The Safety Research Challenges for the Air Traffic Management of Unmanned Aerial Systems (UAS)

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Summary of ATM-UAV Safety Concerns

- Not focusing on sense and avoid...
  1: Hazards from the Spirit of Innovation;
  2: The Complexity of Ground Movements;
  3: ATM Communications and UAS Task Allocation;
  4: Risk Erosion and the Loss of First Person Liability;
  5: Human Factors of Remote Situation Awareness;
  6: Accurate Assessments of UAS Airworthiness;
  7: ATM Interaction with Lost Link Profiles;
  8: ATM Emergency UAV Interaction.

- A partial list...
Introduction

• US military UAS funding increased:

• Civil market €100 million annually by 2010

• Surveillance and reconnaissance ops:
  – monitor forest fires, oil spills, border security.
  – Ops that otherwise threaten crew safety
  – Including long duration operations…

• UAS’ segregated from controlled airspace.
• Safety concerns:
  – higher accident rate than manned aircraft
  – 30-300 times higher for than general aviation (Weigmann & Scott 2003).

• Human factors issues:
  – Lack of skill & knowledge;
  – Poor situation awareness;
  – Inadequate crew coordination.

• Engineering standards also poor:
  – Issues in maintenance and design;
  – SOPs mismatch with operational performance.
Introduction

• What would we need for UAS integration?
  – must not increase risk to other airspace users;
  – ATM procedures same as manned aircraft?

• Hard to apply existing regulations:
  – Title 14 CFR rights of way for aircraft refers to ‘see and avoid’ makes little sense for UAS?

• Emerging regulatory documents:
  – EUROCONTROL’s Spec-0102 on the Use of Military Unmanned Aerial Vehicles as Operational Air Traffic Outside Segregated Airspace
  – UK CAA CAP 722: Unmanned Aircraft System Operations in UK Airspace
Lessons Learned

- UAS segregated as we don't understand the hazards.
- To understand the hazards we need more operational information.
- Recursive argument for exclusion.
- So learn as much as possible from mishaps...
The Nogales Incident

- Predator Type B UAV General Atomics Aeronautical Systems Inc (GA-ASI) crashed northwest of airport.
- US Customs and Border Protection (CBP) agency owned while operated by GA-ASI.
- Demand for improved security along southern US borders.
Introduction: Operation ATHENA

- Lessons from Canadian tactical UAVs:
  - Op ATHENA (August 2003-November 2005);
  - UAVs rushed to meet needs around Kabul;
  - Created significant additional risks...


- Canada supports International Stabilisation Force.
  - 5 successive, 6 month rotations.
  - Foot patrols and surveillance around Kabul.
UAV Safety Challenge 1: Hazards from the Spirit of Innovation

- Testing ground for the deployment of UAVs.
  - ground forces need tactical and operational information;
  - ISAF’s structure complicates conventional air resources.

- Canadian defence minister announces acquisition:
  - 4 UAVs, 2 control stations and support;
    “UAVs will decrease the risk to troops in Afghanistan…”

- ‘Unforecast operational requirement’ takes 17 weeks!

- Canadian Forces Director of Flight Safety
  - ‘high risks associated with deploying a new system directly into the extreme operational environment of Kabul had been identified. The overriding operational requirement for this capability in theatre resulted in the acceptance of this risk’.
• Considerable innovation with UAVs:
  – UAS at the London Olympics.
  – Boeing A160T (YMQ-18A) UAS freight UAV.

• Political pressure as in Afghanistan.
  – ATM seen as limiting factor.
  – ‘Safety concerns are stifling innovation’.

• Challenge to communicate our concerns...
• French Sperwer UAS chosen for the ATHENA operation.

• Five primary components:
  – 1. delta-wing design and a push propeller;
  – 2. Orientable Line-of-Site payload provided imagery;
  – 3. ground control station (GCS) operated the UAV;
  – 4. comms between GCS, UAV and outside agencies;
  – 5. ground support, catapult launch, maintenance etc.

• Recovery using parachute and a number of airbags.

• Max take-off weight was 330 kgs with a 45 kg payload.

• Seven meter wing-span, top speed around 80 knots.
• Sperwer & small UAS land anywhere –
  – assume appropriate risk assessments?
  – Larger UAS need ground control.

• Linate shows loading on ATCOs:
  – Commercial and GA share taxiways;
  – Add remotely controlled UAV?
  – Low visibility ops, restricted camera views...

• Most research on sense and avoid –
  – this is not the main source of concern...
• GCS has 3 working positions.
  – Mission Planner coordinates ops, reports to outside agencies;
  – Air Vehicle Operator controls and monitors the vehicle;
  – Payload Operator monitors and controls imaging equipment.

• Mission Planner and Air Vehicle Operator workstations are identical.

• ATHENA also used Air Vehicle Commander.
  – Air force pilot or navigator without specific control position;
  – Monitors GCS screens of Planner and Air Vehicle Operator.
  – Added to meet ‘airworthiness concerns’.

