AERONAUTICS

LESSON FQ6



Handling Qualities Testing

Why does it matter?

- Flying tasks require certain levels of performance to be effective
  - Performance requirements depend on the task
    - Aerial gunnery
    - Landing
    - Cruising along
- Pilots are required to perform flying tasks *
  - Pilots have finite workload bandwidth
  - Multitasking is required
    - Flying plus shooting/talking/scanning
    - Think Hockey: players must skate and handle the puck
- Handling Qualities (HQ) relate pilot workload & task performance

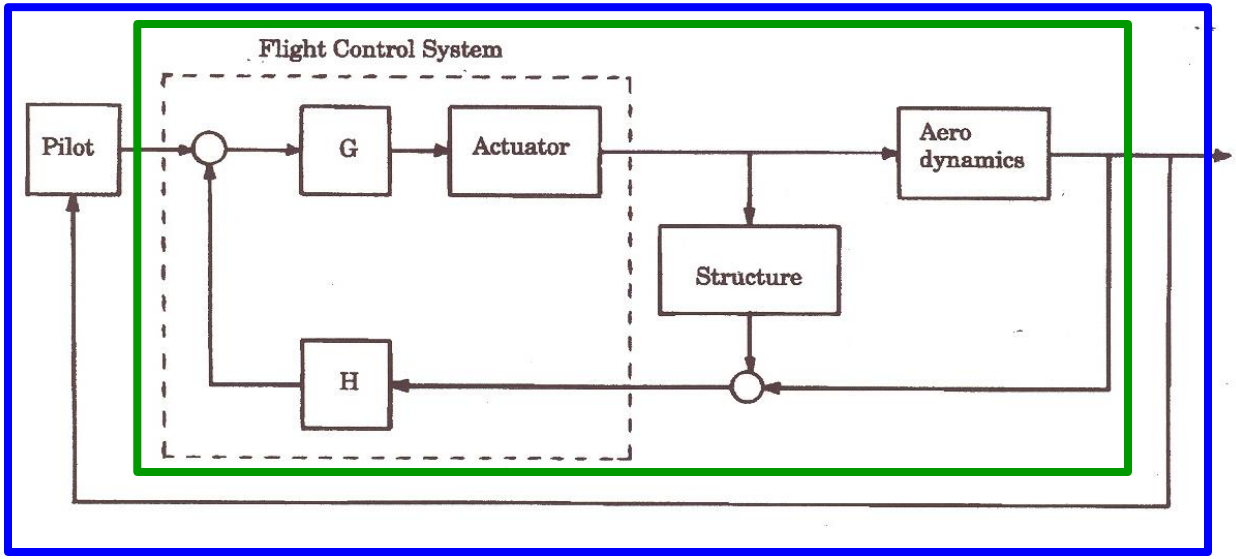
** Yes they are!*

OUTLINE

- Handling Qualities Basics
  - Definition / Importance
  - HQ in the overall flight test picture
  - Where it Fits in AE456
- Handling Qualities Testing
  - Model Verification Method
  - Models used in HQ testing
  - HQ Flight Test (Testing the Model)
- HQ Flight Test Techniques (FTT)

What are "Handling Qualities"

Formal Definition:



Flying Qualities

Interaction of FCS with Aircraft Dynamics -- Aerodynamic and Structural (Augmented Airplane Dynamics or Vehicle Dynamics)

Handling Qualities

Interaction of Pilot with Augmented Airplane (Pilot plus Airplane Dynamics). Aka: "Closed Loop" or "Pilot-in-the-Loop"

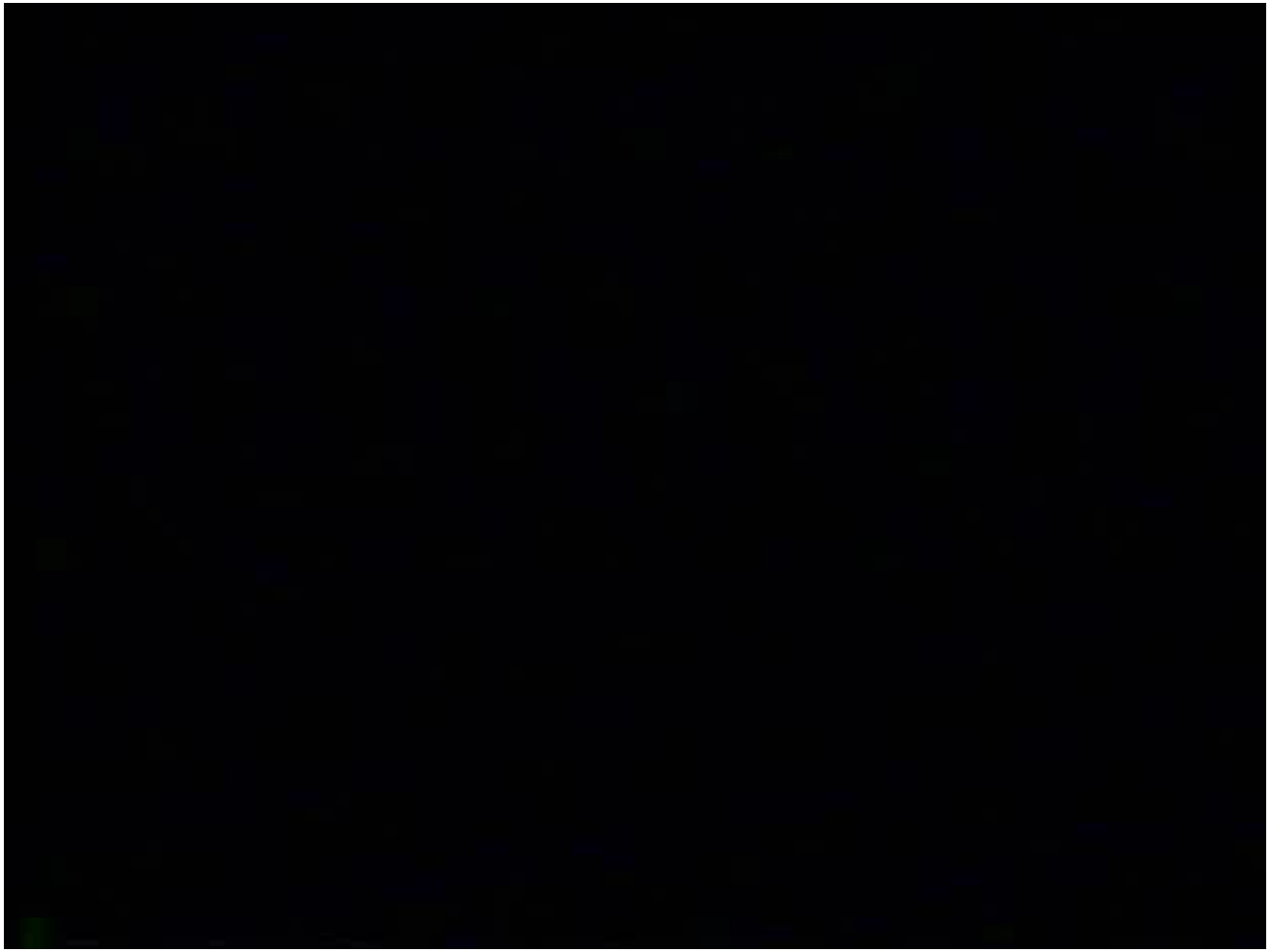
Importance of Handling Qualities Testing

- Discover Hidden Flying Qualities ("Cliffs")
  - Pilot Induced Oscillations (PIO)/Aircraft Pilot Coupling (APC)
  - Test pilot in controlled environment
    - not ops pilot in the field
  - Prevent accidents
  - Improve performance
- First *Operationally Representative* Look at Aircraft
  - Mission suitability
  - Ability to perform mission
  - Level of piloting skills required to perform task
- Overarching driver for ***all*** Aircraft **Flying Qualities** is to achieve *Satisfactory* ***Handling Qualities***

Purpose of Handling Qualities

- Primary Purpose(s) of Flying Qualities Testing
  - Determine if Aircraft is *Safe to Fly*
  - Determine if Handling Qualities are *Suitable for the Mission*
- Additional Purpose
  - Free from Unwanted Aero-Servo-Elastic (ASE) Responses
  - Redundancy Management (Flight Control System Failures)
  - Proper Integration with Other Systems

Bad Handling Qualities!

