… Toward Safe, Secure, and Trusted Unmanned Air Systems

Unmanned Air Systems: Use & Regulation
Government-University-Industry Research Roundtable

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FOCUS

- **sUAS – Unique Systems**
- **Issues and Vulnerabilities**
- **Strategies and Solutions**

UAS IN THE AIRSPACE
Some Key Criteria

- ***Capable of meeting mission needs***
  - Range-payload performance (platform)
  - Speed, timeliness, responsiveness
- ***Compatible with the operational environment***
  - All requisite mission conditions (weather, darkness,…)
  - Not disruptive to other traffic … competing activities
  - Not intrusive (e.g. noise, nuisance, visual distraction)
- ***Trusted … by users, stakeholders, and the public***
  - Reliable … vehicle, system and mission level
  - Safe
  - Secure
  - Not a perceived as a threat

Small UNMANNED AIR SYSTEMS (sUAS) … Unique Class of Systems

Today's sUAS …

Air Vehicle*

Line-of-sight, Continuous Communications

***DJI Phantom 1.1.1 Quadcopter with GoPro Camera … ~2.5 lb. Total weight**

(Mostly) Manual Flight/Mission Control

Several Orders of Magnitude in Size, Weight & Power

Air Vehicle Variety

Examples… < 55 lb. TOGW

SMALL UNMANNED AIR SYSTEMS (sUAS)
… Limited air vehicle size, weight, power & propulsion

- Small Physical Size …
  - Limits “real estate” … reduces options for sensor apertures/antennas
  - Invokes need for component synergy … shared platform infrastructure … especially, sensors
  - Alters the approach to physical integration for the smallest platforms
- Weight Limitations…
  - Constrain overall payload capacity (mass)
  - Invite tradeoffs with performance … range/endurance
- Propulsion and Power Constraints…
  - Tightly coupled attributes
  - Limit ability to compete with winds … weather
  - Limit payload, sensor types and attributes
  - Limit onboard computational capability
  - Affect communications … signal strength(s), bandwidth,…
  - Unique aerodynamic attributes (low Reynolds number) for the very small vehicles

Today's Commercial sUAS ...

ISSUES & VULNERABILITIES

Air Vehicle Limitations and Constraints

- Flight environment compatibility
  - Lightly loaded airframes … varies across vehicle sizes/types
- Airframe pedigree … for smaller UAS
  - Some manufacturers lack aerospace 'know-how'…adherence to standards
  - Fragile construction … structural integrity
  - Exposed propellers/rotor risks, in many designs
  - No provisions for consequences of collision/impact

System-level Command & Control Vulnerabilities

- Limited operator situation awareness
  - Many systems lack an 'out-the-cockpit' perspective
  - Requirement for constant vigilance … workload
- Communications challenges
  - Latency or degraded communications precludes real time control
  - Limited spectrum available (… especially challenging for active payload operations)
  - No accepted beyond-line-of-sight (BLOS) solution for smallest platforms
  - Susceptibility to hostile disruption or exploitation possible … multiple sources

DIVERSE OPERATIONAL ENVIRONMENTS

- Extremely Low Altitudes
  - … 500 ft. down to ‘the blades of grass’
- Few missions exploit VLOS, daylight operations with limited human presence
  - ‘Above-the-clutter’ solutions appear viable in the near term
- Obstacle-rich Topology … is typical
  - Buildings, trees, wires, vehicles, other protuberances … can be dense
  - Communications challenges … especially beyond-line-of-sight (BLOS)
  - Gusting, unpredictable winds and other perturbation sources
- Close Proximity to humans for many missions… incidental and intentional
- Air Traffic Management … today’s rules are inadequate

