The Effects of Rapid Rudder Reversals on Vertical Tail Loads

NTPS

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Background

- AA 587 took off approximately 105 seconds behind a JAL 747
- Flight 587 encountered two wake vortices generated by the 747
  - During the last 8 seconds of recorded data, AA 587 experienced three strong lateral movements
    - Two to the right of 0.3 and 0.4 Gs
    - One to the left of 0.3 Gs.
    - Corresponded to rudder movements
- The rudder and tail fin were found first in the wreckage path indicating that the vertical tail failed first


CAPT: V one.
CAPT: rotate.
09:14:24
0 FT
158 KTS
NTSB
VERTICAL ACCEL
RUDDER: PEDAL
SURFACE
LATERAL ACCEL
TAIL SECTION

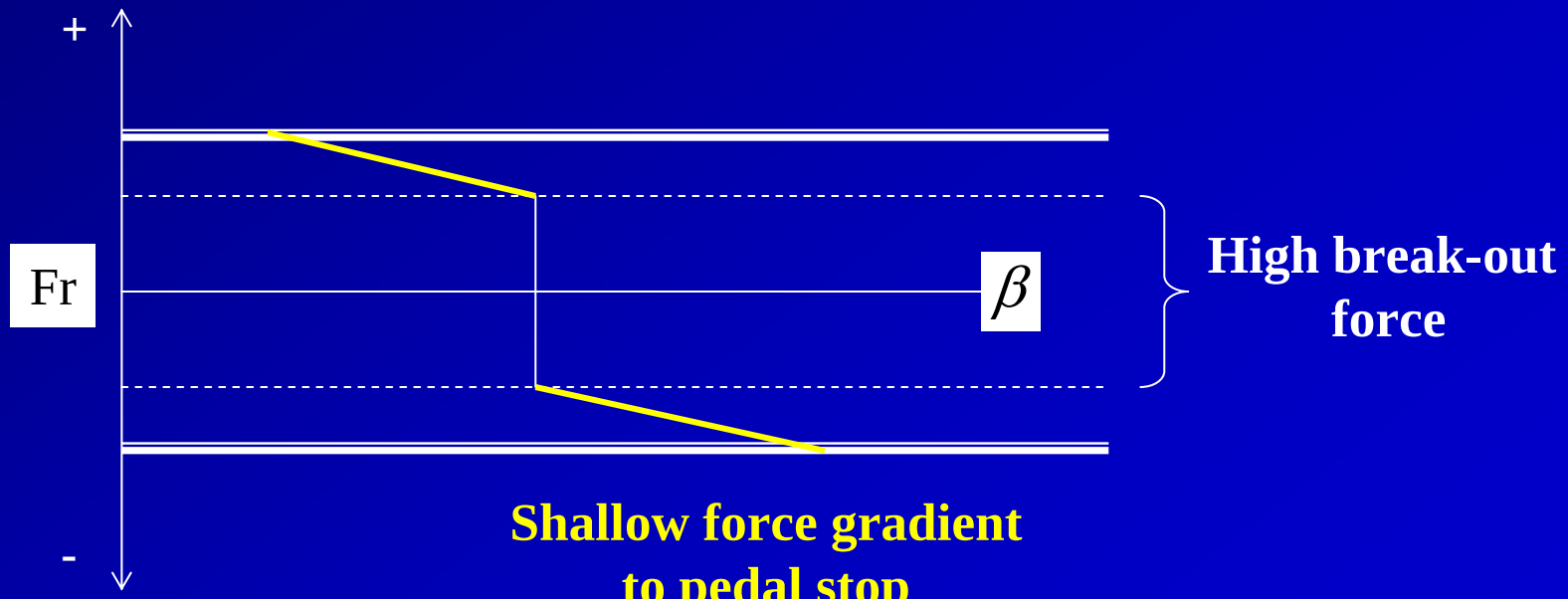
NTPS

Background

Finding:
“. . . the high loads that eventually overstressed the vertical stabilizer were solely the result of the pilot's rudder pedal inputs . . .”