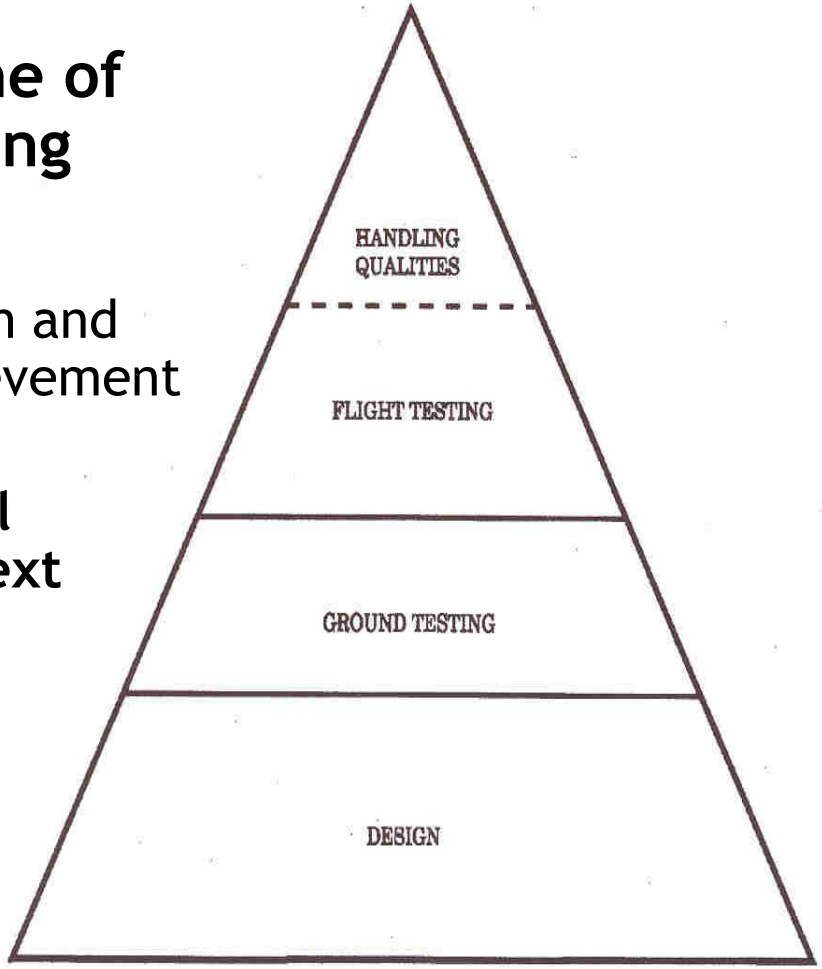


Handling Qualities Basics

Handling Qualities are the Capstone of Flying Qualities Design and Testing

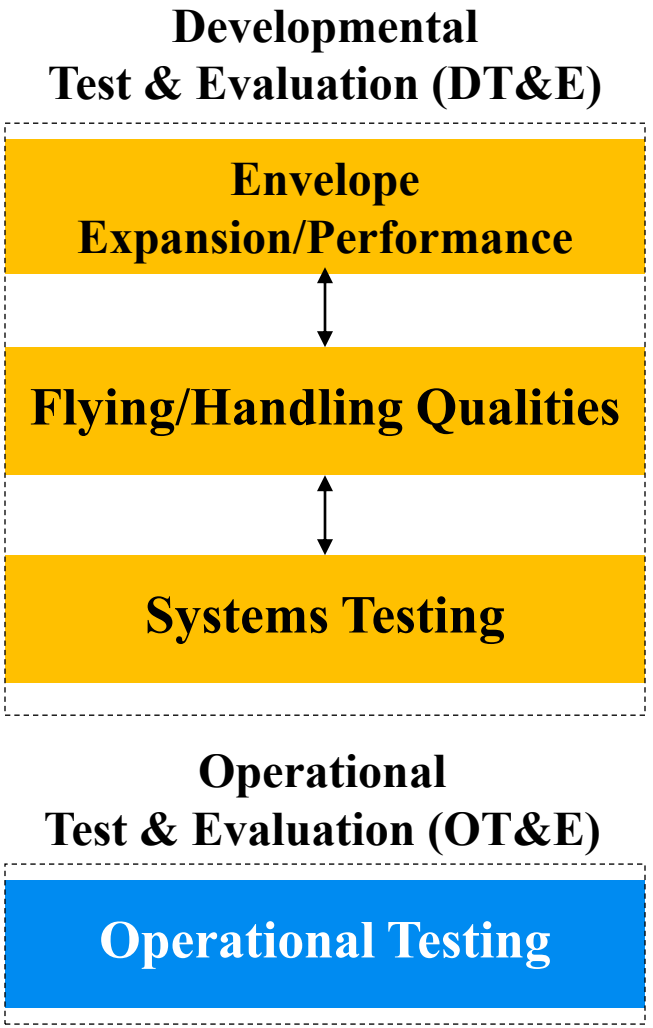
"Everything we do in *flying qualities* design and testing has as its ultimate goal the achievement of satisfactory *Handling Qualities*"

- USAF Test Pilot School
Flying Qualities Text



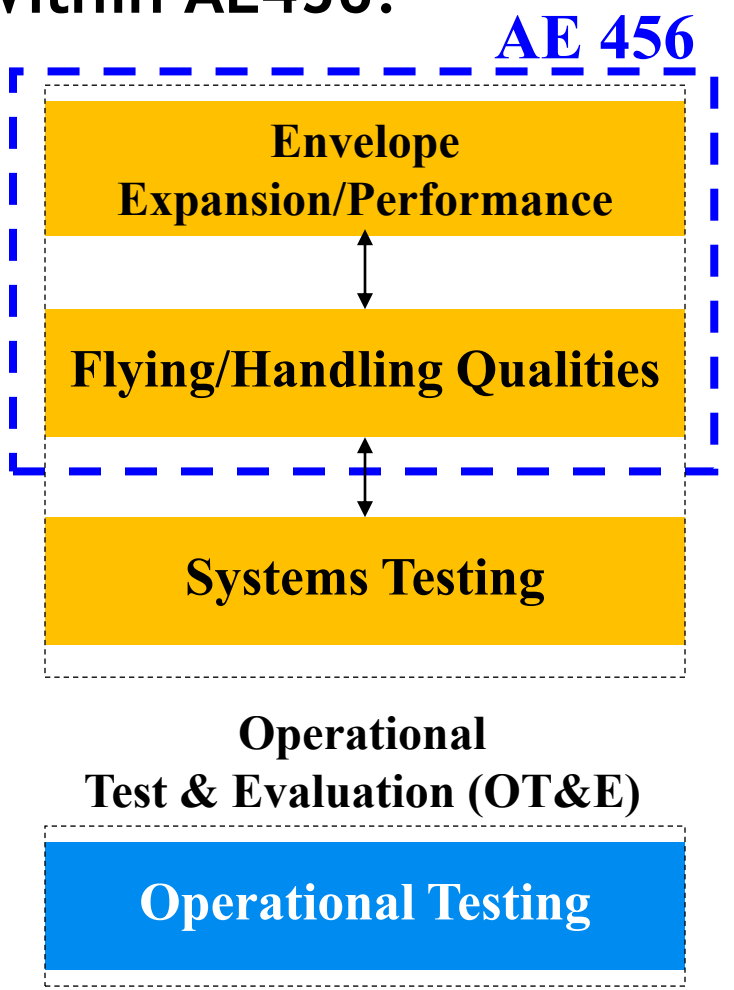
Handling Qualities Basics

- Handling Qualities Testing is Used Throughout Developmental Flight Test
  - Used Extensively during Envelope Expansion
  - Final Goal of Flying Qualities
  - Aircraft Dynamics with Systems and Degraded Modes
  - Thorough understanding of aircraft handling qualities required prior to release for dedicated OT&E



