The Leading Human Factors Deficiencies in Unmanned Aircraft Systems

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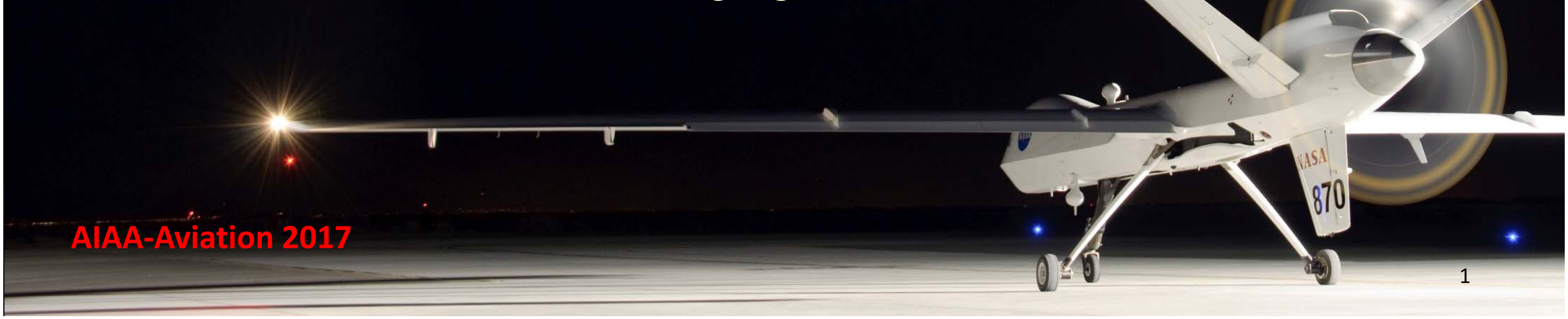

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Scope of Discussion

- ***What:*** **Explore the top human factors deficiencies in unmanned aircraft systems** ***…from a user's perspective***
- ***Why?*** **To educate/encourage UAS designers & testers on:**
  – the importance of "good design" for increased safety and mission success (no matter how that's defined by the operator/user).

Today's Roadmap:

- Why do you care?
- Background ("The Problem")
- Top Human Factors Deficiencies
- Conclusions/Takeaways

"I'm a lot more interested in people than I used to be. I used to be most interested in abstract ideas, and people were an afterthought, but that's changed a bit." -- Malcolm Gladwell

Why Care? (Designers/Testers/Users)

Because Good Human Factors means…

** Less user errors due to interface confusion, info overload, poor ergonomics & interface, automation confusion

Which translates into…

- ***Increases*** **likelihood of "mission" success**
  - Reliable & capable of getting from A to B; & accomplish tasks within desired parameters
- ***Enables*** **safe integration into the National Airspace**
  - Protect lives & property; build/maintain public confidence & trust in UASs
- **Your UAS's success = future "mission" opportunities**
  - FAA trusts it; public accepts it; customer wants more

Is this relevant today?

- Yes → rapid growth of UAS sales, use, and certification.

Background / Perspective

- **Me: 4,100 hrs flight time (USAF operational; test; NASA)**
    - 1800 hrs Manned Flying (900+ hrs F-15C/D)
    - 2300 hrs Unmanned Flying (MQ-1, MQ-9, RQ-4, X-56)
    - Flying unmanned aircraft since 2002
- **Survey: Small sample of current military operators, testers, & former UAS manufacturer pilots**
    - – Slanted towards med-to-large UAS's with cockpit/console style ground control stations (GCSs)
    - – Applies to any UAS with some autonomy <u>and</u> a pilot.