Background

- **Contributing factors**
  - **A300-600 provided very little rudder force feedback**
    - **Little additional rudder force required to drive pedal to the stops after overcoming initial breakout force (22 lbs)**



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Background

- **Contributing factors**
  - **American upset training emphasized the use of rudder in unusual attitude recoveries**
  - **Pilot misconceptions**
    - **Alternating rudder inputs were safe below design maneuvering speed (V_a)**
    - **The rudder limiting system would protect the structure from pilot inputs**

NOTE:
The mishap occurred at < 250 kts
- Well below maneuver speed

NTPS Test Program

- **Primary Objective**
  - **Empirically show that vertical tail loads dramatically increase with rapid rudder reversal**
- **Limitations**
  - **Rudder reversals shall not exceed ½ deflection in the opposite direction and shall be accomplished at 180 KIAS ±5 knots (below Va)**

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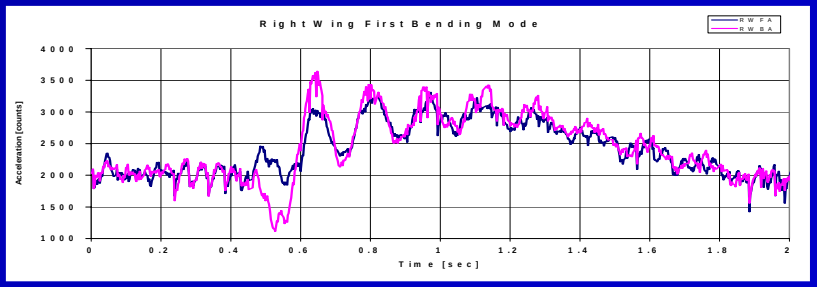
Test Bed
Description

- Impala MB-326 (N155TP)
- 2 seat tandem trainer & light attack
- Single jet engine
- Fully reversible flight controls
- No hydraulic boost
- Cleared to 6Gs (symmetric) and 5Gs (asymmetric)
- Instrumented for loads and flutter flight test training

Test Bed
Description

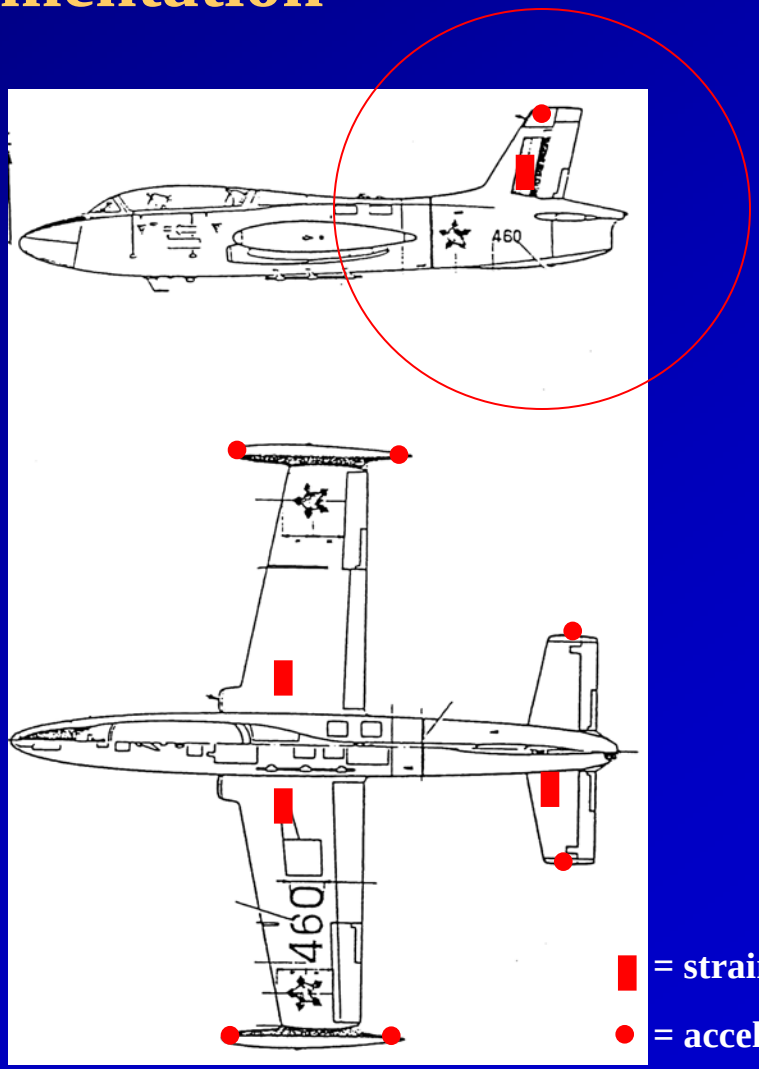
- Sensitive “g” meter
- Telemetry System