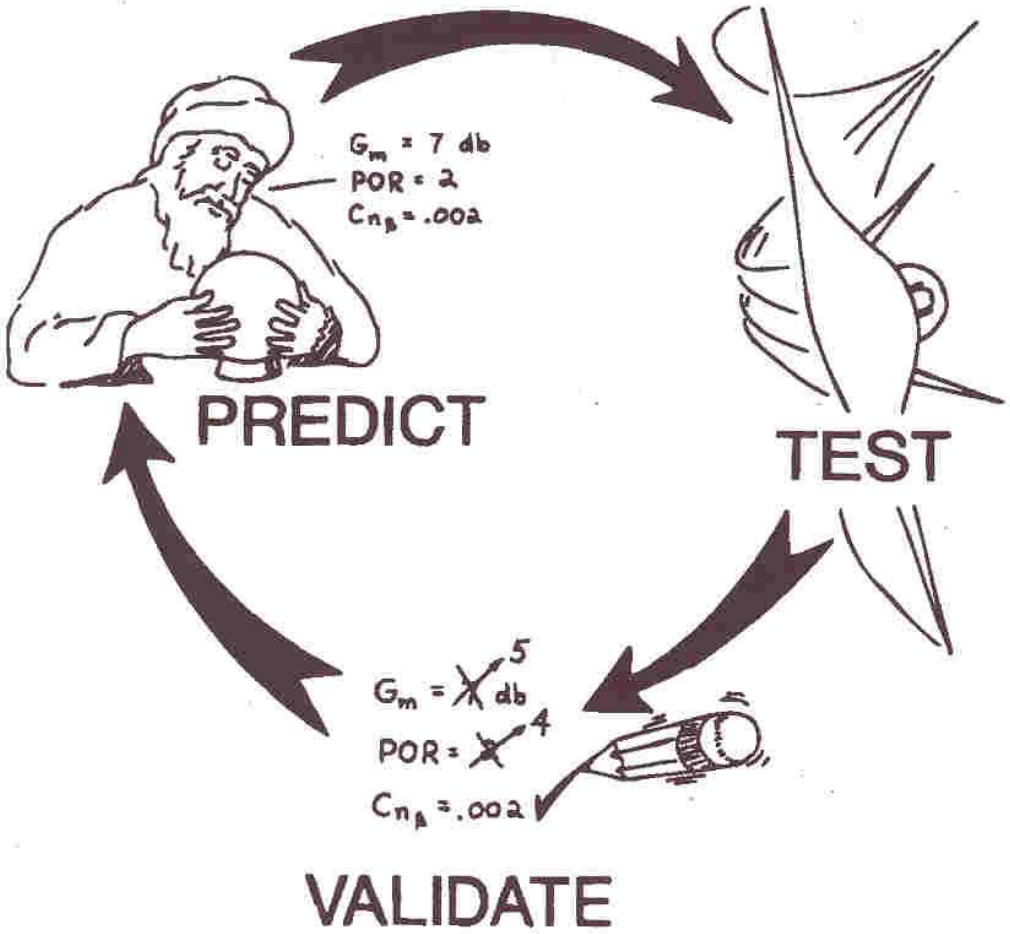
Handling Qualities Basics

- Where Does Handling Qualities Fit Within AE456?
- Performance Lessons
- Flying Qualities Lessons
  - Classical (Open Loop) Modes of Motion
    - Longitudinal Static Stability
    - Maneuvering Stability
    - Lateral-Directional Stability
    - Dynamics
  - *Handling Qualities* (Closed Loop)
    - HQDT, Boundary Avoidance
    - PIO Testing
    - Stalls and Spins



