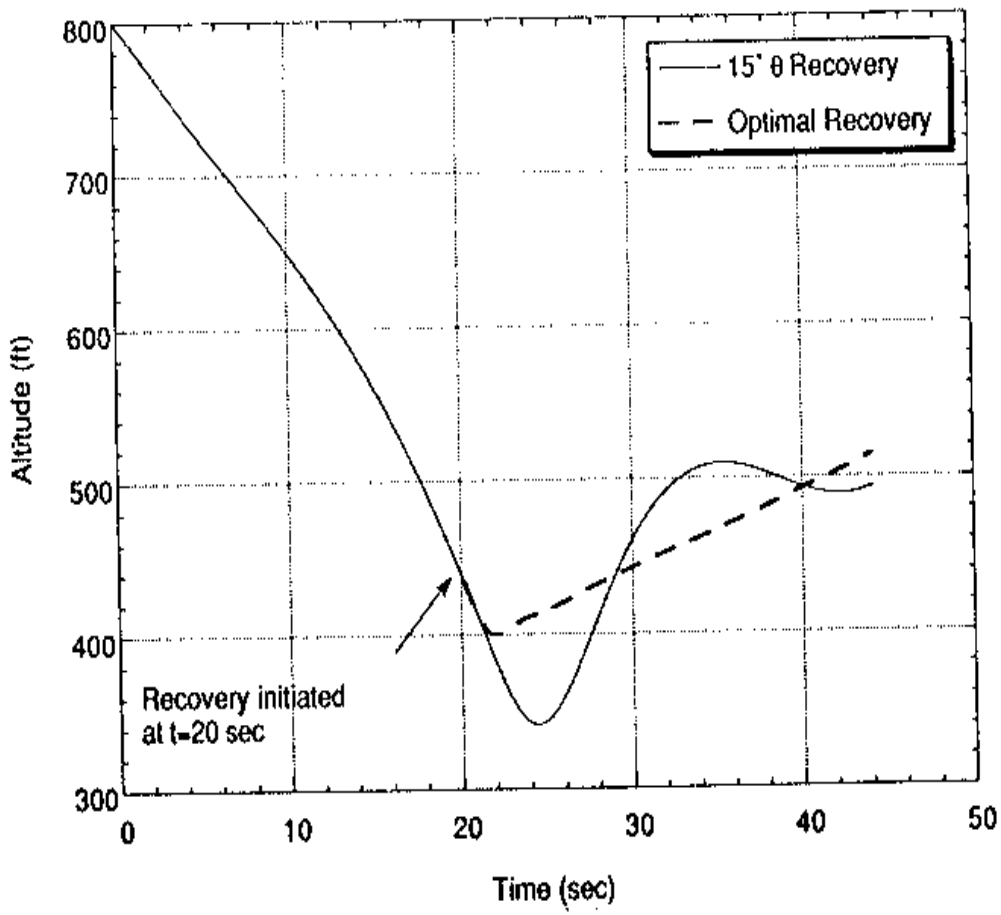


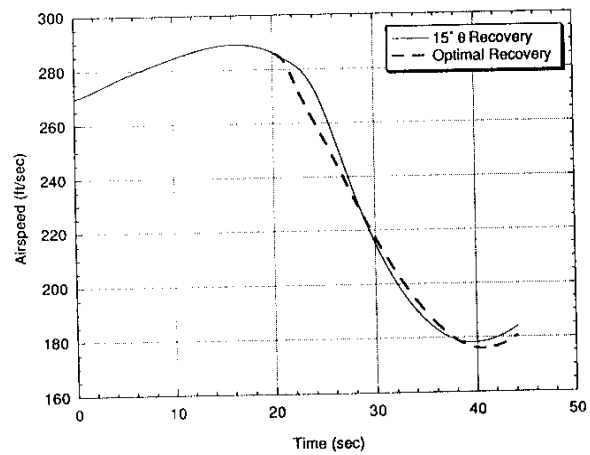


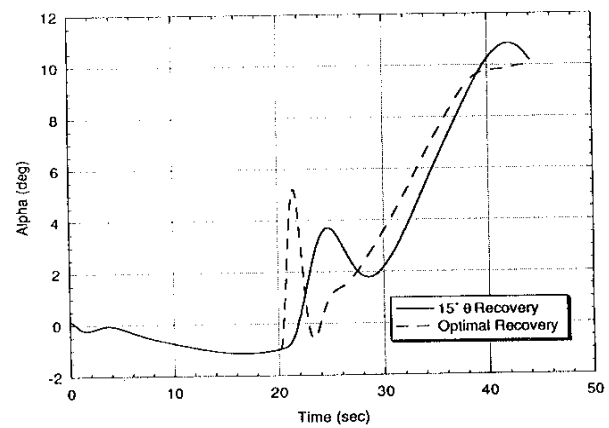


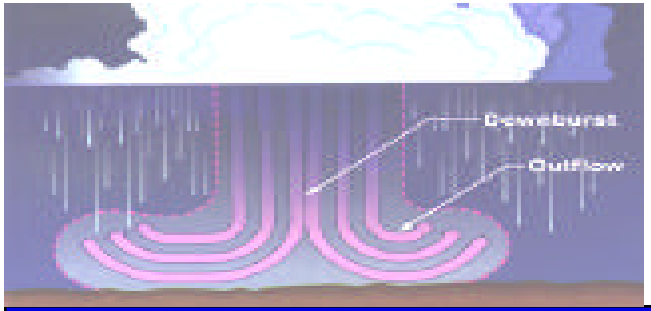
Optimal and 15° Recovery during Microburst Encounter

Graduate Research of *Sandeep Mulgund*









Nonlinear-Inverse-Dynamic Control

- **Nonlinear system with additive control:**

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}) + \mathbf{G}(\mathbf{x})\mathbf{u}$$

- **Output vector:**

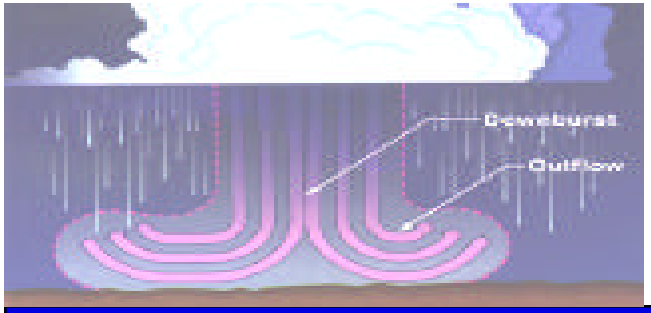
$$\mathbf{y} = \mathbf{h}(\mathbf{x})$$

- **Differentiate output until control appears in each element of the derivative output:**

$$\mathbf{y}^{(d)} = \mathbf{f}^* + \mathbf{G}^*(\mathbf{x})\mathbf{u} = \mathbf{v}$$