- Real time data monitoring via control room

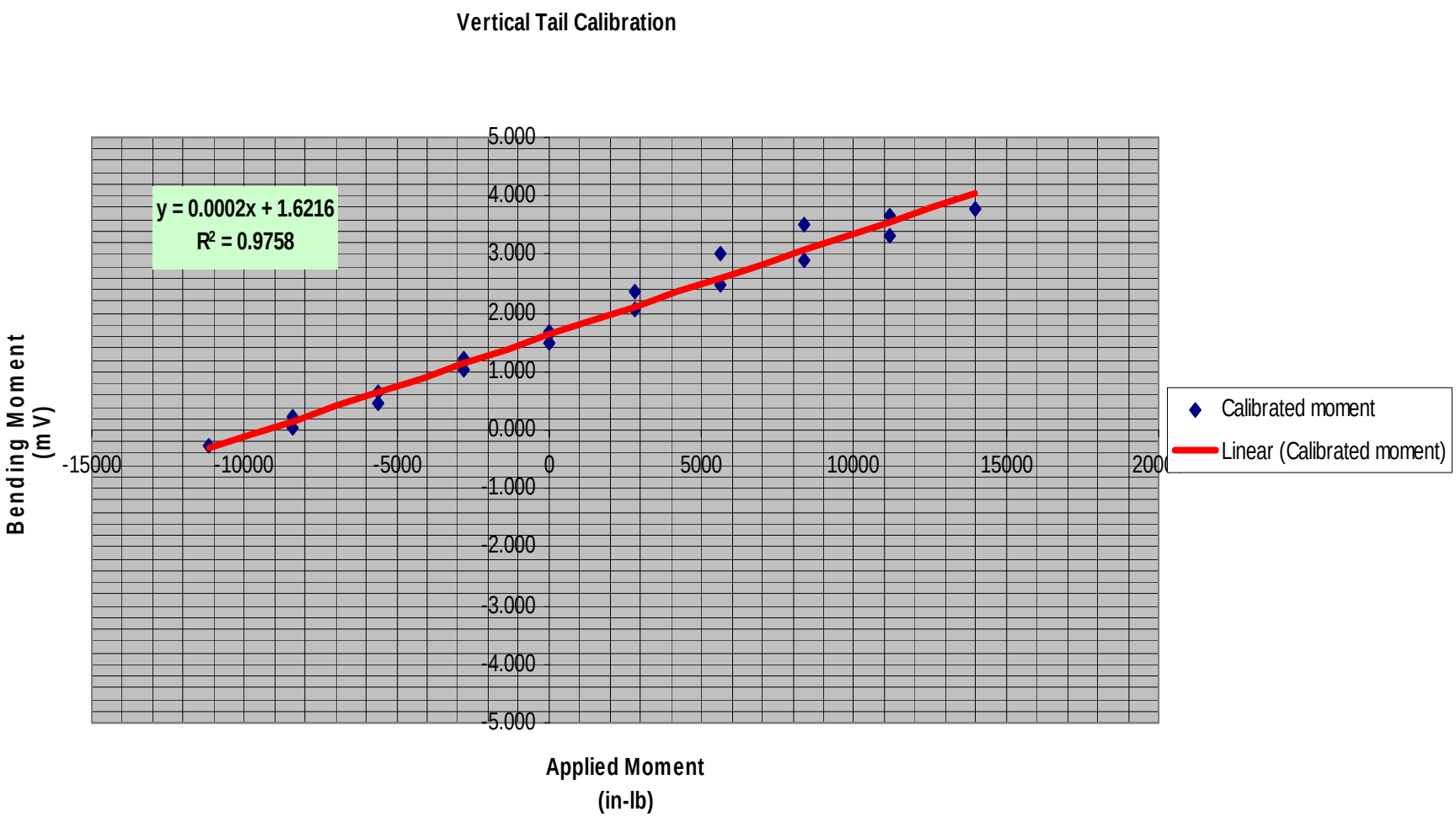


Test Bed
Instrumentation

- Airspeed
- Altitude
- Roll rate
- Pitch rate
- Yaw rate
- Nz
- Elevator deflection
- Aileron deflection
- Rudder deflection
- **Strain gages**
- **Linear accelerometers**

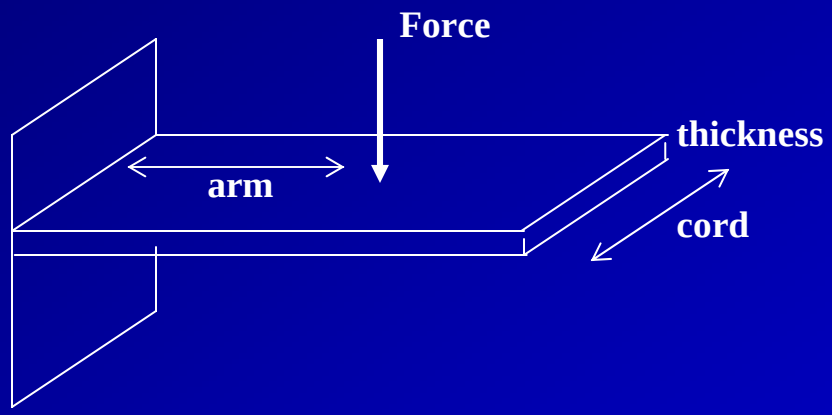


Vertical Tail Calibration



Simplifying Assumptions

Simple cantilever plate model



