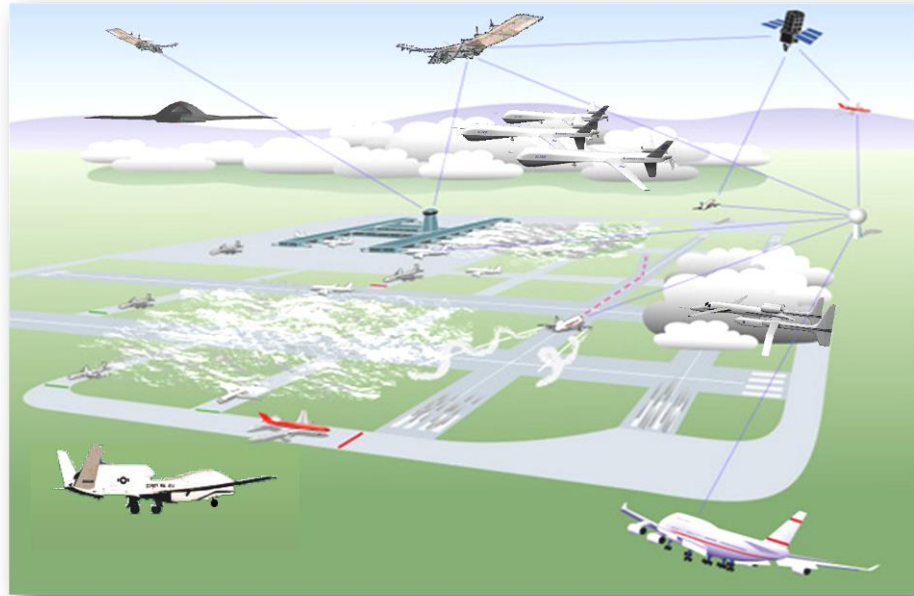


Human Factors of Remotely Piloted Aircraft Systems: Lessons from Incident Reports



Alan Hobbs, Ph.D.

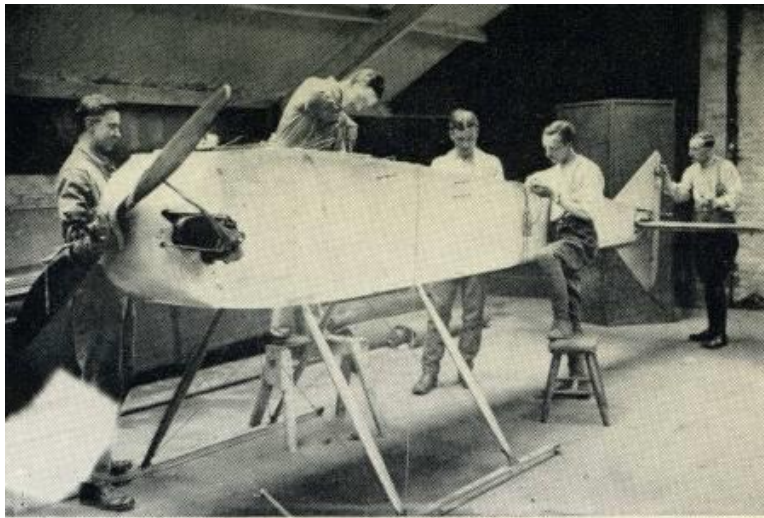
San Jose State University Research Foundation

Human Systems Integration Division

NASA Ames Research Center

Agenda

- Introduction
- Overview of RPAS human factors
- What can we learn from RPAS pilot incident reports?
- Applying the lessons
- Concluding thoughts



Archibald Low's radio-controlled aircraft, 1917



Kettering Bug, 1918



Denny Radioplane, 1945



Civilian Uses of RPAS

- Advertising
- Agriculture
- Building inspections
- Cattle herding
- Construction site survey
- Customs & border protection
- Disaster response
- Environmental sensing & research
- Filmmaking
- Firefighting
- Journalism
- Land surveying & mapping
- Mineral exploration
- Parcel delivery
- Police
- Powerline, pipeline, & rail track inspections
- Real estate photography
- Search & rescue
- Ship inspections
- Telecommunications relay
- Traffic monitoring
- Wildlife monitoring

Three Types of RPAS Operations

Low level
line-of-sight



Low level beyond-
line-of-sight



All classes of civil
airspace



Three Types of RPAS Operations

Low level
line-of-sight



Low level beyond-
line-of-sight



All classes of civil
airspace



Scope

- RPA capable of flight in all classes of civil airspace
- Instrument Flight Rules
- Under the control of a pilot

Accident Record

- Army accident rate¹,
 - Unmanned aircraft: 49 per 100,000 hours
 - Manned aircraft: 4 per 100,000 hours
- USAF hull-loss rates in 2015²:
 - MQ-9: 4 per 100,000 hours flown
 - Manned aircraft: 0.4 per 100,000 hours flown
- Customs and Border Protection
 - MQ-9: 53 per 100,000 hours³
 - General aviation: accident rate 7 per 100,000 flight hours⁴
- Small RPAS: ~ 300 per 100,000 flight hours