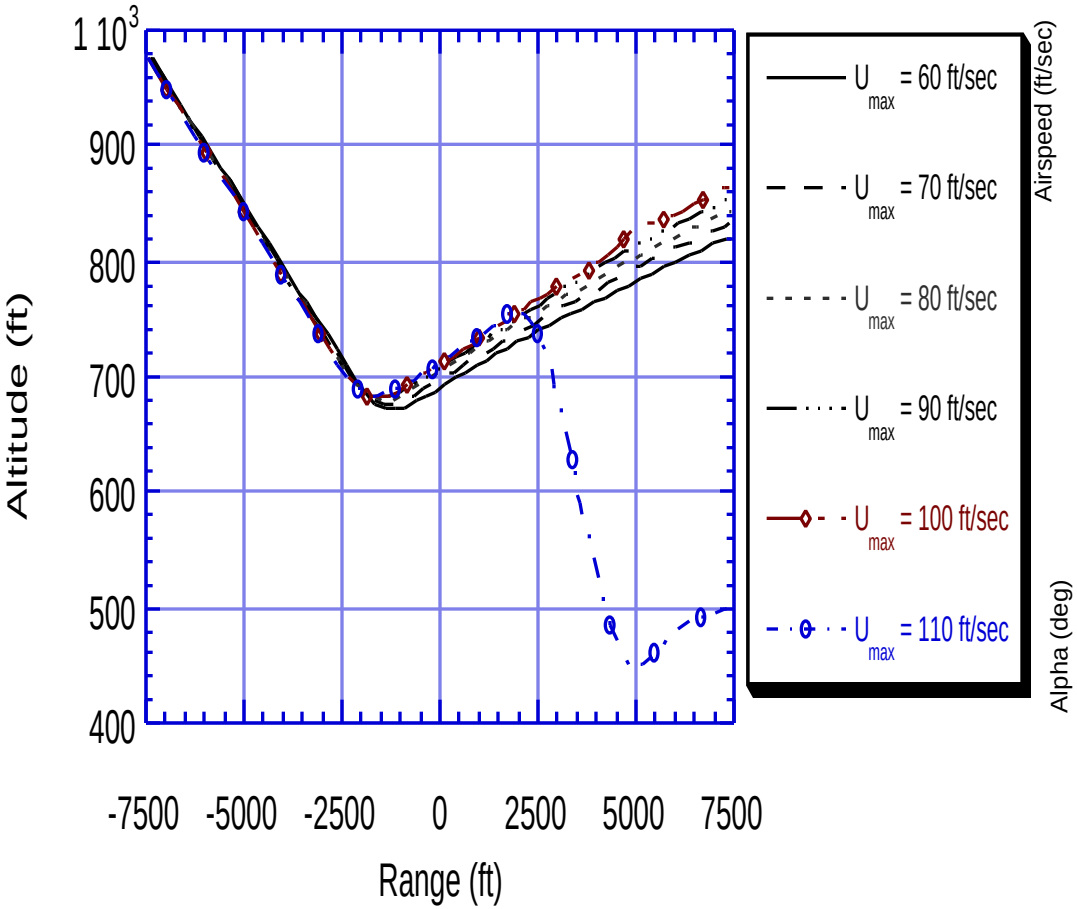
- **Inverting control law:**

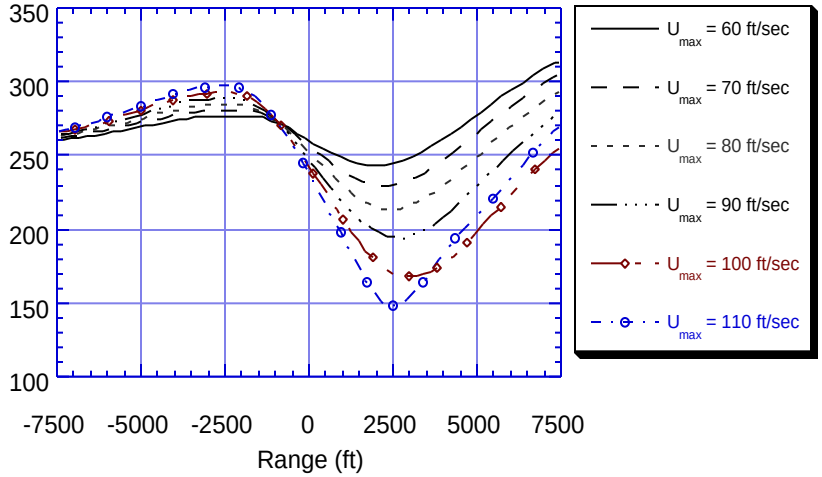
$$\mathbf{u} = \mathbf{G}^{*-1}[\mathbf{v}_{command} - \mathbf{f}(\mathbf{x})]$$