Improving UAS safety & security …

…TOWARD STRATEGIES & SOLUTIONS

- Improve Vehicle-Operator Communications for Situation Awareness
  - Create capability for connectivity ‘on demand’
    - e.g. cellular net access is being explored
  - Develop methods to reduce latency … especially for C2 operations
- Reduce the Level and Predictability of Operator Interactions
  - Increase the level of vehicle *autonomy …* create a smarter machine
    - Exploit “distributed intelligence”
  - Relax the need for real time operator interactions
    - … for situation awareness
    - Reduce contact time for mission and vehicle control
    - Enable lower bandwidth, higher level interactions
  - Enable novel communications security strategies – e.g. …
    - Novel wave-form and connectivity approaches … unpredictable message timing
    - Non-traditional network security architectures
- Develop Active Sensing Strategies that Reduce Threat Exposure

AUTONOMY … TODAY

- Basic Flight Functions …
  - Self-stabilization
  - Air vehicle flight control
  - Auto-takeoff
  - Auto-land
  - Fault and Damage tolerant control (demonstrated)
- Auto-Navigation
  - Waypoint designation
- Simple Contingency Management
  - Flight termination
  - ‘Climb and circle’
  - Return-to-base
- Elements of ‘Obstacle Avoidance’
  - Cooperative methods (e.g. ADS-B based methods
  - Obstacle detection (LIDAR ‘point cloud’) … for helicopters
  - Path planning algorithms
  - Visual Odometry

AUTONOMY … THE FUTURE

… In the Pipeline

- Obstacle avoidance...especially for small, SWAP-limited vehicles
- GPS-denied navigation
- Collision avoidance…moving platforms
- Multi-vehicle collaboration

What's still Missing?

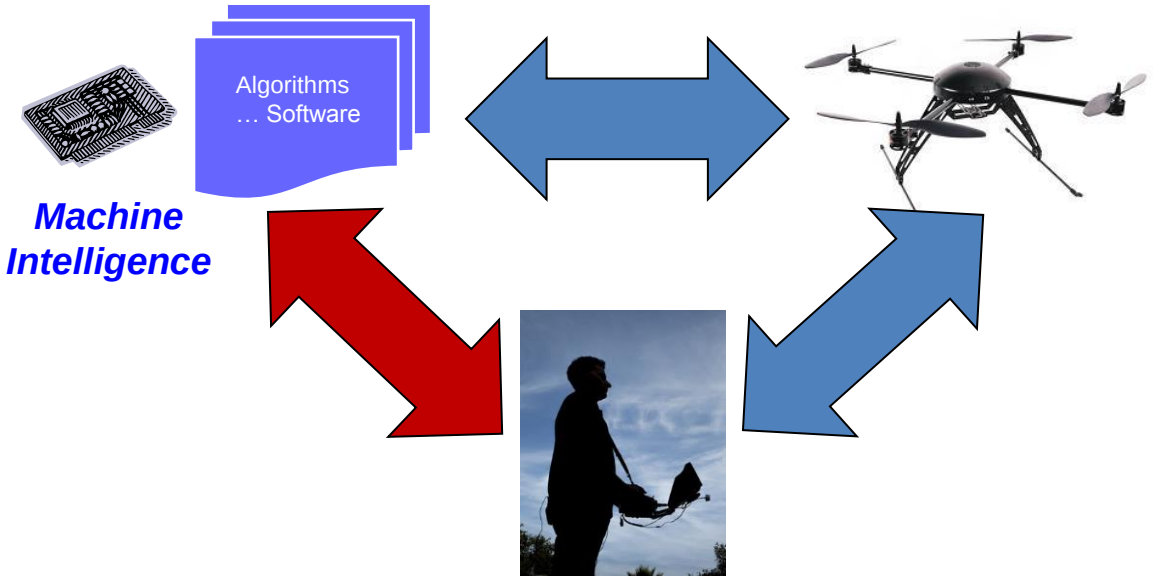
- Mission level autonomy
  - Federated functions vs. integrated solutions
  - Decisions requiring high levels of perception (e.g. inference)
- Mission-level contingency management
  - e.g. Weather or other threat-driven events
  - Complex multi-objective real-time re-planning
  - Subjective judgment
- Certification methodologies for intelligent software systems