Background – Human Factors

- **What is Human Factors (HF) & Human-Machine Interaction/Interface (HMI)?**
  - HF (FAA) – multidisciplinary study of human capabilities and limitations…
  - …applied to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management…
  - for safe, comfortable, and effective human performance
  - HMI – "doing" requires interaction (human & hardware)
    - The Interface: the interactive surface of that hardware

- **"The Problem"** = Rapid development of the machine … Forgetting the operator in the design … Over-reliance on automation

HF - Issues

Automation & Complex Modern Cockpit displays:

- **Pros --** Safety: decrease stress/fatigue; increase thinking/monitoring; reduce human error
- **Cons**
  - False security (overreliance); Insecurity during failures (what's it doing?); Critical info missed (Fixation on peripheral info)
  - Increased reaction time when out of the loop (should I intervene?); Complacency; Confusing info during failures

HF - Issues

UAS Design:

- **Areas of Concern (from FAA, Test Community, etc)**
  - Human-automation interaction *(trust; mode awareness; disengagement behavior);*
  - Pilot-centric GCS design *(displays; sensory deficit);*
  - Traffic information *(separation assurance);*
  - Contingency management *(lost link status);*
  - Disengagement Behavior;
  - **General over-reliance on automation**

Now – on to the specific deficiencies……

Top UAS Human Factors Deficiencies

Overview

1. **Lack of a design standard (ground station HMI)**
2. **Inadequate command interfaces in "highly-autonomous" UASs**
3. **Limitations to See & Avoid capability (& visual nav & recognition)**
4. **Lack of seat-of-the-pants & audio sensory cues**
5. **Lack of depth perception (for landing or other proximity-critical tasks)**

Intro to Cockpit Design Deficiencies

Beech King Air

- **Historically, aircraft were/are required to conform to industry standard aviation HMI design elements (sticks, yokes, throttles, flight instruments, heads up displays, seats, visibility (out the window).**
- **UASs came on the scene – many manufacturers; no rules**
- **We can't dive into this one without first talking about <u>the basics</u> of Human Factors in Design…**

NASA HiMAT UAS *- 1979*

Importance of Cockpit Design

Cockpit design (ergonomics, anthropometrics, information) is important for all sorts of HF reasons:

- **Fatigue – “**mission tasks” and duration should drive design & layout of control station
  - display monitors and graphics design template and environmental lighting (eye fatigue)
  - physical layout and reach considerations
  - seat comfort/adjustability
  - environmental controls (temp)
- **Audio/Aural –** good audio enables good communication
  - selectable feeds; adjustable

Importance of Cockpit Design (cont.)

- **Visual –** many aspects
  - Camera FOV; refresh rate of video link & flight parameters
  - Limited bandwidth - determining critical high-rate parameters vs non critical low-sample data
  - Contrast/color/design scheme of buttons and symbols and switches (software and hardware)
  - Location of critical vs. non critical info (central 30 deg critical visual cone vs peripheral areas); design-eye height of horizon line in plane with pilot's eye (assumes vertical adjustment of seat or displays).
  - Latency (delay between input and desired output); due to processing, signal path, servo speed – Large latency leads to PIO (pilot induced oscillation)
- **Anthropometrics** - accessible to a range of physical body types based on intended pool of pilots

Importance of Cockpit Design (cont.)

- **Cognitive -** info in the right places, understandable, actionable
  - – Standard units? Useful scale? Presentation of values (dials, tapes, raw numbers, bars/sliders; how many?; groupings; density; location/arrangement).
  - – Buttons/switches <u>organized</u> by a familiar (aviation) scheme
    - By context? (Landing checklist; Lost-Link Emergency)
    - By system? (Fuel, Electrical, Link, Navigation, etc)
  - – Avoid information overload (too many parameters)
    - Key info - easy to locate; top layer (not buried)
    - Intelligently bring up the right info at the right time

Importance of Cockpit Design (cont.)

- "Information Overload" … Uniqueness = Unfamiliarity
  - Typical manned pilot - trained in traditional aircraft (FAA-certified standard inceptors, gages, flight displays)
  - Unique UAS GCS designs seem foreign… require experience/much practice to gain safe proficiency.
- Displayed info should simple, without diluting/sacrificing key decision-making info: aircraft state, change (rate of change), command/feedback, environment/surroundings, emergency interfaces.

Cessna Citation Latitude

Importance of Cockpit Design (cont.)