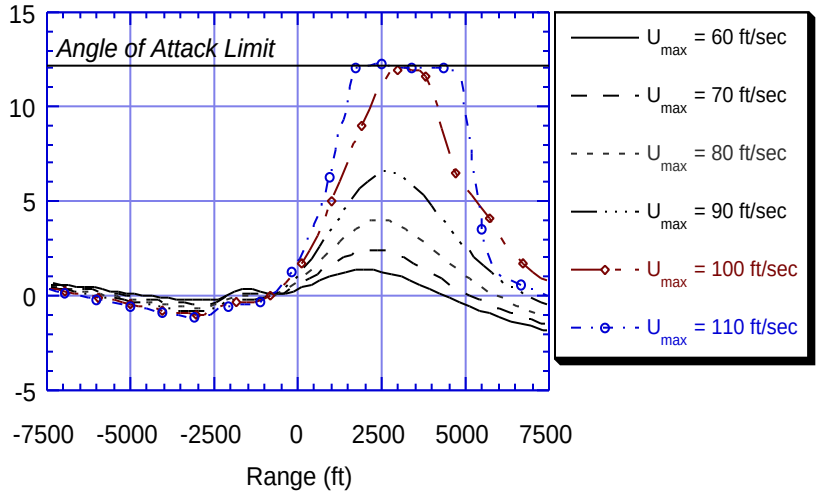


Landing Abort using Nonlinear-Inverse-Dynamic Control

from *Mulgund*

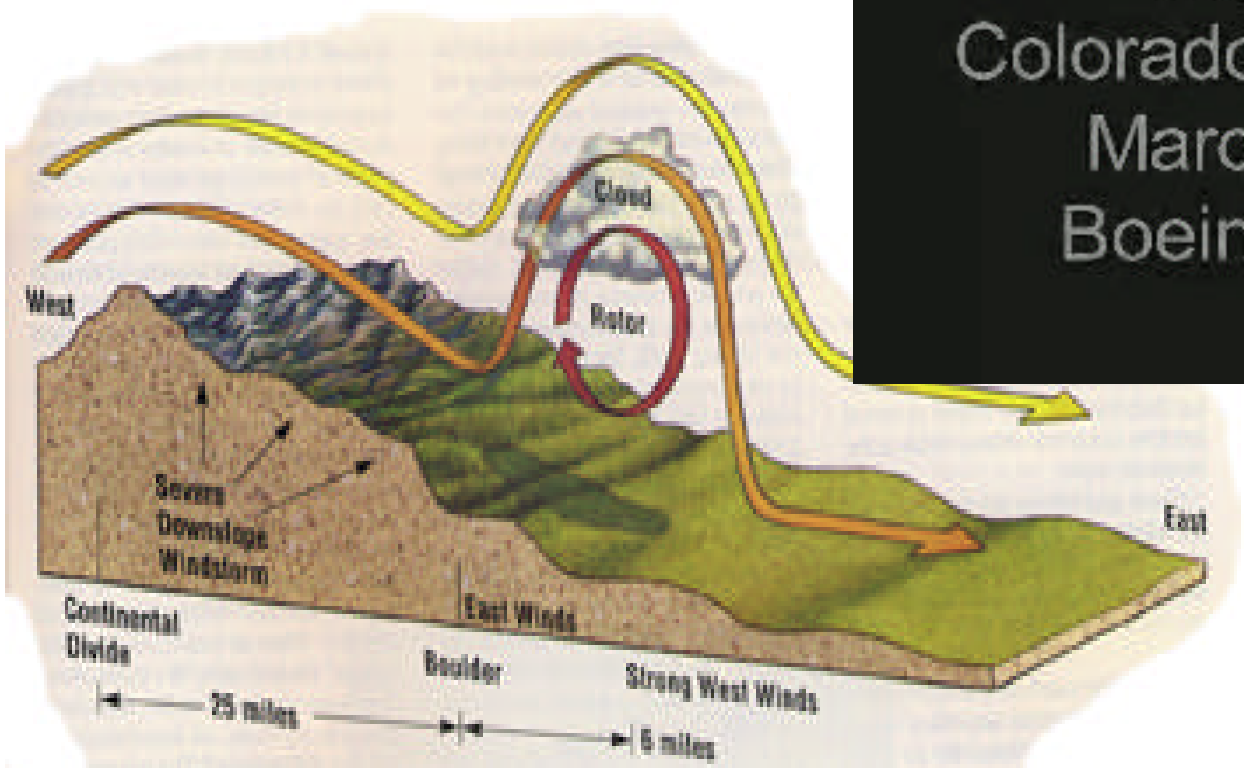


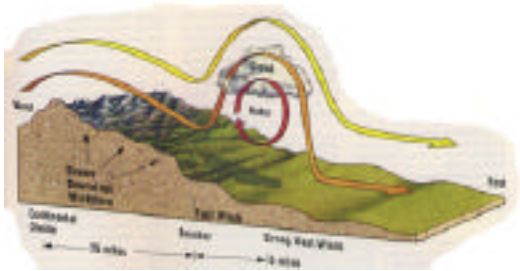




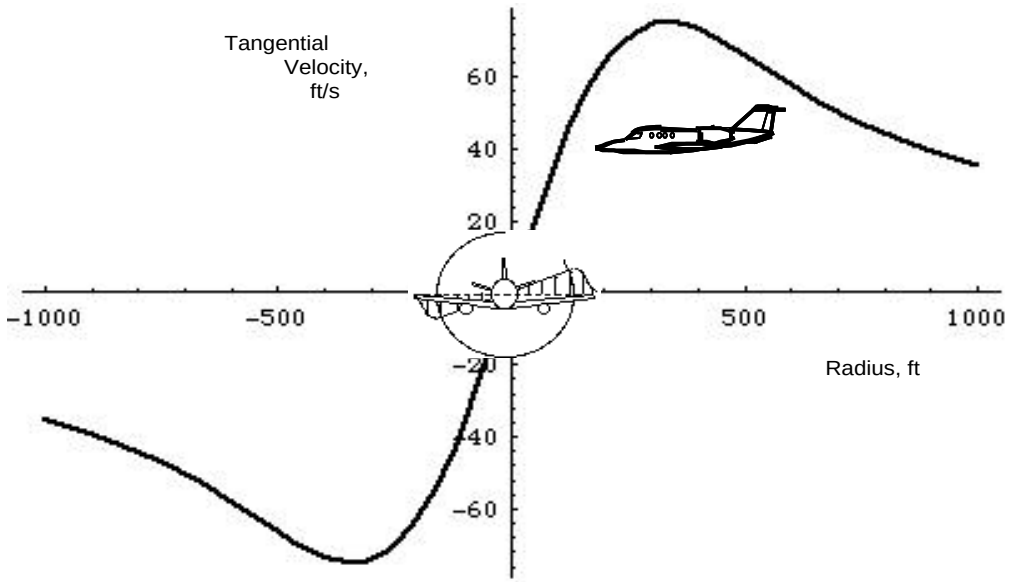
Wind Rotors

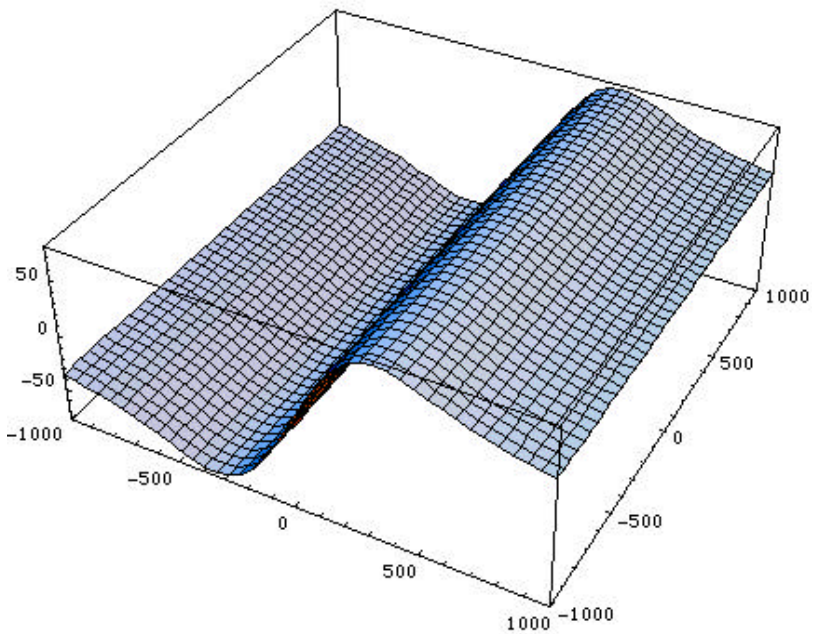
United Airlines
Flight 585
Colorado Springs, CO
March 3, 1991
Boeing 737-200





Aircraft Encounters with a Wind Rotor

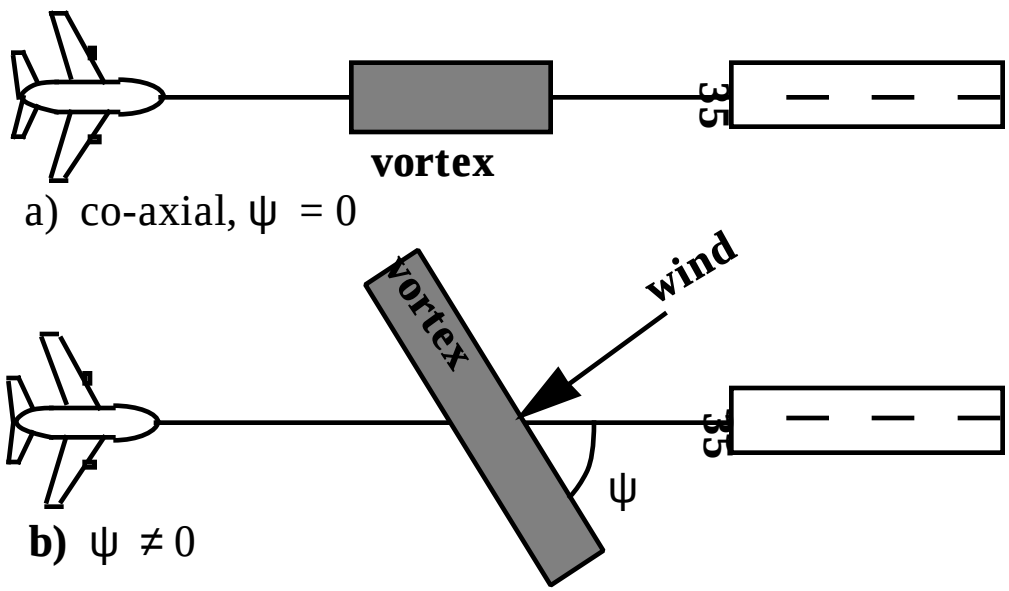


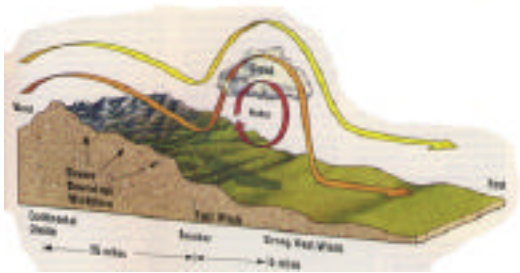


- **Tangential velocity vs. radius for *Lamb-Oseen* Vortex**

Geometry and Flight Condition of Jet Transport Encounters with Wind Rotor

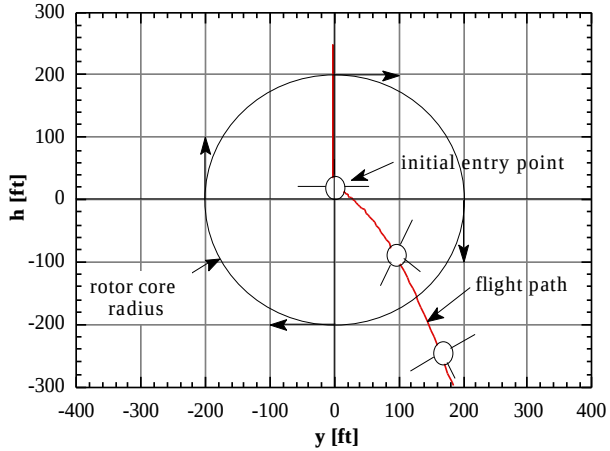
- **Graduate research of *Darin Spilman***
- **Flight Condition**
  - **True Airspeed = 160 kt**
  - **Altitude = 1000 ft AGL**
  - **Flight Path Angle = -3˚**
  - **Weight = 76,000 lb**
  - **Flaps = 30˚**
  - **Open-Loop Control**
- **Wind Rotor**
  - **Maximum Tangential Velocity = 125 ft/s**
  - **Core Radius = 200 ft**