RESEARCH & TECHNOLOGY TOPICS
Short Term Focus

- Expanded autonomous capabilities
  - Mission management functions
  - Contingency response capabilities
- Novel secure communications strategies
  - Segregated communications channels … command & control (C2) vs. payload data transmission
  - New network security ‘architecture’ concepts
    - Multi-band solutions, including cellular … novel encryption schemes
  - Intermittent, asynchronous, hard-to-predict transmissions
    - New waveform options, spread spectrum techniques, …
- Interactive human-machine intelligence integration
  - Integrated system is more capable than the sum-of-the-parts
- New rules for very low altitude operations (e.g. NASA UTM Program)
  - Focus on the unique environment
  - Seamless integration with the rest of the NAS architecture

RESEARCH & TECHNOLOGY TOPICS (cont)

- Build Trust in the System (V&V, Certification Processes)
  - New software & system certification approach required
    - Today, works only for precisely repeatable, predictable, deterministic systems
    - Focus on logical, adequate solutions… should cope with emergent behaviors
    - … The analog of certifying ‘human software’
  - **Need** new approach to ‘intelligent software’ … what and how!
    - Key enabler for new V&V approach
    - Assessable/examinable by domain experts (… not software developers)
    - Communicates with humans at high level



DISCUSSION

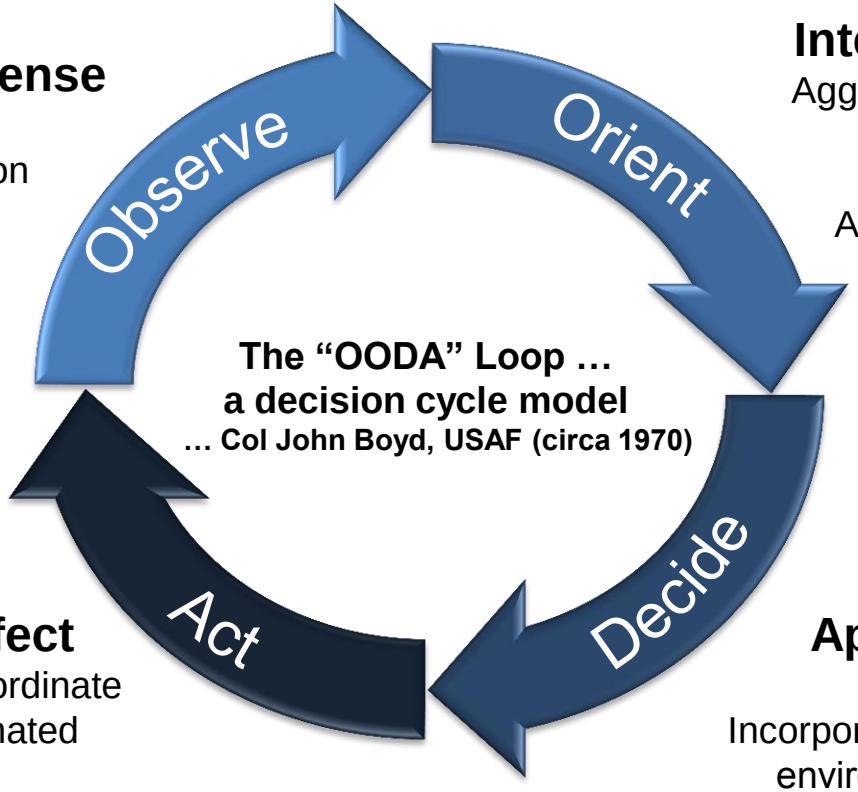
BACK UP SLIDES

AUTONOMY … What does it mean?

