Reverse Engineering Crosswind Limits
A New Flight Test Technique?

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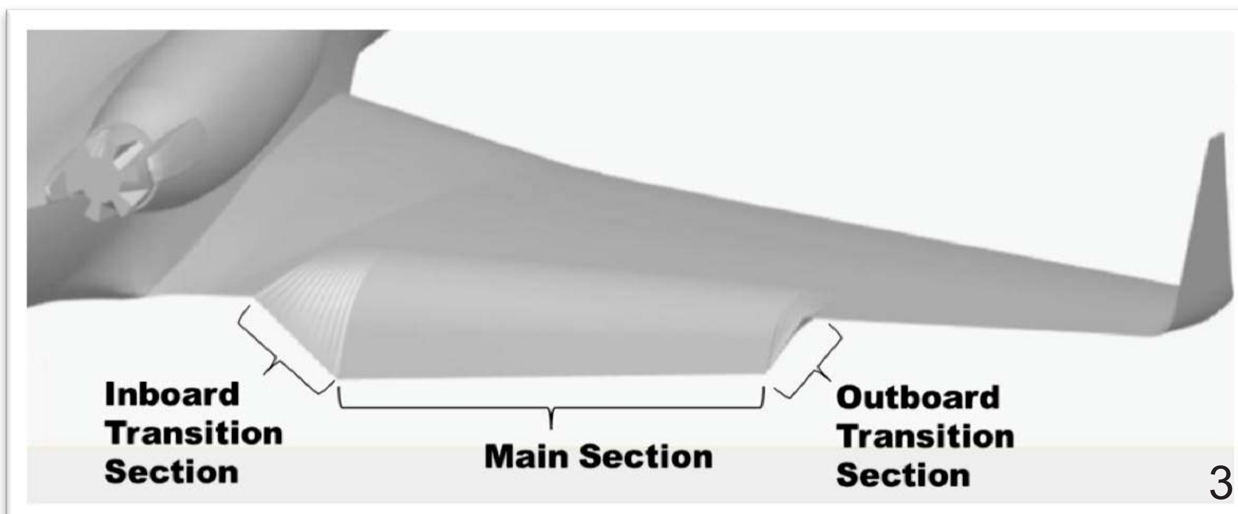
Outline

- Background: Fly without spoilers?!
- Build-up approach
- Math
- A New Flight Test Technique, the SS2B
- Flight test/simulator results
- Lessons Learned

Background

- Adaptive Compliant Trailing Edge (ACTE) project
  - Experimental flight research project within larger ERA project
  - NASA and Air Force Research Laboratory joint effort
- Composite flexible trailing-edge wing flaps
  - Seamless transition between trailing edge surfaces
  - Reduce noise during takeoffs and landings
  - Improve aircraft aerodynamic efficiency



ERA – Environmentally Responsible Aviation

Test Article

NASA 804

- NASA Dryden Gulfstream III, N804NA (NASA 804) is a G-1159A
- Designated as a SubsoniC Research Aircraft Testbed (SCRAT)
- Low-wing, twin fanjet, pressurized transport category aircraft
- **Lateral control: ailerons and 3 spoilers on each wing**
  - **Ground spoilers, speed brakes and low speed roll control**
- **Flight controls hydraulically powered with a manual reversion mode**
- **Demonstrated max x-wind 21 knots**

- 45,000 feet; 340 KIAS/0.85M
- 38,570 lbs empty; 69,700 lbs max
- Fowler flaps – 0°, 10°, 20°, 39°

The Problem

- Replace fowler flaps on a G-III with ACTE flaps
  - All wing spoilers had to be removed
  - Some aileron also needed to counter lateral asymmetries inherent in ACTE
- Would ‘residual roll capability’
  - Be sufficient for control in crosswinds
  - Be sufficient for control in failure states
- Is this a suitable testbed?

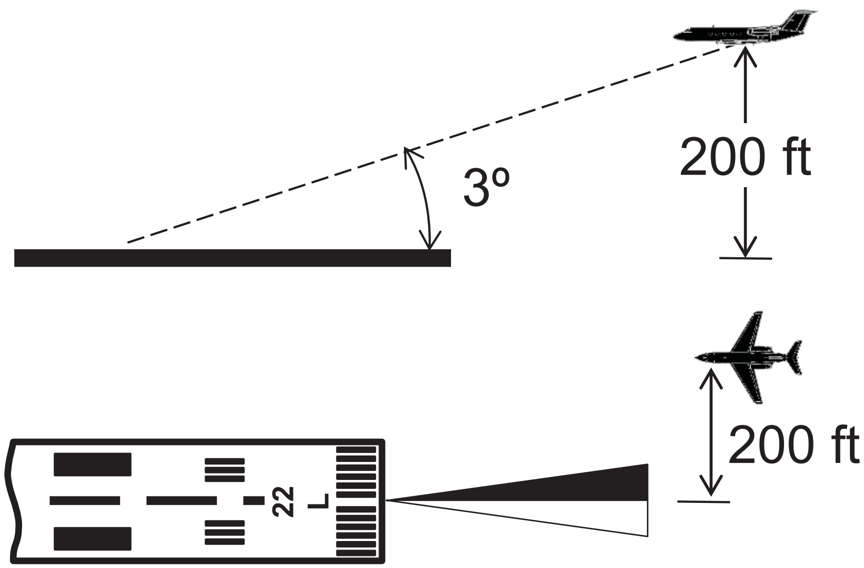
Buildup

- Building a **Simulator**
  - Used transport category sim
  - Basic aeromodel from pilot training sim
  - Updated *iteratively* throughout program

- Phase 0A – Baseline Aircraft in **“Stock” configuration**
  - Normal flight mode
  - Stability & Control, Performance, Aeromodeling data
  - Manual Reversion mode – **Spoilers Off ‘Up-and-Away’**
- Phase 0B – Fowler flaps, **Spoilers Disabled**
  - Four flights – SS2B FTT, aero-model, bank-to-bank, HQ
- Back to the Simulator – revalidation of HQ

Offset Landing Task

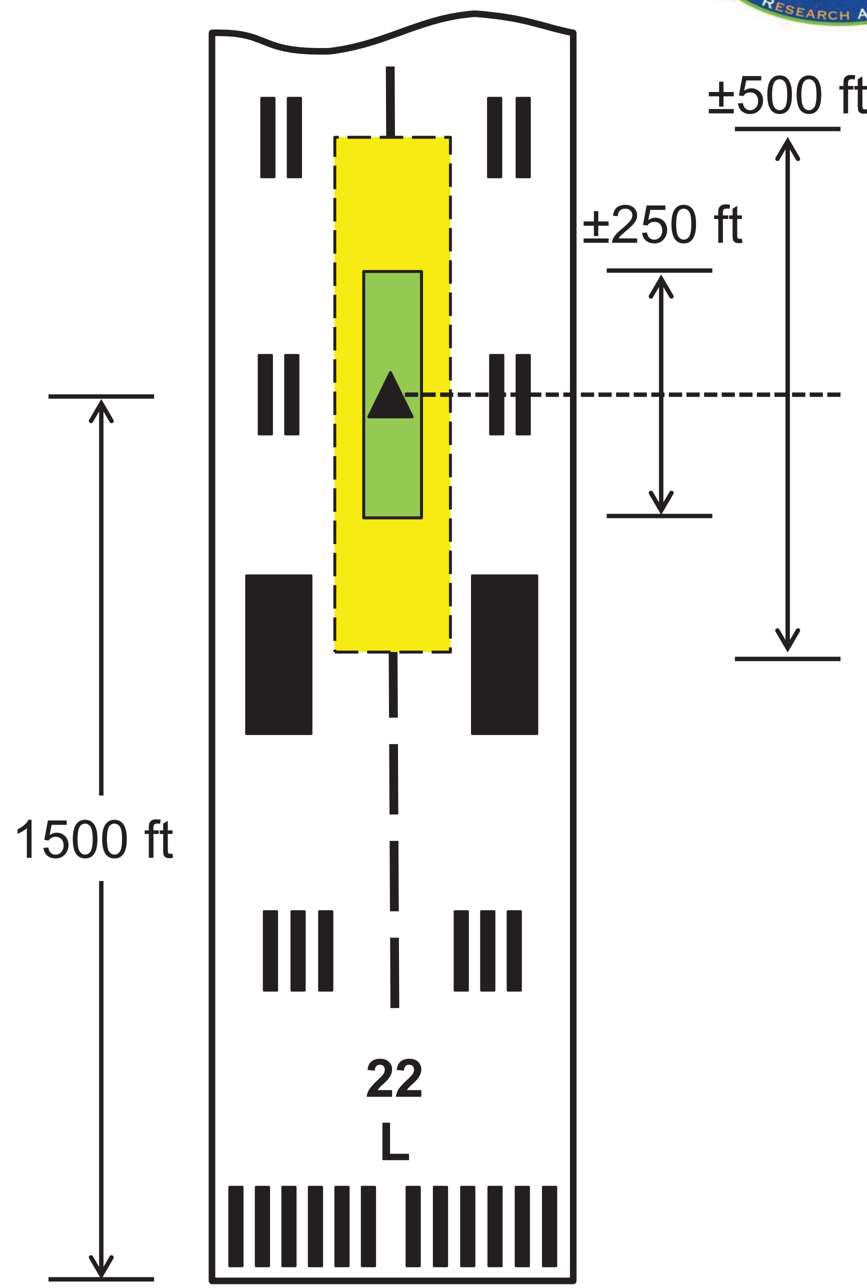
- Setup on ILS approach
- 1-dot width right (~200 ft) of Localizer; on Glidepath
- At 200 ft AGL, correct to land
  - On Centerline
  - Wings level
  - 1500 ft from the approach end
  - Vref -10 knots



Offset Landing Task

Performance Criteria
Desired
±10 ft of runway centerline
± 250 ft downrange*
±5kts of V_{ref} -10
Smooth touchdown
Adequate
± 75 ft of runway centerline
± 500 ft downrange*
+10/-5kts of V_{ref} -10

