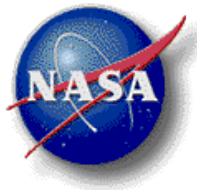

Expanding the Envelope of UAS Certification

What It Takes To Type Certify A UAS For Precision Agricultural Spraying

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(NASA Langley)
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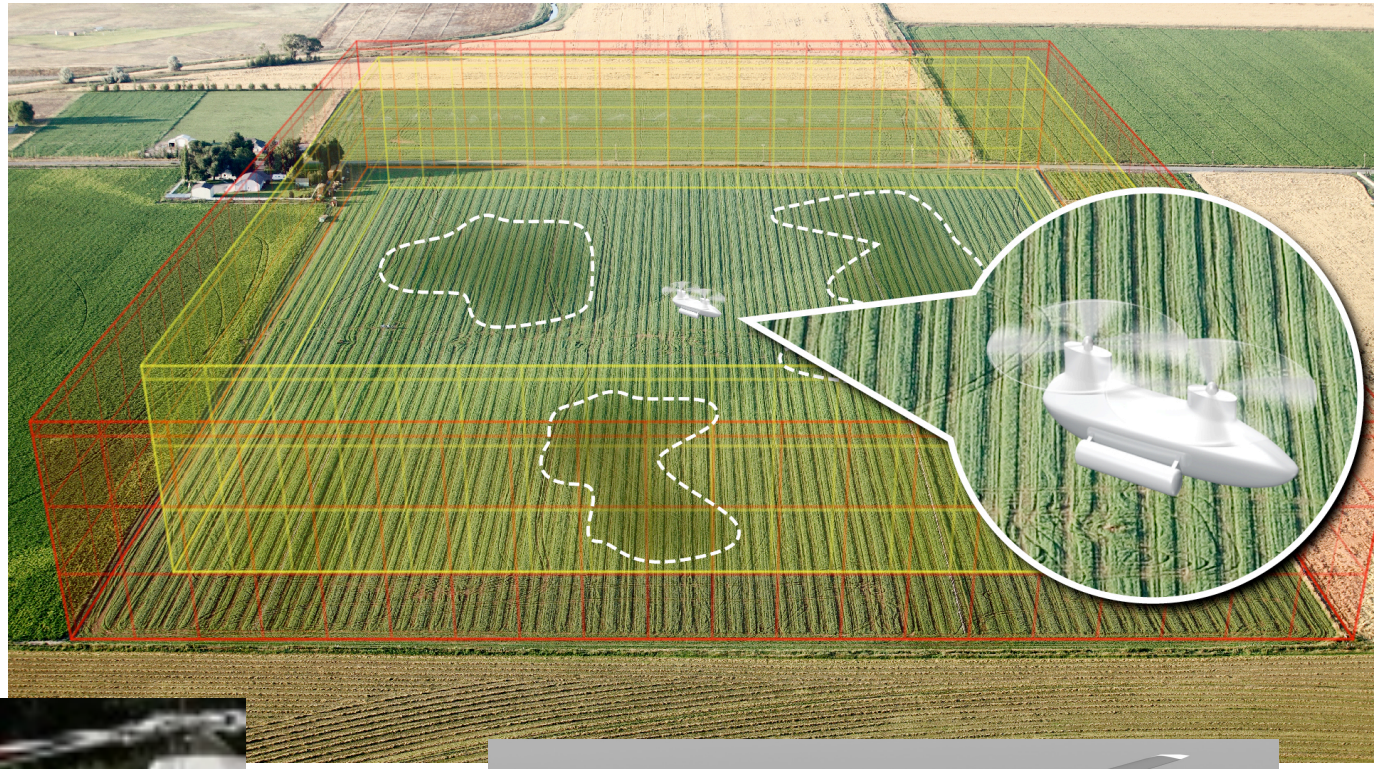
May 4th, 2016

Case Study for UAS Spraying

Unmanned helicopter (~1000 lb) for precision application of agricultural chemicals