Public Tolerance of Risk

Unfamiliar

- Water fluoridation

- Genetically modified organisms
- Radioactive waste
- Hydraulic fracturing

- Pesticides

- Lead paint

Involuntary exposure

- Smoking

Nuclear weapons •

- Skateboards

- Commercial aviation

Home swimming pools •

Trampolines •

- Automobile accidents

Familiar

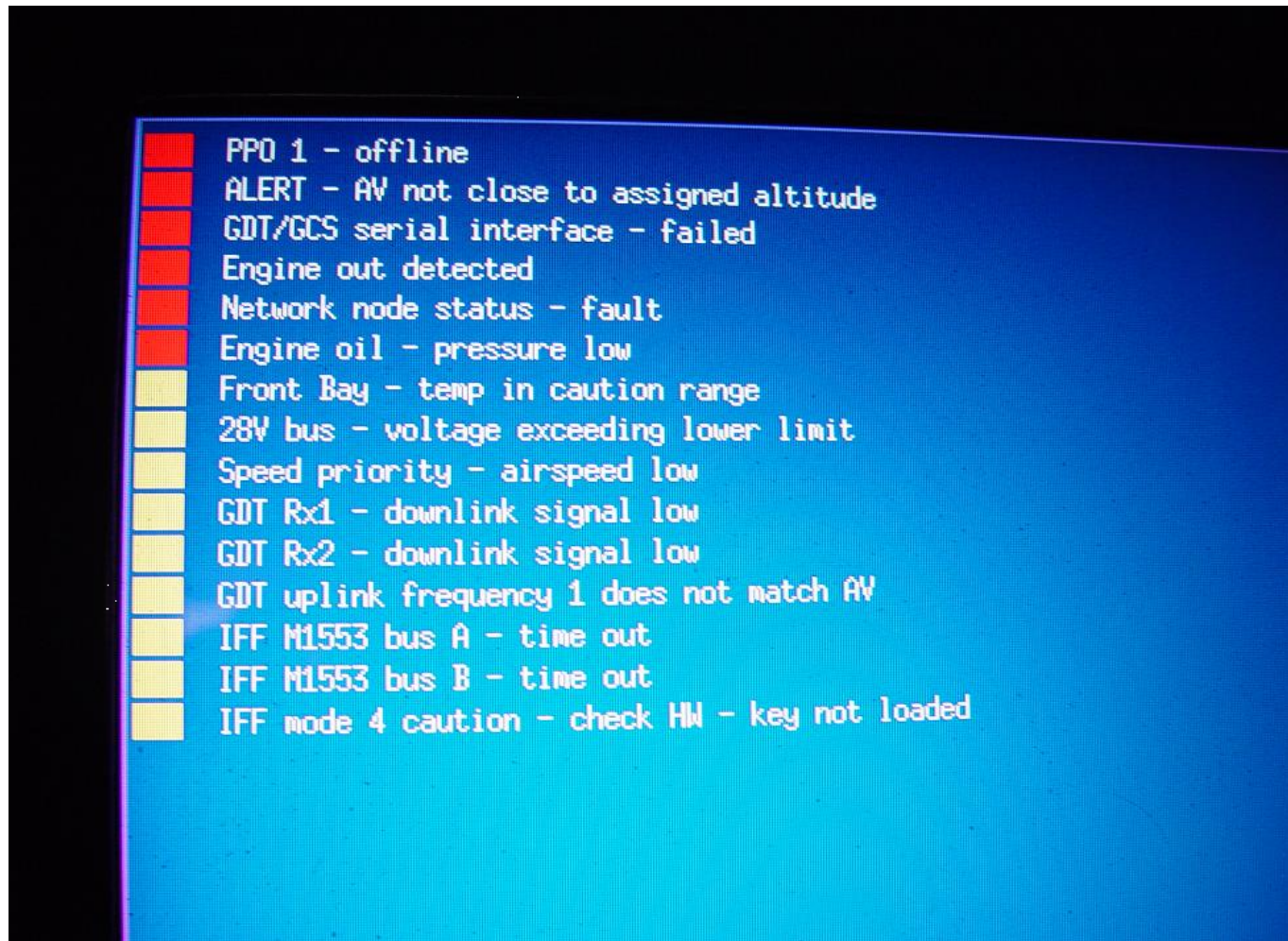
Predator B Accident at Nogales



Predator B Accident at Nogales



Predator B Accident at Nogales



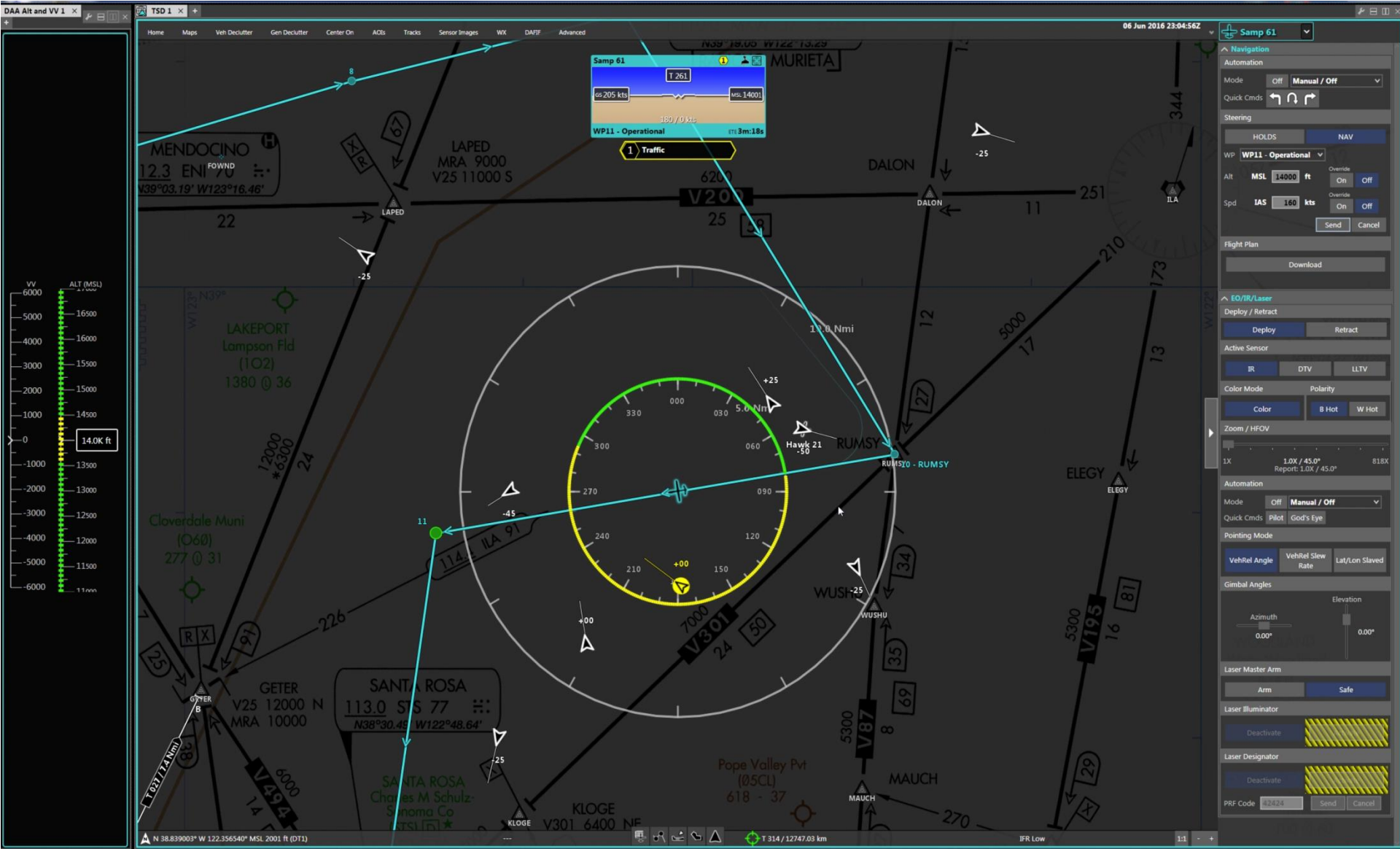
Overview of RPAS Human Factors

