The Science of Drones

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Outline

- Overview
- What is a drone?
- Drone types and systems
- Challenges for wider drone operations
Overview

• Aviate

• Navigate

• Communicate
What is a “Drone”?

• Terminology
  o **Drone**: the public’s term for any flying vehicle that doesn’t have a pilot onboard
  o **Unmanned aircraft system** (UAS): preferred civil term that emphasizes the drone as a “system”
  o **Unmanned aerial vehicle** (UAV): older but common term, especially in academia
  o **Remotely piloted aircraft system** (RPAS): the military’s most common term for a drone, and probably the most accurate
Common Drone Types

- **Small multicopter (hobbyist, commercial)**: DJI Phantom, Yuneec Typhoon, Intel Aero

- **Small/medium fixed wing and rotorcraft**: DJI Phantom, Yuneec Typhoon, Intel Aero, Fire Scout (RQ-8), Shadow (RQ-7)

- **Large fixed wing**: DJI Phantom, Yuneec Typhoon, Intel Aero, Fire Scout (RQ-8), Shadow (RQ-7), Predator B (MQ-9), Global Hawk (RQ-4), X-47
# Drone Classification System

<table>
<thead>
<tr>
<th>Category</th>
<th>Size</th>
<th>Maximum Gross Takeoff Weight (MGTW) (lbs)</th>
<th>Normal Operating Altitude (ft)</th>
<th>Airspeed (knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>Small</td>
<td>0-20</td>
<td>&lt;1,200 AGL*</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Group 2</td>
<td>Medium</td>
<td>21-55</td>
<td>&lt;3,500</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Group 3</td>
<td>Large</td>
<td>&lt;1320</td>
<td>&lt;18,000 MSL**</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Group 4</td>
<td>Larger</td>
<td>&gt;1320</td>
<td>&lt;18,000 MSL</td>
<td>Any airspeed</td>
</tr>
<tr>
<td>Group 5</td>
<td>Largest</td>
<td>&gt;1320</td>
<td>&gt;18,000</td>
<td>Any airspeed</td>
</tr>
</tbody>
</table>
Drone Subsystems

- Electric motors
- GPS antenna
- Flight controller
- Battery
- Propellers

- Arm
- Landing gear
- Secondary computer (additional processing)
- 915 MHz radio receiver and antenna
- Electronic speed controller (ESC)
Drone Subsystems

- GPS antenna
- Flight controller
- Battery
- Jet engine
- Ku-band SatComm antenna
- Landing gear
- Secondary computer(s) (additional processing)
- Ultra High Frequency (UHF) radio antenna
# Vehicles and Airspace Operations

## Advanced Vehicle
- Detect and avoid (separation and collision)
- Tracking
- Control system
- Geo-fencing conformance
- Safe Landing
- Cyber security
- Low-noise
- Long endurance
- GPS-free/degraded
- Autonomous Last/first 50 feet

## Airspace Operations
- Architecture and roles/responsibilities
- Planning, scheduling, sequencing and separation
- Weather
- Alerts
- Data exchange protocols
- Cyber security
- Spectrum
- Dynamic and static geo-fence definition
- Contingency management
Detect and Avoid (DAA) Overview for Small UAS

Detect and avoid for UAS replaces “see and avoid” for pilots

- **Instrument Flight Rules (IFR) Traffic**: Separation by airspace segregation
- **Visual Flight Rules (VFR) Traffic**: TBD non-cooperative intruder detection system, UTM
- **Small UAS**: TBD vehicle-to-vehicle (V2V) cooperative data exchange, UTM

Increasing time and distance
Detect and Avoid (DAA) Overview for Large UAS

Detect and avoid for UAS replaces “see and avoid” for pilots

Instrument Flight Rules (IFR) Traffic
Separation managed by air traffic control

Visual Flight Rules (VFR) Traffic
Separation mostly managed by “see and avoid” with support from ATC workload permitting

Increasing time and distance

Requirements?

Interoperability?

Detect and Avoid

Collision Avoidance

Air Traffic Control

UAS
### UTM Technical Capability Levels (TCLs)

**Capability 1: Demonstrated how to enable multiple operations under constraints**
- Notification of area of operation
- Over unpopulated land or water
- Minimal general aviation traffic in area
- Contingencies handled by UAS pilot

*Product: Overall con ops, architecture, and roles*

**Capability 2: Demonstrated how to enable expanded multiple operations**
- Beyond visual line-of-sight
- Tracking and low density operations
- Sparsely populated areas
- Procedures and “rules-of-the road”
- Longer range applications

*Product: Requirements for multiple BVLOS operations including off-nominal dynamic changes*

**Capability 3: Focuses on how to enable multiple heterogeneous operations**
- Beyond visual line of sight/expanded
- Over moderately populated land
- Some interaction with manned aircraft
- Tracking, V2V, V2UTM and internet connected