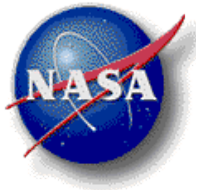


Precision Agriculture Case Study

- Goal: Develop a candidate *Type Certification Basis*
- Type Certification Basis is…
  - the first step in an aircraft certification process
  - a collection of airworthiness requirements
  - a set of operational limitations
  - initially used as part of the design process
- Case Study
  - Based on a “real” vehicle
  - Based on a detailed Concept of Operations
  - Based on review/analysis of Part 27 and JARUS requirements, with rationale
    - JARUS = Joint Authorities for Rulemaking on Unmanned Systems
- Results captured in a openly available technical report (Google: NASA type certification basis)

Expanding the Envelope

- What can we do with this Type Certification Basis?
- Overarching goal: help fill the void in certification requirements for larger UAS
- Expand results to other vehicles or operations
  - Corridor operations
  - Package Delivery
- Lessons learned
  - Risk-based certification
  - Hazard analysis
  - Mitigations
  - Factors relevant to hazards and risks



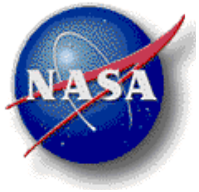
Outline

- Introduction
- Risk-based Certification
- Hazard Analysis
- Classification Factors
- Conclusions

Risk-Based Certification

- A certification approach in which the imposed requirements are proportional to the operational risk
  - Only considering safety risks

General Characteristics of Airworthiness Standards for Conventional Aircraft	Expected Characteristics of Risk-based Airworthiness Standards for UAS
Originate from experience with system designs, performance, and limitations	Will originate from *a priori* functional and operational hazard analysis for an aircraft and operation
Operation agnostic	Will be operationally driven
Based on aircraft designs from 1950's and 1960's	Will not presuppose a reference aircraft
Focus on protection of people onboard	Will focus on protection of people on the ground and in other aircraft
Both performance-based safety objectives and prescriptive (technology-centric) requirements	Will primarily be performance-based safety objectives



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Hazard Analysis

- A *hazard* is a “Condition … that could lead to or contribute to an … undesired event.”
  - From FAA System Safety Handbook
- Hazard Analysis Process
  - Identify ➔ Classify ➔ Mitigate
- Won’t over-regulate or under-regulate
  - Yeah!

Hazard Analysis

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- Hazard Analysis Process
  - Identify ➔ Classify ➔ Mitigate
- Won't over-regulate or under-regulate
  - Yeah!

“Undesired Events”

http://news.naver.com/main/read.nhn?mode=LSD&mid=sec&sid1=102&oid=003&aid=0002804520
http://www.getwestlondon.co.uk/news/west-london-news/plane-near-miss-flying-drone-9707697
http://edition.cnn.com/2015/12/23/sport/marcel-hirscher-drone-crash/

Hazard Severity Definitions

- Provide categories of *severity* of hazard
  - Labeled: catastrophic, hazardous, major, minor, or no safety effect
- Definition for conventional airplanes (ref AC23.1309)
  - Catastrophic: Failure conditions that are expected to result in: multiple fatalities of the occupants, or incapacitation or fatal injury to a flight crew member normally with the loss of the airplane.

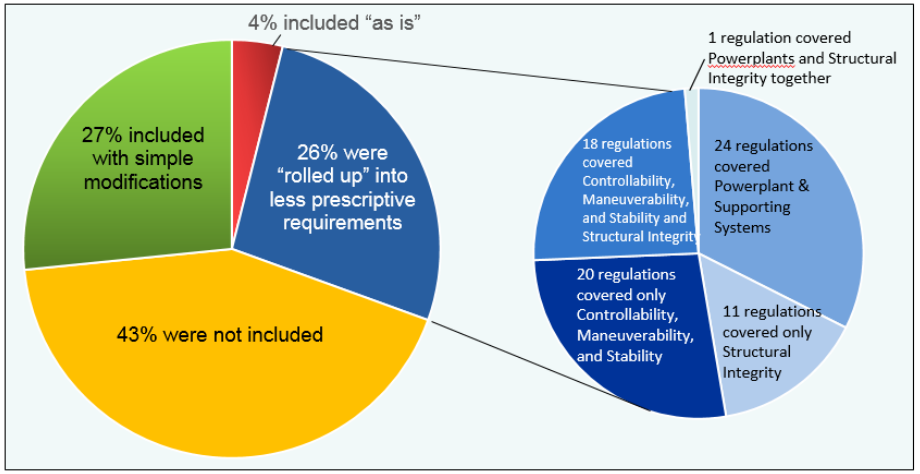
- One proposed definition for UAS (JARUS)
  - Catastrophic: Failure conditions that could result in one or more fatalities.
- Our proposed definition
  - Catastrophic: Failure conditions that are expected to result in: (1) fatality or fatal injury to any person; (2) complete loss of safety margins; or (3) complete loss of the UAS crew's ability to perform their safety role.

