Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Detect and Avoid
Outline

Present:

- UAS Integration into the NAS
- RTCA SC 228 MOPS and Autonomy
- ICAO RPAS Panel and Autonomy

Future:

Single operator control of multiple A/C
Playbook
Human-Autonomy Teaming
Patterns
HAT Model
Manned and unmanned aircraft will be able to routinely operate through all phases of flight in the NAS, based on airspace requirements and system performance capabilities.
DAA Operational Environments

Legend
Current Research Areas (FY14- FY16)
Proposed Research Areas (FY17 – FY20)

60’ MSL

18K’ MSL

10K’ MSL

MINIMUM ENROUTE ALTITUDE

DAA System for Transition to Operational Altitude (> 10kft MSL)

C2 Datalink

Terminal Area Ops

Ground Based Radar

GBSAA Data

UAS Ground Control Station

DAA System for Operational Altitudes (> 500ft AGL)

C2 Datalink

Class 2 & 3 UAS

Alternative DAA Sensors

ACAS Xu

ADS-B & TCAS-II

ACAS Xu

DAA Sensors

Non-cooperative Aircraft

Cooperative Traffic

HALE aircraft

Airborne Radar

ADS-B & ACAS-Xu

Airborne Radar
• Phase I MOPS RTCA SC- 228 complete and published (March, 2017)
  – Transition to Class A airspace
  – DAA MOPS
  – On-board RADAR MOPS
  – C2 Terrestrial Radio MOPS

• Phase 2 (2021)
  – Operation in Class C, D
  – Terminal Area Operations
  – Low SWAP A/C, sensors
  – GBSAA
General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.

Piloted “see and avoid” = UAS “detect and avoid”

Pilots vision replace by sensors (on- or off-board or both)

Pilot judgment of well clear = mathematical expression of well clear

Horz Miss Distance = 4000ft; Vert Miss Distance = 450ft; modTau = 35sec; DMOD = 4000ft
Two Functions:

1) Maintain well clear
   1) See and avoid

2) Collision Avoidance
   1) TCAS
   2) ACAS-Xu
• An early critical question for the Phase I MOPS for DAA systems was what, if any, level of DAA maneuver guidance would be required to support acceptable performance on maintaining well clear?

• Phase I MOPS assumptions specify that the pilot in command will execute maneuvers to remain well clear
  – i.e., No automatic/autonomous DAA capability

• Display types given level/type of maneuver guidance:
  – **Informative**: Provides essential information of a hazard that the remote pilot may use to develop and execute an avoidance maneuver. No maneuver guidance automation or decision aiding is provided to the pilot
  – **Suggestive**: Automation provides a range of potential resolution maneuvers to avoid a hazard with manual execution. An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers
  – **Directive**: Automation provides specific recommended resolution guidance to avoid a hazard with manual or automated execution. An algorithm provides the pilot with specific maneuver guidance on when and how to perform the maneuver
Draft MOPS Informed by HITLs: Surveillance Range

- **Approximate detection range = 8 nm**
  - Detect Intruders
  - Pilots Determine Resolution
  - Negotiate Clearance with ATC and uplink maneuver to aircraft

- **Approximate detection range = 6 nm**

- **TOTAL RESPONSE TIME:**
  - ~90 sec
  - ~80 sec
  - ~65 sec
  - ~35 sec
  - 0 sec

- **Latency**
- **ATC Interaction Time (≈10 sec)**
- **Pilot Response Time (≈15 sec)**
- **Aircraft Maneuver Time (≈30 sec)**
- **Well Clear Threshold (≈35 sec)**
- **NMAC**

