CONVERGENT AERONAUTICS SOLUTIONS

Manned Versus Unmanned Risk and Complexity Considerations for Future Midsized X-planes

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Outline

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Purpose

- Objective: Improve complexity, risk and cost understanding between piloted and unmanned X-planes

- Identify differences and similarities between vehicle types

- Shape and guide development of future X-plane requirements

Introduction

- **Qualitative and Quantitative**
- **Expert group evaluations from a diverse set of pilots, unmanned vehicle pilots, operational engineers, flight test engineers, and other experts with over 400 years experience.**
- **3 complexity topic categories**
- **3 risk topic categories**
- **About 50 topics**
- **Created a simplified rating system using "Complexity" and "Risk"**
  - Complexity ≈ Schedule + Cost
  - Risk ≈ Crew + Mission
- **Did not use time weighting due to the results of first order analysis being negligible**

Background: X-plane Specifications

♦ Generalized Research Goals and Issues

- Understand full-scale dynamics, handling qualities, and pilot workload impacts
- Boundary layer ingestion (BLI) propulsion system performance
- Low-speed stability and control performance
- Noise, acoustics analysis validation (engine shielding and airframe noise)
- Flight controls for tailless vehicles
- Unique pressurization geometries
- Efficient transonic performance
- Quantifiable structural efficiency gains

♦ General Configuration Description

- Scale: 40% to 65%
- Wingspan: 55 to 75 ft.
- Empty weight: 14,000 lbs. to 40,000 lbs.
- Primary Flight Condition: High subsonic to low transonic
- Altitudes from 20,000 ft. to 35,000 ft.

Background: Assumptions

	Assumption	Manned	RPV	Autonomous
1	No ejection seat will be implemented on the test vehicle	✓	N/A	N/A
2	Generalized evaluation of a medium-sized aircraft configuration	✓	✓	✓
3	Risk to pilot and vehicle were not independently considered	✓	N/A	N/A
4	Vehicle will be statically stable	✓	✓	✓
5	Vehicle will operate subsonic and possibly transonic	✓	✓	✓
6	Vehicle will be flown in the Edwards AFB range	✓	✓	✓
7	Autonomous operation will not be a research objective	✓	✓	✓

Background: Topics

Topic Examples		
Airframe noise (RC)	Flight envelope restrictions (OR)	Mission timeline (OR) (F-TS)
Airframe performance (RC) (DE)	Flight instrumentation and data recording (VR) (VS)	Navigation (VR) (VS)
Airspace availability (VS)	Flight termination system (VR) (VS)	Operations workforce – Physical Danger (OR) (F-TS)
Airworthiness process (OR) (F-TS)	Pilot display instrumentation (VR) (VS)	Operations workforce – Program (OR) (F-TS)
Autopilot/Auto throttle/Auto land (VR) (VS)	Flutter (RC) (DE)	Pilot situational awareness (VS)
Chase aircraft (OR) (F-TS)	Frequency requirements (OR) (F-TS)	Pilot workload quantification (RC)
Cockpit/Ground control station (VR) (VS)	Ground operation (OR)	Power requirements (VR) (VS)
Command and control link (VR) (VS)	Ground tests - Preflight, GVT, etc. (OR) (DE)	Radar (VS)
Control law development (RC) (DE)	Ground tests - Taxi, etc. (OR) (F-TS)	Radio communication (VR) (VS)
Egress (VR) (VS)	Instrumentation ground testing (F-TS)	Sense and avoid - airspace availability (VR)

Qualitative Analysis Results

- **Interviews and data that identified supporting reasoning and challenges for each of the piloted, remotely piloted and UAS vehicles.**
- **Piloted**
  - **In support**
    - Vehicle operations are familiar, practiced, and tend not to increase flight test complexity.
  - **Challenges**
    - Although challenges that were identified affect flight-testing, eliminating each item was not expected to greatly reduce the overall complexity (pressurization, egress, etc.),
- **RPV**
  - **In support**
    - Supporting information for remotely piloted vehicles included modeling-to-vehicle software assimilation and enabling control law research.
  - **Challenges**
    - Often requirements involve lost link risk mitigation as well as flight termination system for situations where vehicle control is lost. Stringent uplink and downlink requirements increase complexity in testing (synthetic vision, etc).

Qualitative Analysis Results (Continued)

- ## Autonomous Vehicles
  - **In support**
    - Extended mission timelines and enabling control law research.
  - **Challenges**
    - Implementation of a flight termination system, uplink and downlink testing and air ground testing restrictions,
    - Autonomous vehicles require digital flight control system that greatly increases complexity of development, validation and testing. Mission management identified as lengthy and complex process.