Hazard Identification (Examples from spraying operation)

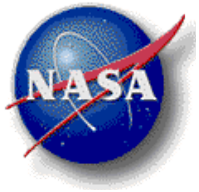
- Hazards affecting the crew's ability to perform their safety role
  - Loss of command and control (C2) link used for contingency management (e.g., flight termination)
- Hazards that pose harm to any person
  - Loss of or inadequate structural integrity, especially of the rotor system (that could lead to release of high energy parts)
- Hazards that affect aircraft safety margins and functional capabilities
  - Failure to stay within authorized operational area

Airworthiness Standards

- Examined Part 27 conventional helicopter airworthiness standards
  - 43% were not applicable
  - 26% were “rolled up” into less restrictive requirements
  - 31% essentially kept as-is



- Proposed new requirements for UAS-unique characteristics
  - Example: Command and Control (C2) link
  - “The C2 link shall … be available in all vehicle attitudes under all foreseeable operating conditions throughout the containment volume…”



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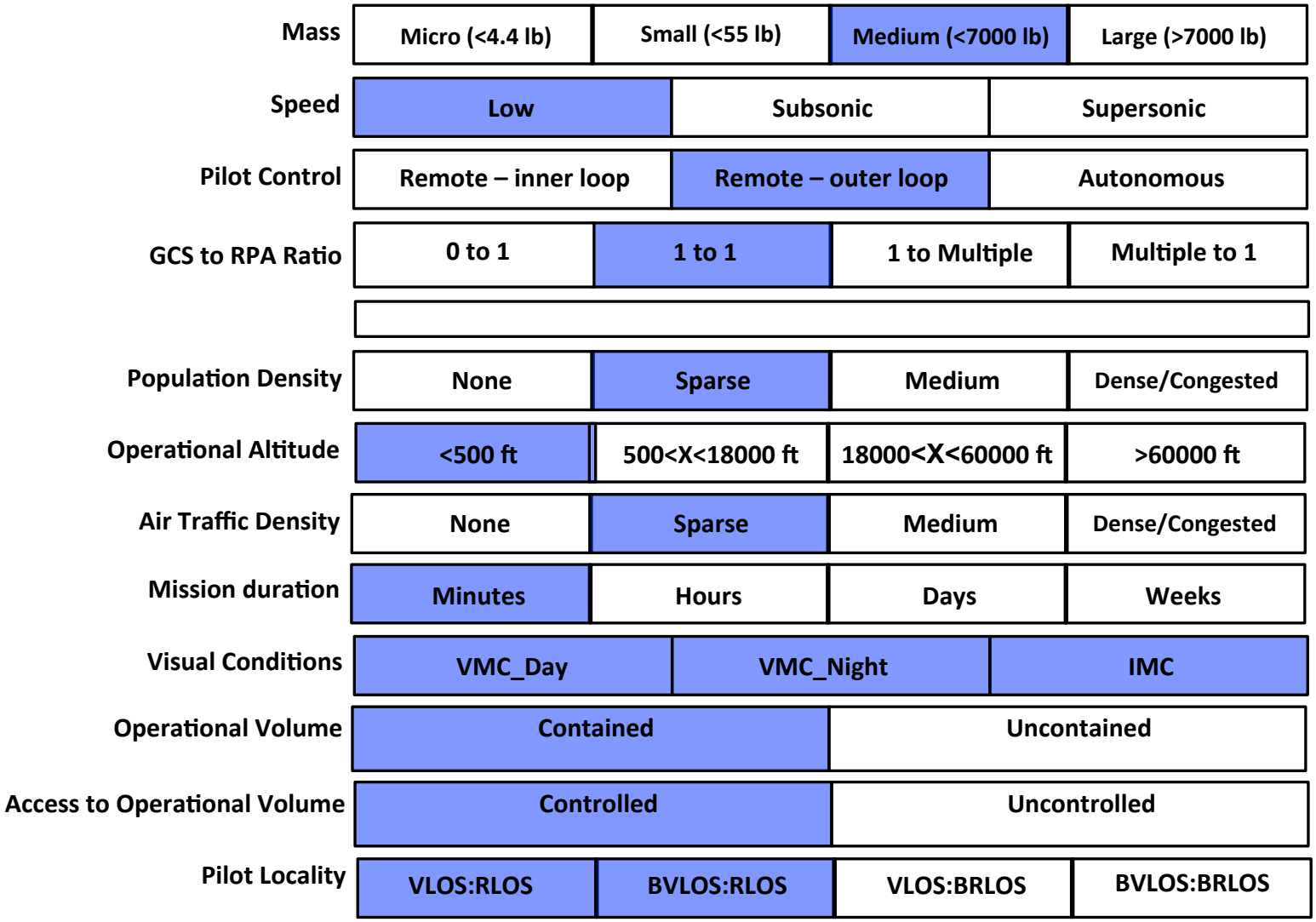
Factors Relevant to Risk