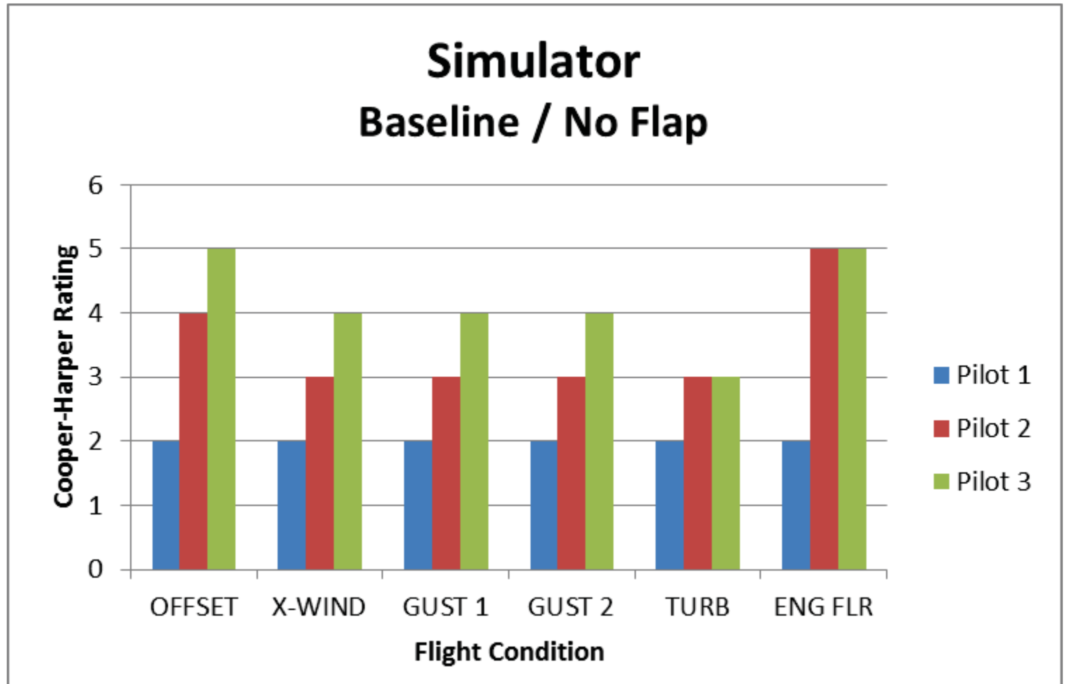
* Note: started with ±200 ft but concluded downrange wasn't relevant to the task other than to increase pilot gains. Therefore, increased this to 250 feet.



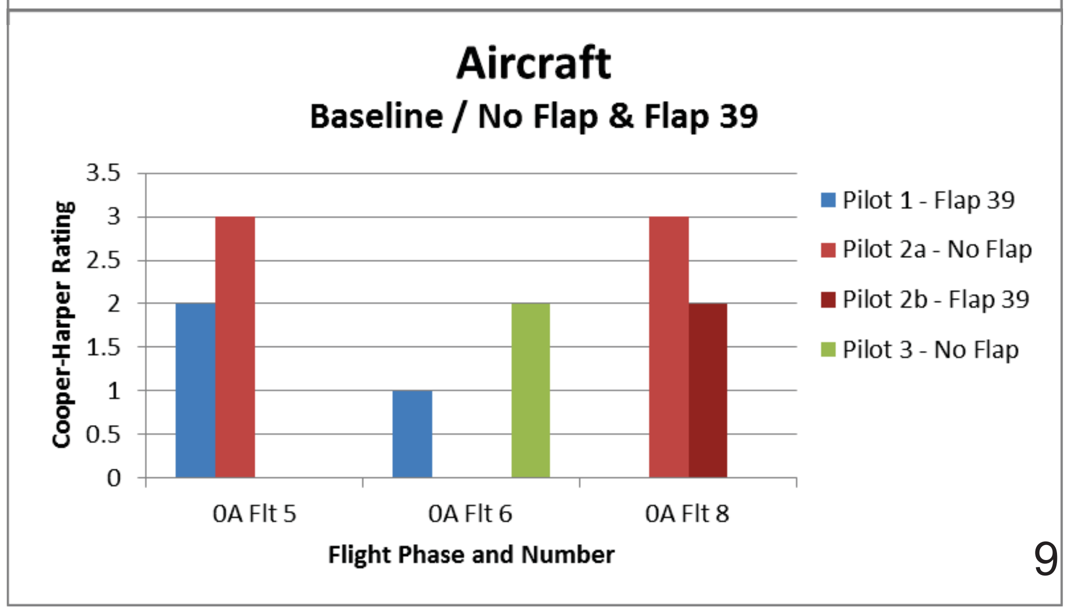
Phase 0A HQ Results

Stock Aircraft

- Simulator aeromodel still immature at this point
- Sim improved over time



- Aircraft, as expected
- No HQ in Man Reversion mode – open loop only



Phase 0B Crosswind Predictions

- Wing low crosswind landing is a steady heading sideslip
  - Use lateral directional equations of motion
    - P, R, $\dot{P}$, $\dot{R}$, $\dot{\beta}$ = 0
    - Side force reduces to
    - Roll reduces to
    - Yaw reduces to

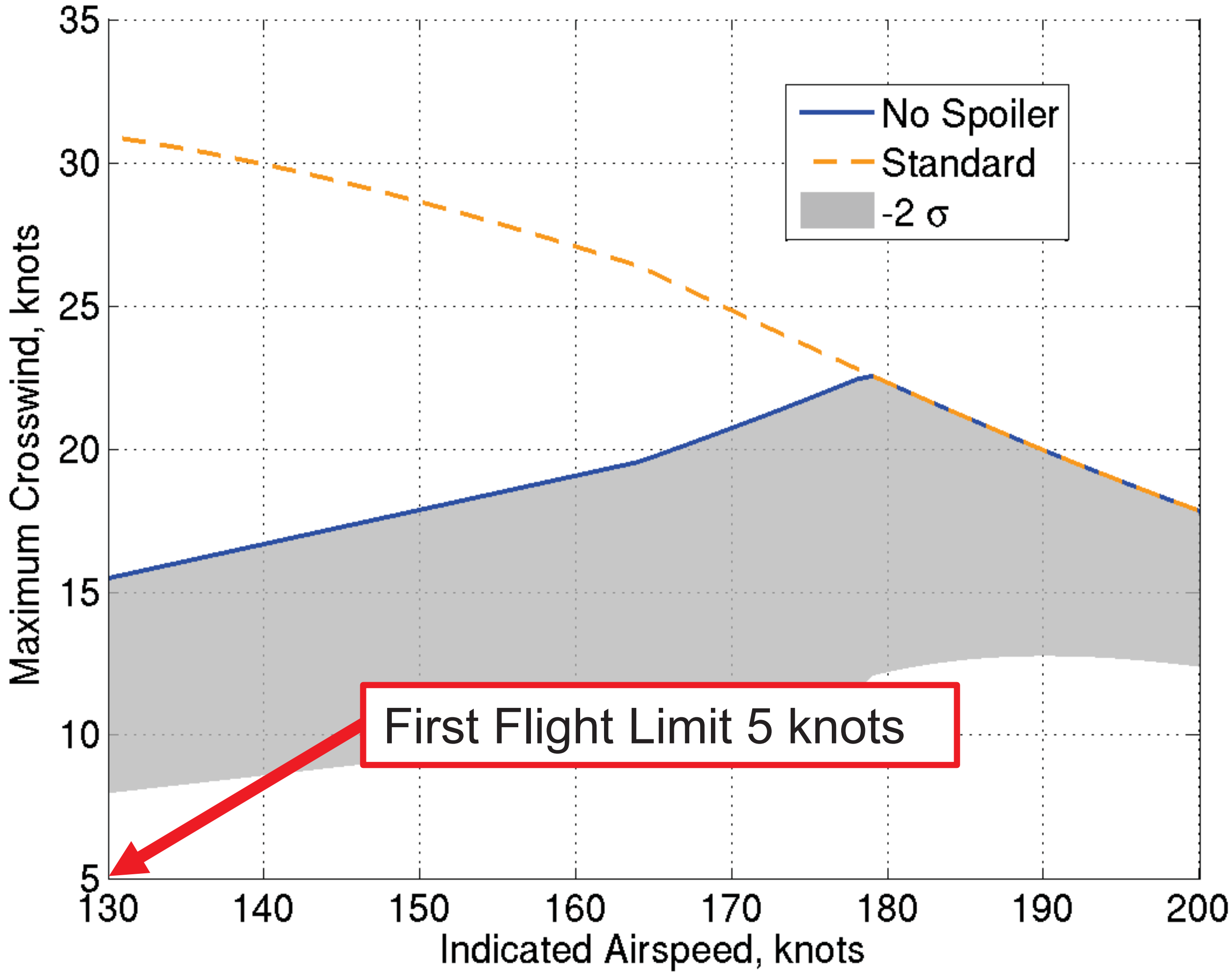
$$-g\phi = Y_{\beta}\beta + Y_{\delta r}\delta r + Y_{\delta a}\delta a$$

$$0 = L_{\beta}\beta + L_{\delta r}\delta r + L_{\delta a}\delta a$$

$$0 = N_{\beta}\beta + N_{\delta r}\delta r + N_{\delta a}\delta a$$

  - **3 equations 4 unknowns $\boldsymbol{\phi, \beta, \delta r, and\ \delta a}$**
    - Solve each unknown as a function of β ($\frac{\phi}{\beta}, \frac{\delta r}{\beta}, and\ \frac{\delta a}{\beta}$)
    - Find β at the limit for $\phi,\ \delta r,\ or\ \delta a$ (75% for Mil-Std-1797)
  - **Convert β to lateral velocity**