1. Loss of natural sensing
2. Teleoperation via radio link
3. Remote pilot station
4. In-flight transfer of control
5. Flight termination

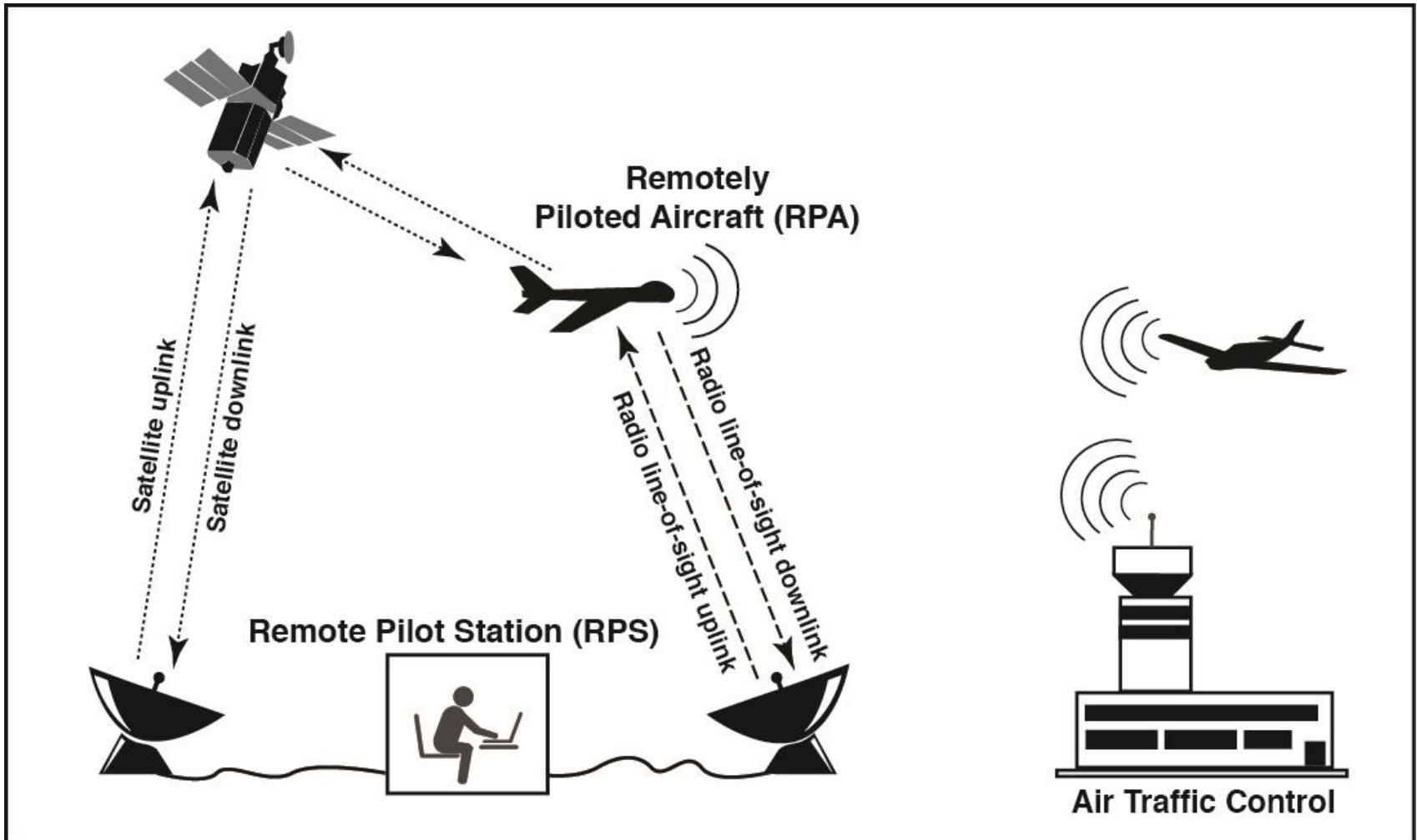
1. Loss of Natural Sensing

- System and state awareness
- May make error detection and recovery more difficult
- Detect and avoid

Detect and Avoid Display



2. Teleoperation Via Radio Link



2. Teleoperation Via Radio Link

- Pilot can be located anywhere
- Latencies & link outages = need for on-board automation
- Pre-programmed lost link maneuver