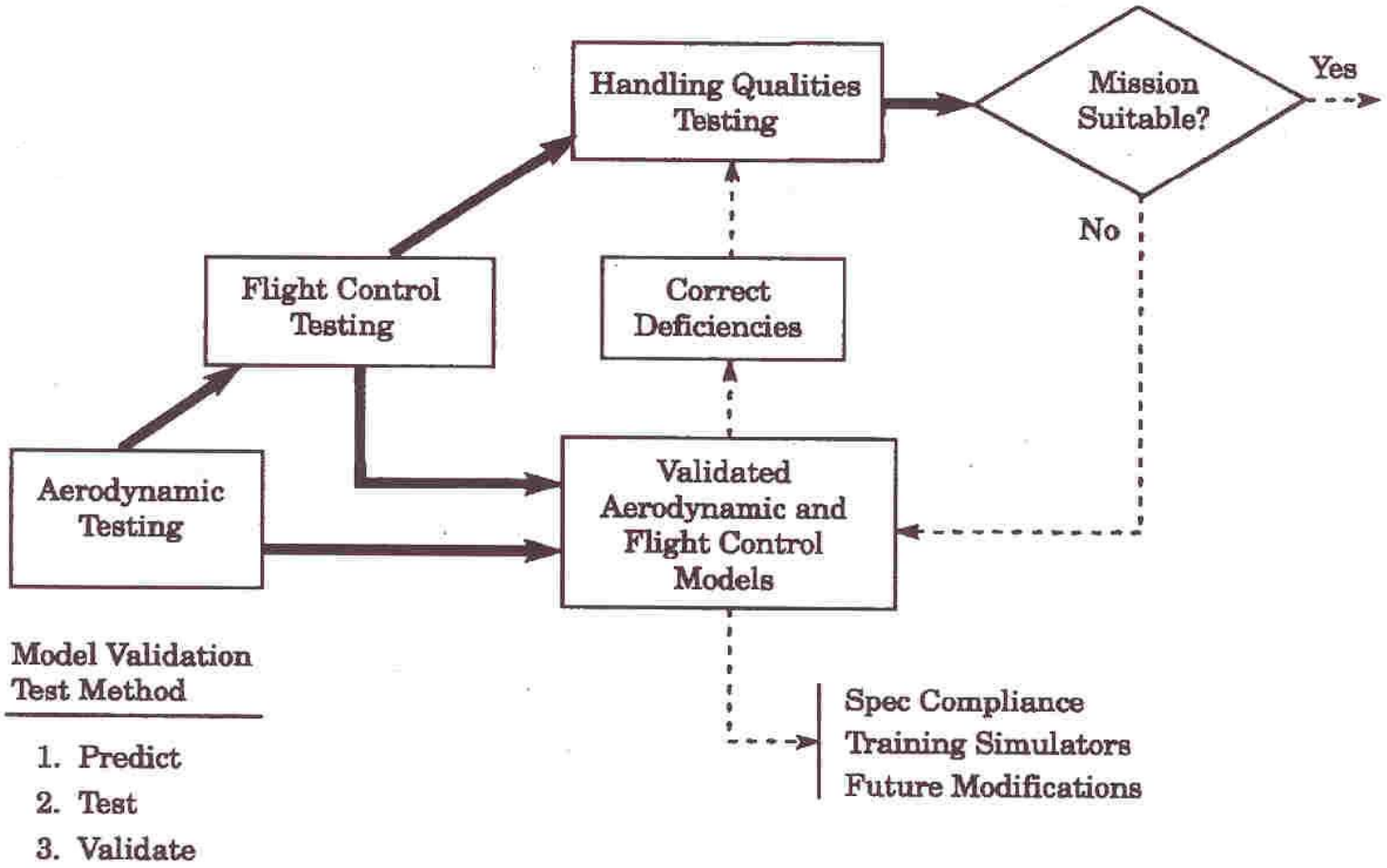
Handling Qualities Testing

- **Model Verification Method**

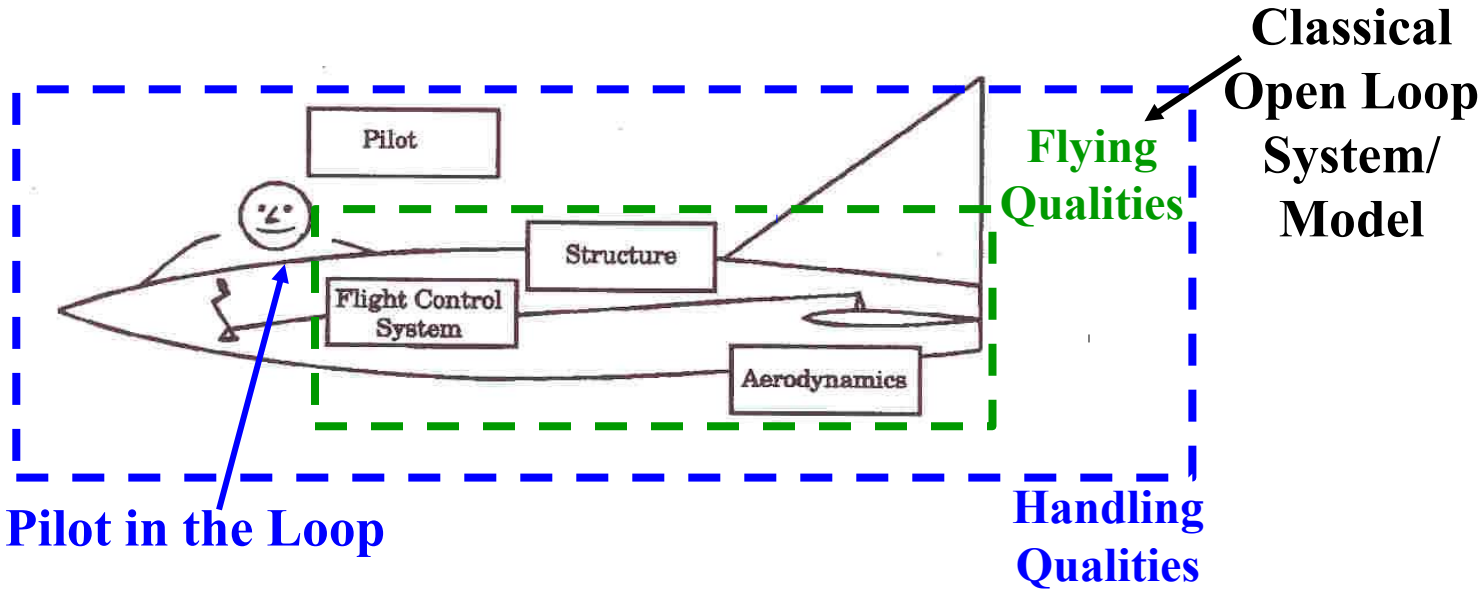


Handling Qualities Testing

- **Model Verification Method**



Handling Qualities Models

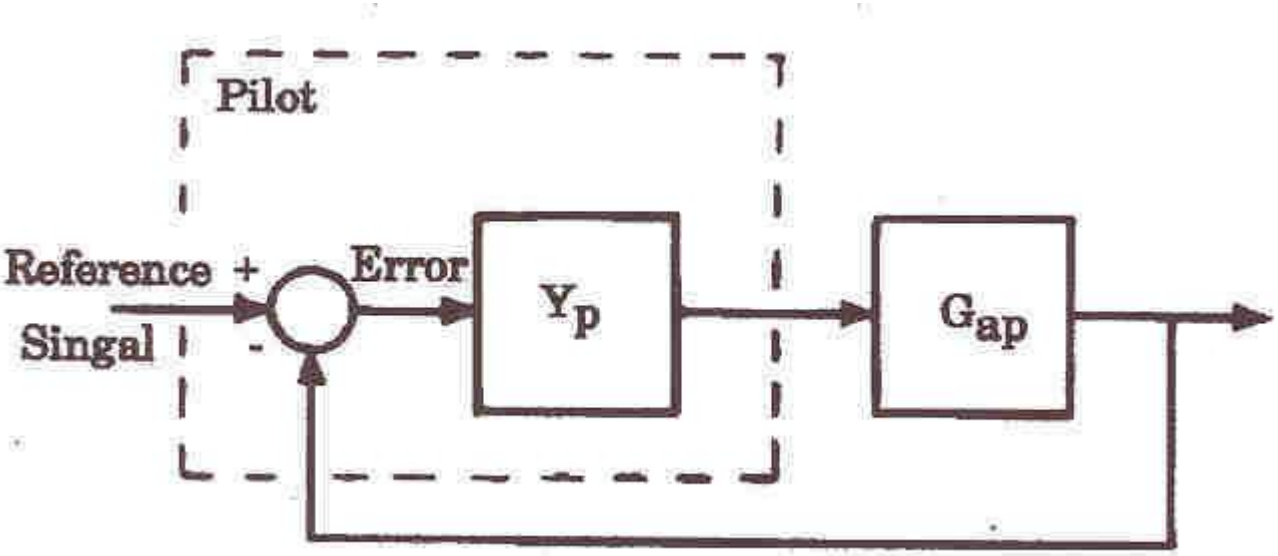


Models Used to Predict Handling Qualities

- Unaugmented Airplane Model
  - Aerodynamic Model
  - Structural Model
- Flight Control System (FCS) Model
- Pilot Model

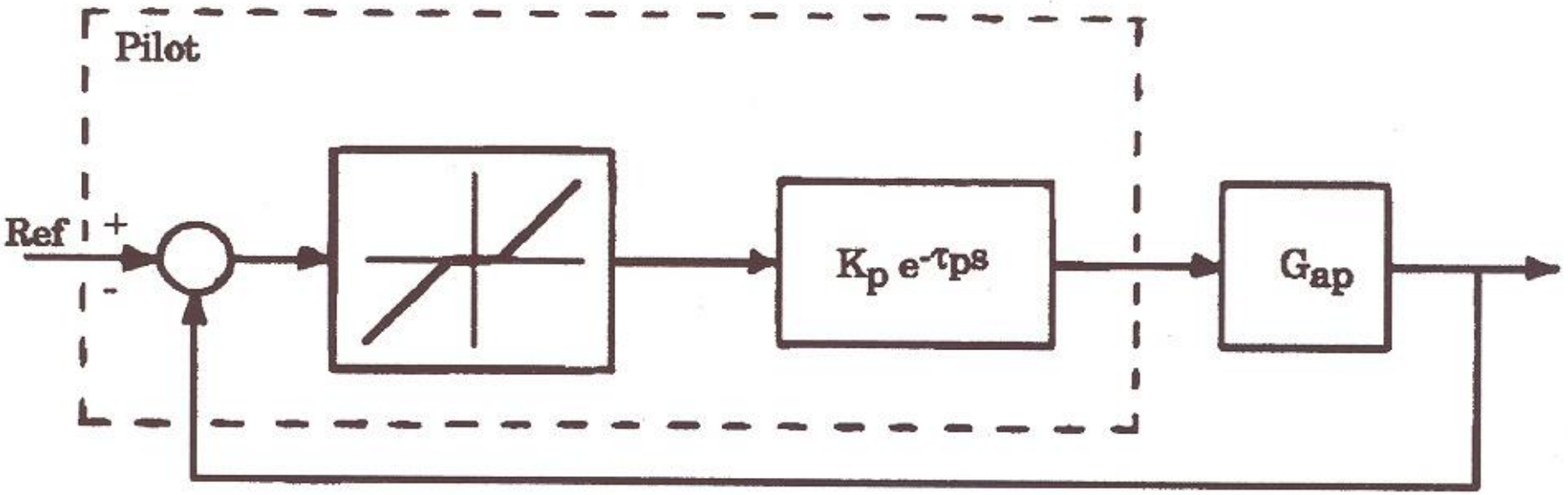
Handling Qualities Pilot Models

Primitive Pilot Model (Gain with Time Delay)