• Line of sight communications between GCS and UAV:
  – Once lost, goes to pre-programmed flight sequence for 15 mins;
  – Opportunity for ground teams to re-establish communications;
  – If no further contact is made UAV deploys parachute.
UAV Safety Challenge 3: ATM Communications & UAS Task Allocation

• Conventional crews - clear task allocation:
  – 3 to 2 crew members, loss of flight engineer;
  – Cheaper and reduced comms problems.

• Not so clear with UAS, 2, 3 or 4 operators?
  – Not just determined by platform but by SOP;
  – Huge impact on human factors of control.

• More operators reduces workload but
  – Hard to keep distributed situation awareness;
  – Both within the team and with ATM...
During initial deployment tests.

- Wind at Camp Julien 3m/sec. Standing eddies.
- Cause UAV to climb of 12m in half a second.
- Exceeded escape velocity of drogue-spring.
- Main chute did not deploy, airbag not triggered.
- UAV glides in 7-degree nose-high pitch.
- On-board computers waited for parachute.
- Line of sight communications lost.
Rapid procurement because:
- Assume UAVs pose less risks than conventional;
- Assume UAVs require a much lower skill set.

NATO political pressure for Canadas UAVs.
- Time constraints add to risk of deployment.
- Deployed no comprehensive test & acceptance.
- Crews lacked training and documentation
• But this was a military operation.
• Civil regulators would prevent this?
• NTSB on Nogales:
  – “Five of the training events listed on the AFMC Form 68 MQ-9 Pilot Conversion form were not accomplished during the pilot's training. Those events were: Mission Planning/ Briefing/ Debriefing, Handover Procedures - Ground, Mission Monitor/MFW Procedures, Operational Mission Procedures, and Handover Procedures – Airborne”
UAV Safety Challenge 4: Risk Erosion and the Loss of First Person Liability

• Arguably, UAV training more important
  – than it is in conventional aviation

• Ground based UAV operators:
  – Control flight profile, build situation awareness;
  – Using unreliable communications networks
  – With primitive systems compared to conventional aircraft.

• If UAS training is poor, no surprise there are failures in ATM communications.
• Crew on 2\textsuperscript{nd} flight after 61 day layoff:
  – Practicing recovery at lower & lower altitudes.
  – UAV hit terrain in final turn to approach.
  – No SOPs, Standard Manoeuvre Manual,

• Crew lack experience:
  – Explains why they further reduce approach.
  – Explains why camera at 90 degrees:
  – Looking at recovery area as they hit mountain.
• Crew set alt warning at 200 not 300m AGL.
  – Less spurious alarms in mountainous terrain;
  – No time to respond, crew ignore alarms...

• Poor situation awareness because
  – Vehicle Operator’s displays engine monitoring
  – Not the altitude screen for terrain cues.

• Manufacturer’s documentation stresses:
  – AVO needs to monitor engine parameters;
  – Eg to ensure correct fuel mixtures;
  – limited value during recovery stage of the flight.
• Operational deadlines no time to write SOPs.

• Simulators for crew focus on flat terrain!
  – So crew did not focus on altitude screen.

• Once in field, hard to address problems
  – created by rapid deployment of complex systems.
• Again UAS crews need more training;
  – Not less training than conventional aircrews.

• Camera operator lacks direct vision:
  – must support surveillance and monitor terrain.

• But could ATM provide external input?
  – Might have warned operators of risks?

• Integrating UAS into controlled air space:
  – might paradoxically increase safety!
• Incident suggests need for transition period.

• UAS operations in segregated air space
  – but with ATCO supervision.

• Rehearse communications protocols
  – explore detailed levels of control;
  – place constraints on what is permissible.

• At the moment it can be the Wild West...
UAV Safety Challenge 6: Accurate Assessments of UAS Airworthiness

- Training exercise to familiarise new crew.

- Shortly after take-off:
  - UAV into shallow descent;
  - towards a populated suburb of Kabul;
  - AVC notes insufficient thrust to sustain flight;
  - ordered an emergency recovery before Kabul.

- Parachute deployed too low.

- Insufficient power
  - fuel mixture too rich, Lean mixture preset screw
  - beyond recommended ¾ turn, in maintenance.
• Incorrect setting for lean mixture preset:  
  – gradual fall in power in flights 15th-17th March.

• Unnoticed by operators and maintenance:  
  – did not note Gas Temperatures between cylinders.

• Manufacturer said these values should be analysed in a Service Information Letter.

• Document not received before accident.

• Manufacturer’s service bulletins did not look at detailed engine management.
UAV Safety Challenge 6: Accurate Assessments of UAS Airworthiness

- UAV routinely on edge of performance.
- Crews lack documentation to tell if ok to launch.
- 2 crew had 4.5 hours between two duty periods.
- UAV never entered climb phase so crew had no opportunity to alter fuel mixture.
- Insufficient time for them to complete any adjustments in short interval before the crash
UAV Safety Challenge 6: Accurate Assessments of UAS Airworthiness

• Lower standards of maintenance for UAVs.
  – Frequently seen as experimental;
  – Many modifications tailor vehicles for operations;
  – not typical for manned systems.

• Segregation (incorrectly) seen to mitigate lower standards of maintenance.