- **Time until CPA**

- **Detect Intruders**

- **Pilots Determine Resolution**

- **Negotiate Clearance with ATC and uplink maneuver to aircraft**
## Alerting

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Pilot Action</th>
<th>Buffered Well Clear Criteria</th>
<th>Time to Loss of Well Clear</th>
<th>Aural Alert Verbiage</th>
</tr>
</thead>
<tbody>
<tr>
<td>![TCAS RA]</td>
<td><strong>TCAS RA</strong></td>
<td>• <em>Immediate action required</em></td>
<td><em>DMOD = 0.55 nmi</em></td>
<td>0 sec (+/- 5 sec)</td>
<td>“Climb/Descend”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Comply with RA sense and vertical rate</td>
<td><em>ZTHR = 600 ft</em></td>
<td>(TCPA approximate: 25 sec)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Notify ATC as soon as practicable after taking action</td>
<td><em>modTau = 25 sec</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>![DAA Warning Alert]</td>
<td><strong>DAA Warning Alert</strong></td>
<td>• <em>Immediate action required</em></td>
<td>DMOD = 0.75 nmi</td>
<td>25 sec</td>
<td>“Traffic, Maneuver Now” x2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Notify ATC as soon as practicable after taking action</td>
<td>HMD = 0.75 nmi</td>
<td>(TCPA approximate: 60 sec)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 450 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 35 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>![Corrective DAA Alert]</td>
<td><strong>Corrective DAA Alert</strong></td>
<td>• <strong>On current course, corrective action required</strong></td>
<td>DMOD = 0.75 nmi</td>
<td>55 sec</td>
<td>“Traffic, Avoid”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coordinate with ATC to determine an appropriate maneuver</td>
<td>HMD = 0.75 nmi</td>
<td>(TCPA approximate: 90 sec)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 450 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 35 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>![Preventive DAA Alert]</td>
<td><strong>Preventive DAA Alert</strong></td>
<td>• <strong>On current course, corrective action should not be required</strong></td>
<td>DMOD = 0.75 nmi</td>
<td>55 sec</td>
<td>“Traffic, Monitor”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coordinate with ATC to determine an appropriate maneuver</td>
<td>HMD = 1.0 nmi</td>
<td>(TCPA approximate: 90 sec)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ZTHR = 700 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>modTau = 35 sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>![Guidance Traffic]</td>
<td><strong>Guidance Traffic</strong></td>
<td>• <em>No action required</em></td>
<td>Associated w/ bands outside current course</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Traffic generating guidance bands outside of current course</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>![None (Target)]</td>
<td><strong>None (Target)</strong></td>
<td>• <em>No action required</em></td>
<td>Within surveillance field of regard</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No coordination required</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* These values show the Protection Volume (*not well clear volume*) at MSL 5000-10000ft (TCAS Sensitivity Level 5)
Autonomous CA is optional.

Manufacturers can, if desired, automate collision avoidance – much as Airbus has automated TCAS in the A380.

Autopilot mode to execute the Resolution Advisory.

No action for a traffic advisory.

Autonomous Maintain Well Clear (MWC) function is out of scope. Partly because the solution is suggestive.

Phase 2 – closure rates are slower, but A/C are closer, aircraft are less agile – timelines may dictate auto-DAA. Initial study of the trade space (OSU-Woods).
Autonomous aircraft: An unmanned aircraft that does not allow pilot intervention in the management of the flight.

Autonomous Operation: An operation during which a remotely piloted aircraft is operating without pilot intervention in the management of the flight.

and

the *RPAS Manual on Remotely Piloted Aircraft (RPAS)* restricts the scope to exclude “autonomous aircraft and their operations ...”
However, Lost link operations, by definition, are operating without pilot intervention (i.e., pilot out of the loop, section 2.13). Therefore, based on the descriptions (section 2.1) and the restriction in scope, lost link operations are excluded from the RPAS panel scope. However, these operations are discussed in chapters 4, 8, 9, 10, 11 and 14 of the RPAS Manual.

The ICAO definition of autonomous operations inadvertently excludes lost link operations.
### Automation Table

#### Ability of pilot to intervene

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Pilot can intervene</th>
<th>Pilot can’t intervene (lost link)</th>
<th>Pilot can’t intervene (design)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterministic</td>
<td>Automation</td>
<td>Automation*</td>
<td>Automation</td>
</tr>
<tr>
<td>Stochastic</td>
<td>HAT</td>
<td>Autonomy</td>
<td>Autonomy</td>
</tr>
</tbody>
</table>

ICAO: Automation is in scope, Autonomy is out of scope.

* Current lost link.
Multi-dimensional nature

• LOA
  – Sheridan
  – Parasuraman, Wickens and Sheridan

• Aviation Systems
  – Aviate
  – Navigate
  – Communicate

• Phase of flight
  – T.O.
  – En route
  – Approach
  – Landing

Waypoint Navigation:
RPAS xx is automated at level xx, in nav, for the en route phase.
Single operator control of multiple UAS

DoD – AFRL “Heterogeneous-UAS Integration in a single-operator VSCS Environment (HIVE)”

UAS EXCOM Science and Research Panel’s (SARP) - Workshop on multiple UAS controlled by a single operator, June 27 & 28.