- Emergencies
  - Upon detection, emergency info should be prioritized, highlighted, and displayed
  - Only essential info to understand the problem and resolve the emergency (buttons/dialogues)
  - Include airspace awareness to get to safe landing site.
  - Critical "emergency-only" switches should normally be "guarded" with 2-step actuation, but quickly/intelligently accessible.
  - Increases pilot's capacity to respond to the EP
- **Pilot involvement in design is critical for it to be relevant & effective.**

Now, on to the list…

1. Lack of a Design Standard (GCS)

- FAA airworthiness certification standards (UAS) lag the rapid growth and arrival of UAS into the NAS structure…






- **Wide range of GCS designs, from various designers** (some with little aviation experience; or failing to involve aviators in the design process)… **resulting in designs shaped by:**
  - Incorrect/underdeveloped mission requirements
  - Marketing novelty
  - Rough edges of very new Tech
  - Misapplied manned cockpit traditions
  - Divergence from aviation standards (video game/smartphone)
  - Detrimental modifications (hasty/no pilot involvement)

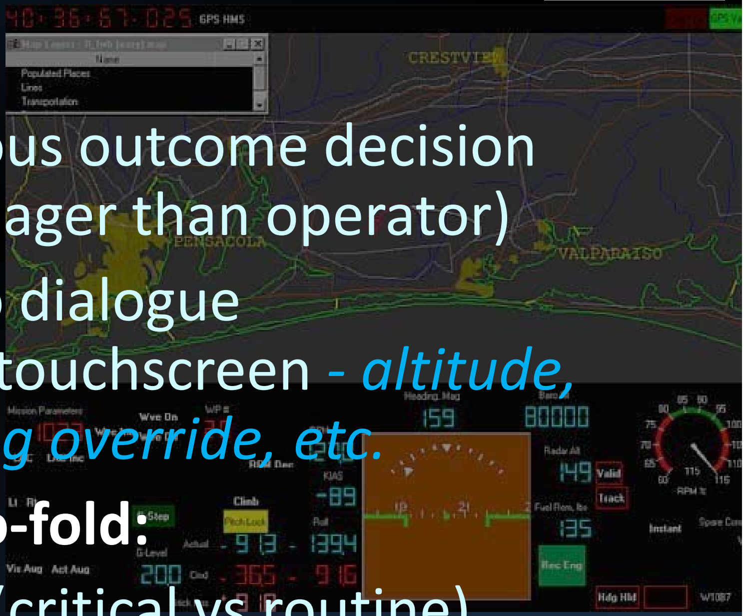
1. Lack of a Design Standard (cont.)

- **Impact** = huge variety in interface configs and very non-standard flight control inceptors.
- **Consequence of non-standard, poor HMI:** pilot confusion, fatigue, errors, damage/loss of UAS.
  - Pilot misperceives UAS's status in emergency…
  - Maybe critical info is not currently in view… *ie. "Battery - Low! Land within 5 minutes!"*
  - Misprioritizes actions, incorrectly responds to emergency … leads to unexpected vehicle behavior, & maybe loss of mission, airspace violation, or damage / loss of vehicle.

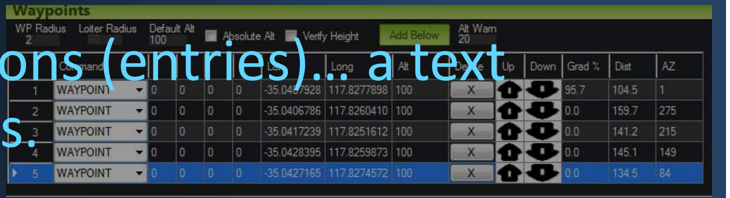
2. Inadequate Command Interfaces

- (Particularly for "Highly autonomous" UAS)
  - “Highly” (not fully): operator has command of only higher levels of automation *(autopilot commands; mission routing; transponder; radio)*
- **Poor Interface(s) - Can lead to pilot input errors & unintended aircraft responses.**
- **GCS Configurations**
  - Commonly configured w/ stick & throttle; sometimes also keyboard/mouse
  - Highly-autonomous UAS may only have keyboard/mouse since automation does not require pilot inputs to pitch/roll/yaw/throttle (i.e. RQ-4)

2. Inadequate Command Interfaces (cont.)



- **Highly Autonomous UAS HMI**
  - Programmed with many autonomous outcome decision trees; (pilot more of a mission manager than operator)
  - Interface - Commands entered into dialogue boxes/sliders/etc, via mouse/keys/touchscreen *- altitude, orbit/loiter mode, airspeed, heading override, etc.*
- **Problem with simple text entry is two-fold:**
  - Text entry fields can look identical (critical vs routine).
    - Highlight and/or “Guard” (2-step) critical inputs (prevent accidental activation).
  - No tactile interface with a text box; Place cursor in the proper field; Eyes jump from keyboard to text field (and back) to verify entry; opportunity for errors!
    - A knob may have 3 discrete positions (entries)… a text field may have 100s of possibilities.