3. Remote Pilot Station (RPS)



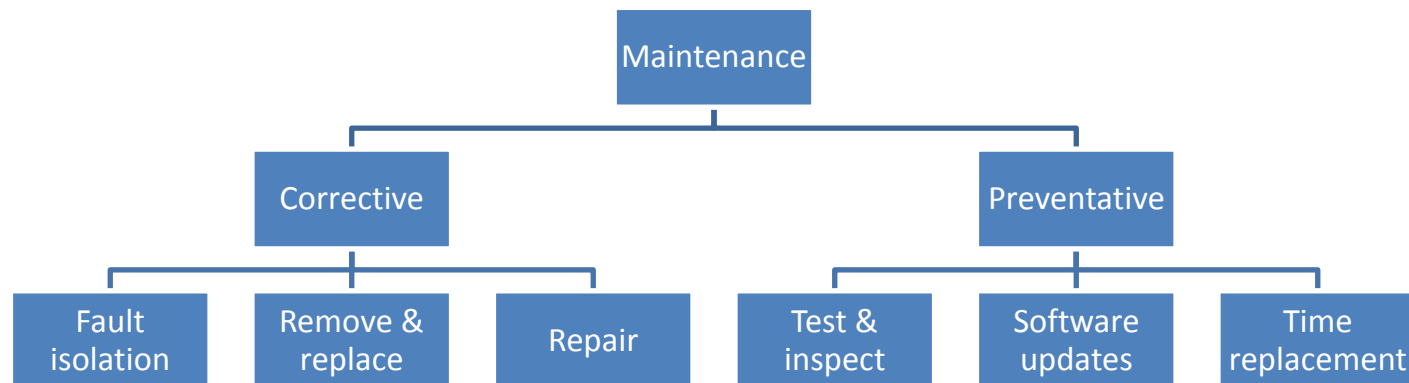
Laptop Pilot Station

The screenshot displays a comprehensive flight control interface. At the top, a menu bar includes options like FLIGHT DATA, FLIGHT PLAN, INITIAL SETUP, CONFIG/TUNING, SIMULATION, TERMINAL, HELP, and DONATE. On the right, there are controls for TCP (set to 115200) and a DISCONNECT button. The main interface is divided into several sections:

- Top Bar:** Shows flight parameters: 285, 300, NW, 330, 34145, N, 15, 30.
- 3D View:** A central 3D perspective of the drone. The word "DISARMED" is prominently displayed in red. A battery level indicator shows 100% at 14:41:01. Altitude is shown as 4747 > 0. Bottom status includes: Bat 12.59v 0.0 A 100%, EKF, Vibe, GPS: 3D Fix.
- Map:** A Google Maps view of Canberra, Australia, with a "Guided Mode" path and a green location pin. The map shows various landmarks like Mt Majura Nature Reserve and Jerrabomberra.
- Gauges:** A row of four circular gauges at the bottom left: VSI (Vertical Speed Indicator), speed, Alt (Altitude), and a heading indicator.
- Bottom Bar:** Contains a "Quick Actions" menu, a "Status" window, and a "GPS Track (Black)" legend. The bottom right shows coordinates: GEO -35.363261 149.165230 0.00m and controls for Tuning, Auto Pan, and Zoom (set to 11.0).

Physical Environment of the RPS

- Monotony
- Discomfort
- Accessibility
- In-flight maintenance
 - Corrective vs preventative



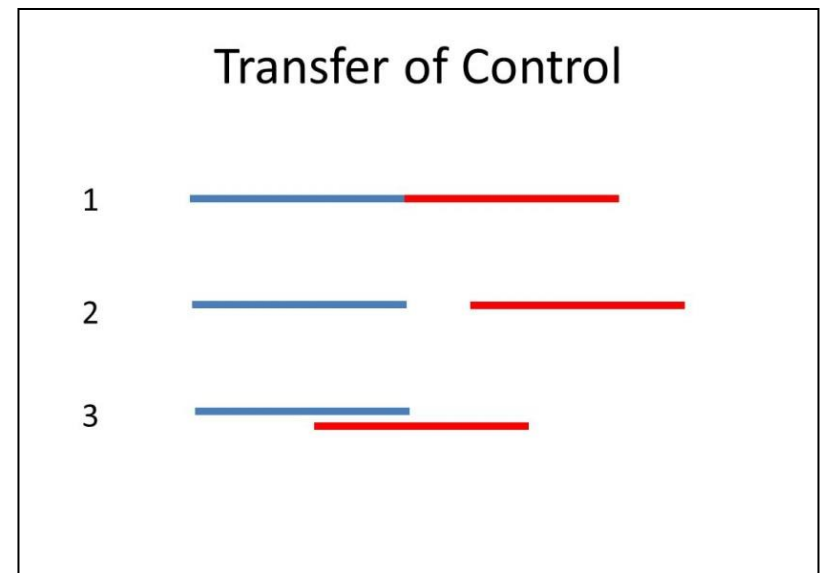
RPS Interfaces

- Inadequate feedback to crew on system state
- Multi-function controls
- Difficult-to-read fonts and colors
- Placement of critical controls next to non-critical controls
- Unreachable controls
- Reliance on text displays
- Proliferation of display screens



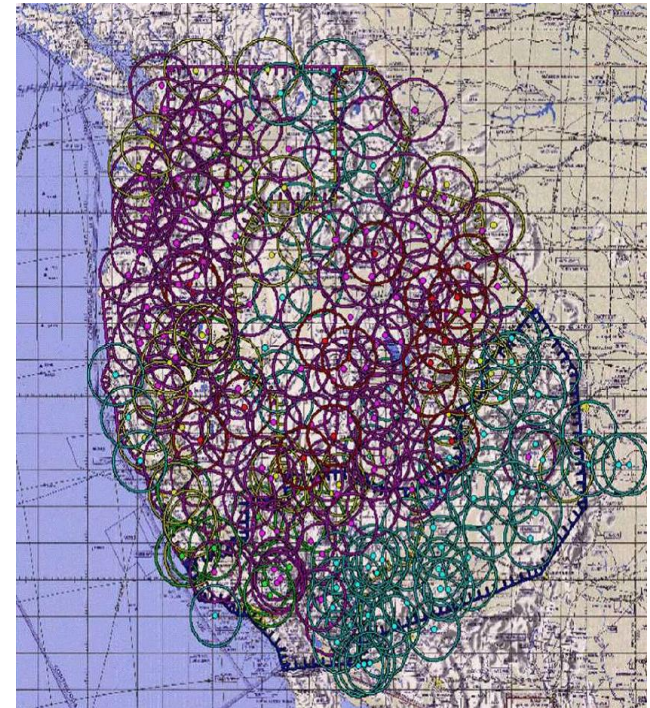
4. In-flight Transfer of Control

- Handovers at same console
- Radio link changes
- Transfers between consoles in same RPS
- Transfers between RPS