- Which characteristics of the vehicle and operation most relate to hazards and risks?
- Example vehicle factors:
  - Mass: hazard to people
- Example operational factors
  - Operational Altitude: degradation of safety margin
  - Pilot locality: interference with crew safety role
- Preliminary work…

Factor Analysis for Spray Application



Factor Analysis for Applications

Agricultural Spraying Application

Mass	Micro (<4.4 lb)	Small (<55 lb)	**Medium (<7000 lb)**	Large (>7000 lb)
Speed	**Low**	Subsonic	Supersonic	
Pilot Control	Remote – inner loop	**Remote – outer loop**	Autonomous	
GCS to RPA Ratio	0 to 1	**1 to 1**	1 to Multiple	Multiple to 1
Population Density	None	**Sparse**	Medium	Dense/Congested
Operational Altitude	**<500 ft**	500<X<18000 ft	18000<X<60000 ft	>60000 ft
Air Traffic Density	None	**Sparse**	Medium	Dense/Congested
Mission duration	**Minutes**	Hours	Days	Weeks
Visual Conditions	**VMC_Day**	**VMC_Night**	**IMC**	
Operational Volume	**Contained**	Uncontained		
Access to Operational Volume	**Controlled**	Uncontrolled		
Pilot Locality	**VLOS:RLOS**	**BVLOS:RLOS**	VLOS:BRLOS	BVLOS:BRLOS

Rural Package Delivery through Corridors

	Micro (<4.4 lb)	Small (<55 lb)	**Medium (<7000 lb)**	Large (>7000 lb)
	Low	Subsonic	Supersonic	
	Remote – inner loop	**Remote – outer loop**	Autonomous	
	0 to 1	**1 to 1**	1 to Multiple	Multiple to 1
	None	**Sparse**	Medium	Dense/Congested
	<500 ft	500<X<18000 ft	18000<X<60000 ft	>60000 ft
	None	**Sparse**	Medium	Dense/Congested
	Minutes	**Hours**	Days	Weeks
	VMC_Day	**VMC_Night**	**IMC**	
	Contained	Uncontained		
	Controlled	**Uncontrolled**		
	VLOS:RLOS	**BVLOS:RLOS**	**VLOS:BRLOS**	BVLOS:BRLOS