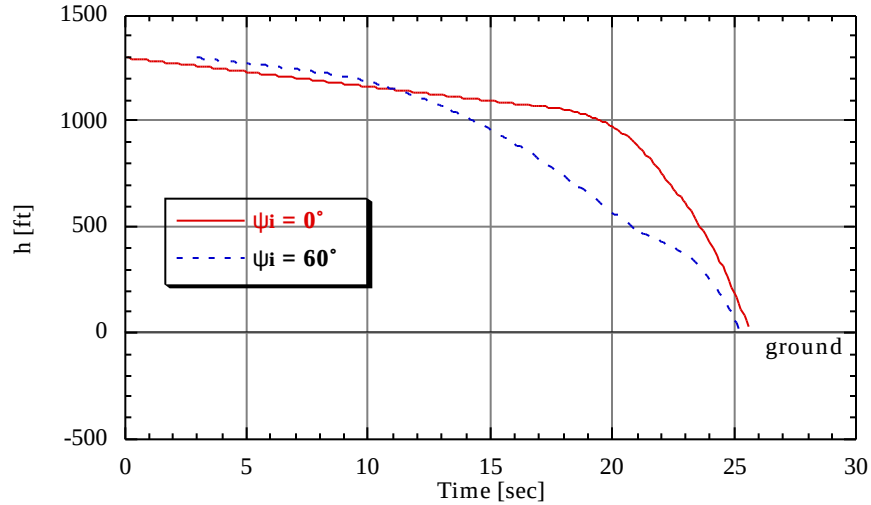


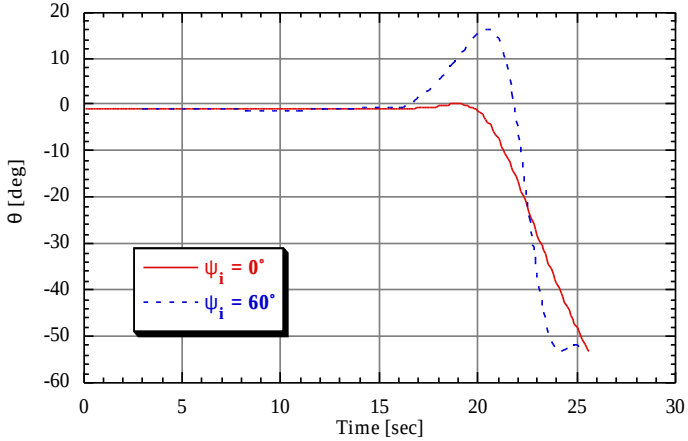


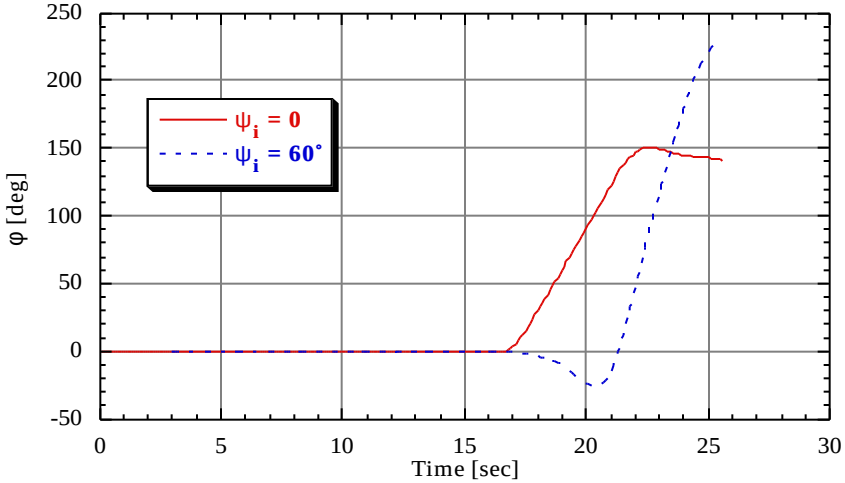
Typical Flight Paths in Wind Rotor Encounter

