Limits Based Monitoring of Dynamic Flight Test Maneuvers

*Human Factors Considerations in Control Room Displays*

Presented by: William “K9” Kuhlemeier
Duh!

That’s **SO** Obvious!
Aha!

Sometimes the *Obvious* can become a *Revelation*
A lot of Human Factors *Aha Moments* *Should be* *Duh!*
Purpose

• After the Tragic Loss of a Pilot and Aircraft There Needed to be a Better Way

• The Purpose of this Project/Paper
  – Develop and Implement Improved Control Room Display Methodologies for Dynamically Maneuvering Flight Test
    (in other words: Making Better Data Displays)
  • Test Conductor Displays Specifically
    – TC is Only Engineer Communicating Directly with the Pilot
    – Time Critical Decisions
Introduction

*Flight Test 101*

- Data is Presented to Engineers in Control Room via various Data Display Techniques
  - Strip Chart Recorders (older technology)
  - Mechanical Gauges (older technology)
  - Computer Graphic Displays (most current technology) using IADS® Software by Symvionics
- Graphics display capabilities are evolving rapidly and dramatically
  - Touch Screens
  - Google Glass?

*Resistance is Futile!*
Introduction

• *How* data is presented in a Control Room has **not** always taken into consideration:
  – Ease, Accuracy and Efficiency of Data *Interpretation*
  – *Human Factors* Components
    • Colors
    • Placement
    • Format etc…
  – Screen Design, in many cases, has been to: “*Make it all fit on the Screen*”
Example of Non-Human Friendly Display

Not Duh! But Duh? (Seriously?!)
Initial Interview/Survey

- Flight Test Professionals Interviewed on “Data Display Use” Experiences:
  - Approx: 50 Professionals (FTE & Pilots)
  - Broad Range of Ideas and Experiences
  - Data Quantity: 2 Pilots = 3 Opinions!
  - Open Ended Questions and Discussions

- “Steam Gauges” vs Graphical Displays
  - (Steam Gauge is term for basic round gauge with needle pointer)
- Limit Markers
  - Usage and Importance
- Color Code Usage
- Trend Monitoring
- Task Saturation
Interview/Survey Results

• **Steam Gauge vs Graphical Displays**
  – Transition *to* Graphical Displays = Easy
    • From = **Not** so Easy
  – Gauges require more training for *interpretation*
    • Learning Good vs Bad Values
  – Graphical Displays “**Build a Picture**” *(not just a play on words!)*
    • Gauges require the picture to be “**built in your head**”
Interview/Survey Results

• **Limit Marker Usage and Importance**
  Limit mark is a reference ON an indicator to show some specific value has been reached
  – Early Markers on Gauges used colored tape
  – Some gauges used colored areas
  – Provide help in Decision Making
    • Once a Limit has been reached, some action is required
  – *Settable* markers allow better task focus
    • Specific to individual tasks and actions
      – Existing Cockpit examples: Altitude/Heading Bugs
  – Limit Markers “Free up *Brain Bytes*”
    • *Brain Bytes* = *Highly Technical Term*
Interview/Survey Results

• Color Code Usage
  – **Red** = Bad
  – **Green** = Good
  • These colors appear to be *universal* in meaning
    – HOWEVER...Universal ONLY because of Cultural Experience
  – *Transition* to a color, especially **Red** = Attention!
Interview/Survey Results

• Trend Monitoring
  – *Trends* of Data can be *as* important as the value itself. (...and sometimes even MORE important)
  • Help to *Predict* the Immediate Future
    – Specific Actions may be required *soon* i.e. KIO or Recover
  • Some techniques can cause confusion in interpreting trend *polarity*
  • **Intuitive** Techniques are important to prevent a *requirement for training* to overcome possible confusion in interpretation
Interview/Survey Results

• **Task Saturation**: “Mental state characterized by unnaturally high stress and loss of “Situational Awareness.””
  
  – When Task Saturation goes UP, ability to effectively monitor multiple indications goes DOWN.

  • Ability to *Declutter* displays is important to reduce visual distractions in Task Saturated situations.
  