5. Flight Termination

- Parachute deployment
- Ditching
- Off-airport landing
- Aerodynamic flight termination
- Controlled impact



RPAS Critical Incident Study: Rationale

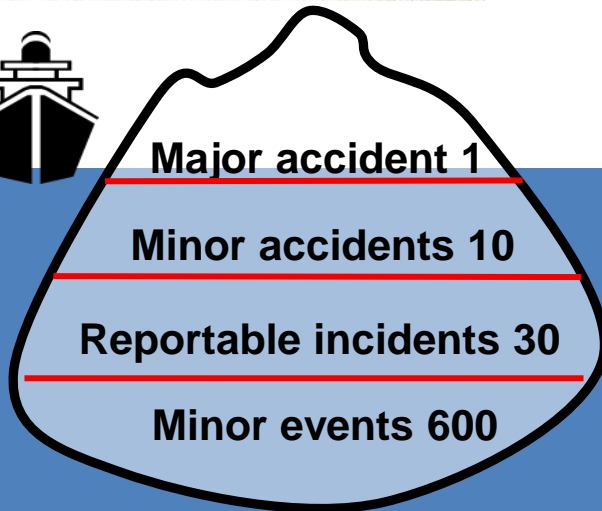


- “Tombstone safety” approach used in 20th century

RPAS Critical Incident Study: Rationale



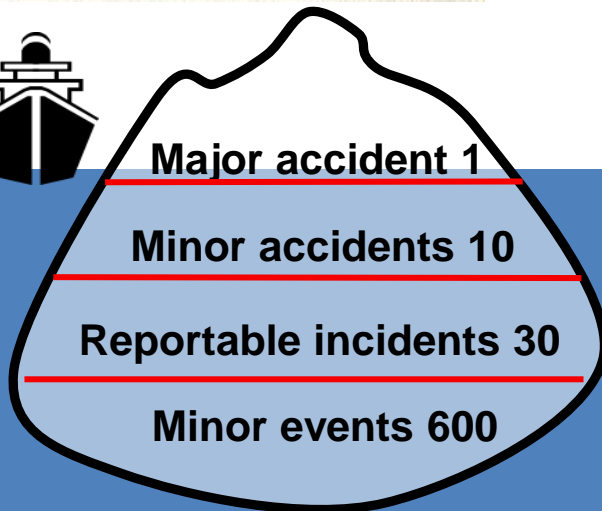
- “Tombstone safety” approach used in 20th century



RPAS Critical Incident Study: Rationale



- “Tombstone safety” approach used in 20th century
- Lack of data on minor RPAS events



Critical Incident Technique

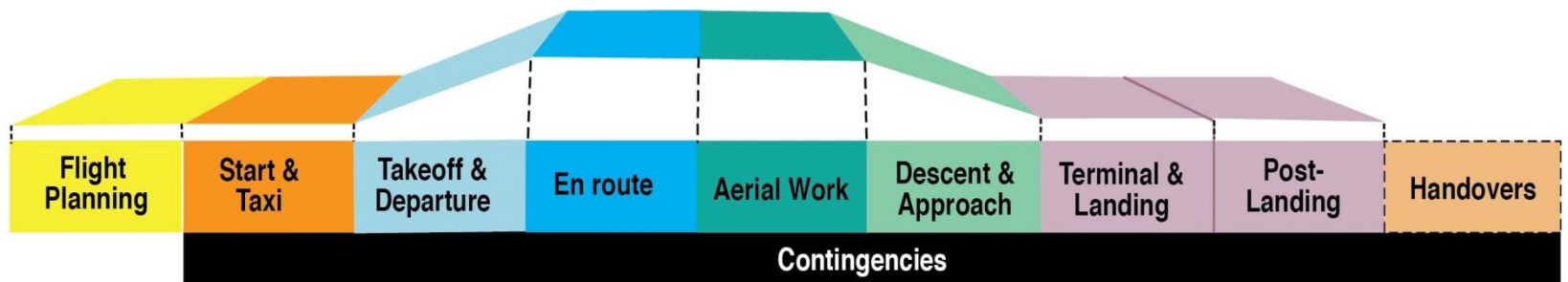
- In 1940s, researchers asked pilots to recall pilot error incidents
 - Many “errors” reflected poor cockpit design
 - Results led to standardized cockpit design in modern aircraft

RPAS Critical Incident Study: Goals

- Examine the feasibility of a method to collect the operational experiences of RPAS pilots
- Provide independent and complementary data to supplement NASA simulations and flight tests

RPAS Critical Incident Study: Approach

- Focus groups with 2-3 pilots at a time
- Participants asked to recall events experienced while operating a remotely piloted aircraft
 1. A hazardous situation or error
 2. The rectification of a hazardous situation or error
- Only reports that can be made public