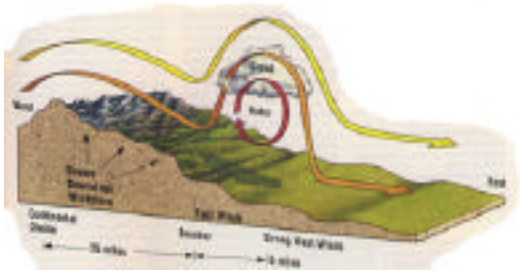
from *Spilman*





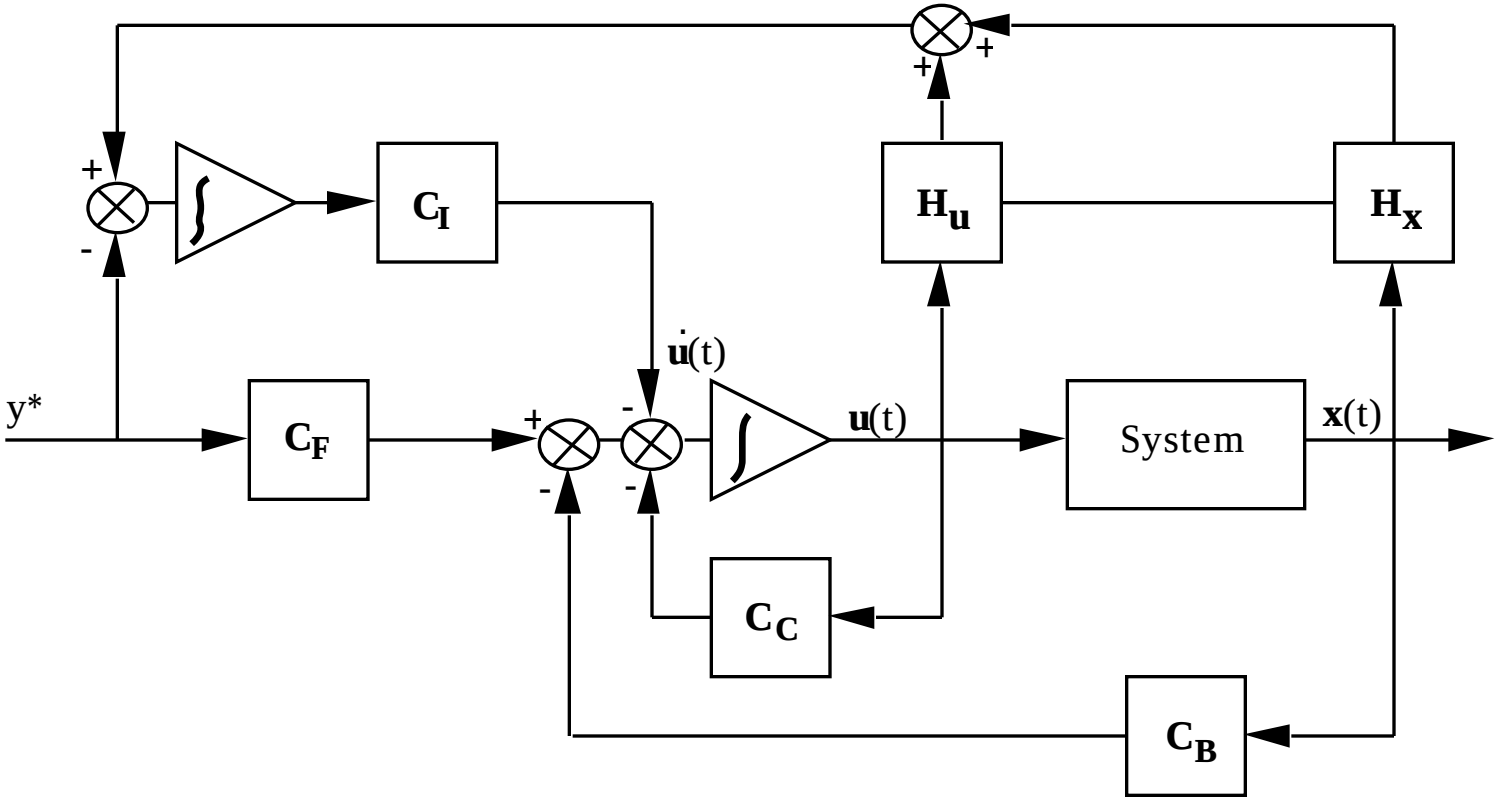


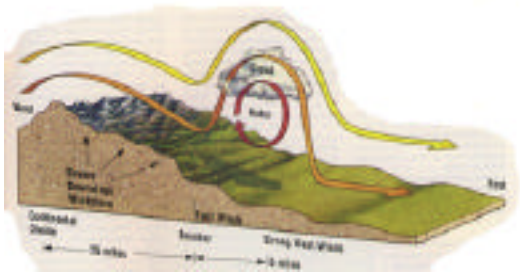




Linear-Quadratic/Proportional-Integral Filter (LQ/PIF) Regulator

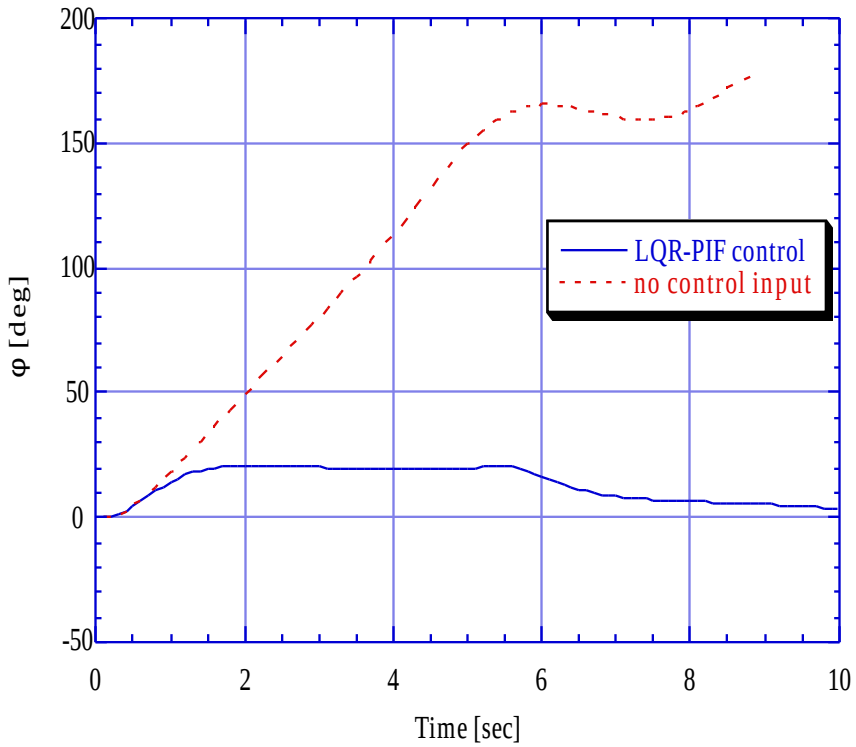
- from *Spilman*

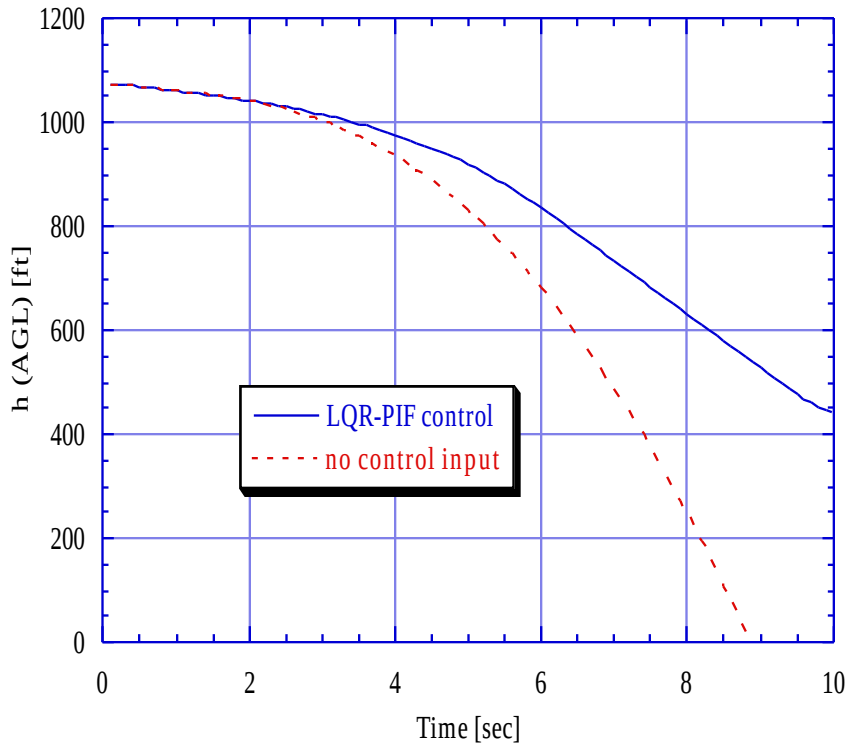


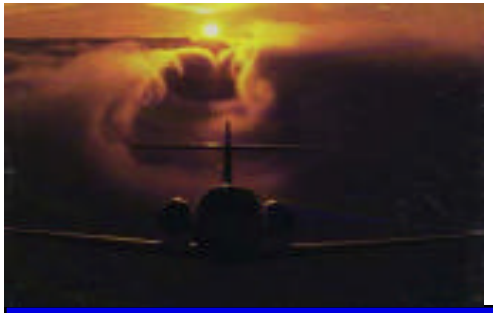


LQ/PIF Regulation of Wind Rotor Encounter

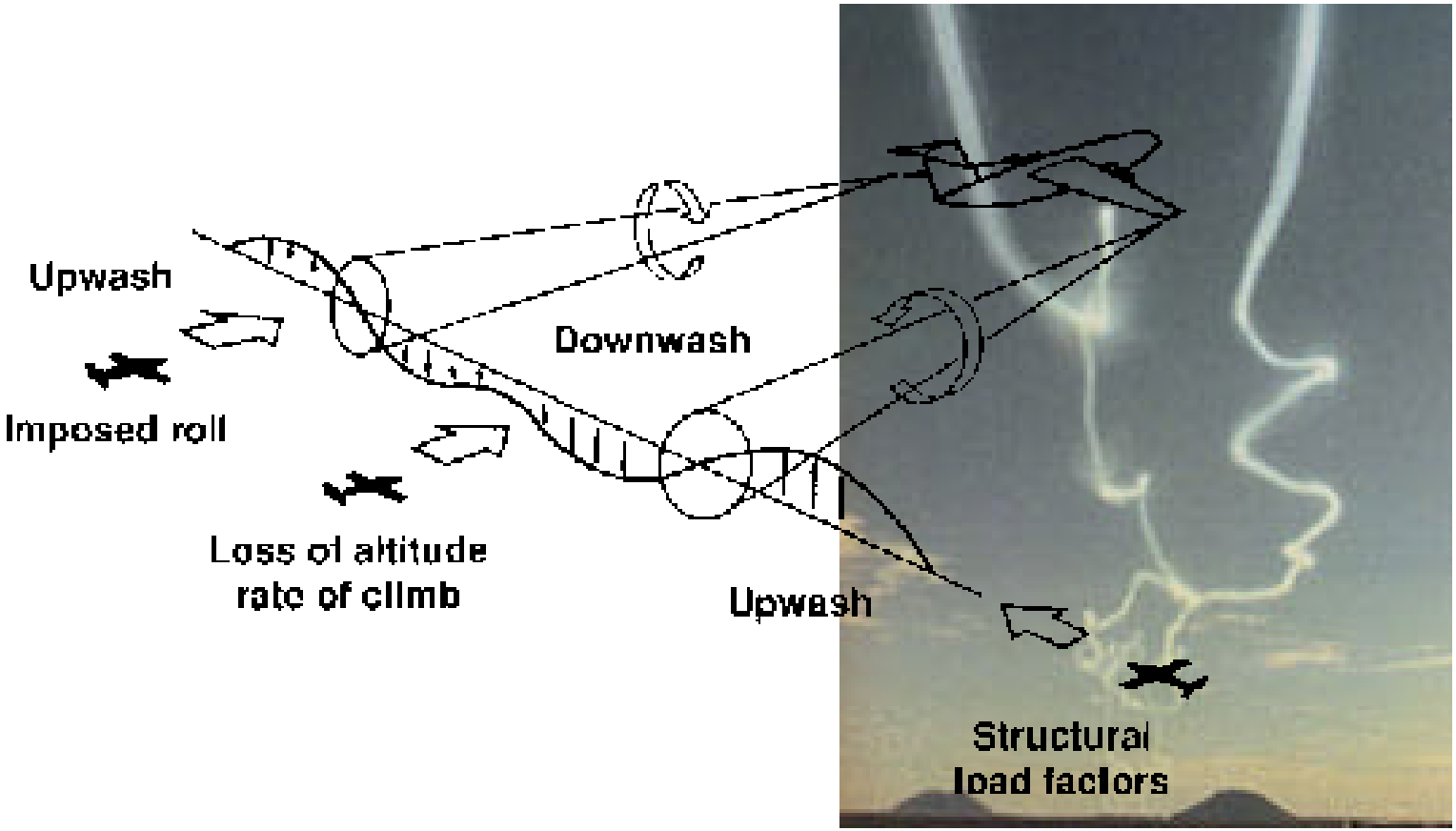
- from *Spilman*