Boeing – “don’t see a business model without it.”

Supervisory control – a step before network management (UTM).
Delegation Control: Playbook®

- Delegation: one way humans manage supervisory control with heterogeneous, intelligent assets
- Playbook®: one means of delegation
- Plays: analogous to football
  - Quick commands – complex actions

- A Play provides a framework
  - References an acceptable range of plan/behavior alternatives
  - Requires shared knowledge of domain Goals, Tasks and Actions
  - Supervisor can further constrain/stipulate

- Potentially facilitates intuitive cooperative control of Unmanned Systems

A page from Alonzo Stagg’s 1927 Playbook
Example: Prosecute Target

**Tools:**
Arm laser ➔ Lase target ➔ Send coordinates to weaponized UAV ➔ Toggle UAVs ➔ Arm missile ➔ Fire

**Scripts:**
Select ‘Lase’ script ➔ Toggle UAVs ➔ Arm weapons ➔ Fire

**Plays:**
Select ‘Prosecute Target’ play ➔ Fire

**Higher Accuracy for Plays**

**Shorter Reaction Time for Plays**

**Plays had lower workload**

**NASA-TLX Ratings**

**Secondary Task Performance (% Correct Hits)**

**Levels of Automation Simulation**

**Control Mode**

Primary Task Performance (RT)

0 10 20 30 40 50 60

Plays Scripts Tools

Target Acquisition Target Prosecution

Target Acquisition Target Prosecution

Primary Task Performance (RT)

Control Mode

0 10 20 30 40 50 60

Plays Scripts Tools

Overall Rating

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

Plays Scripts Tools

Control Mode

Reaction Time

Primary Task Performance (RT)

0 10 20 30 40 50 60

Plays Scripts Tools

Control Mode

0% 10% 20% 30% 40% 50% 60% 70% 80%

% Correct

Plays Scripts Tools

Control Mode

% Correct

0% 10% 20% 30% 40% 50% 60% 70% 80%

% Correct

Plays Scripts Tools

Control Mode

% Correct

0% 10% 20% 30% 40% 50% 60% 70% 80%
Manned-Unmanned Teaming: MUM

Level IV Control:
Control of Payload and Vehicle
Excluding Take-off and Landing

Extend to simultaneous control of multiple heterogeneous UAS
Manned-Unmanned Teaming: MUM

Goals:

• Apply Playbook® methodology and DelCon lessons learned to helicopter cockpit; Test in simulation

• Increase capability and efficiency of UAS control by helicopter pilots

• Supervisory control of multiple, heterogeneous UAS

• Develop infrastructure and lay foundation for later efforts
Results

Propportion of Targets Marked by Control Mode (Out of Total Possible)

Higher Accuracy Playbook

p < .05

NASA – TLX Ratings

No UAV  |  Manual  |  Playbook

Temporal |  Frustration |  Performance |  Overall

Average Rating

p < .05

Lower Route Planning Time for Playbook

Lower workload for Playbook on several dimensions

UAS Route Planning Time by Control Mode

p < .05

NASA – TLX Ratings

No UAV  |  Manual  |  Playbook

Temporal |  Frustration |  Performance |  Overall

Average Rating

p < .05

Lower Route Planning Time for Playbook

Lower workload for Playbook on several dimensions
Flight Demonstration 2009

**Ft. Ord CA, 23 APR 2009**

**Goal:**
- Demonstrates initial proof of concept of Delegation Control (Playbook) in flight – supervisory control of multiple air/ground assets in MOUT Scenario

**Method:**
- Live/Virtual Demo – Controlling RMAX, CMU MAX Rover and 2 virtual UAS with Delegation Control
- Voice RGN Control (USAF)

**Features:**
- Delegation control human-machine interface supports control and monitoring 4 payloads
- Automation Transparency
- Live UGV-UAV coordination for slung load drop
- Reduced operator workload/high situation awareness
Flight Demonstration 2011

Ft. Hunter-Liggett CA, 19 May 2011

Purpose:
• Build on previous simulations and flight test examining single operator control of multiple heterogeneous ground/air unmanned systems through delegation control employment
  – Operator performance data collection/workload assessments
  – Heterogeneous flight assets: Boeing Scan Eagle and Yamaha RMAX; two virtual UAS
  – Testing in operationally relevant mission scenarios
  – Multi-sensor cross-cue in support of both targeting and convoy support
• Army AFDD/Boeing CRADA

Key Objective:
• Develop and test DelCon Top Priority Plays; route recon, convoy support, troops in contact
Demonstrated in numerous simulations and flight tests (even NOPE).