Limit With 75% Aileron Deflection



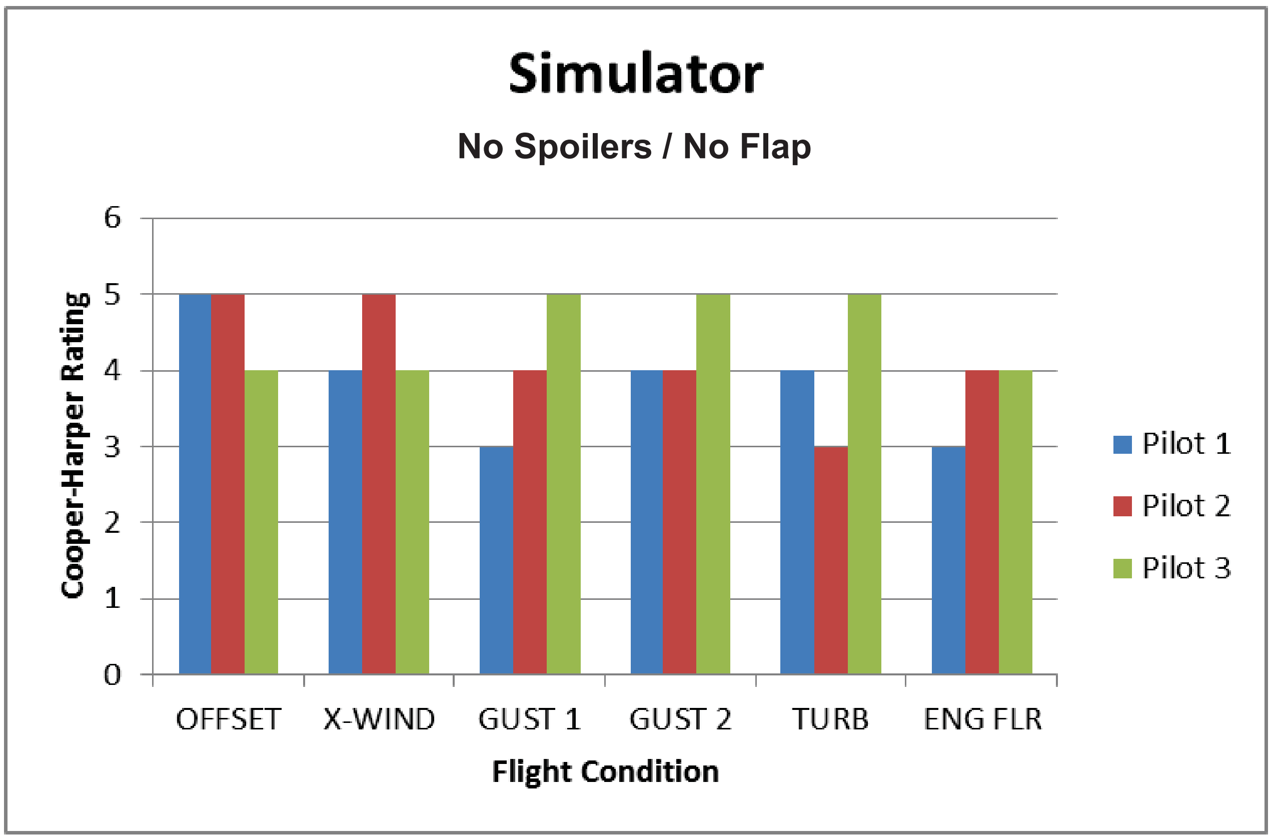
Predictions

Skeptical that 25% aileron deflection would be sufficient

Pre-Phase 0B

No Spoilers

- Flew test profile and several scenarios in the simulator
  - Simulator included all Phase 0A data including man reversion
  - Crosswind landings done with up to 10 knots of crosswind

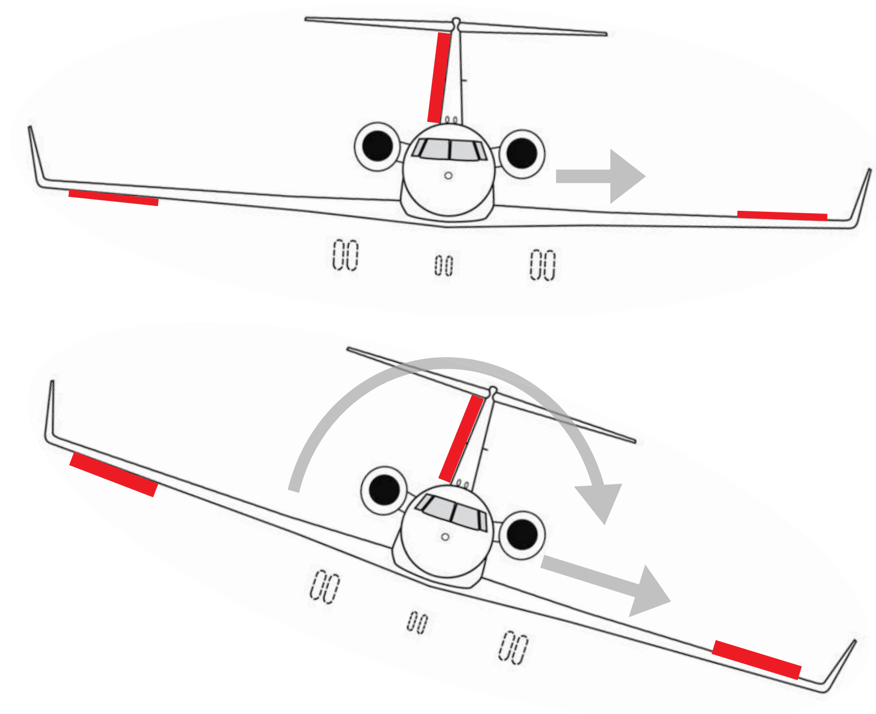


Determining Residual Roll Rate

- Crosswind limit questions
  - Is 5 knots crosswind too conservative?
  - Is 25% residual aileron deflection enough?
  - How much residual roll rate is enough?
- Original plan
  - Steady Heading Sideslip + Bank-to-Bank Roll
  - Calculate resulting residual roll rate
- Why not just measure it!

The Sideslip-to-Bank Maneuver
(SS2B)

1. Backwards "Steady-Heading Sideslip"
   - Establish desired bank angle first
   - Then feed in rudder to maintain heading
   - Stabilize for 10 seconds
2. "Bank-to-Bank Roll"
   - Full yoke into established bank
   - Rudder fixed
3. Terminate at max bank angle
4. Recover to wings level



Sideslip-to-Bank Maneuver

- No Flap
- 1.2 V_{stall} = 133 KIAS
- 3/8 initial yoke deflection

Test Matrix

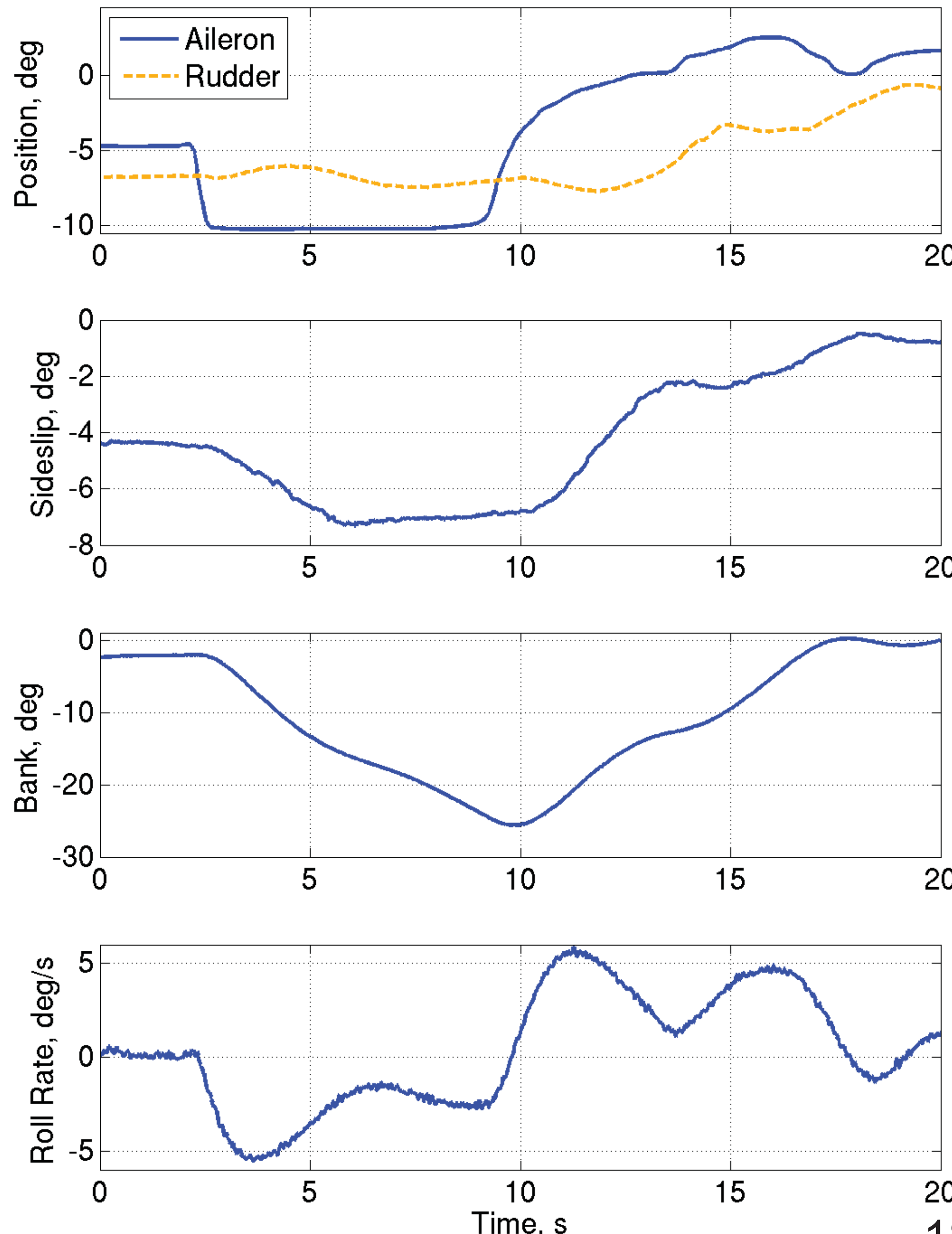
- 10,000 ft; 1.2 Vstall
- Heavy weight – early in flight (≈ 58,500 lbs)
- Light weight – end of flight (≈ 44,000 lbs)
- Yoke deflections (both left and right)
  - 3/8
  - 1/2
  - 5/8
- Flap Positions
  - 0°
  - 10°
  - 20° (man rev limit)
- Terminate roll at 20° bank

Sideslip-to-Bank Maneuver

- Flaps 20-deg
- 1.2 V_{stall} = 115 KIAS
- 1/2 initial yoke deflection

Sideslip-to-Bank Time History

- SHSS, time < 2 s
  - Sideslip used for crosswind
  - Aileron usage
- Full aileron, time 3 to 9 s
  - Residual roll rate
- Return to wings level coordinated flight, time > 10s