Ability of the aircraft to fly and conduct mission operations safely and reliably … without human intervention

Detect & Sense
Sensor Data
New Information
Commands

Integrate & Perceive
Aggregate/Fuse Information
Synthesize Information
Assess Context
Apply Historical Influence
… Learned Behavior
Hypothesize
Intuit
Assess results of prior cycle



The "OODA" Loop …
a decision cycle model
… Col John Boyd, USAF (circa 1970)

Implement/effect
Command and coordinate
Actuate for coordinated movement

Apply Decision Logic
Meet task objectives
Incorporate physical, behavioral, & environmental considerations…
Eliminate conflicts

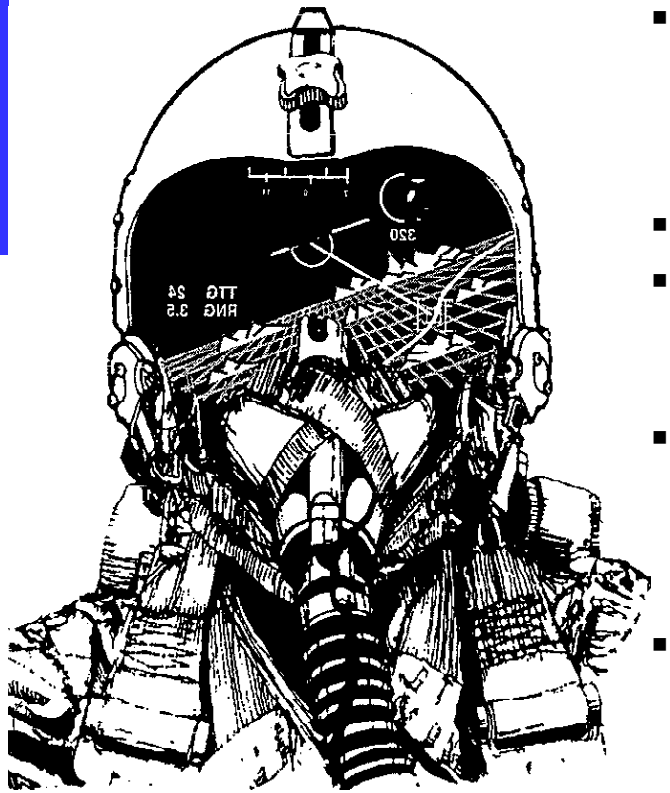
The machine is capable of executing the entire decision cycle for all autonomous functions

A CASE FOR UNMANNED

… Eliminating Crew Risk

The Contribution

- **Critical Decisions**
  - Life or Death
  - Safety
  - Mission Planning
  - Tactics
- **Data Interpretation**
- **Information Synthesis**
- **Direct Sensing (WVR)**
- **Manual Control**



The Penalty

- **Environmental Adaptation**
  - Oxygen
  - Pressurization
- **Human Interfaces**
  - Displays
  - Switches
  - Comfort
- **Safety/Level of Risk**
- **Susceptibilities**
  - Disorientation (e.g., Vertigo)
  - Motion Sickness
- **Limitations**
  - Acceleration (g's)
  - Gravitational Orientation
  - Endurance
- **Heat of Battle Effectiveness**
  - Workload
  - Stress
- **Training and Proficiency**
- **Additional Infrastructure**
  - Aircrew Support Systems
  - Search and Rescue

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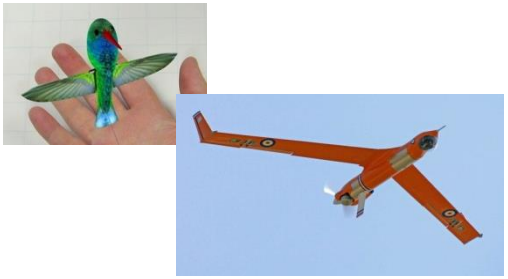
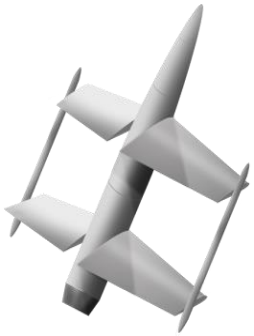
EXPANDED VEHICLE DESIGN SPACE

… Exploiting ‘Unmanned’