Bending stress = bending moment/sectional modulus

Sectional modulus = (cord x thickness^2)/6

Bending strain = bending stress/Young's modulus

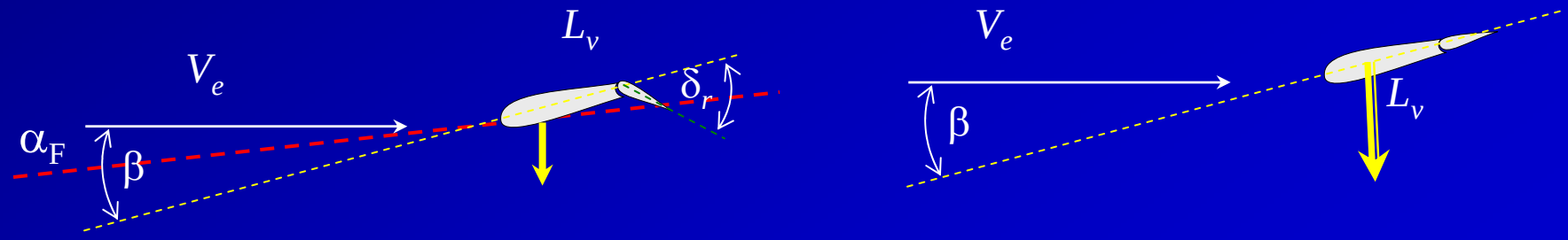
Young's modulus = 10.8 x 10^6 psi

Vertical Tail Calibration

- **NOTE: BASED ON MODEST INSTRUMENTATION AND SIMPLIFYING ASSUMPTIONS**
  - **NOT CONCERNED WITH ABSOLUTE VALUES**
  - **INTERESTED IN RELATIVE VALUES**