- AFRL – Base security, UAS ground station
- RCO – Dispatch, cockpit
- HAT
HAT Agent

Alerts
Context
Responses to Queries
- Alternatives
- Transparency info
- Predicted Outcomes
- Reasoning
- Confidence level

Context
- Time Pressure
- User Info
- more

HAT Agent

Plays
- Goals
- Risks to
achieving goals
- Mitigations

Transparency Info

Authority Info

Scratch Pad

Etiquette Rules/Contextual

Sensitivity

Interface

Display
Audio
Visual

Operator

Queries/Requests
- A v. B
- Why?
- What If?

Automation

Requests
Polling for Risks
Problems with Automation

• Brittle
  – Automation often operates well for a range of situations but requires human intervention to handle boundary conditions (Woods & Cook, 2006)

• Opaque
  – Automation interfaces often do not facilitate understanding or tracking of the system (Lyons, 2013)

• Miscalibrated Trust
  – Disuse and misuse of automation have lead to real-world mishaps and tragedies (Lee & See, 2004; Lyons & Stokes, 2012)

• Out-of-the-Loop Loss of Situation Awareness
  – Trade-off: automation helps manual performance and workload but recovering from automation failure is often worse (Endsley, 2016; Onnasch, Wickens, Li, Manzey, 2014)
HAT Solutions to Problems with Automation

• Brittle
  – **Negotiated decisions** puts a layer of human flexibility into system behavior

• Opaque
  – Requires that systems be designed to be **transparent**, present **rationale** and **confidence**
  – Communication should be in terms the operator can easily understand (shared language)

• Miscalibrated Trust
  – Automation **display of rationale** helps human operator know when to trust it

• Out-of-the-Loop Loss of Situation Awareness
  – **User directed interface**; adaptable, not adaptive automation
  – Greater interaction (e.g., **negotiation**) with automation reduces likelihood of being out of the loop
Legend

Human Operator

Intelligent / Cognitive Agent

Automated Tools

Communication Only

Supervisory Relationship

Cooperative Relationship

Co-location (e.g., onboard an airplane, in ground station)

Both imply bi-directional information flow, usually using automated tools
FLYSKY12 is en route from SFO to BOS. There is one POB and a dispatcher flight following.

• Onboard automation detects fuel imbalance and alerts POB and dispatcher.
• POB requests automation diagnose fuel imbalance. Automation reports to POB a leak in left tank.
• POB requests that agent manage fuel. Agent opens the cross feed and turns off the pumps in the right side to draw fuel from the left.
• POB contacts dispatch about need to divert.
• Dispatcher requests divert planning from dispatch automation.
• Dispatcher uplinks flight plan to POB. POB inspects the flight plan and agrees.
• POB requests agent coordinate divert with ATC. Agent reports divert is approved. POB tells agent to execute.
Top-Level Actor Relationships

- **WObj: Airline Flight**
  - Onboard Pilot
  - Onboard Agent
  - Worker | Tools

- **WObj: Ground Operations**
  - Ground Operator
  - Ground Agent
  - Worker | Tools

- **WObj: ATC Operations**
  - ATC
  - Worker | Tools

- **WO: Aircraft**
Top-Level System Work

- **WO: Aircraft**
  - **WProc: Airline Operations**
    - **WObj: Airline Flight**
      - Onboard Pilot
      - Onboard Agent
      - Telemetry data
      - Voice comm
      - Fly aircraft
      - Direct traffic (e.g., clearances)
      - Provide information (e.g., traffic)
      - Voice comm
      - Alerts (e.g., weather)
      - Mitigations (e.g., reroutes)
      - Voice comm

- **WO: Ground Operations**
  - **WObj: Ground Operations**
    - Ground Operator
    - Telemetry data
    - Voice comm

- **WO: ATC Operations**
  - **WObj: ATC Operations**
    - ATC Operator
    - Telemetry data
    - Voice comm
Summary

• Autonomy
  – Not in today’s “approved” UAS
  – Words Matter
    • ICAO

• Business case for single operator supervisory control of multiple UAS
  – Playbook delegation is one successful method

• HAT
  – Cooperative agent with knowledge of work domain
  – Shared world knowledge
  – Can we extended to network supervision