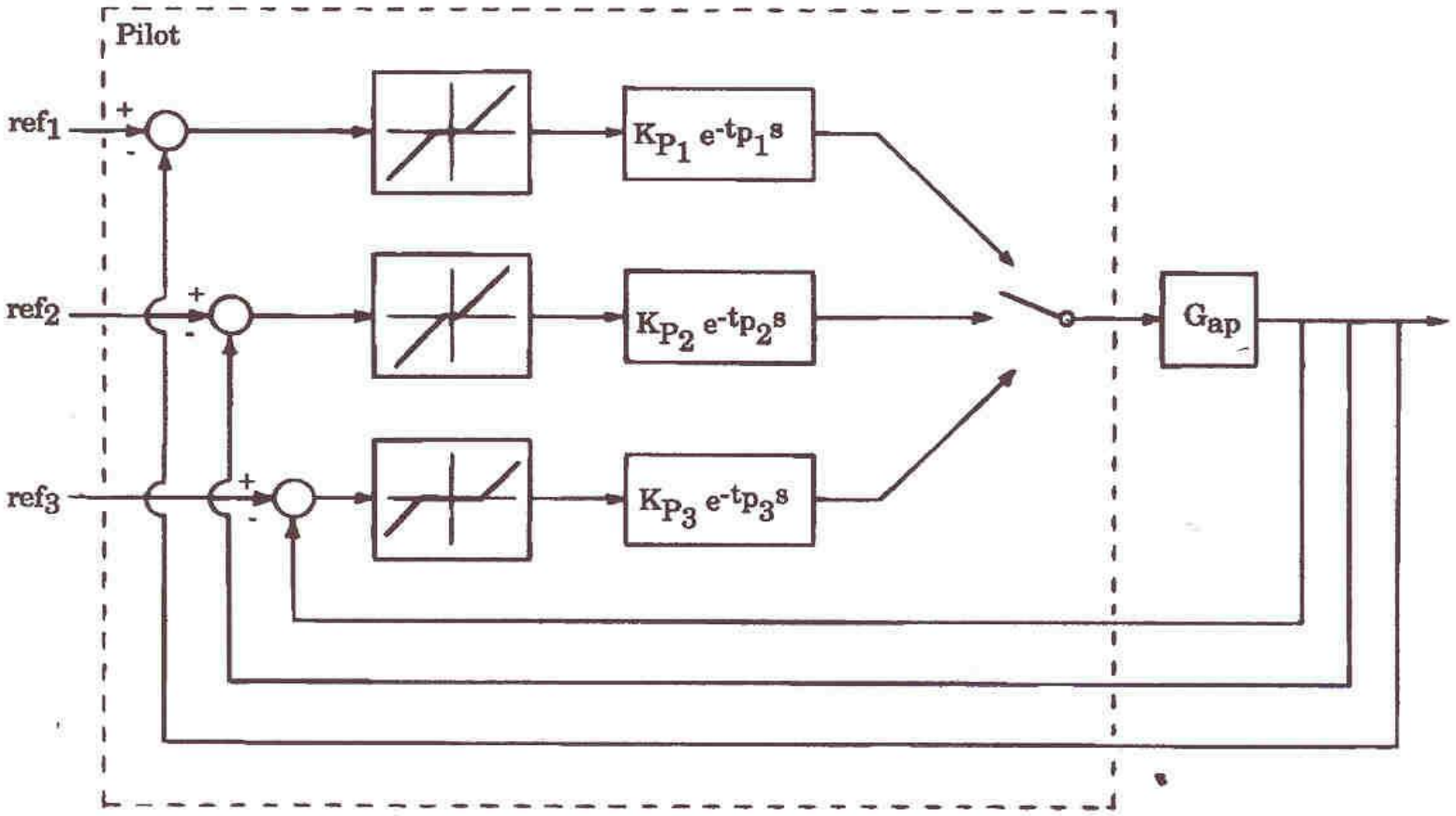
Handling Qualities Pilot Models

Primitive Pilot Model *Add* Threshold



Handling Qualities Pilot Models

Add **Threshold <u>and</u> Switching (w/lead or lag compensation)**



Handling Qualities Testing Observations

- Observations About "Modeling" a Pilot (for HQ predictions)
  - Assume pilot must track a *reference signal* (i.e. gunning a target)
  - HQ are closely related to Pilot Gain, Bandwidth, and Compensation
  - Experienced Pilots adopt the lowest gain piloting technique consistent with reasonable track performance
  - Pilots switch to High Gain when stress exceeds a threshold
- *A Complete Handling Qualities Evaluation Must Ensure Full Range of Pilot Gain, Bandwidth, and Compensation is Fully Explored*

Challenge: How does a good pilot act like a bad pilot?

- Measurable?
- Repeatable?
- Relevant?

Handling Qualities Testing Complications

- Model Uncertainty
  - Aerodynamic Model Errors/Non-Linearities
  - Structural mode errors or unknowns
  - Flight Control System unknowns or cliffs
  - Pilot (Most Complex and Difficult to Model)

- Model Uncertainty = Reason for Flight Test

Closed Loop Handling Qualities

- MIL-SPEC evaluations are open-loop flying qualities
- Need a method to evaluate flying qualities with the pilot in the loop (closed loop)
  - PIO susceptibility
  - Level of pilot compensation required
- Tasks must be well defined
  - Frequently misunderstood
  - Should be high-gain tasks to excite any undesirable characteristics
  - Handling Qualities During Tracking (HQDT), offset landings, aerial refueling, fingertip formation, boundary avoidance, and others

Closed Loop Handling Qualities

- Terms
  - Controllability: ability to command a desired response
    - No consideration of amount of attention required
    - No consideration of mission accomplishment
  - Adequate performance : aircraft can marginally perform the mission
    - System should be improved
    - No consideration of amount of pilot compensation required
  - Desired performance : aircraft is satisfactory for the mission
    - Does not mean it is perfect
    - No improvements required

- Pilot comments are as important (if not more) as numerical rating (HQR)

Handling Qualities FTTs

- **Handling Qualities During Tracking (HQDT)**
  - *A "Pilot-in-the-Loop" (Closed Loop) task where the pilot captures, then tracks a reference signal (target)*
    - Examples=Air-to-Air Gun Tracking, Air Refueling, Spot Landing
- **Boundary Avoidance Tracking (BAT)**
  - *A "Pilot-in-the-Loop" (Closed Loop) task where the pilot must avoid exceeding limits of opposing boundaries*
    - Examples=Landing/Flare, Air Refueling, Fingertip
- **Handling Qualities Stress Testing (HQST)**
  - *High gain/bandwidth HQDT with no pilot compensation*
    - Simulates a Situation Where the Pilot is Accomplishing a Task Under Great Stress
    - Used to Uncover Hidden Undesirable Handling Qualities

Handling Qualities FTTs

- **Safety Requires an Orderly "Build-Up" Approach**
- **Tracking Tasks Broken Into Three Categories (Used in Order to Ensure Proper Build-Up Approach)**
  - **Phase 1 – Low Gain/Bandwidth HQDT**
    - Allows Pilot to Get Feel for Basic Handling Qualities
  - **Phase 2 – High Gain/Bandwidth HQDT**
    - NO Pilot Compensation (Aka Handling Qualities Stress Testing)
  - **Phase 3 – Operational Handling Qualities Evaluation**
    - Pilot Compensation Included