  • Too Much Information can cause a *Keyhole* Effect
    
    – Looking *through* the clutter keyhole to the real data
Interview Summary

• **Graphical** better than Steam Gauges

• **Limit Markers** aid Decision Making
  – **Color** Usage *Adds* to Limit Marker information

• **Trend** Monitoring predicts the Future
  – Can be *as* or *more important* than a value

• **Task Saturation** can block the Important Information.
Literature Review

• Other Entities with “Control Rooms”
  – Nuclear Power Generation
  – Complex Automated Manufacturing

• Other Industries have learned:
  – There are opportunities to improve Data Displays
  – Too Much Data in Too Small of space is bad
    • Also Too Much Data in Too Big of a space is bad
      – Keyhole or Panoramic View
      – Needs to be a Balance
  – Color Codes ARE Significant
    • Important to consider “Color Blind” operators

Doh! or Duh!
Literature Review

- Heads Up Displays (HUD) Flight Test Version
  - Displays for Cockpits, developed *Graphical Techniques*, some of which are transferrable to a Control Room.
### Trend Evaluation

**Confusion**

<table>
<thead>
<tr>
<th>Time 0</th>
<th>Time 1</th>
<th>Time 2</th>
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<tbody>
<tr>
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<td>190</td>
<td>210</td>
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<tr>
<td>100</td>
<td>120</td>
<td><strong>140</strong></td>
</tr>
</tbody>
</table>

Tape is physically moving **DOWN** (in relation to the arrow marker) as Time increments from $T_0$ to $T_2$.

**Movement seen (tape), is down as value goes up**

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<table>
<thead>
<tr>
<th>Time 0</th>
<th>Time 1</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
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<td>100</td>
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</tr>
</tbody>
</table>

Tape/Scale is stationary and the arrow is moving **UP** (in relation to the tape/scale) as Time increments from $T_0$ to $T_2$.

**Movement seen (pointer), is up as value goes up**

**Limitation**: Scale is now limited to a specific range.
Literature Review

• An Aviation Study in Human Factors cited the Importance of What/How Data Is Presented:

  “The Big 4”
  – Provide WHAT Data is Necessary
  – Provide ONLY What Data is Necessary
  – Provide the Data WHEN it's Needed
  – Provide data in an EASY to UNDERSTAND Manner

• These 4 Issues were the Primary Considerations for any improvement in the current Display Methodology
Display Technique Scenarios
Evaluation and Survey

• Flight Test Professionals Surveyed again on Potential Display Techniques
  (survey based on previous Interviews and Literature Review)
    – Ease of Interpretation
    – Intuitiveness \textit{(yes this is a real word)}
      • Human Factors that happen Automatically
    – Ability to Determine Trend information
    – Scan Consideration
    – Color Usage
    – Personal Preference
• Many Scenarios for Evaluation Presented to Testers
  – Summarized here for Time
  – No Advance Meaning of Indications given
  – Looking for “Intuitiveness”
Display Technique Evaluation

A

B

C

D

E

F

23.37

27.73

37.68

38.67

39.76

23.37

27.73

37.68

38.67

39.76
Display Technique Evaluation - Summary

• Multi Row Interpretation Summary
  – Color Codes were Universal (at least among the population tested)
  – Clockwise is Universal as an Increase in Value
  – UP is Universal as an Increase in Value
  – Red = Bad    Green = Good    Purple = ?
  – Digital Numbers can be difficult to interpret for Trend

• Preference was for use of Fixed Vertical Scales, Moving Pointers with Red / Green Color Codes.
Developing New Display Parameter Selection

• Selecting the “What” an Engineer needs:
  – **Primary** Parameters Provide
    • Flight Conditions (with specific limits)
      – Specifics to Flight Maneuver
      – Safety Considerations
    • **Secondary** Parameters
      – Situational Awareness
      – Non-Limited Parameters (“Nice to Haves”)
Developing New Display Parameter Selection

• **Primary** Parameters for New Display (Based on current and future test requirements)
  – **Altitude** (flight condition, safety)
  – **Airspeed/Mach** (flight condition, safety)
  – **G Force/Load** (flight condition, safety)
  – **Angle of Attack** (flight condition)
  – **Dive Angle** (safety)
  – **Total Temperature** (safety)
Parameter Selection

• **Secondary** Parameters for New Display
  (all enhance *Situational Awareness*)
  – Attitude
  – Stick Position
  – Rudder Position
  – Throttle Position
  – Weapon Bay Door State
  – Conventional Altimeter
  – Fuel Quantity Indicator

*Trying hard to avoid “Specification Creep” that would lead back to The Keyhole Effect*
New Display Development

- Old Test Conductor Display
New Display Development

• Old Display Summary
  – Over 50 Parameters displayed
    • Many NOT required for current or future tests
      – Keyhole Effect!
  – Lots of Raw Value Digital Displays
  – Very little, efficient use of Color *as Data*
  – Many different Display Techniques and Styles
  – No ability to *Show* or *Set* Limits
New Display Development