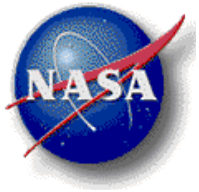
Merged Factor Analysis

Mass	Micro (<4.4 lb)	Small (<55 lb)	Medium (<7000 lb)	Large (>7000 lb)
Speed	Low	Subsonic	Supersonic	
Pilot Control	Remote – inner loop	Remote – outer loop	Autonomous	
GCS to RPA Ratio	0 to 1	1 to 1	1 to Multiple	Multiple to 1
Population Density	None	Sparse	Medium	Dense/Congested
Operational Altitude	<500 ft	500<X<18000 ft	18000<X<60000 ft	>60000 ft
Air Traffic Density	None	Sparse	Medium	Dense/Congested
Mission duration	Minutes	Hours	Days	Weeks
Visual Conditions	VMC_Day	VMC_Night	IMC	
Operational Volume	Contained	Uncontained		
Access to Operational Volume	Controlled	Uncontrolled		
Pilot Locality	VLOS:RLOS	BVLOS:RLOS	VLOS:BRLOS	BVLOS:BRLOS

Factor Value for Precision Agriculture Operation

Factor Value for Corridor Operation

Factor Value Shared by Both Operations



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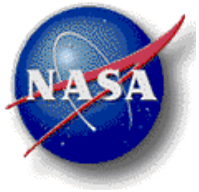

Conclusions

- Current airworthiness certification processes, with tailoring, can be used
  - Significant modifications are needed to individual Part 27 regulations
- Hazard analysis approach enables risk-based certification
  - Should not pose undue burden while maintaining safety (under regulation)
  - Points towards performance-based standards
- Future work:
  - validation, assurance requirements, autonomy

Questions?

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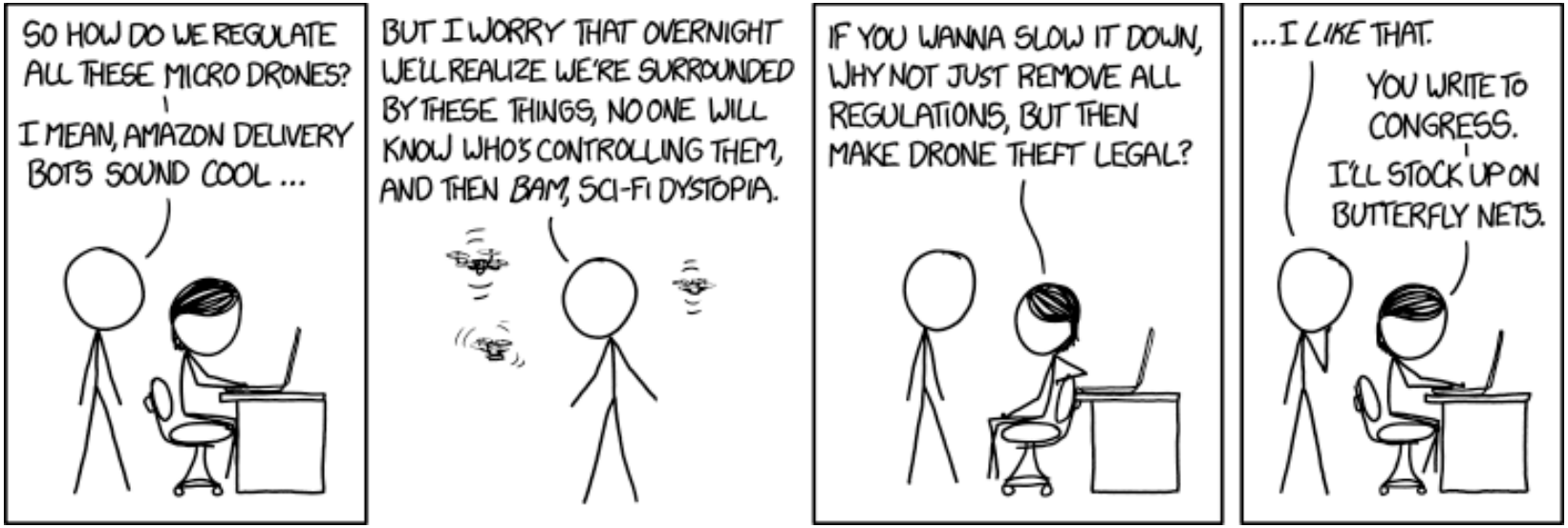

Oh, weird, Amazon is out of butterfly nets…

https://xkcd.com/1523/