Long endurance operation
…Very high altitudes

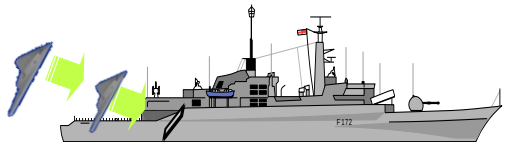


Small, mini & μ- air vehicle



Arbitrary orientation

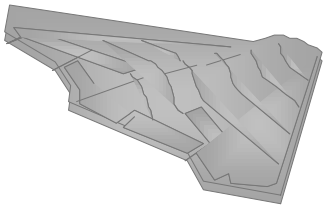
Expanded Operational Envelope



Novel launch & recovery

Unique configurations

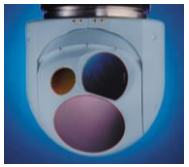
Extreme agility



‘Attritable’ platforms

THE CHALLENGES AHEAD

The Information Revolution and Its Impact

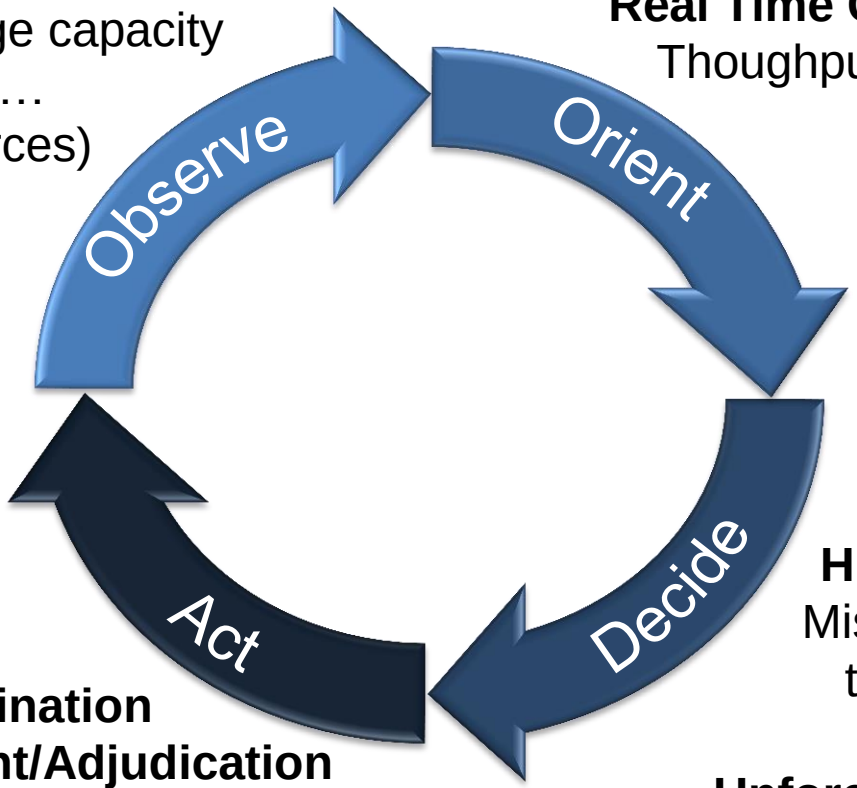


- Major Drivers
  - Computing power – throughput speed and memory capacity
  - Miniaturization, including reduced power components
  - Digital communications … networked systems
  - Sensors … for payloads and platforms
    - GPS … for timing and navigation
    - Imaging systems & technologies
- New & Emergent Capabilities for Aerospace
  - Integrated Air & Space capabilities
  - Unmanned & Robotic systems
  - Machine Intelligence and Autonomy
  - Enhanced & New Capabilities…Missions

AUTONOMY … CHALLENGES FOR sUAS

Sensors –
Number, size, resolution, reach
Databases –
Onboard data storage capacity
Real time upgrades …
(off-board sources)

Information Fusion
Perception – …beyond detection
Real Time Computing
Thoughput limitations



“Machine Learning”
Mission-level lessons
High Level Reasoning
Mission-to-platform logic
transition & integration
Conflict Resolution
Unforeseen Contingencies
Decision logic

Multi-effector Coordination
Decision Assessment/Adjudication