• New Display to have:
  – Parameter Selection Consideration
    • Primary and Secondary (previously defined)
      – Flight Science Missions only
  – Techniques
    • Vertical Stationary Scales with Moveable Pointers
    • Red/Green “Set-able” Data Bands “Understandable”
    • Limit Based Alarm (Knock It Off ) “Less Brain Bytes”
    • Declutter Modes “Only What & When”
    • Screen Preparation (limit tailoring) from desktop prior to mission
      – Specific Limits for Specific Test Points in Advance
### New Display Development

**Prototype Concept Design (starting point)**

<table>
<thead>
<tr>
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<th>AoA</th>
<th>Dive Angle</th>
<th>Mach</th>
<th>Altitude</th>
<th>KCAS</th>
<th>G</th>
<th>Total Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max:</td>
<td>##</td>
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</table>

(The what was given to the Software Engineer to Code)
New Display Development

• First Version Actual Implementation

(What the Software Engineer came back with, first effort)
New Display Development

• **Display tested in Flight Simulator**
  – Low Risk Environment
  – Survey Participants as *Evaluators*
  – Repeatable Side-by-Side Comparison
    • Old Display vs New Display

• **Results**
  – New Display Deemed a *Great Improvement* over the old display
    • Great Trend Indications
    • Settable limit markers very useful and Intuitive
    • Only Minor Revisions required for Actual Control Room use
New Display Development

• After Revisions – Implemented in Control Room (Display became known as: “KIO Display”)

Circled Parameters for reference between displays. Actual Test Point, Same Moment in Time.
Old vs New Video

– Maneuver *(significant to some of us in the audience)*

  • 1.65 M (+/- .02)
  • 20,500 (+/- 2000) (Ground is at 2500)
  • Max G (expected 7.5G)
    – Techniques
      » Setup at 24K’ 1.65M *(isn’t this an awesome machine?)*
      » Split S and pull

Click for Video

003 ADAPS SplitS.wmv
Old vs New Video

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      » Setup at 24K’ 1.65M
      » Split S and pull
  
  • **Obvious KIO Opportunities** with Limits and Alarms.

Click for Video

012 KIO Display Split S. wmv
New Display Development

• Final Evaluation in a **Real Test Mission**
  – Display a Success
  – Universally Preferred to old display
  – Future Improvement Opportunities
    • False Alarms were experienced due to spurious data spikes and Data Dropouts
      – Data Filtering needs to be developed
    • *Limit Tailoring* in advance was extremely useful, but requires verification before Mission Starts.
      – Critical that Limits are Verified before they are to be relied on!
      – Q.A. Procedures and Processes were put in place.
Breaking News!

This just in:

• These Display Techniques are Now being used on Automatic Ground Collision Avoidance System (AGCAS) with Great Success!
  – Flying the airplane directly at the ground Waiting/Hoping that the Computer Takes Over and flys the jet safely away. Woo Hoo!
    • Many parameters to watch for potential KIO Limits
    • Preloaded Limits for ALL test points
Lessons Learned

• Human Factors have NOT always been considered in Data Displays
  – Actual Users (FTEs) need to be involved in Screen Design
    • “Making things fit” vs Actual Usability
    • Key Hole Effect prevalent
    • Beware of Technology to lead down the path back to the Keyhole!
  – Human Factors are not as Obvious as they seem
    • Duh! and Aha! Factor
    • Green = Good, Red = Bad, Purple = What?! (Duh?)
    • Up or CW = More, Down or CCW = Less
  – Automation of Decision Making STILL Needs Human Filtering
    • Data spikes and TM dropouts need to be recognized to prevent erroneous KIO Calls.
Conclusion

• Existing Control Room Displays Can be Improved

• Human Factor Elements are Key to the Improvements
  – *What, Only What, When* and *Easily Understandable* were implemented
  – Settable Limits Markers and Universal Color Codes are now the Norm
  – Current AGCAS Testing has Adopted THESE display techniques with great success

• YOU Can do This Too!
  – This is NOT a Product, this is a “Technique”
    • Existing Display Software can be used.

Bottom Line

• Efficiency of Data Interpretation was improved, which *Directly Improves the Safety of Flight Testing.*
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Questions?
Backup/Bonus
Breaking News!

RECOVER
Old vs New Video

New Flight Test Technique

– Maneuver *(significant to some of us in the audience)*

• 1.65 M (+/- .02)
• 20,500 (+/- 2000) (Ground is at 2500)
• Max G (expected 7.5G)

– Techniques
  » Setup at 30K’ 1.65M *(isn’t this an awesome machine?)*
  » Set FIXED Dive Angle (Gamma)
  » Pull to Max G (Full Aft Stick)