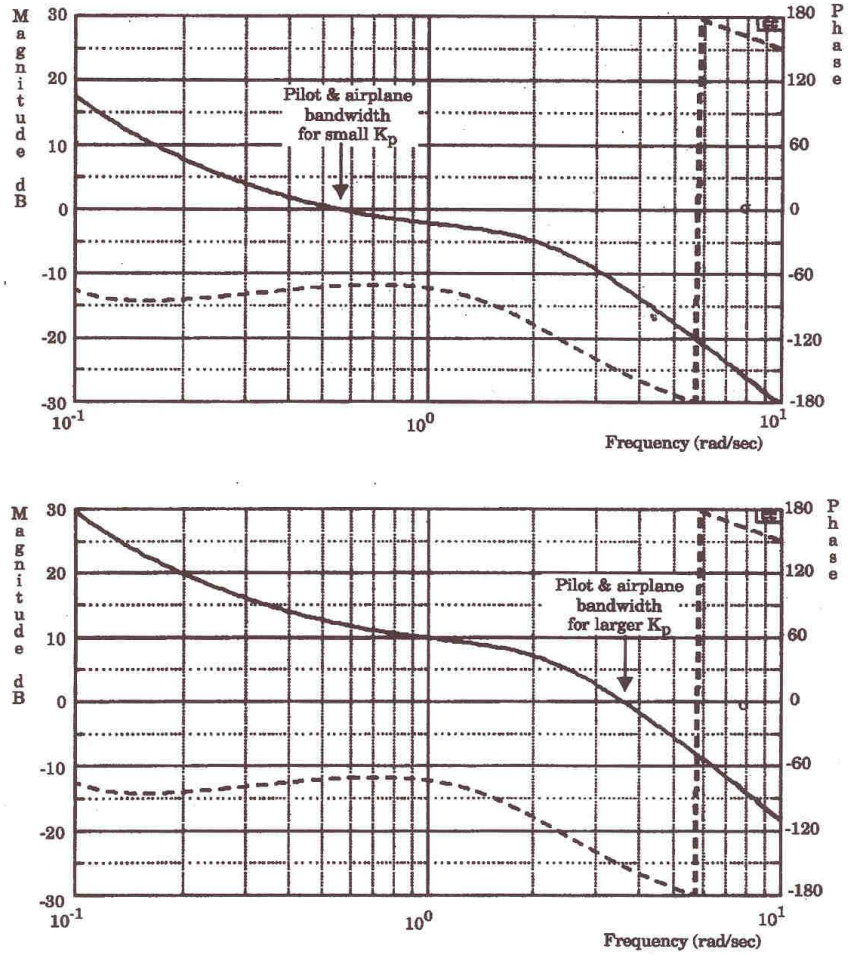
Handling Qualities Testing and Analysis

- **Accomplish both Qualitative and Quantitative Analysis of Results**
  - **Quantitative techniques include**
    - **Frequency and time domain curves**
  - **Qualitative techniques include**
    - **Cooper-Harper Handling Qualities Rating Scale**
    - **Pilot Induced Oscillation (PIO) Rating Scale**

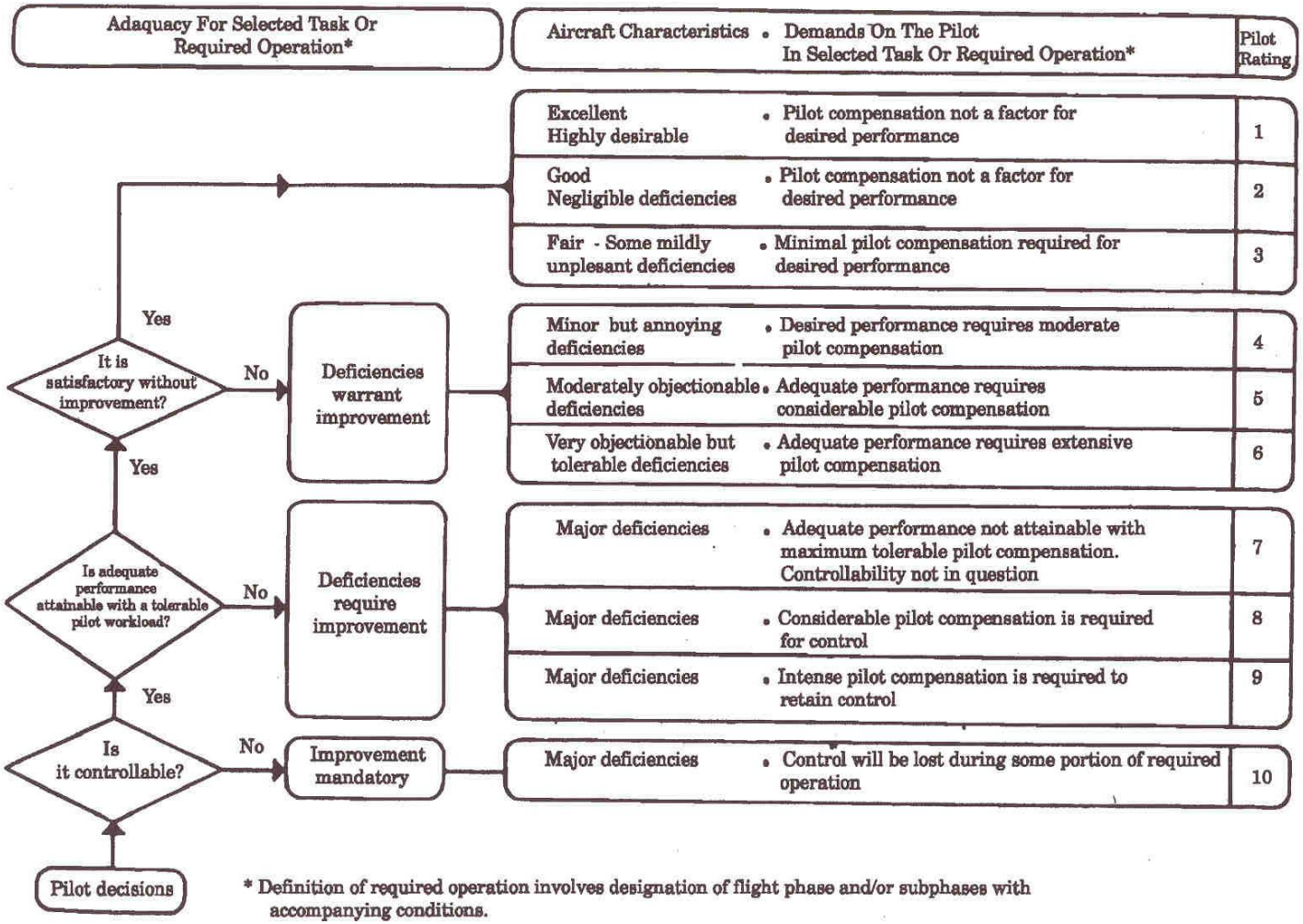
Quantitative HQ Data Reduction

- **Frequency response curves allow simple graphical analysis to determine system gain, bandwidth, phase and gain margins**
  - **Bode Plots** (shown)
  - **Nichols charts**
    (Log Mag and linear phase combined)
  - **Nyquist plots**
    (polar versus rectangular coordinates)

- **Why use log curves?**
  - **Mult & div = add & sub**
  - **Quickly determine margins**



Cooper-Harper Ratings



Sat

Marginal

Unsat

Cooper-Harper Ratings (cont)

- Use of the Cooper-Harper Rating Scale
  - The key is to select a well defined, mission-realistic task
    - Performance criteria must be:
      - Well defined
      - Measurable
      - Realistic
      - Reflect the task
    - Workload ratings likewise must be:
      - Well defined
      - Commonly understood by all pilots testing
      - Considerate of the experience of pilot who will eventually fly it
  - Qualitative Pilot Comments are just as important (or More Important) than the "Score"
  - *Do not* average or fractionalize the scores
  - Cooper-Harper used to elicit sensible and relatable pilot comments



Switch Induced Simulated PIO (SISPIO)

- Start lined-up on a target point
- Offset by some Δ (100 ft alt, 5° heading, etc)
- Apply a fixed control input to correct delta
- Reverse input when target point crossed
  - Repeat/continue until peak equals double/half Δ
- Observed convergence/divergence
- Repeat with increasing fixed control inputs

Data Reduction

- Divergence suggests PIO potential

PIO Examples

- Calspan In-flight Simulator
- Edwards T-38
- F-22 Take-off
- Airliner (roll)
- F-8
- Space Shuttle
- Gripen
- F-4
- C-17
- Cessna on landing
- Piper on landing
- Edwards F-16

PIO Rating Scale

- PIO Rating similar to Cooper-Harper

PIO Rating

Did I experience a PIO?