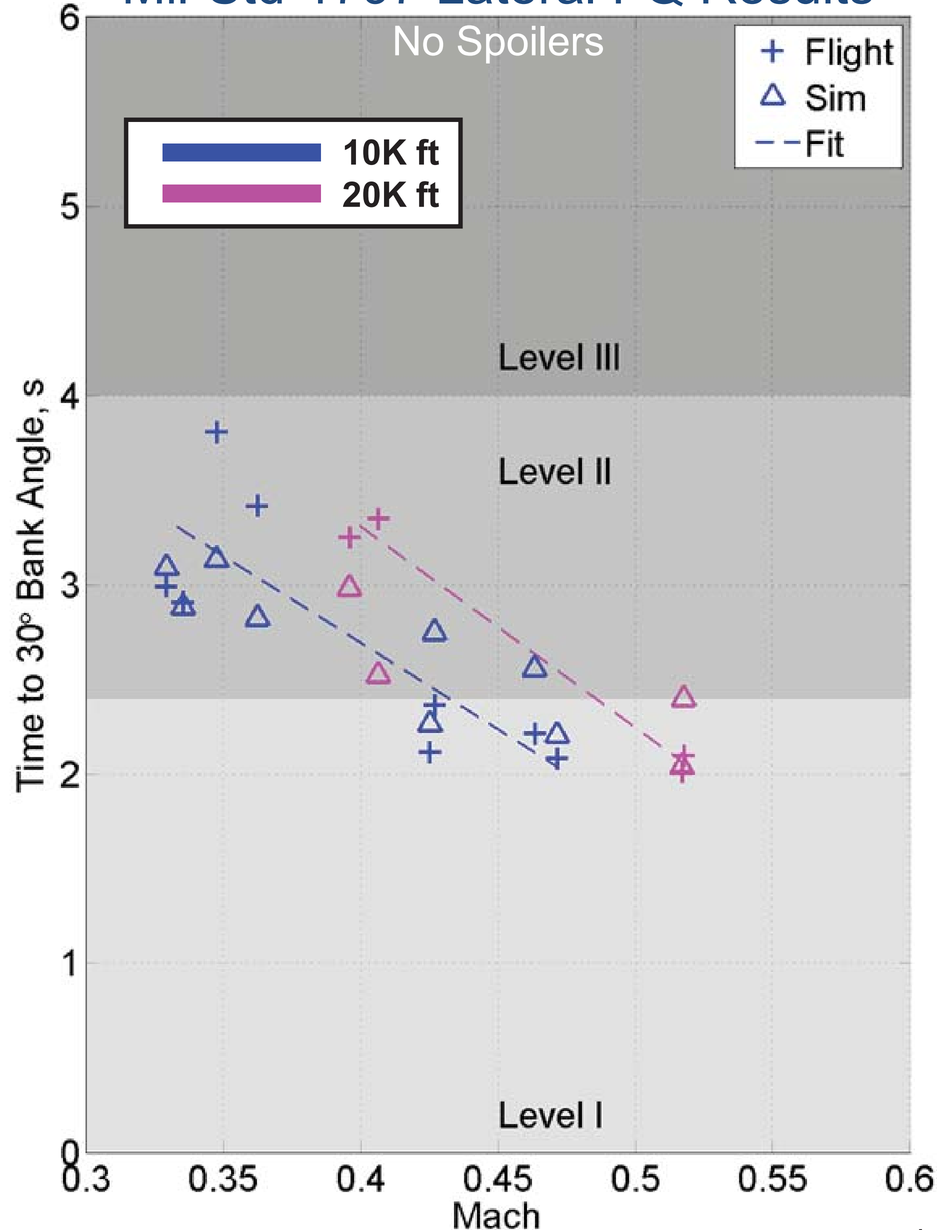


Initial Phase 0B Results

- Phase 0B pilot comments
  - Aircraft acceptable for flight in *controlled* environment with ≤ 50% yoke deflection
  - Easily handle > 5 kts wind
- Need to expand the crosswind limit

Safety vs. Usability

Mil-Std-1797 Lateral FQ Results



Research

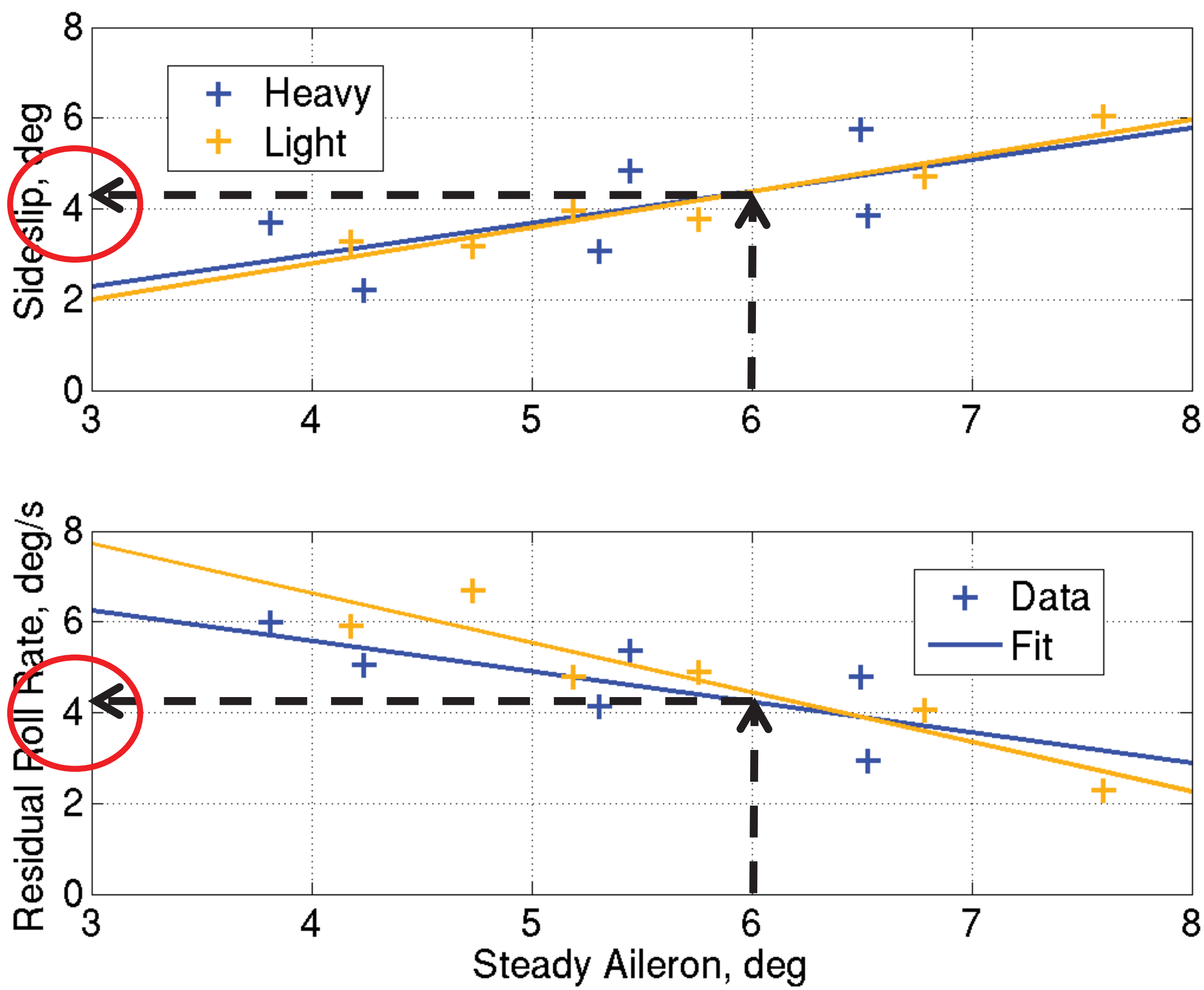
- How much roll rate is needed for crosswind landings?
  - 14 CFR Part 25
    - No "exceptional pilot skill, alertness, or strength"
  - Mil-Std-1797
    - < 75% roll control authority (retains level II FQ)
    - No roll rate guidance
  - NASA TN-7062
    - Roll rates > 5°/sec had "acceptable" pilot ratings
    - 45%-60% control deflection was Satisfactory
- Tire Speed (182 knots)
- FAA handbook 8110.8 allows (4° crab)

Design Criteria

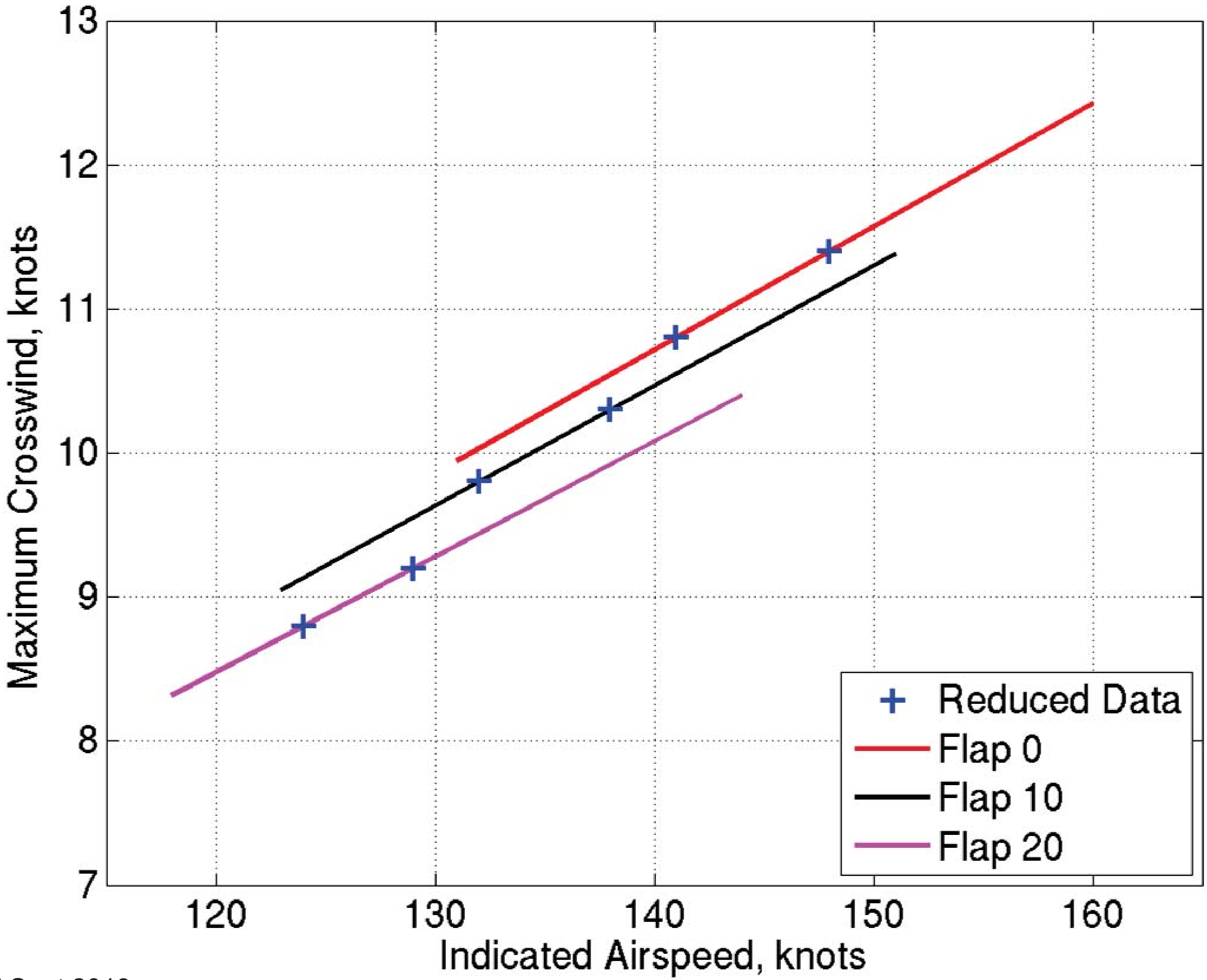
1. Maximum 50% control wheel deflection to maintain runway alignment
2. Takeoff and landing does not require "exceptional pilot skill, alertness, or strength"
3. Touch down at less than 182 knots ground speed
4. Maximum of 2 degrees crab angle at touch down