FAR Requirements

- **Section 25.351 dictates the**
  - **Start at trim**
  - **Suddenly displace rudder either to its stop or the position resulting from a specified force limit: 300 lbs below Va (maneuver speed) and 200 lbs above Va.**
  - **Once the aircraft is stable at the equilibrium beta, suddenly return the rudder to its neutral position.**
  - **Resulting load determines structural compliance**



Test Method

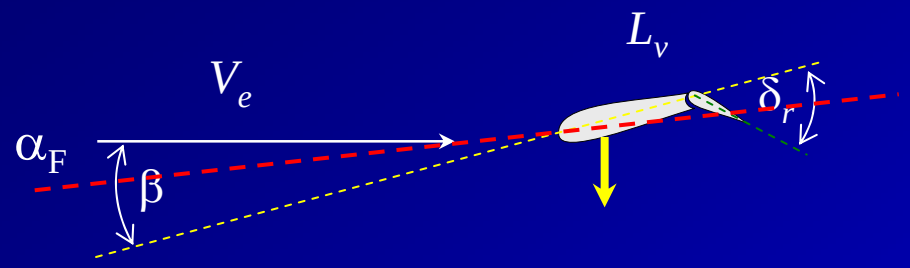
- **Steady Heading Side Slips**
  - **¼, ½, ¾ & full right rudder deflection**

    [Determine baseline loads]

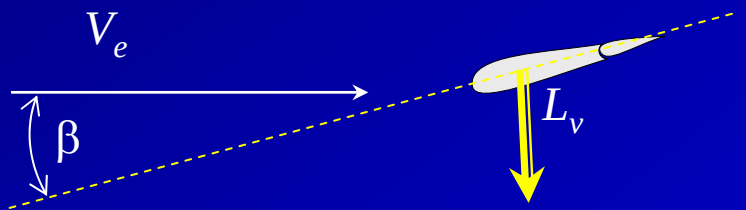
- **Abrupt Rudder Reversal**
  - **Full rudder rapidly released to neutral**
  - **Full rudder rapidly released to ½ opposite direction**

    [Determine transient loads]