• Less ‘corporate responsibility’ in some UAV ops?
• FAA Section 6 of 08-01:
• “UAS Maintenance Technician certification will parallel existing standards for manned aviation. As with airworthiness standards, Maintenance Technicians Requirements will be reviewed as part of the data collection process."

• These requirements should be strengthened

• Avoid sense of complacency in UAS maintenance and management.
• UAV comms lost 15km from recovery zone:
  – ‘Lands’ in civilian area, complex causes...
  – Link first lost as UAV descends to 3000m ASL.
  – Mountain ridge interrupted signal transmission.
  – Comms back as crew use emergency checklist.
  – Vehicle enters into autonomous recovery mode.

• Comms again lost but in line of sight.

• Board: 55amp spike before voltage drop:
  – Voltage similar to an engine shut-down.
  – Avionics show UAV still generates power?
• Numerous faults in the vehicle.
  – W34 alternator cable not properly installed;
  – Allows cable to rub against a retaining nut;
  – Creates short circuit, interrupts power to UAV.
• Manufacturer’s guide has detailed diagram.
• Other ‘systemic’ maintenance failures in maintenance of TUAV’s during ATHENA.
  – Operational demands from rapid deployment.
  – Maintenance training ‘rushed’ as well.
Importance of lost-link profiles for
- Flight patterns executed autonomously:
  - when UAVs lose contact with ground based control.
  - fly to a fixed location and circle until fuel exhausted.

Problems for ATCOs:
- mission demands lead UAV from lost link profile;
- if communications lost, vehicle autonomously crosses airspace between present location and initial waypoint for lost link profile.

This is what happened in Nogales...
UAV Safety Challenge 7: ATM Interaction with Lost Link Profiles

- FAA 08-01 stresses need to:
  - create and maintain lost link profiles.
  - “In all cases, the UAS must be provided with a means of automatic recovery in the event of a lost link. There are many acceptable approaches to satisfy the requirement. The intent is to ensure airborne operations are predictable in the event of lost link”.

- During the Nogales incident:
  - 3 profiles stored on ground control system;
  - Pilot can change active plan during operation;
  - If UAV moved to different area…
UAV Safety Challenge 7: ATM Interaction with Lost Link Profiles

- CBP plans to climb for 50 seconds:
  - to gain time and help reacquire the signal.

- Waypoint 2.5nms on profile heading.

- If waypoint reached or after half an hour, UAV flies rest of profile.

- If contact cannot be re-established:
  - Predator will crash when fuel exhausted.
• FAA Guidance 08-01:
  – “applicants must demonstrate that injury to persons or property along the flight path is extremely improbable...UAVs with performance characteristics that impede normal air traffic operations may be restricted in their operations”.

• NTSB
  – “was no standardized safety-based method for determining the routes for the lost-link flight path and that inadequate consideration was given to ensuring the flight path did not include flight over population centers, property, or other installations of value”.
• FAA Guidance 08-01
  – Pilots must have immediate radio contact with relevant ATC;
  – CBP should have notified FAA/ATC of changes in lost link profiles;
  – Updates would help to coordinate any response to an emergency;
  – This was not done prior to the accident…

• NTSB ‘real potential for an in-flight collision’
  – UAV created significant hazard for other NAS users.
UAV Safety Challenge 8: ATM Emergency UAV Interaction

- If communications lost, pilot should tell ATC:
  - UAS call sign.
  - UAS IFF (Identification, Friend or Foe) squawk.
  - Lost link profile.
  - Last known position.
  - Pre-programmed airspeed.
  - Usable fuel remaining (expressed in hours and minutes).
  - Heading from the last known position to the destination of any lost link emergency mission maneuver.

- No communications with Albuquerque ACC.
UAV Safety Challenge 8: ATM Emergency UAV Interaction

- UAV loses functionality relies on battery power.
  - Shut down satellite comms and transponder.
  - Loss of transponder mode C altitude data
  - ATC cannot track UAV to warn other airspace users.

- Should be explicit in FAA 08-01;
  - Transponder more critical than in other forms of aviation.
UAV Safety Challenge 8: ATM Emergency UAV Interaction

- UAV authorized in temporarily restricted airspace:
  - other aircraft had to contact ATC before entering;
  - CBP air space 14,000 -16,000 feet MSL along border;
  - Loss of power prevents UAV from maintaining altitude;
  - Predator breached lower limit of the restricted zone.

- UAV autonomous in unprotected airspace...
• ATC contacts pilot after transponder fails.

• Pilot did not tell them UAV below 14,000ft.

• Pilot or ATCO should have:
  – declared an emergency
  – alerted traffic in the area.
  – alerted neighboring centers
  – Increase surveillance
  – eg Western Area Defense Sector height finding radar.
UAV Safety Challenge 8: ATM Emergency UAV Interaction

- ATCOs only provided mandatory training on UAS:
  - 30-minute briefing and PowerPoint presentation.

- Improve reviews between UAS ops and ATC:
  - “These operational reviews should include, but not be limited to, discussion on lost-link profiles and procedures, the potential for unique emergency situations and methods to mitigate them, platform-specific aircraft characteristics, and airspace management procedures” (NTSB)
Conclusions

- Not focusing on sense and avoid...

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