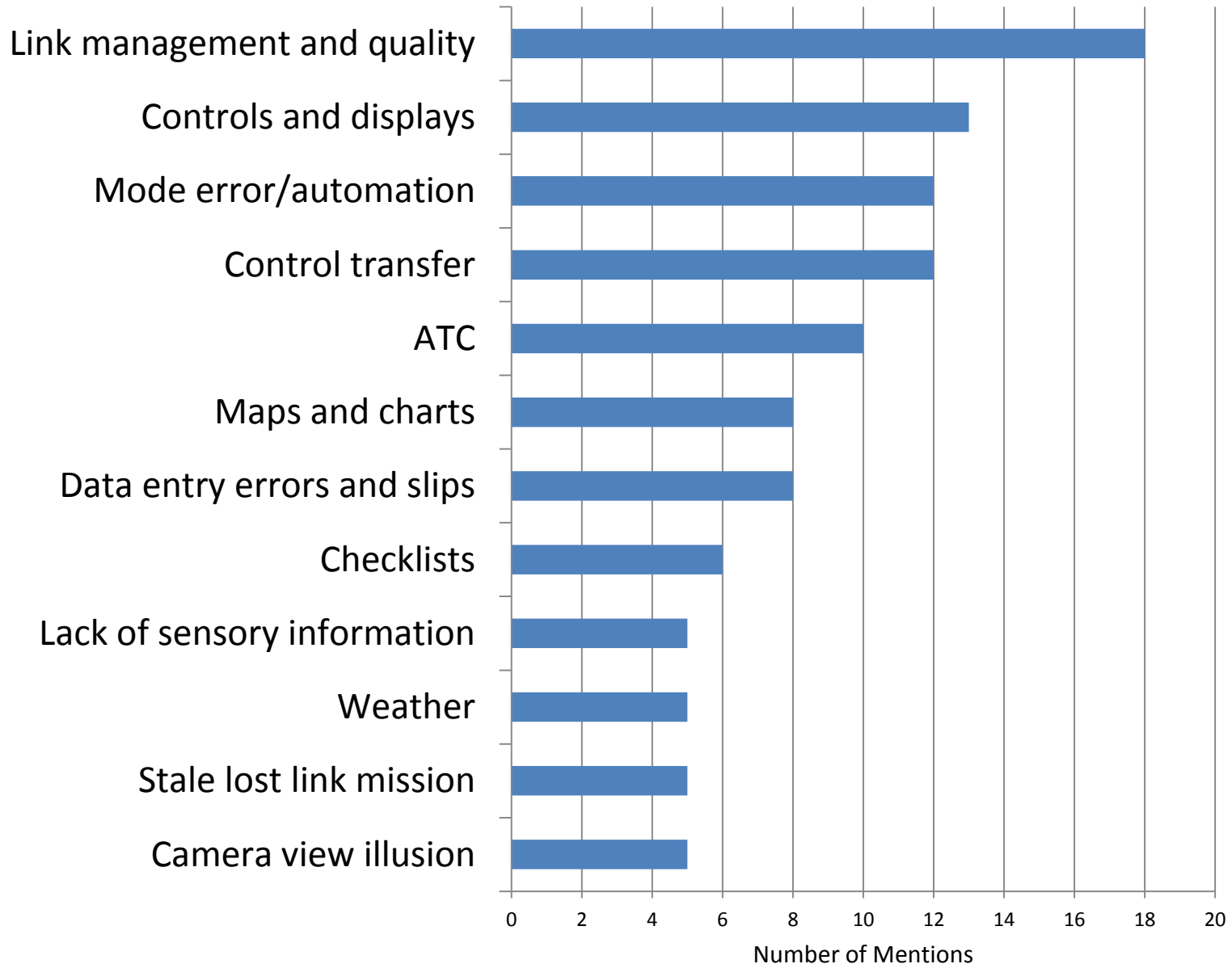


Preliminary Results

- 23 participants
- 90 incidents described
- Weight classes of the remotely piloted aircraft:

<i>Aircraft max takeoff weight</i>	<i># of reports</i>
Less than 400 lbs	17
2000-15,000 lbs	60
Greater than 15,000 lbs	13

Problems Mentioned in Reports



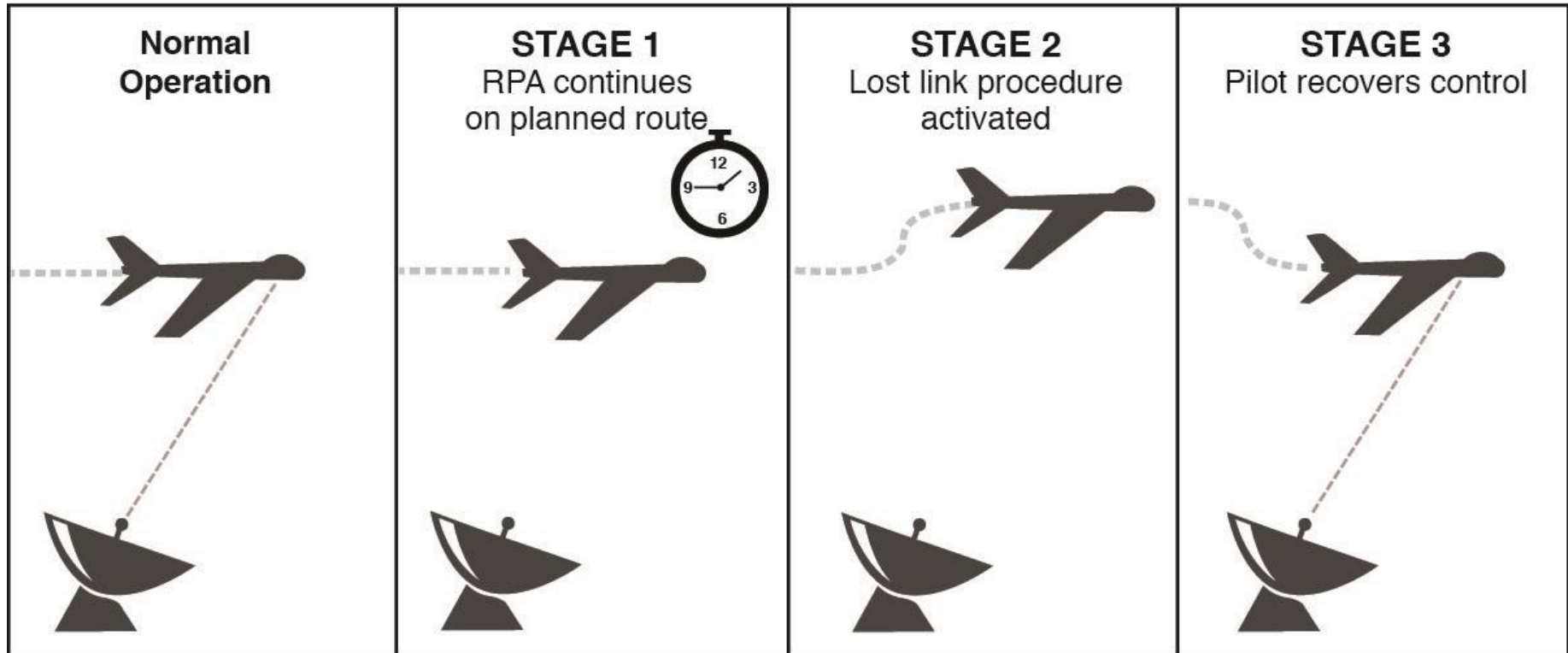
Example: Lost Link

“We were flying really far out ... about 90 kilometers from the antenna. But I passed some random mountain peak for about one second and the aircraft went into emergency mode. Luckily I had the correct emergency mode programmed. If I didn't, I could've lost the aircraft.”