No

Did I experience undesirable motion?

No 1

Yes

Did undesirable motion *tend to occur*? 2

Was undesirable motion *easily induced*? 3

Yes

While attempting abrupt maneuvers or tight control

Was the PIO *bounded*? 4

Was the PIO *divergent*? 5

While exercising normal control 6

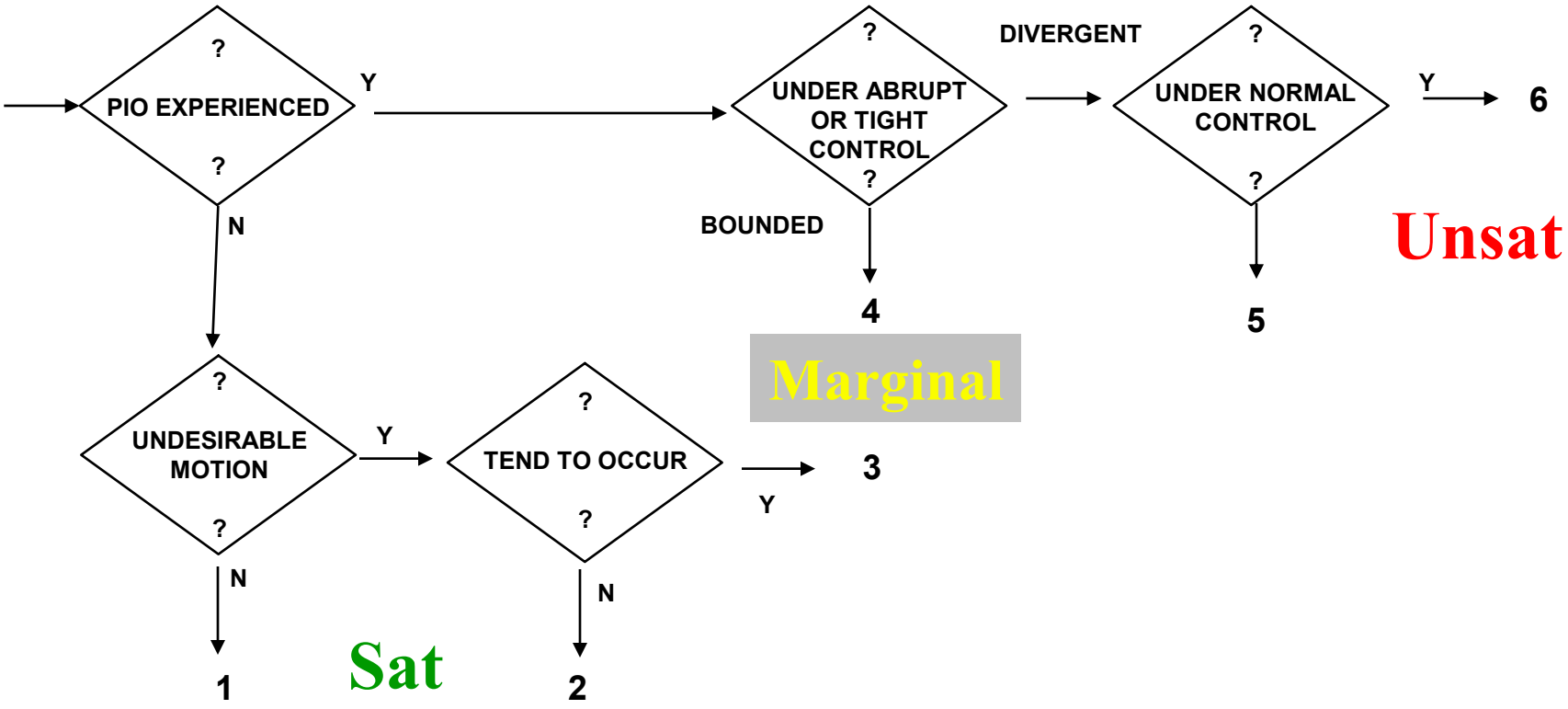
- Quantitative Scores Have Good Value
- Qualitative Comments are Still Extremely Important
- Not Appropriate to Fractionalize or Average Scores

PIO Rating Scale (cont)

- PIO Rating similar to Cooper-Harper

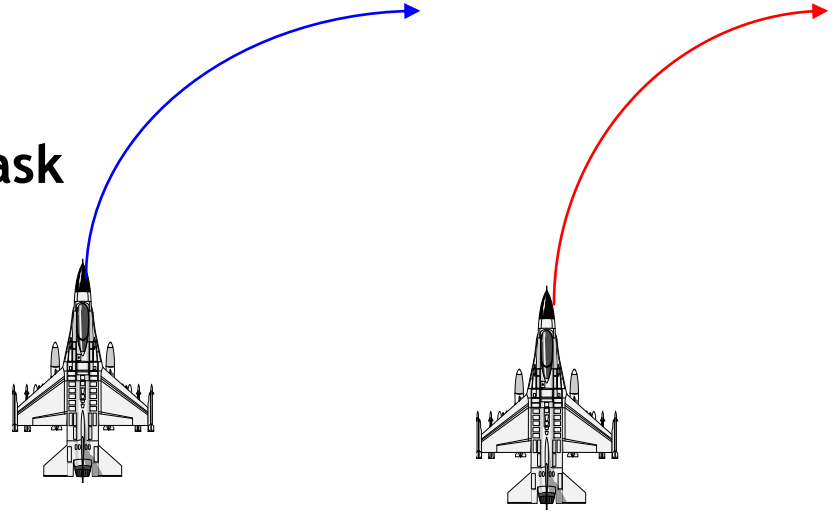
Pilot-in-the-loop Oscillation (PIO) Scale	
Description	**Rating**
No tendency for pilot to induce undesirable motions.	1
Undesirable motions tend to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.	2
Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated, but only at sacrifice to task performance or through considerable pilot attention and effort.	3
Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.	4
Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must open loop by releasing or freezing the stick.	5
Disturbance or normal control may cause divergent oscillation. Pilot must open control loop by releasing or freezing the stick.	6