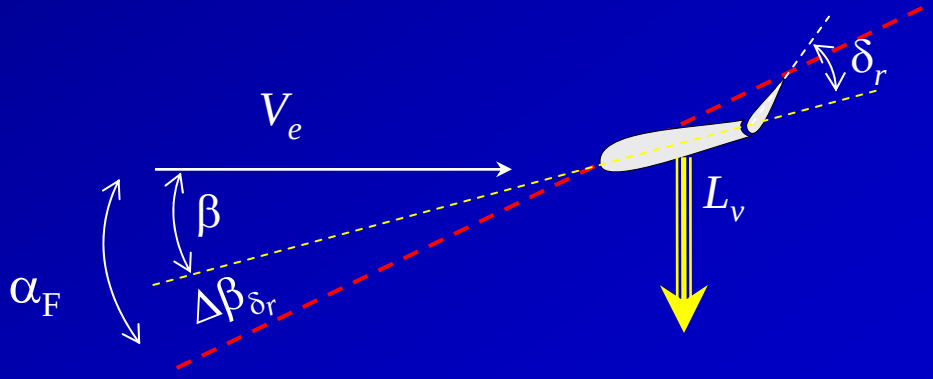
Data & Analysis



Steady State Load

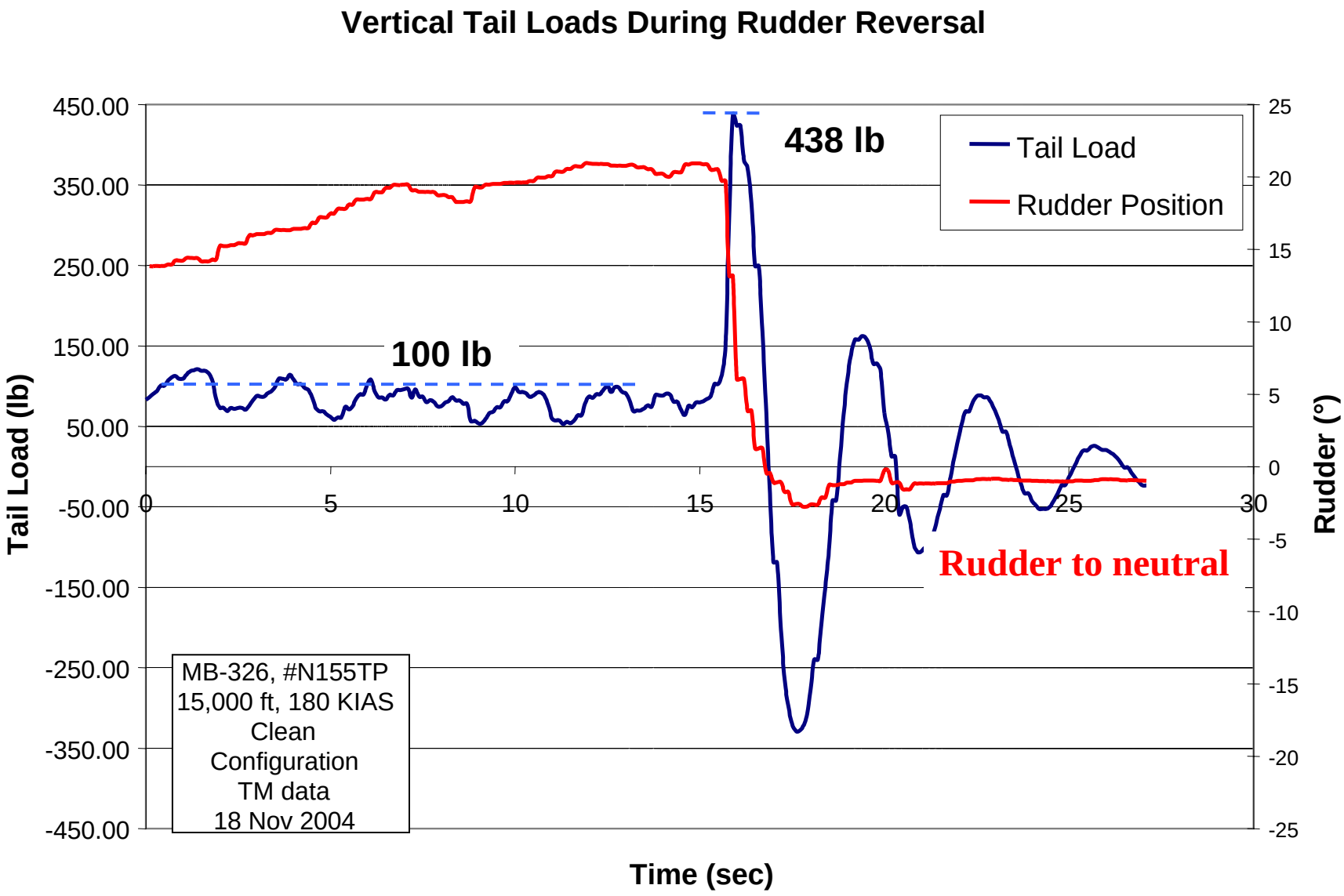


Compliance Load

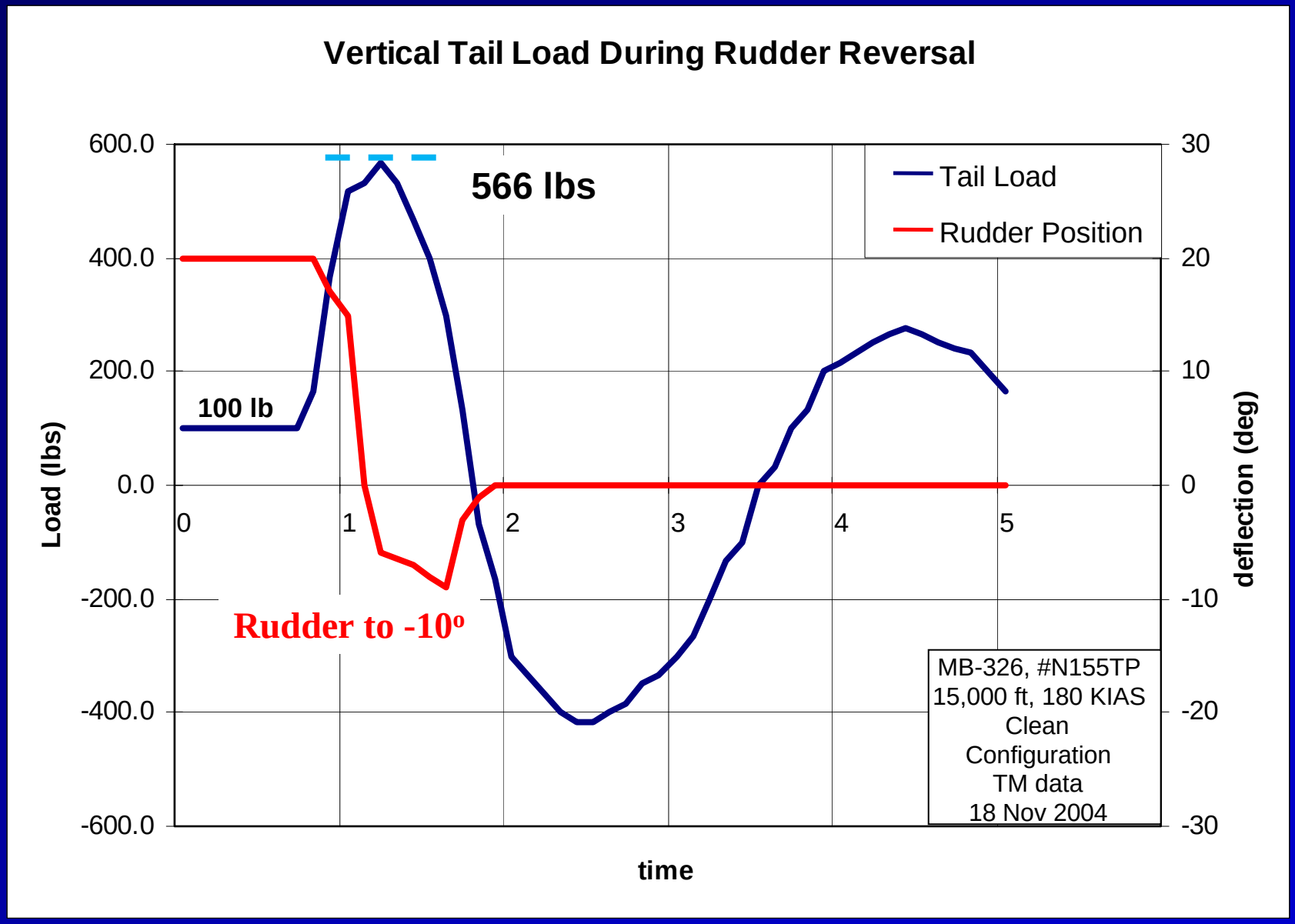


Reversal Load

Data & Analysis



Data & Analysis



Conclusions

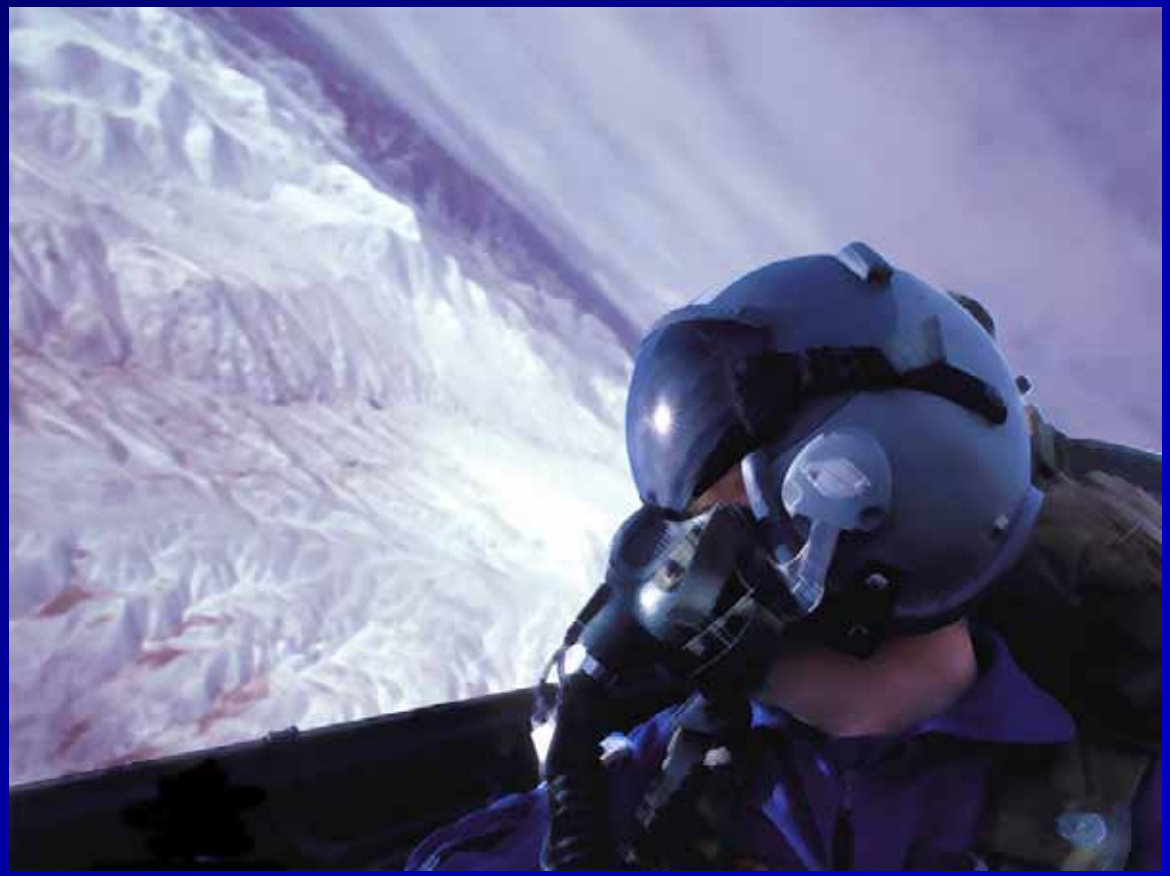
- **Rapid rudder reversals dramatically increase vertical tail loads**
  - **Approximately 3x increase when rudder returned to neutral**
  - **Approximately 5x increase when rudder driven past neutral by 1/2**
- **Flying below maneuvering speed does not protect you**
- **Aircraft vertical tail loads are certified for full rudder deflection steady heading sideslips and return to neutral – not for rapid rudder reversals**
- **Full rudder inputs may not be the best solution for unusual attitude recovery**

Epilog

- **An FAA/industry working group developed a clarifying note to add to the definition of "Design Maneuver Speed."**
  - **Caution that rapid and large alternating control inputs -- especially in combination with large changes in pitch, roll, or yaw (e.g., large sideslip angles) -- may result in structural failures at any speed, even below design maneuver speed.**
- **A Boeing/Airbus/FAA working group developed specific training programs for rudder usage on all transport category airplanes.**

NTPS

National Test Pilot School



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