Example: Multiple Lost Link

“One day the power company severed a power line. We lost link to all UASs ... The uninterrupted power system (UPS) in the GCS has a maximum of 18 minutes of power available until the generators are up and running, but power ran out before the back-up generators were up and running.”

Stages of Lost Link



- Flight Modes
- Basic Tuning
- Standard Params**
- Advanced Params
- Full Parameter List
- Full Parameter Tree
- Planner

Write Params Refresh Params Find Advanced Menu View

GCS failsafe enable (FS_GCS_ENABL)
Description: Enable ground control station telemetry failsafe. Failsafe will trigger after FS_LONG_TIMEOUT seconds of no MAVLink heartbeat messages. There are two possible enabled settings. Seeing FS_GCS_ENABL to 1 means that GCS failsafe will be triggered when the aircraft has not received a

HeartbeatAndREMRSSI

Long failsafe action (FS_LONG_ACTN)
Description: The action to take on a long (FS_LONG_TIMEOUT seconds) failsafe event. If the aircraft was in a stabilization or manual mode when failsafe started and a long failsafe occurs then it will change to RTL mode if FS_LONG_ACTN is 0 or 1, and will change to FBWA if FS_LONG_ACTN is set to 2. If the aircraft was in an auto mode

ReturnToLaunch

Long failsafe timeout (FS_LONG_TIMEOUT)
Units: seconds
Description: The time in seconds that a failsafe condition has to persist before a long failsafe event will occur. This defaults to 5 seconds.

30.00 1 300

Short failsafe action (FS_SHORT_ACTN)
Description: The action to take on a short (FS_SHORT_TIMEOUT) failsafe event. A short failsafe even can be triggered either by loss of RC control (see THR_FS_VALUE) or by loss of GCS control (see FS_GCS_ENABL). If in CIRCLE or RTL mode this parameter is ignored. A short failsafe event in stabilization and manual modes will cause an change to CIRCLE mode if FS_SHORT_ACTN

CIRCLE

Short failsafe timeout (FS_SHORT_TIMEOUT)
Units: seconds
Description: The time in seconds that a failsafe condition has to persist before a short failsafe event will occur. This defaults to 1.5 seconds

1.50 1 100

Throttle Failsafe Value (THR_FS_VALUE)
Description: The PWM level on channel 3 below which throttle failsafe triggers

950 925 1100

Example: Lost Link Timer

“A pilot programmed “lost link okay” for a 3-hour period while the aircraft was loitering on satellite control. While he had the aircraft it actually went into lost link and it was still lost link when I came in to take over. I didn’t want to take an aircraft that I have no idea where it’s at or what it is doing. I did eventually take over the aircraft and another GCS, who had line-of-sight control, finally took over the aircraft.”

Stale Lost Link

- Pilot awareness of lost link mission
- Lost link mission needs regular updating
- Lost link mission can be a form of “automation surprise”

Example: Stale Lost Link

“At the beginning of the flight, the lost link procedure was valid, but the procedure was not updated later in the flight. At one point, had the lost link procedure been activated, it would’ve had the aircraft fly through terrain in an attempt to reach the next waypoint. However, the aircraft didn’t lose link and the error was caught in the handover to the next set of operators.”

Example: Voice Latency

“There is a delay between clicking the press-to-talk and talking. This is very difficult to manage when in very busy airspace, and listening for a gap to talk. Sometimes by the time we press the talk button, with the satellite delay, the gap is gone and we step on other aircraft.”

Controls and Displays

- Some RPS interfaces particularly error-productive
- Keyboard and consumer interfaces
- Shared payload and flight controls

Example Narrative: Keyboards

A QWERTY board is a problem because you can miss hit a button and input the wrong information. ... one time an operator placed his manual on top of [the keyboard]. Accidentally, this activated the GUI. Then more pressure was applied through handling the manual, on the space bar. As a result, it highlighted and armed, through several steps, the flight termination button. Luckily, the operator saw the countdown and caught it in time to deactivate this command.

Example: Mode Error during Control Station Transfer

“During preflight, handover checks were being done ... we had the aircraft engine at idle with the parking brake set, but when the radio handover switched to XXX, he didn't have the parking brake set and the power was set at 80% The result was the engine revving up, and the aircraft jumping its chocks.”

Example: Unintended Transfer

“I was preparing to take control of the aircraft from the MCE. The transmitters from my GCS were accidentally left on. When I slewed the directional antenna to get the picture of the aircraft (the down link info), this automatically gave me control of the aircraft. I was not intending to take control of the aircraft at this time.”

Example: Data Entry Errors and Slips

“I went to put the gear down, but instead I turned the SAS [Stability Augmentation System] off using the red emergency button. The aircraft went into a 20-degree bank and 5-degrees nose down. I was able to recover the airplane. I had developed muscle memory with the activation of the SAS disengagement button.”