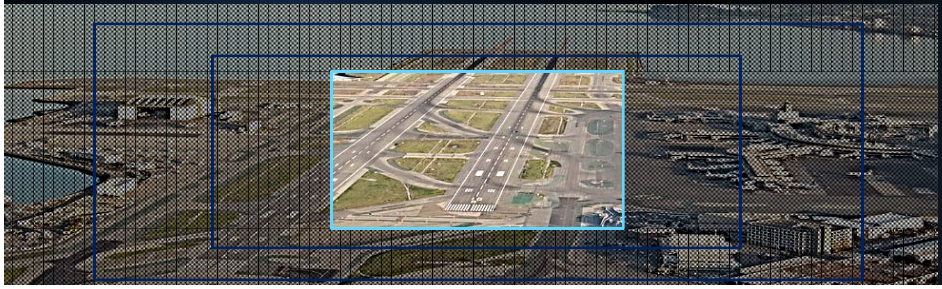
3. Limitations to See & Avoid Capability

- (includes navigation and feature recognition)
- **Due to video technology limitations (cost, bandwidth, size), remote pilots' eye receives less visual information than the airborne pilot's human eye.**
  – Lack of Depth perception (mono-vision)
  – Limited in higher contrast settings (sunrise, sunset, sun/lights in camera FOV); Low light environments.
  – Wide FOV vs human peripheral vision, & Zoomed FOV vs human focal vision; Auto-focus
  – Bandwidth / framerate / latency / (cost)
  – Video quality dependent on data link quality
    - *Graceful degradation vs. sudden loss*
  – Resolution / Acuity - as displayed in GCS
  – Tracking - human eye capability coupled with head motion (fast, precise, integral, stable, always ON).

3. Limitations to See & Avoid (cont.)

- UAS Advantages: Zoom, multispectral (IR), image processing (de-haze), info overlay (lat/long, elevation, shape recognition, other aircraft location)… *multiple cameras*

- **Less info = difficulty noticing:** traffic, weather changes, distant landing airfields, small terrain references, obstructions on the runway/taxiway, or things obscured by the sun.
  - Cameras
    - FOV Trade off: Zoomed detail vs. peripheral info vs. “displayed” FOV (i.e. wrap-around monitors)
    - Fixed (landing) camera: stable/known
      - aligned with aircraft's flightpath
    - Slewable camera: find, track targets, clear the way



4. Lack of Sensory Cues

- Specifically, Seat-of-the-pants & Audio cues
- **Lack of cues limits pilot's ability to easily/immediately understand the aircraft's state or changing state(s).**
- **SOTP + Audio are 2 significant senses missing from UAS flying**

  - Engine vibration (normal/abnormal)
  - Engine noise changes
  - G-force changes (turns/vertical maneuvers; turbulence; aircraft configuration changes--flaps, CG shift, etc)
  - Airframe vibrations/oscillations (flutter; mech failures)
- **Requires "replacement" cues: other sensing & cueing relayed or synthesized to the GCS pilot**
  - Can be real (relayed) or synthetic (simulated) stimuli
    - *Aircraft sensors:* Engine noise (rpm); wind noise (high airspeed); rumbling/buffeting (near stall speed)

Lack of Sensory Cues (cont.)