Flight Data

- 50% yoke deflection criteria
- Resulted in 4 deg/s roll rate minimum



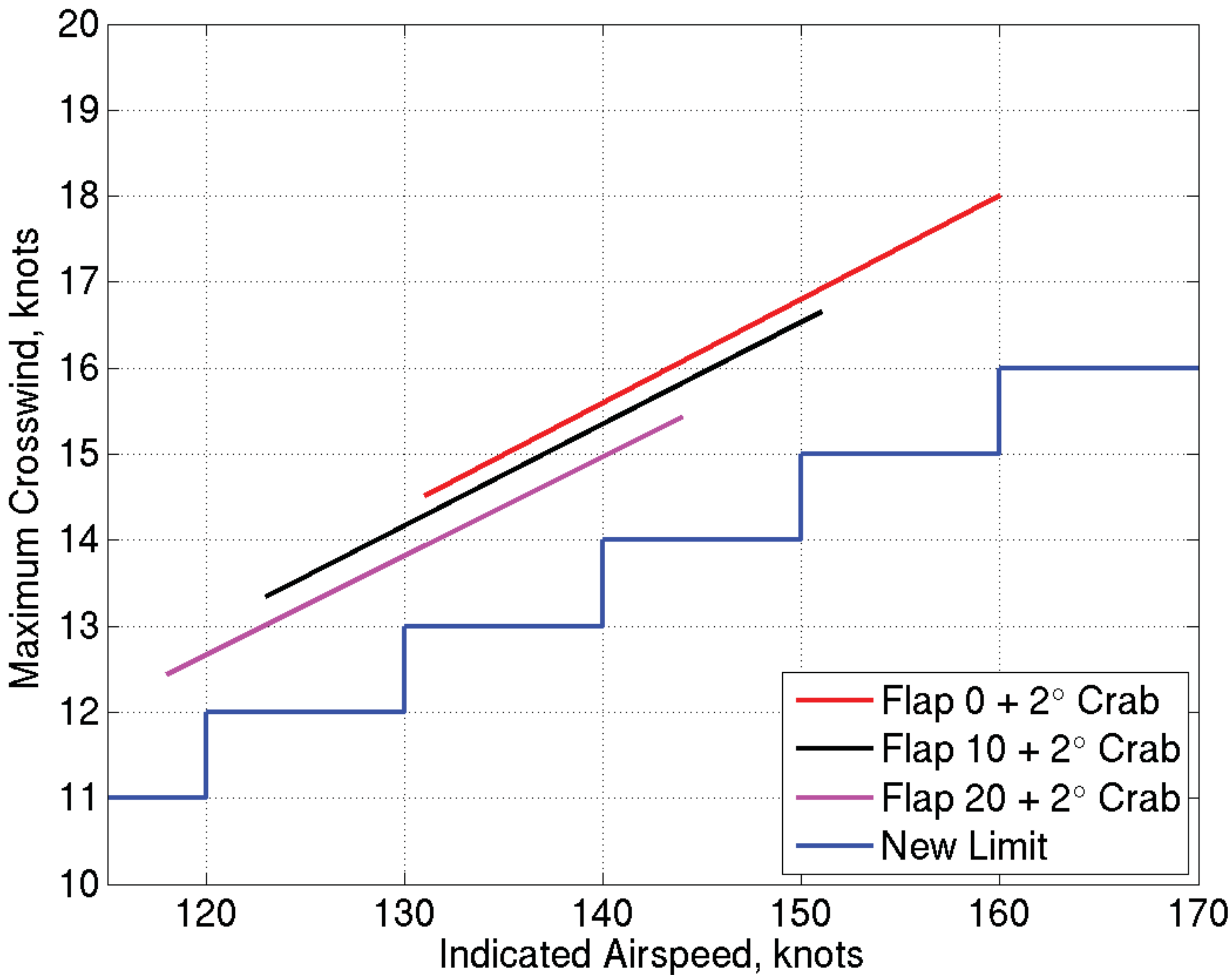
Results



13
12
11
10
9
8
7
Maximum Crosswind, knots
120
130
140
150
160
Indicated Airspeed, knots
Reduced Data
Flap 0
Flap 10
Flap 20

New Crosswind Limit

- Crosswind limit is based on landing speed (V_{ref})
  - Added 2° crab angle to increase usability (+ 4 to 5 knots)
- Adjust V_{ref} to 10 times the crosswind component ("Pilot Math")

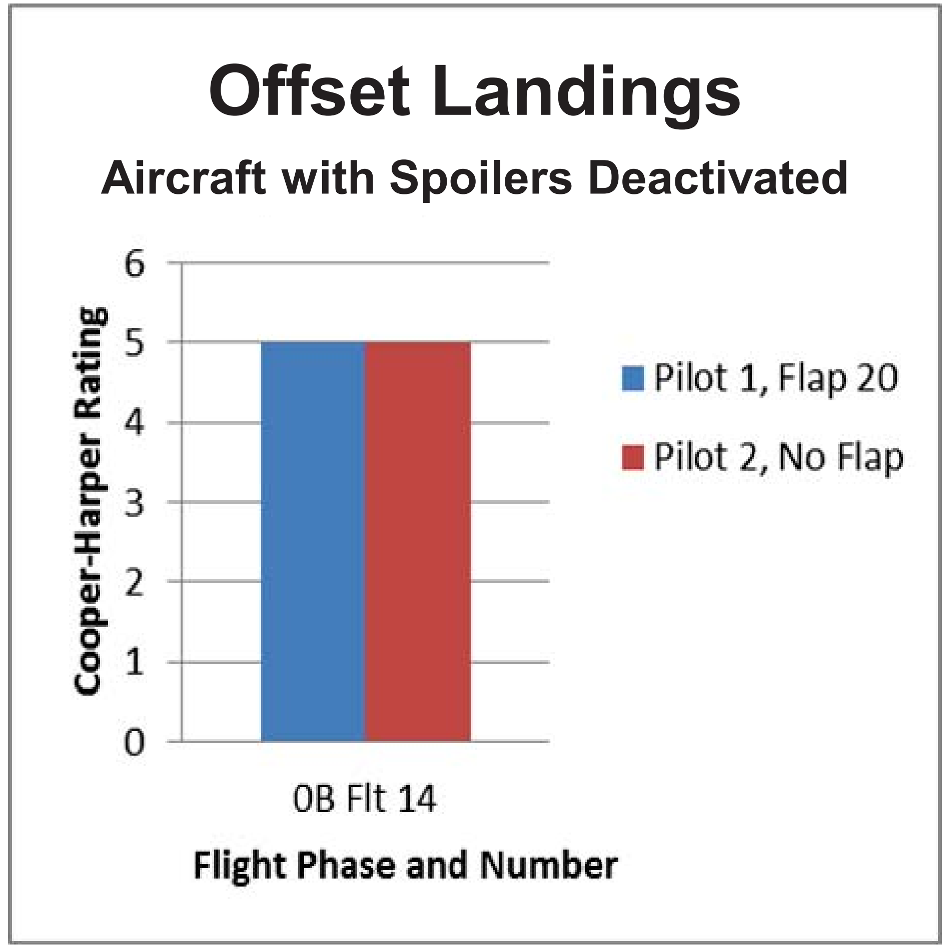


Crosswind (knots)	Min Vref (KIAS)
12	120
13	130
14	140
15	150
16	160

Phase 0B

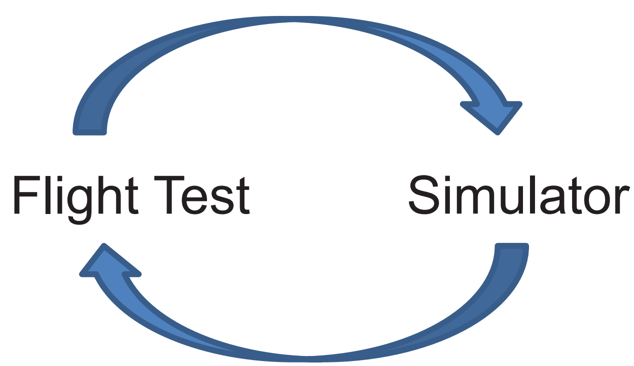
New Crosswind Limits

- Practiced 1st in the sim
- 2 Flights
  - 1st – 8 knot crosswind
  - 2nd – offset landings (with action at 250 ft)
- Data gathered in-flight was minimal to support results
- Returned to the simulator