Evaluating PIO Ratings



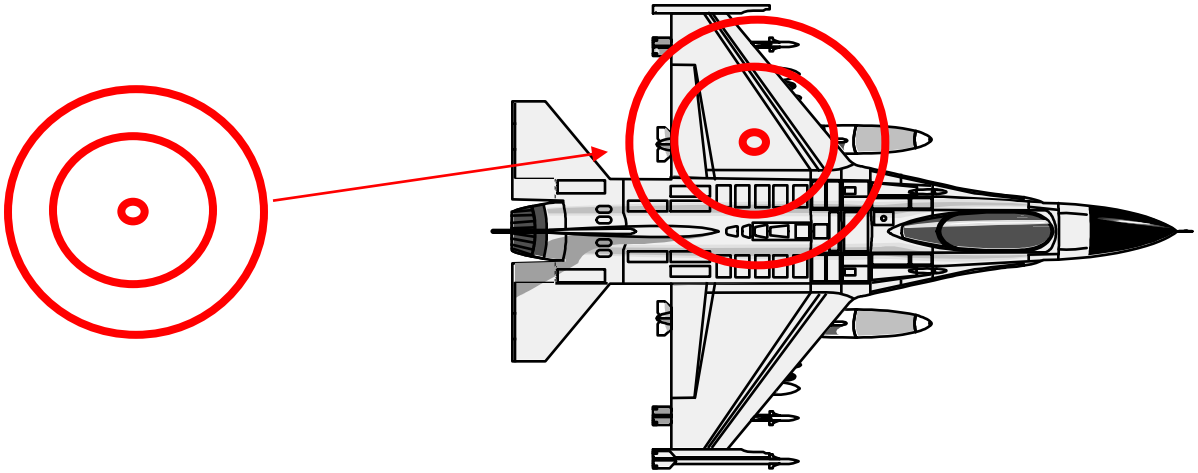
Example HQST Handling Qualities Stress Test

- **Setup:**
  - 20,000 ft pressure altitude, 400 KIAS
  - Target aircraft 1000 ft abeam, 500 ft below
  - “Fight’s on” : Target selects MIL power, 3 g level turn away
- **Task:**
  - Pull target to HUD & Shoot
  - Missile – Gross Capture Task
  - Gun – Fine Capture & Tracking task



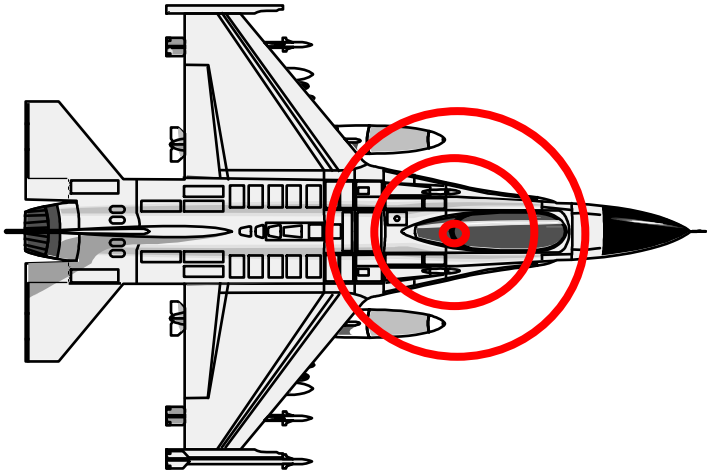
HQST Capture Task

- Apply Stress
  - Shoot within XX seconds
  - Use maximum allowable turn and pitch rates
  - Capture Precision Requirements
    - Simulated IR missile employment parameters
      - Desired Performance: Within 25 mils, no more than 1 overshoot
      - Adequate Performance: Within 50 mils, no more than 2 overshoots
    - Simulated Gun employment parameters
      - Desired Performance: Within 5 mils, no overshoot
      - Adequate Performance: Within 10 mils, no more than 1 overshoot



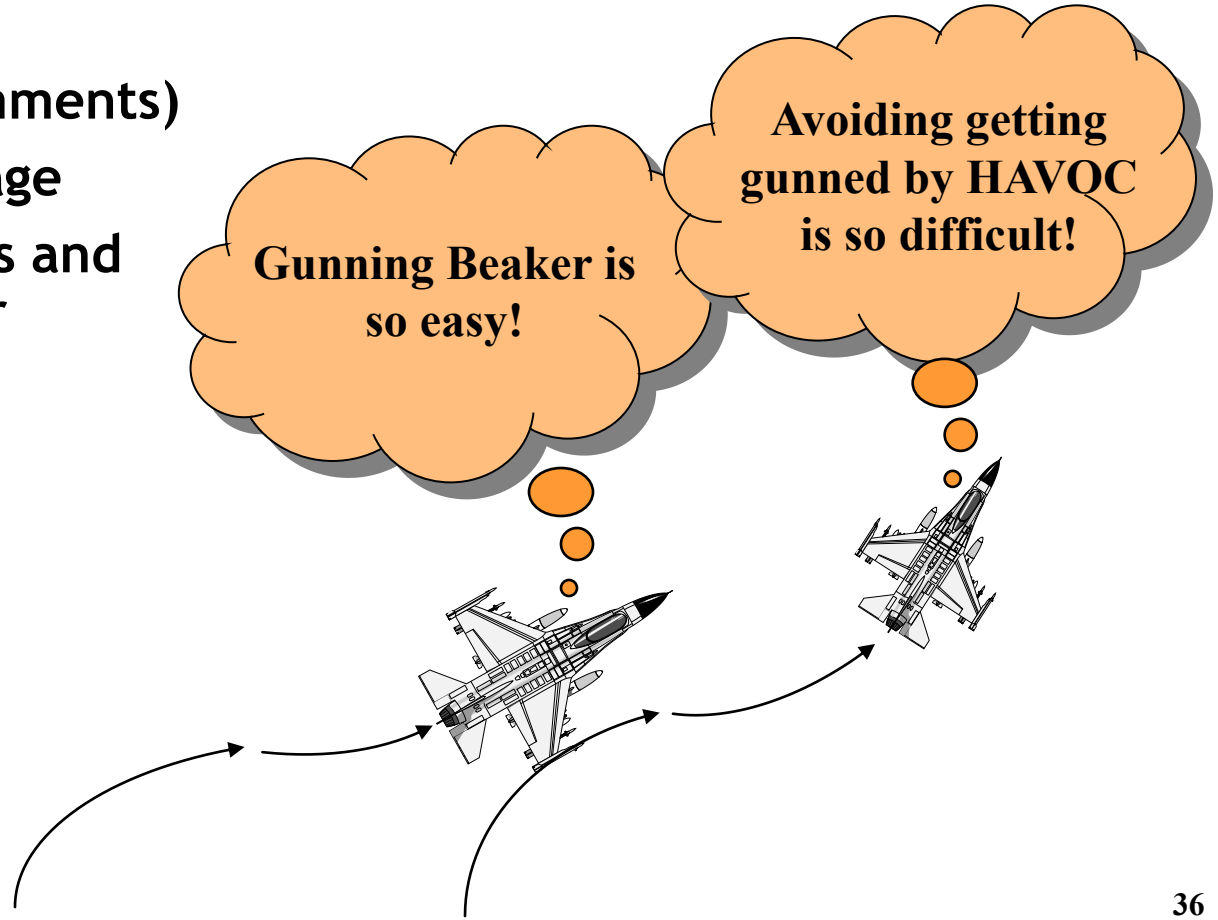
HQST Tracking Task

- Apply, Maintain, & Increase Stress
  - Simulated Aerial Gunnery (Fine Tracking)
    - Apply Stress
      - Desired performance:
        - Pipper within 2.5 mils of RCP 50% of time, max excursion of 10 mils
      - Adequate performance:
        - Pipper within 5 mils of RCP 50% of time, max excursion of 15 mils
    - Maintain Stress - Track for 20 seconds
    - Increase Stress – Target reverses direction



Example HQ Flight Test Technique (FTT)

- Typical Data Collection
  - Cooper-Harper Rating (WITH COMMENTS!!)
  - PIO Rating (With Comments)
  - Video Tracking Footage
  - Record control inputs and Flight Parameters for Analysis as required



REVIEW AND CONCLUSIONS

- Handling Qualities
  - Pilot-in-the-Loop Aircraft Response
- Satisfactory Handling Qualities
  - Goal of the Designer
  - Required by the War Fighter
- Handling Qualities Testing
  - Capstone of Flying Qualities Testing
  - Model Verification Method/Build-Up Approach Used for Safe, Effective, and Efficient HQ Flight Test
  - CAN'T BE TESTED WITHOUT A PILOT!!!

Lectures Complete
Questions?