- Adequate sensory “feed” vs. available link bandwidth
- Cues must be intuitive, low-latency, and distinguishable even under higher pilot workload
  - Visual displays, heads-up cues, audio, seat-rumble, stick shaker, other physical cueing)
- More is not always better (saturation) – *Balance!*
  - Don’t overuse Visual: Lights, symbols, gages & numbers
  - Audio considerations: freq; warble; pulse; repetition; pattern; variation (approaching limits); or even voice.
    - Bad: too many; not intuitive; emergency similar to normal tones; voice not clear
  - Seat "knocker" (gear/touchdown)
  - Stick shaker (command received; approaching limit)
  - Less critical cues - able to be silenced/decluttered
  - Tolerable/comfortable for duration of the mission

5. Lack of Depth Perception

- (for landing or other proximity-critical tasks)
- **Landing is more challenging without depth perception (stereo vision)**
  - Inaccurate height estimation for touchdown (ground-rush)… causes inconsistent timing of landing flare maneuver
  - <u>Manned landing</u> *relies* on the senses -- a memorized, repeatable 3D "sight picture" of runway shape, distance, location in windshield, & closure rate; plus G-forces, engine vibration, wind noise, & stick/throttle position
    - GCS pilot needs these translated into useful cues!
      - When to start the flare; How much to correct?
  - Replacement Cues - Laser Altimeter; Heads-up symbology; speed/throttle position aids; Rate of descent cues (symbols, tones)

5. Lack of Depth Perception

– Depth perception is critical for ground operations too!
  - Landing roll – Speed vs. required braking vs. runway remaining (critical for larger/heavier UAS)
  - Taxi, turns, identifying taxiway/crossings/parking spot
  - Obstacles - light poles, fences, overhangs, gates, powerlines – requires "replacement" mitigation (i.e. distance cues; proximity/closure rate; HD video; obstacle/shape recognition; line-following guidance).

– Ultimately lack of depth perception is "less info"
  - Results in delayed pilot decisions & inputs.

Conclusion/Recommendations

- Instead of burying important data or switches … Make an intuitive, easy to navigate operator menu hierarchy
- Instead of wasting valuable hardware/screen real estate with unneeded data … Organize & prioritize important info/switches, to be accessible without hiding important info… smart/intuitive.
- Instead of pilot's video being an afterthought, pursue quality new technologies (video and bandwidth) that are mission-enhancing
- Don't underestimate the "missing" senses; consider ways to incorporate other sensory cues in the design
- Don't underestimate importance of safety surrounding takeoff & landing phases; design for it, & incorporate pilot design inputs.
- Pursue further info/education on standard (best) design practices (source material for design guidelines)

Conclusion/Recommendations (cont.)

- Instead of overreliance on autonomy and making design for Highly autonomous UAS GCSs an afterthought, use intuitive Command Input means (displays, buttons, layouts) & ensure special critical buttons are guarded.
- To compensate for challenges with video and monovision,
  - use new/reliable tech such as stereovision
  - miniaturized ultra HD video
  - automated modes for finding/tracking traffic or points of interest (360° camera; head-tracking device; etc.)
  - Develop depth-perception aids - stereoscopic vision, sensors, displays with enhanced cues & heads up info.

Success Criteria?

- **Video Goal** = No measurable difference between the system and a pilot's eye while conducting relevant flight tasks.
- **Overall Goal** = UAS should be equal or better at conducting the mission than a manned aircraft ……..*Obtainable?*

…….*Obtainable!*

Summary - Takeaways

- **Making it intuitive… means anticipating what the user will think, need, & do in any situation**
  - Know the Mission – team together (engineers, designers, pilots) to understand what/how to accomplish the mission.
  - Rely on industry standards/styles, new tech, common (best) design practices… to design the UAS & GCS around a well-thought out set of mission requirements.

- **BE CREATIVE!** ***AND IMPLEMENT IT THE RIGHT WAY***

QUESTIONS?

Suggested Reading:

- Role of Human Factors in the FAA (FAA)
- Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls (FAA)
- Human Factors Design Guidelines for Multifunction Displays (FAA, 2001)
- GAMA Pub #12 – Recommended Practices and Guidelines for an Integrated Cockpit/Flightdeck in a 14 CFR Part 23 Certificated Airplane
- Integration of Civil UAS in the NAS Roadmap (FAA, 2013)
- FAA Human Factors Policy (Order 9550.8)
- FAR Part 23 & Part 25 – Airworthiness Standards; Subpart F

Backup: Photo References

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