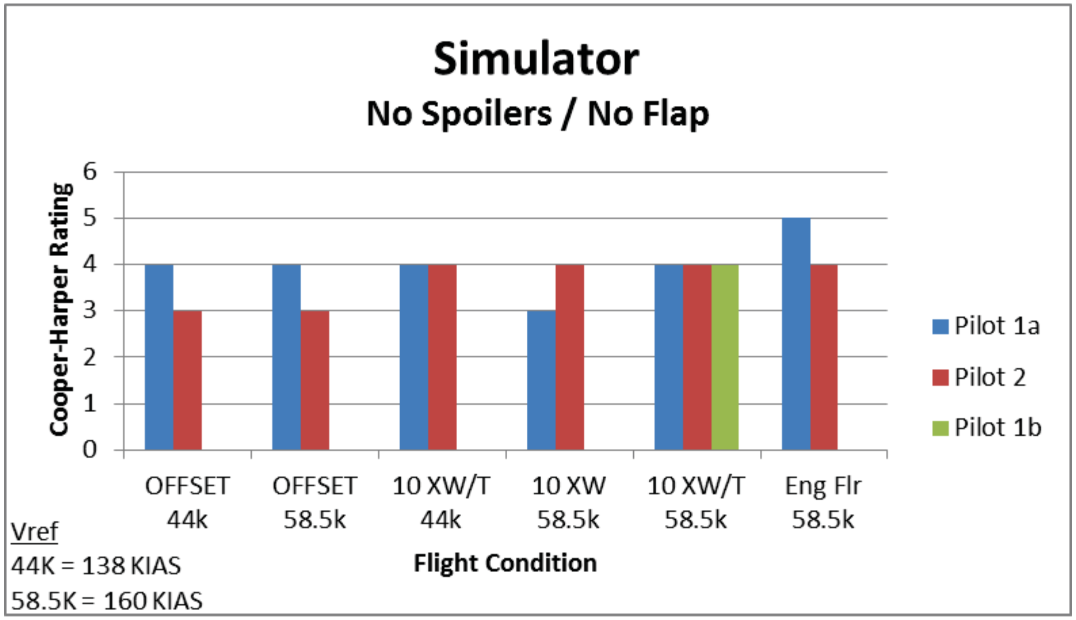


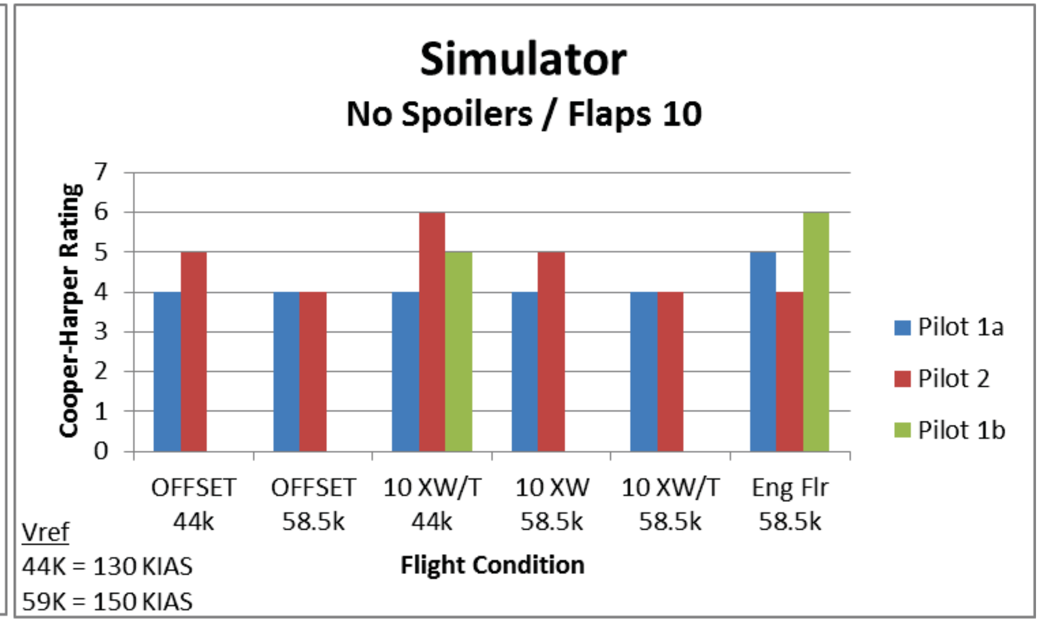
Simulation Handling Quality Validation

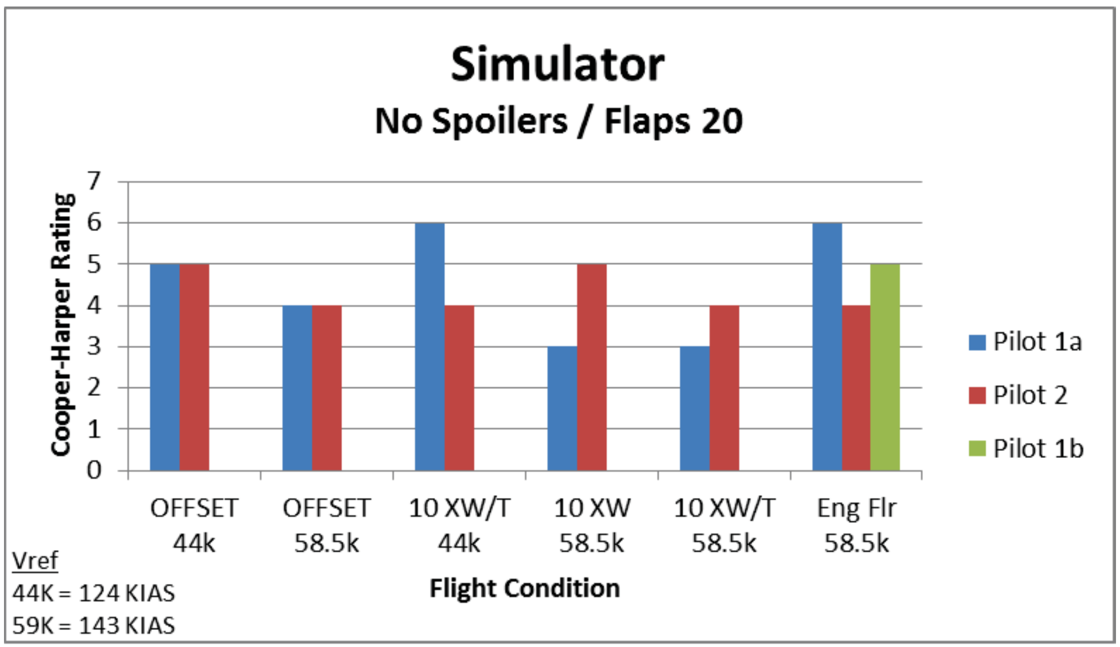
- How do we know these crosswind limits are safe yet useable?
  - Evaluate HQ in the simulation with 10-20 knot crosswinds
- Does simulation accurately represents the aircraft?
  - Compare HQ using offset landing task
- Flight simulation
  - Enabled the team to focus primary safety concerns on crosswind landing capability
  - Enabled a scaled degradation of a aileron authority to determine handling quality limits
  - Supported flight test and in return flight test data supported a more accurate simulator model



Back in the Sim







Lessons Learned

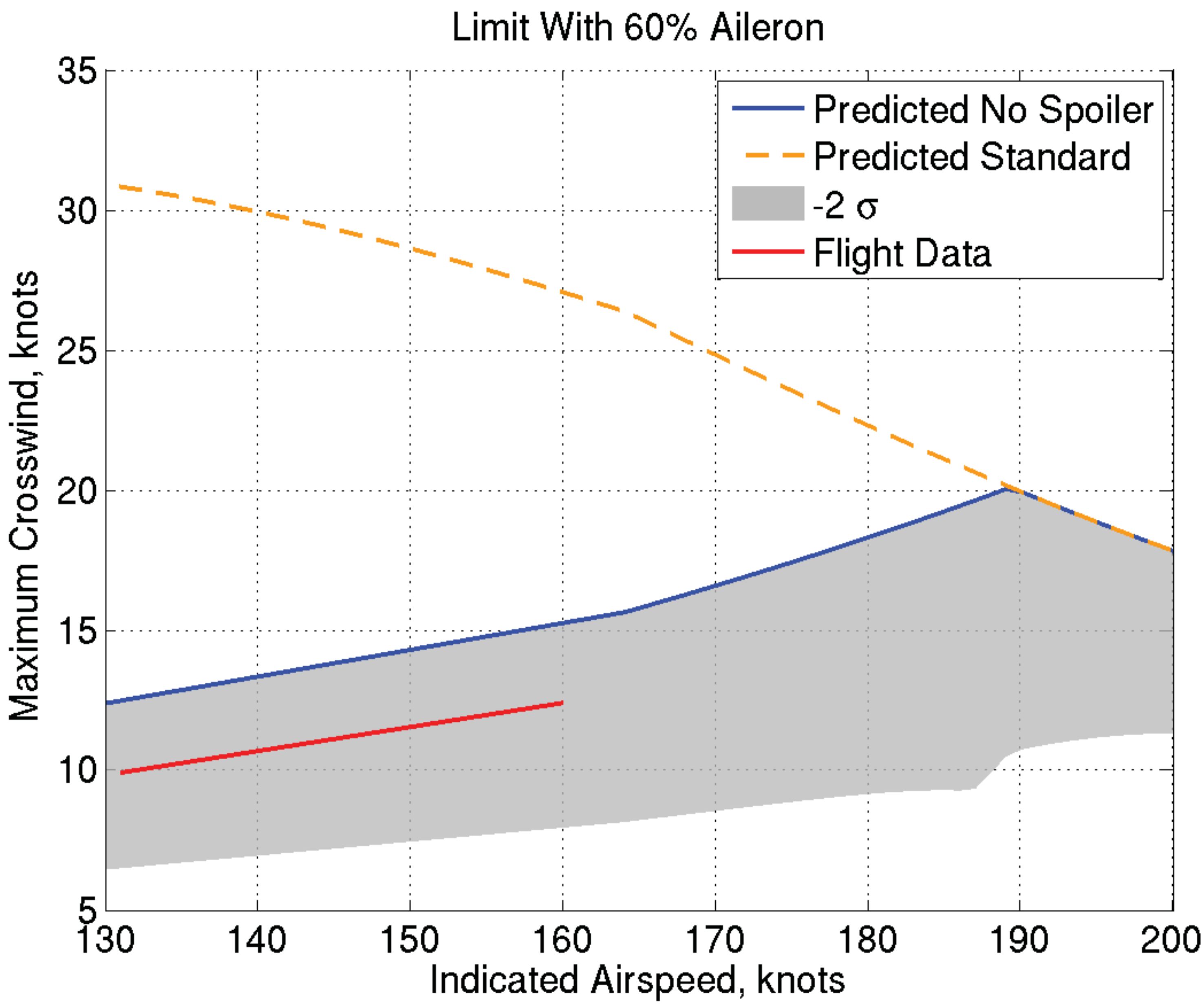
- The Sideslip-to-Bank maneuver can be an accurate predictor of residual roll rate capability in the presence of sideslip
  - For a modified G-III, it resulted in a limit that is safe yet useable
  - Chosen criteria are critical to the final outcome
- An accurate flight simulator is an essential tool
  - Practice/refine FTTs without wasting precious flight time
  - Evaluate modified aircraft before taking any in-flight risk
  - Accurate evaluation of analytical predictions
  - Continue research in a meaningful way after flying was over

Fight for a simulator for your project and do what is necessary to keep it!
It will pay for itself 10 times over.