Example: Camera View Illusion

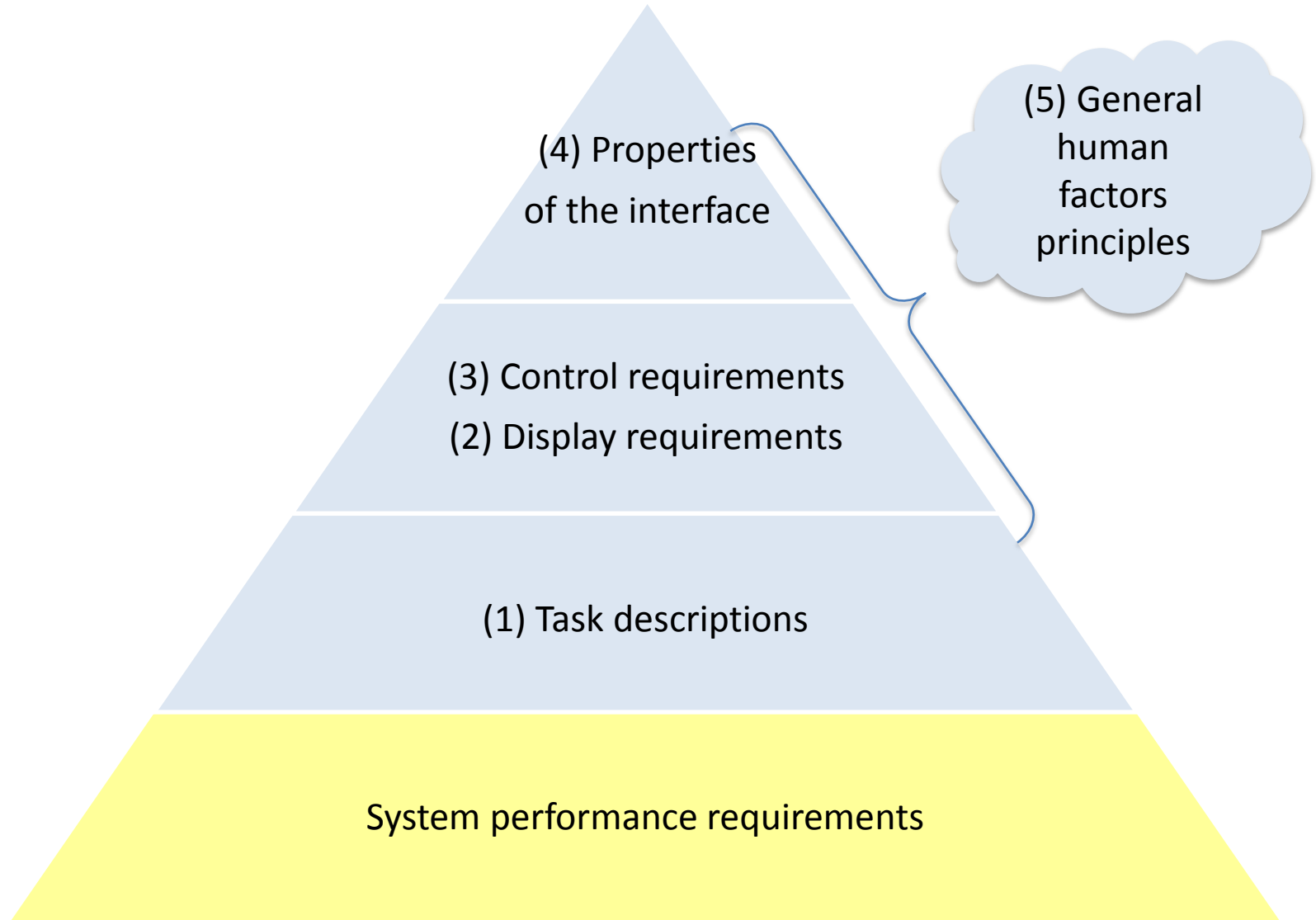
“Depending on how I do the landing [the moveable sensor camera] ...will be used to make sure that we clear the turns. But sometimes, the sensor operator will move the camera, which will make it look like that I’m turning but I’m actually not turning. So I have to concentrate and make sure I don’t respond to that erroneous camera view.”



Example: Lack of Sensory Cues

“We fly based on digital gauges. We don't hear or feel anything, like RPM changes The aircraft is supposed to level off, at say, 5,000', and there is a delay due to data link to know if it actually leveled off. ... As opposed to a real aircraft [where] you can feel the airplane leveling off, I couldn't determine if it was still climbing until I noticed it was 300' past its command altitude.”

Applying the Lessons to RPS Guidelines



Manage

1. Aviate

- 1.1 Monitor and control aircraft systems, including automation
- 1.2 Monitor consumable resources
- 1.3 Monitor and configure control station
- 1.4 Maneuver to avoid collisions with other aircraft or terrain
- 1.5 Monitor and control status of links
- 1.6 Transfer control

2. Navigate

- 2.1 Control and monitor location and flight path of aircraft
- 2.2 Remain clear of terrain, airspace boundaries and weather
- 2.3 Remain well-clear of other aircraft
- 2.4 Review and refresh lost link mission as necessary.
- 2.5 Terminate flight

3. Communicate

- 3.1 Communicate with ATC
- 3.2 Communicate with other airspace users
- 3.3 Communicate with other flight crew or ground support
- 3.4 Communicate with ancillary services (e.g. weather)

Guidelines

- 160 RPAS-specific guidelines
- Examples:
 - The aural warning for lost control link should be a unique sound, not also used to signify other conditions.
 - The RPS should enable the pilot to set the duration of a link outage that must occur before a lost link response is triggered.
 - Two distinct and dissimilar actions of the RPAS crew should be required to initiate the flight termination command.
 - Payload controls should be separate from controls with safety-of-flight functions.

Concluding Thoughts

- RPAS pilots are willing to share their experience
- Incident reports are helping to identify under-examined topics
- Results are being used to inform design guidelines for RPAS control stations

Unanswered Questions

- What guidelines are needed for control station design?
 - Should there be an RPAS equivalent of the “Basic T” flight instruments?
- Could one remote pilot manage multiple RPA?
- What does ATC need to know about each RPA flight?
- How much voice delay is too much?
- Do remote pilots need experience flying a conventional aircraft?
- What information is needed for flight termination decision making?
- What RPS maintenance tasks should be permitted while an aircraft is in flight?
- How do we make the best use of human capabilities?
- Will conventional aircraft start to look more like RPAS?



Questions?