*Product: Requirements for heterogeneous operations*

**Capability 4: Focuses on enabling multiple heterogeneous high density urban operations**
- Beyond visual line of sight
- Urban environments, higher density
- Autonomous V2V, internet connected
- Large-scale contingencies mitigation
- Urban use cases

*Product: Requirements to manage contingencies in high density, heterogeneous, and constrained operations*

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Risk-based approach: depends on application and geography
UTM TCL2: Scheduling and Executing Multiple BVLOS Operations

Conflict Alerts
Alert triggered by proximity to other aircraft

Intruder Alerts
Alert triggered from radar submitted warning regions to UTM research prototype

Contingency Alerts
Simulated in-flight emergency reported to the UTM research prototype and relayed to impacted operations

Flight Conformance Alerts
Alert triggered from departing from operational area and relayed to impacted operations

Priority Operations
Users with special privileges are given priority of the airspace and impacted operations are informed of any conflicts

Scheduling and tracking operations and contingency management
Comm&Nav (C&N) Working Group (WG) is one among 4 NASA-FAA RTT working groups, the others being Data Architecture, Concept and Operations, Sense and Avoid.

**C&N WG Objectives**
Develop C&N guidance to industry for ensuring that

- Unmanned Aircraft (UA) are under operational control of the pilot
- UA remain within a defined area
NASA Guidance to Industry (Comm)

CG01. UAS operator should have a means to detect loss of Command and Control (C2) radio link
CG02. UAS operator should make the means to detect loss of C2 known to public
CG03. UAS operator should define steps to mitigate loss of C2 link
CG04. UAS operator should make loss of C2 link contingency mitigation steps known to public
CG05. When loss of C2 link occurs, UAS operator should gather contextual and digital data that can describe this event for further review
CG06. UAS operator should have a means verify Unmanned Aircraft (UA) execution of a maneuver command from the operator
CG07. UAS operator should make the means to verify Unmanned Aircraft (UA) execution of a maneuver command from the operator known to public
CG08. UAS operator should define steps to mitigate a condition where UA does not execute a maneuver command from the operator
CG09. UAS operator should make steps to mitigate a condition where UA does not execute a maneuver command from the operator known to public
CG10. When UA does not execute a maneuver command from the operator, UAS operator should gather contextual and digital data that can describe this event for further review
NG01. UAS operator should know position error of their UAS system
NG02. UAS operator should know velocity error of their UAS system
NG03. UAS operator should have a means to detect loss of navigation
NG04. UAS operator should make the means to detect loss of navigation known to public
NG05. UAS operator should define steps to mitigate loss of navigation
NG06. UAS operator should make loss of navigation contingency mitigation steps known to public
NG07. When loss of navigation occurs, UAS operator should gather contextual and digital data that can describe this event for further review
NG08. UAS operator should define boundary of operational airspace where UA will stay within
NG09. UAS operator should make operational airspace boundary known to public
NG10. UAS operator should make UA’s operation time in its operation airspace known to public
Flowchart for Current Spectrum Use

- **UAS Communication system based on spectrum use**
  - Agencies – NTIA, FCC, NIST, DOD, ANSI

- **Licensed**
  - Coverage
  - Capacity
  - Coexistence / interference
  - Power consumption
  - Latency
  - Security

- **Requirements /QoS**
  - Reliability and resiliency
  - Most systems covered under FCC Title 47, Part 15
  - Follow certification or verification standards as referred to ANSI

- **Unlicensed**
  - Potential systems covered under Title 47, Part 18 for ISM
Lessons Learned from Flight Tests

• Altitude standard
• Density altitude
• Up drafts
• High/low temperature grade equipment
• Manned-unmanned vehicle interaction
Manned and unmanned vehicle interaction

LSTAR Radar

PIPER CUB

LANCASTER 5

500 FT AGL

300 FT AGL

BRAMOR RTK

Manned Aircraft

GCS 3

GCS 5
National UAS Standardized Testing and Rating (NuSTAR)

- Current State of the Art
  - Many performance measures are considered for UAS
  - Capability to assess and certify performance benchmarking is a huge gap
- Proposed Solution
  - Responsible, credible, collaborative tests and data
  - Parallel: Underwriter’s Laboratory, Consumer Reports, JD Powers
- Approach
  - Drop tests
  - Urban, rural, atmospheric conditions (e.g., fog, smog, rain)
  - Sense and avoid, Simulated obstructions, GPS denied conditions, etc.
- Data oriented rating, acceptance, and assurance
- Every UAS vehicle model goes through
- Support UAS manufacturers, consumers, FAA, insurance companies, and public at large through objective assessments
Summary

- Vehicles will get more capable over time
- Airspace operations capabilities will remain important for scalability
- NUSTAR will help pave the way for assessment of vehicle performance
Thank you!

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References

- **UTM**
  - https://www.aviationsystemsdivision.arc.nasa.gov/publications/category/utm.shtml
  - https://utm.arc.nasa.gov/documents.shtml

- **Unmanned aircraft systems**
  - https://www.aviationsystemsdivision.arc.nasa.gov/publications/category/uas.shtml