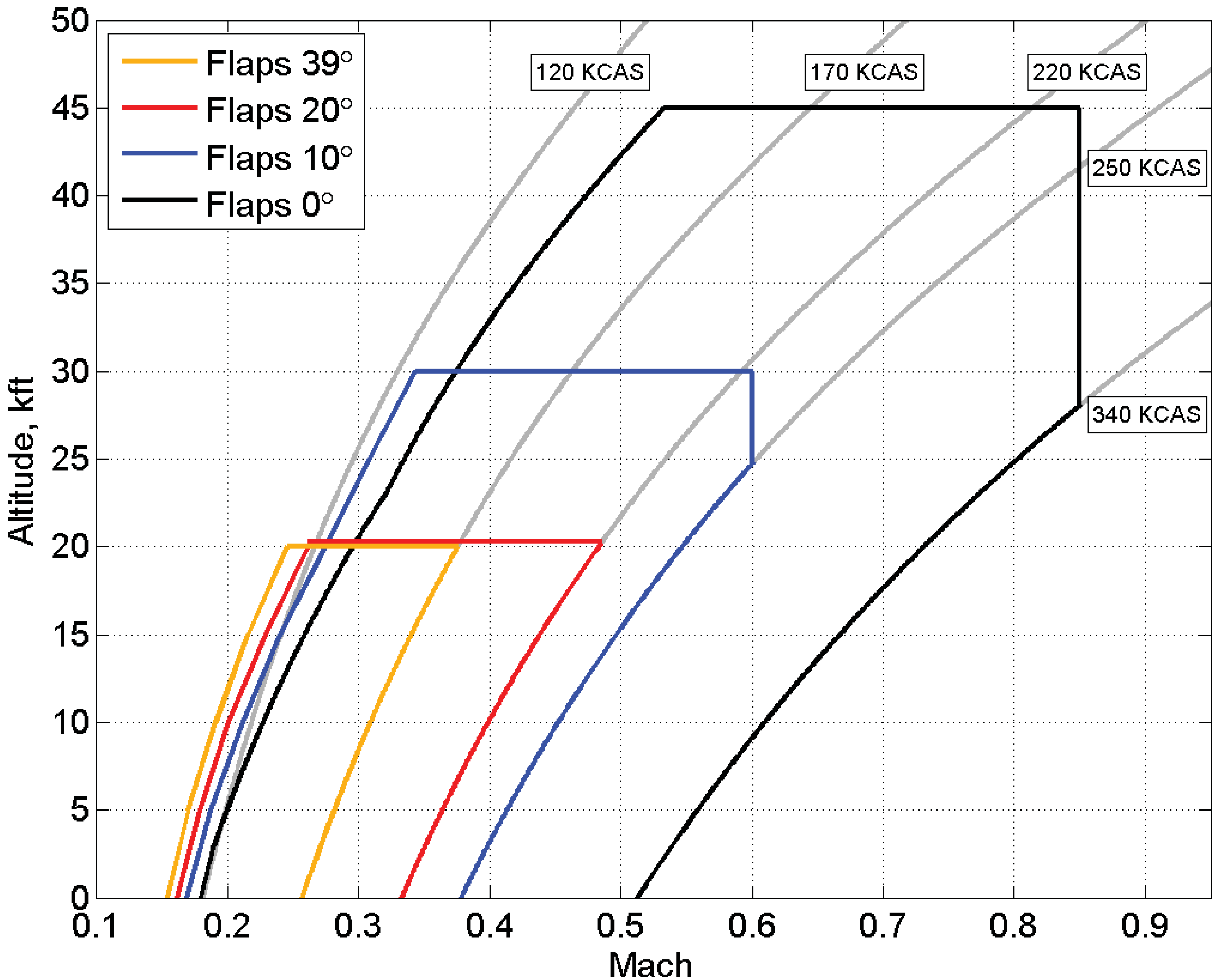

Questions?