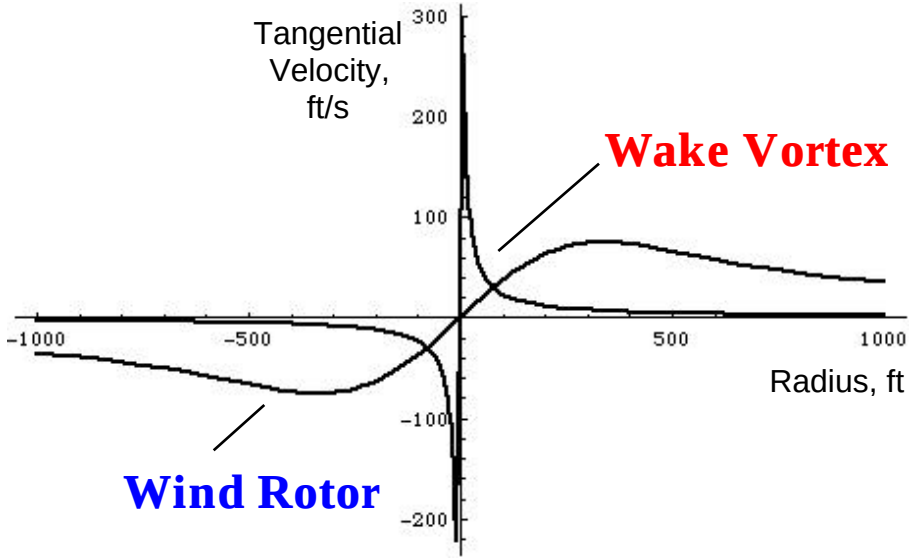


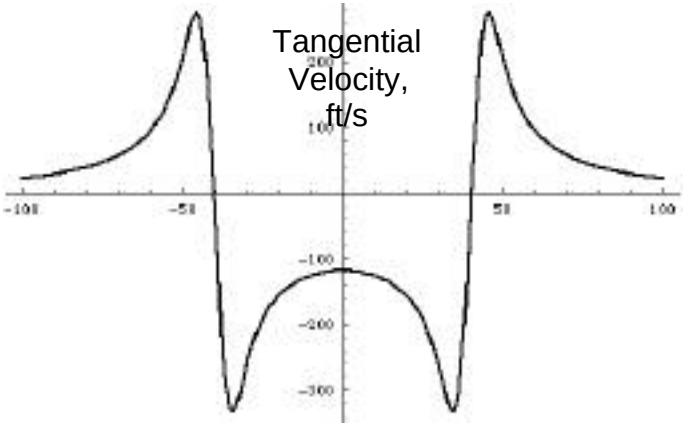


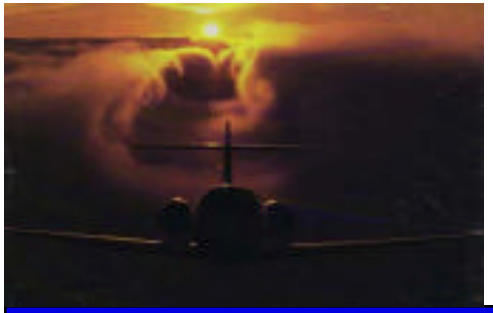
Wake Vortices



Models of Single and Dual Wake Vortices

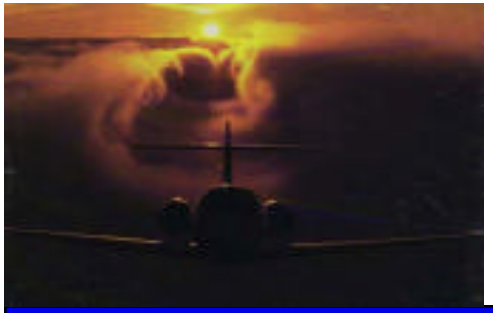




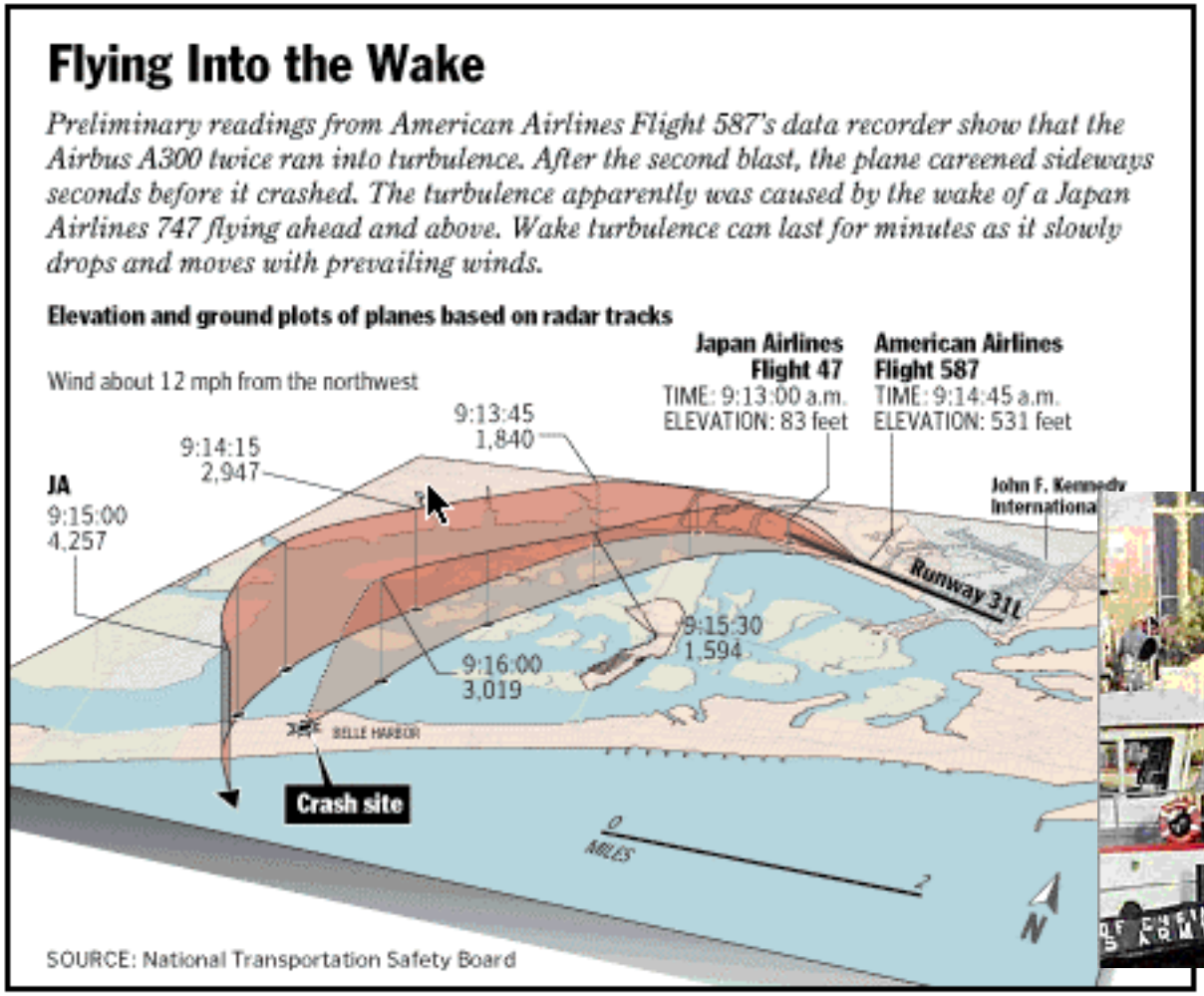


FAA Wake Vortex Flight Test and NTSB Simulation of US Air 427

- B-737 behind B-727 in FAA flight test
- Control actions subsequent to wake vortex encounter may be problematical
- US427 rudder known to be hard-over from DFDR

