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

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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 rate\textsuperscript{1},
  – Unmanned aircraft: 49 per 100,000 hours
  – Manned aircraft: 4 per 100,000 hours
• USAF hull-loss rates in 2015\textsuperscript{2}:
  – 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 hours\textsuperscript{3}
  – General aviation: accident rate 7 per 100,000 flight hours\textsuperscript{4}
• Small RPAS: \sim 300 per 100,000 flight hours

Public Tolerance of Risk

Voluntary exposure

- Skateboards
- Home swimming pools
- Trampolines
- Lead paint

Unfamiliar

- Water fluoridation
- Genetic modified organisms
- Radioactive waste
- Hydraulic fracturing
- Pesticides

Involuntary exposure

- Smoking
- Nuclear weapons
- Commercial aviation
- Automobile accidents

Familiar

- Genetically modified organisms
- Radioactive waste
- Hydraulic fracturing
- Pesticides

After Paul Slovic, 2000
Predator B Accident at Nogales

Source: NTSB
Predator B Accident at Nogales
Predator B Accident at Nogales

Source: NTSB
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
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

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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:

<table>
<thead>
<tr>
<th>Aircraft max takeoff weight</th>
<th># of reports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 400 lbs</td>
<td>17</td>
</tr>
<tr>
<td>2000-15,000 lbs</td>
<td>60</td>
</tr>
<tr>
<td>Greater than 15,000 lbs</td>
<td>13</td>
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</table>
Problems Mentioned in Reports

- Link management and quality
- Controls and displays
- Mode error/automation
- Control transfer
- ATC
- Maps and charts
- Data entry errors and slips
- Checklists
- Lack of sensory information
- Weather
- Stale lost link mission
- Camera view illusion

Number of Mentions
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

Normal Operation

STAGE 1
RPA continues on planned route

STAGE 2
Lost link procedure activated

STAGE 3
Pilot recovers control
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, it will change to AUTO, AUTO_CIRCLR, or AUTO_CIRCLE if FS_LONG_ACTN is set to 3.

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.

Short failsafe action (FS_SHORT_ACTN)
Description: The action to take on a short (FS_SHORT_TIMEOUT) failsafe event. A short failsafe event 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 is set to 1, or AUTO, AUTO_CIRCLR, or AUTO_CIRCLE if FS_SHORT_ACTN is set to 2.

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.

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

950
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 accidently 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.”
“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

System performance requirements

(1) Task descriptions
(2) Display requirements
(3) Control requirements
(4) Properties of the interface
(5) General human factors principles
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?