Back-up

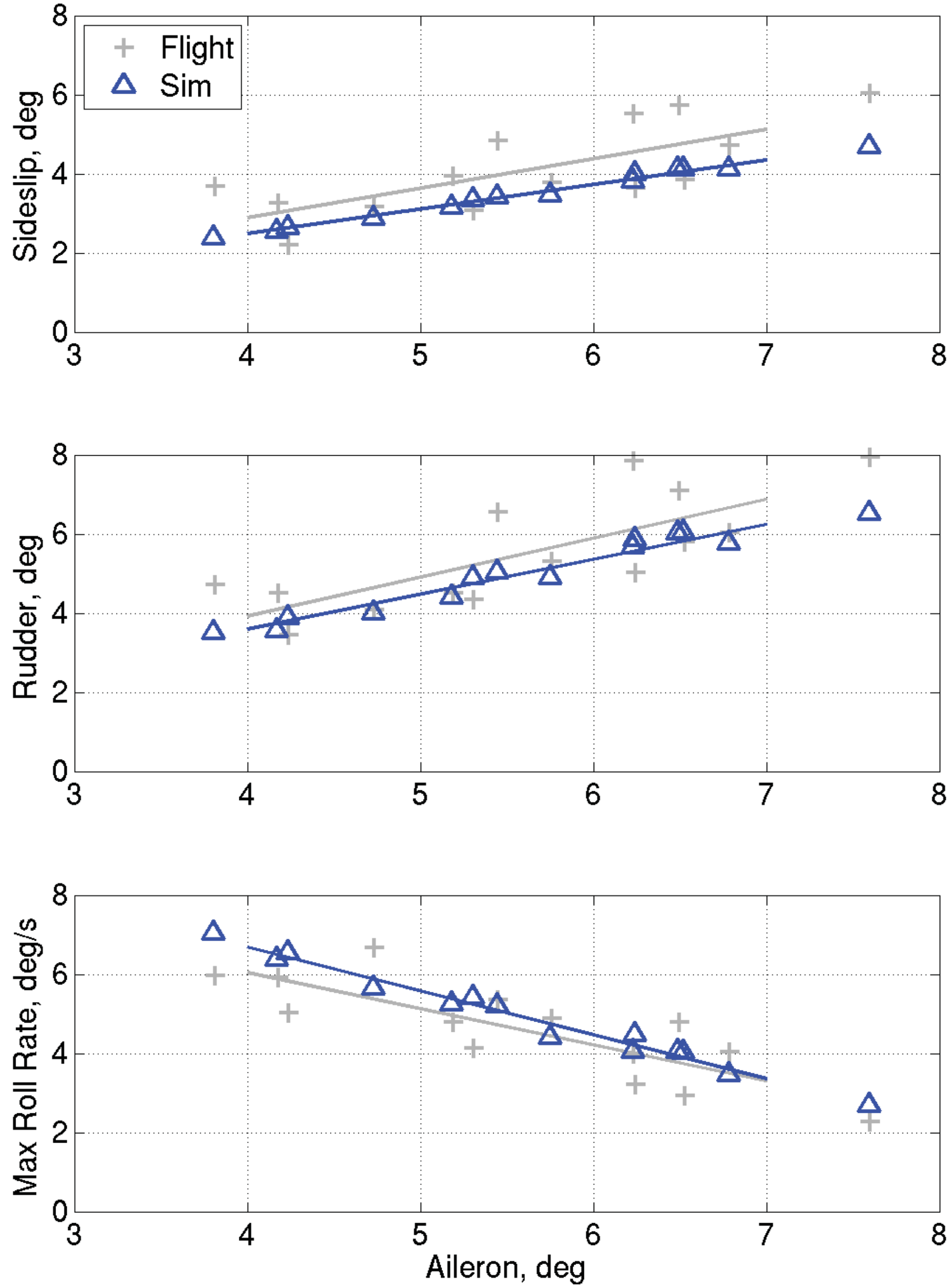
Prediction versus Actual



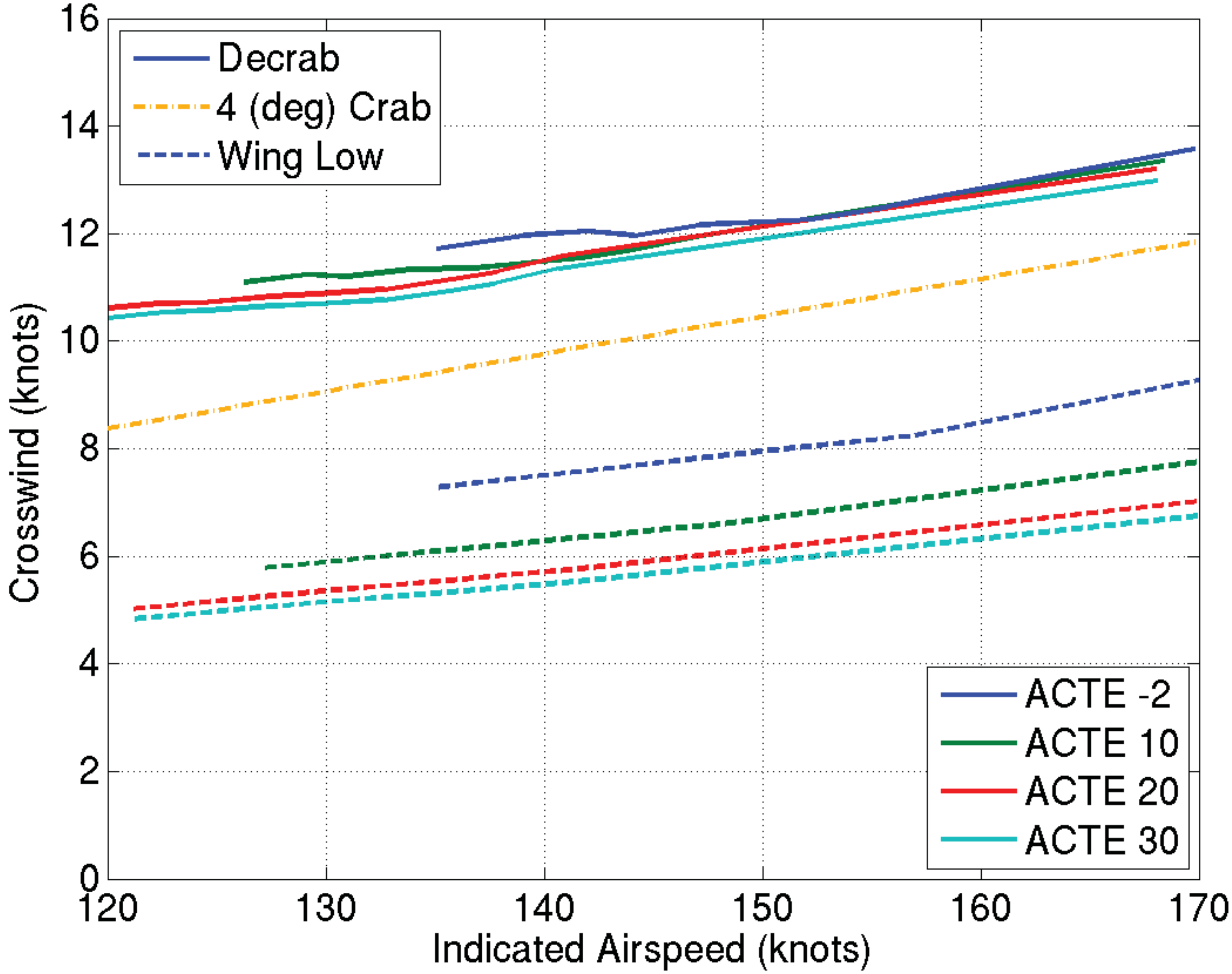
G-III Flight Envelope



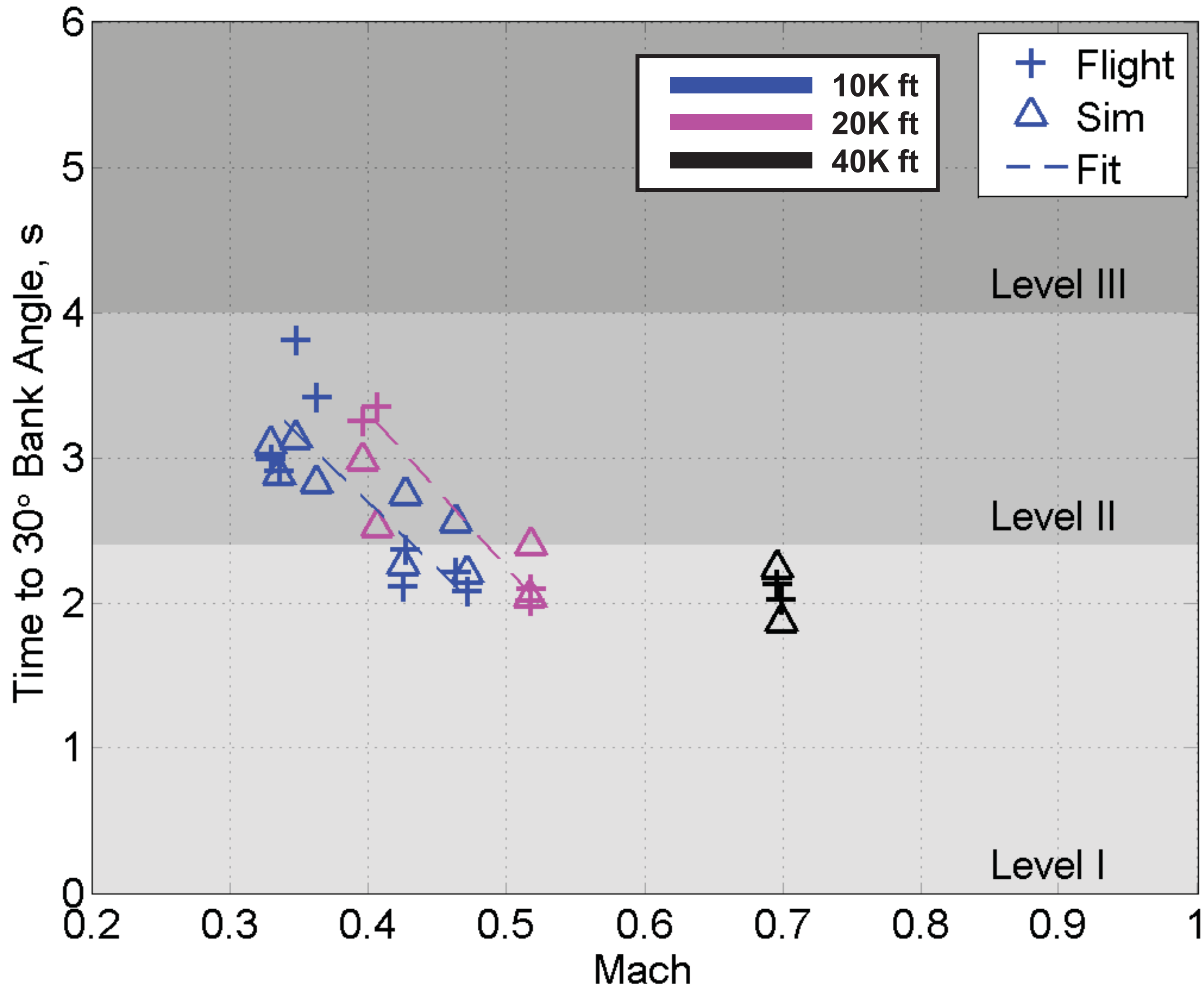
Flight to Simulation Comparison



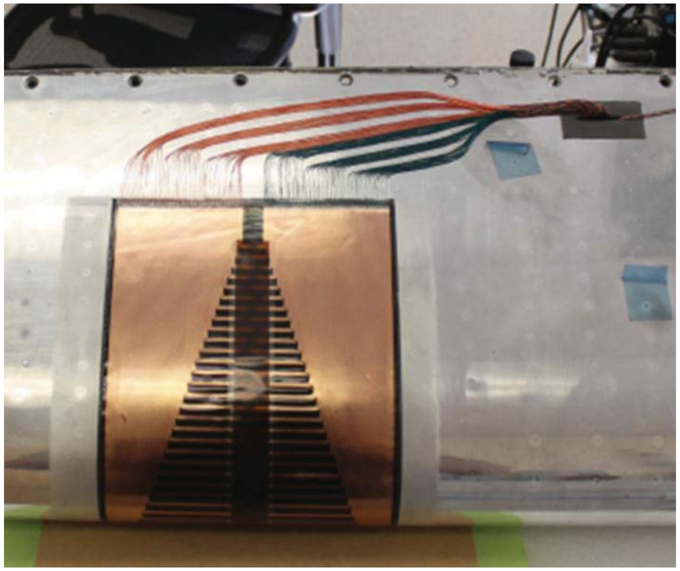
Technique Comparison



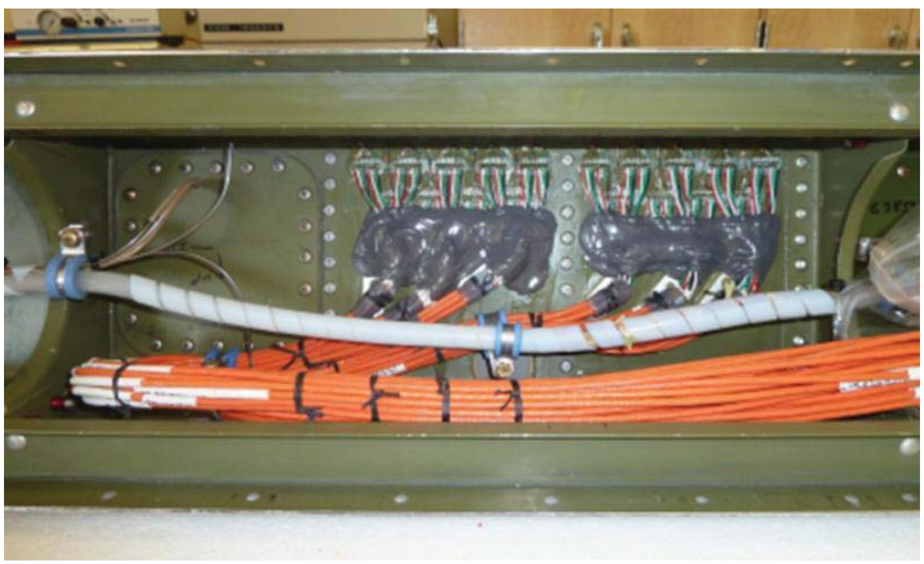
Spoilerless Roll Handling Qualities



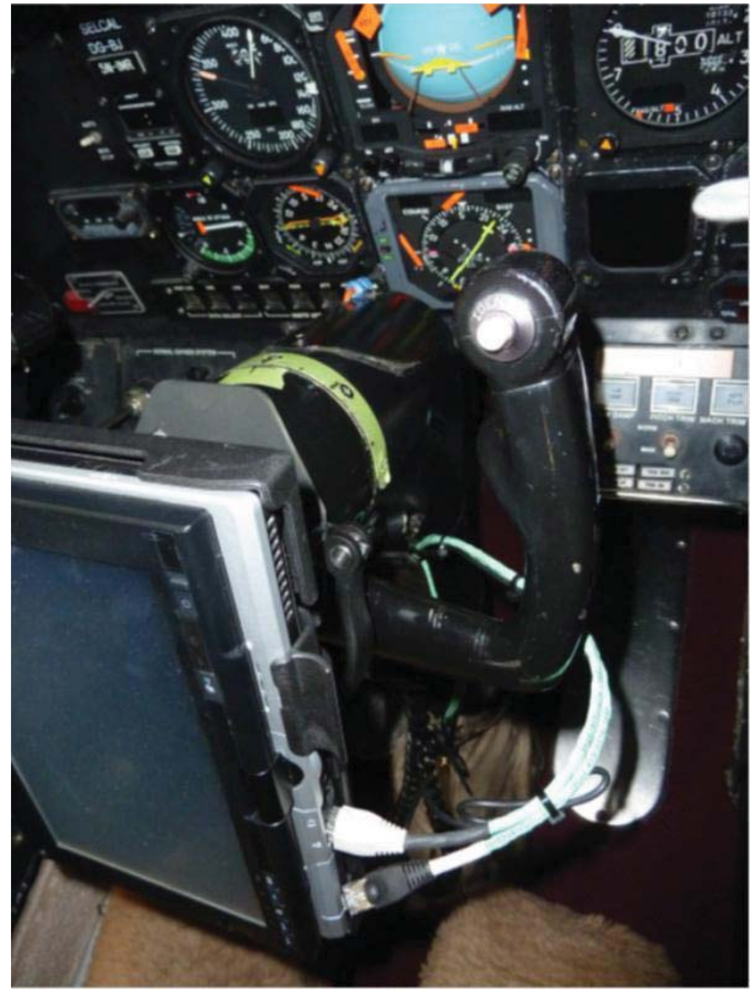
Instrumentation



Hot Films



Leading Edge Wiring



Cockpit Instrumentation

Instrumentation