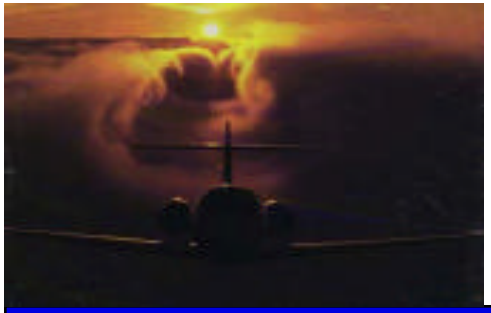


American 587 (Airbus A-300-600)

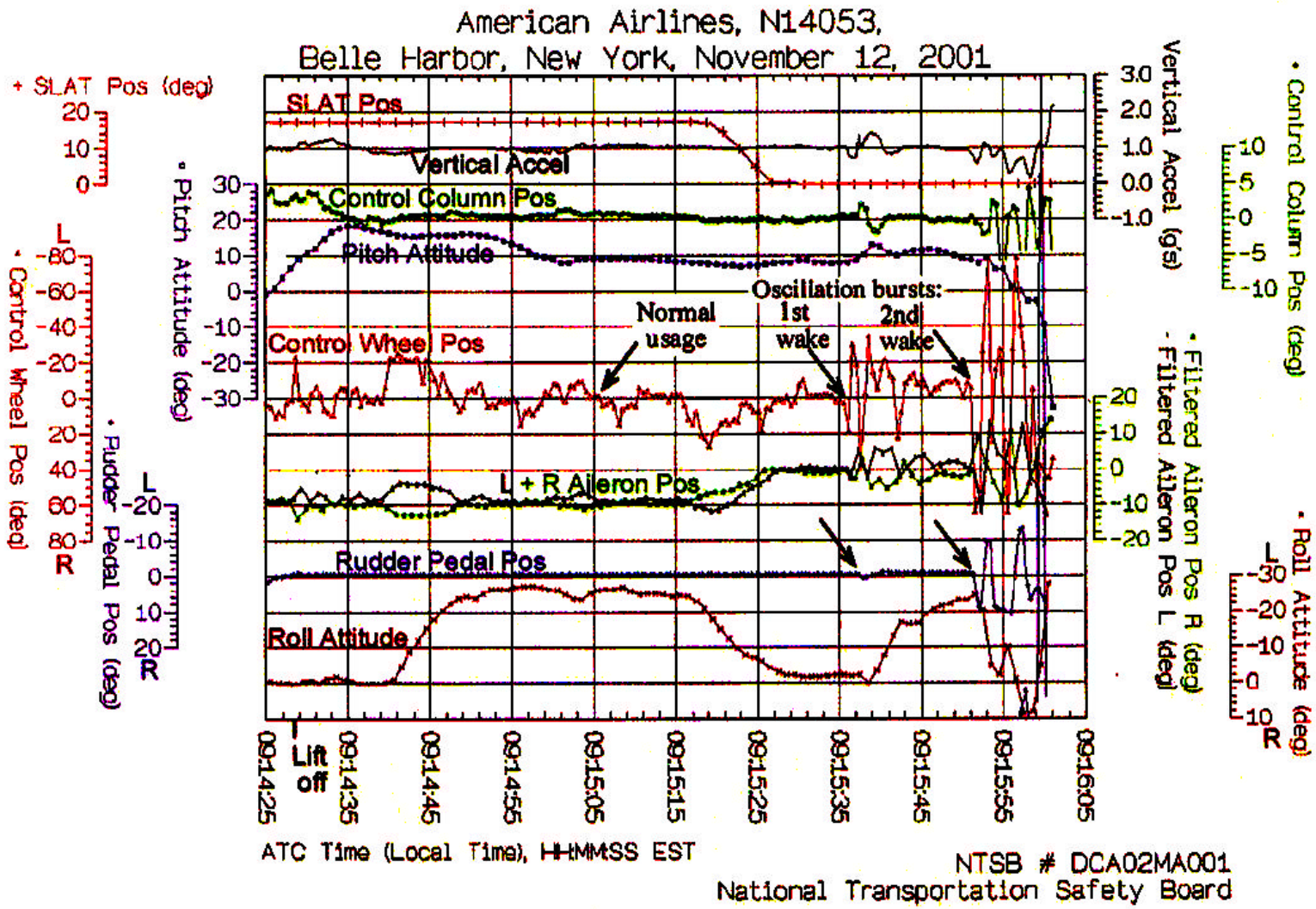


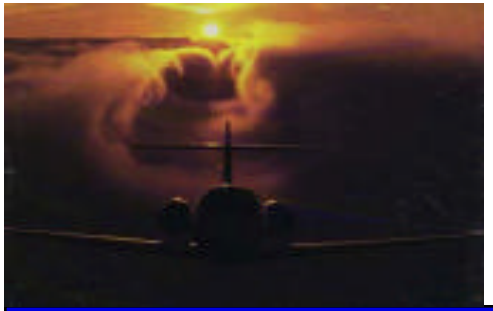
BY RICHARD FURNO—THE WASHINGTON POST

- **PIO and/or aggressive use of rudder seen as possible cause**
- ***Aviation Daily*, 5/22/02: Boeing Issues Detailed Guidance On Rudder Use For Roll Control**



Digital Flight Data Recorder Data for American 587

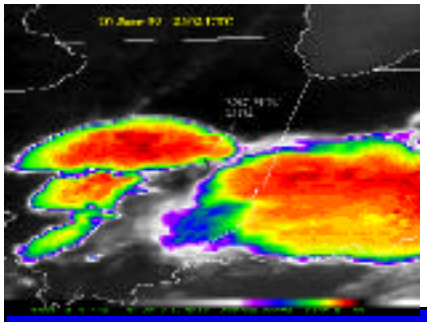




NTSB Movie and Simulation of American 587

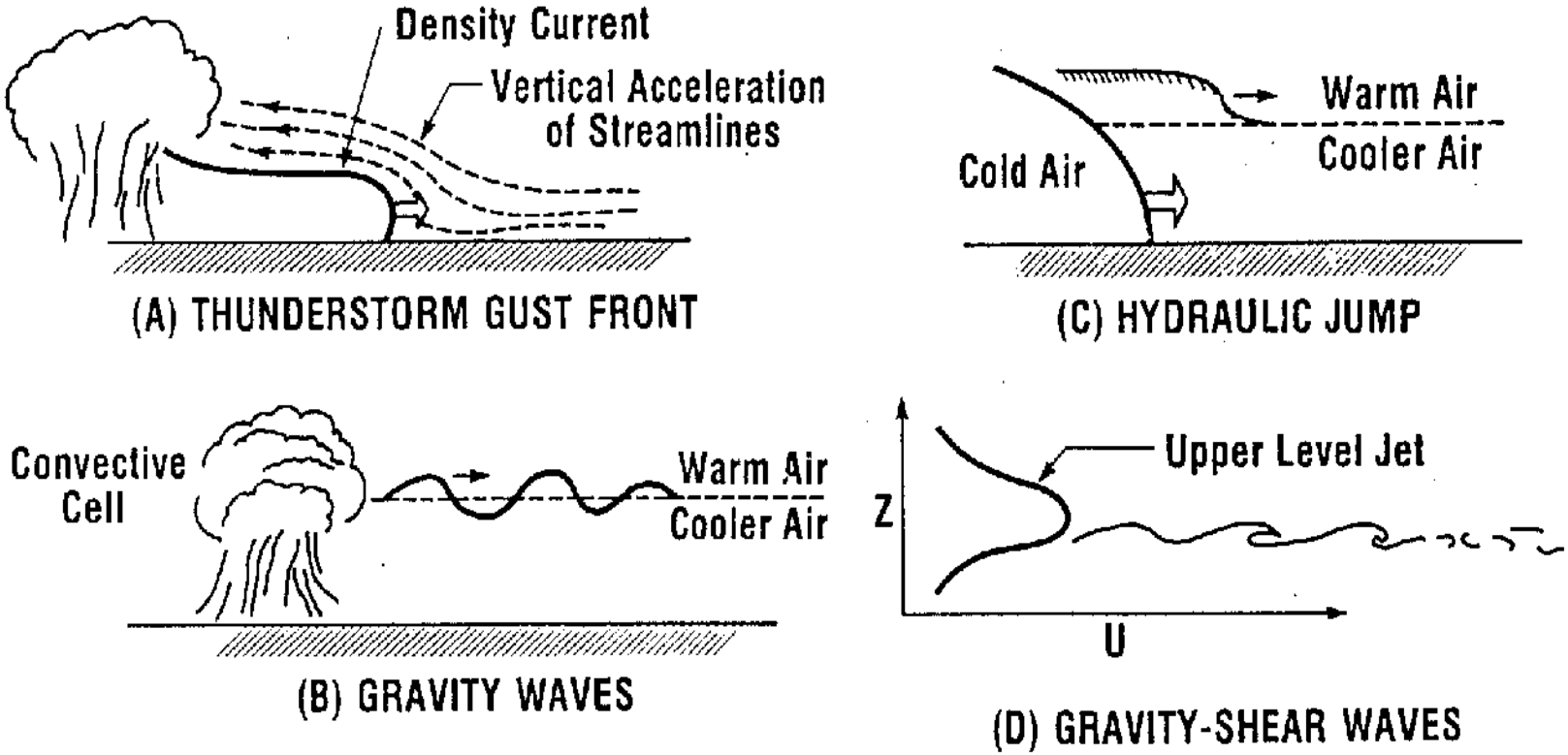
- Flight simulation obtained from digital flight data recorder (DFDR) tape

- Amateur video from airport construction site



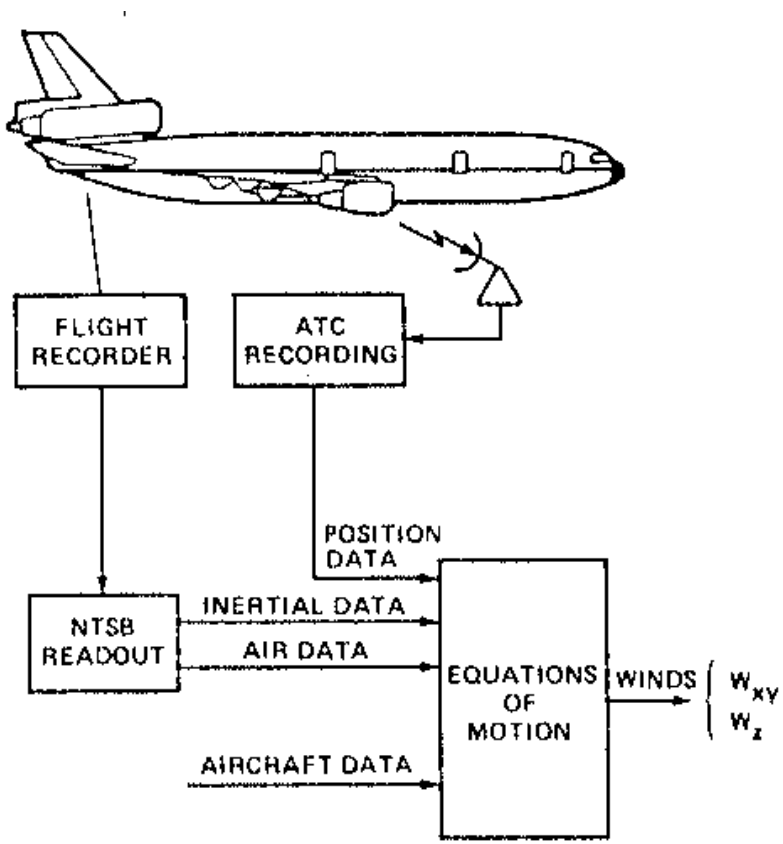
Causes of Clear Air Turbulence

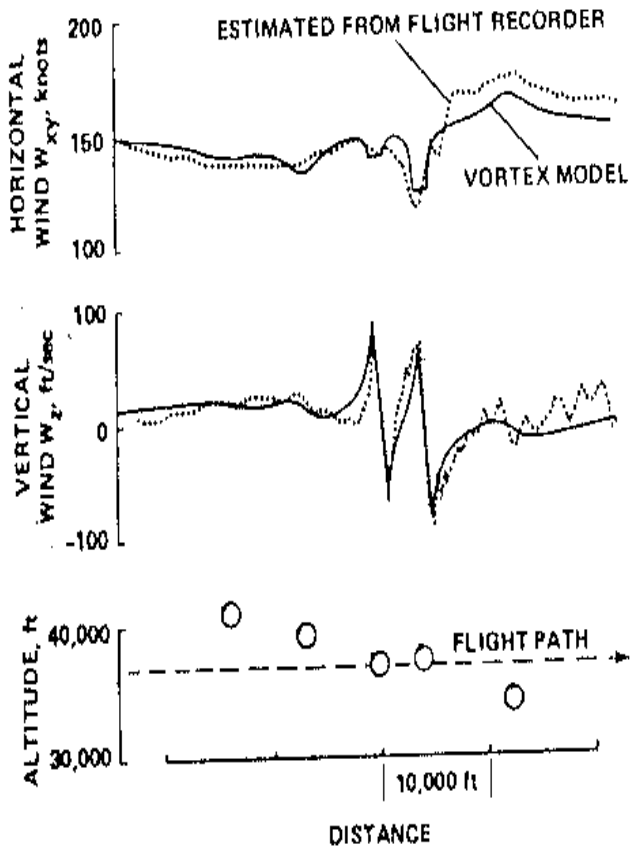
- from *Bedard*

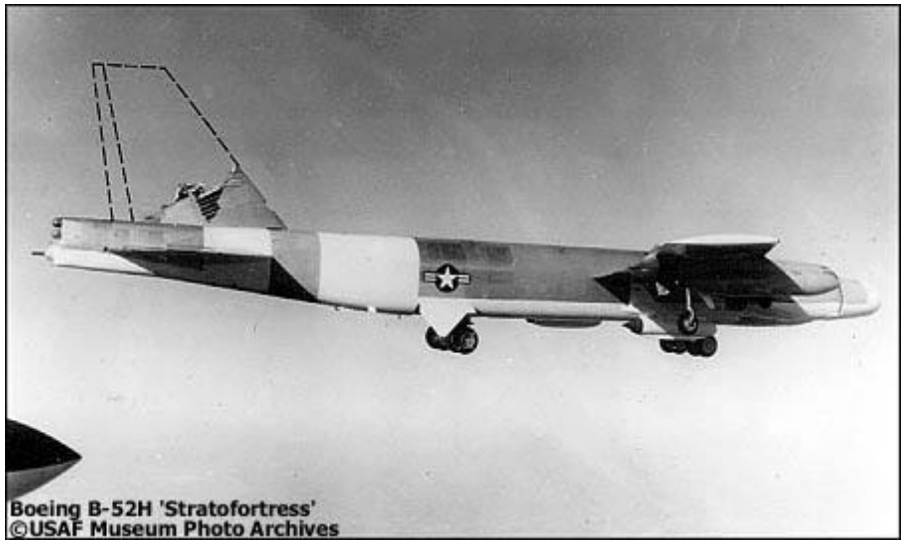


DC-10 Encounter with Vortex-Induced Clear Air Turbulence

- from *Parks et al*





DC-8 and B-52H Encounters with Clear Air Turbulence

- DC-8: One engine and 12 ft of wing missing after CAT encounter over Rockies
- Specially instrumented for air turbulence research after some operational B-52s were lost
- Tail lost after a severe and sustained burst (+5 sec) of clear air turbulence violently buffeted the aircraft
- The Boeing test crew flew aircraft to Blytheville AFB, Arkansas and landed safely