- ## Applicable to all vehicles
  - Requires chase aircraft in envelope expansion phases, which would include all if not most of the flight test program. The chase aircraft requirement can be complex depending on scheduling, availability, and matching capabilities of the test and chase aircraft.

Qualitative Analysis Insights

- **Unmanned vehicle functions have a way of becoming a large part of the test program,**
  - Which would likely distract from the fundamental flight experiment and/or increase costs,
  - CAS X-planes focused on flight physics, *not* autonomy demonstrations.

- **All of the vehicles under consideration were heavy and large, not "expendable" like smaller unmanned vehicles.**
  - Meaning risk avoidance approach is similar as with a crewed vehicles.

- **Unmanned operations at EAFB are strictly constrained.**

- **RPV and Autonomous vehicles General Result Increased complexity and risk.**

Quantitative Analysis

Rating Value	Topic Rating Criteria (Technical, Schedule, Cost)
5	Very complex topic that was technical and/or contributed largely to cost and schedule
4	Complex topic that was technical and/or contributed to cost and schedule
3	Moderately complex topic that was somewhat technical and/or contributed to cost and schedule
2	Mildly complex topic that was not very technical nor a considerable contribution to cost and schedule
1	A requirement but not difficult to accomplish
0	Not a requirement or not applicable

Risk and Complexity Themes			
Complexity	Vehicle Requirements (VR) 22 Topics	Research Capability (RC) 9 Topics	Other Requirements (OR) 17 Topics
Risk	Vehicle Subsystems (VS) 20 Topics	Developmental Engineering (DE) 12 Topics	Flight-Test Support (F-TS) 13 Topics

Quantitative Analysis Results

Complexity						
	Manned	%	RPV	%	Autonomous	%
Vehicle Requirements (VR) 22 Topics	27	19.4	52	37.4	60	43.2
Research Capability (RC) 9 Topics	21	23.9	31	35.2	36	40.9
Other Requirements (OR) 17 Topics	36	22.0	62	37.8	66	40.2
Total (48 Topics)	84	**21.5**	145	**37.1**	162	**41.4**

Risk						
	Manned	%	RPV	%	Autonomous	%
Vehicle Subsystems (VS) 20 Topics	27	19.7	55	40.1	55	40.1
Developmental Engineering (DE) 12 Topics	22	25.6	28	32.6	36	41.9
Flight-Test Support (F-TS) 13 Topics	23	23.5	35	35.7	40	40.8
Total (45 Topics)	72	**22.4**	118	**36.8**	131	**40.8**

Quantitative Analysis Results

Com[illegible]						
	Manned	%	RPV	%	Autonomous	%
Vehicle Requirements (VR) 22 Topics	[illegible]	19.4	[illegible]	37.4	[illegible]	43.2
Research Capability (RC) 9 Topics	21	23.9	31	35.2	36	40.9
Other Requirements (OR) 17 Topics	36	[illegible]	62	[illegible]	66	[illegible]
Total (48 Topics)	84	**21.5**	145	**37.1**	162	**41.4**

Ri[illegible]						
	Manned	%	RPV	%	Autonomous	%
Vehicle Subsystems (VS) 20 Topics	[illegible]	19.7	[illegible]	40.1	[illegible]	40.1
Developmental Engineering (DE) 12 Topics	22	[illegible]	28	32.6	36	[illegible]
Flight-Test Support (F-TS) 13 Topics	23	[illegible]	35	[illegible]	40	[illegible]
Total (45 Topics)	72	**22.4**	118	**36.8**	131	**40.8**

Quantitative Analysis Results (Continued)

Complexity	Manned	RPV	Autonomous	Total	St Dev
Line of sight	0	3	2	5	1.25
Flight termination system	0	3	3	6	1.41
Sense and avoid - Pilot SA	1	2	3	6	1.25
Stability and control (VR)	1	1	4	6	1.41
Egress	4	1	1	6	1.41
Mission management	1	2	4	7	1.25
Command and control link	0	4	3	7	1.70
Lost link - Mitigation	0	4	3	7	1.70
Cockpit/Ground control station	1	4	3	8	1.25
Autopilot/Auto throttle/Auto land	1	2	5	8	1.70
Ground operation	1	3	4	8	1.25
Flight control - conventional	1	3	4	8	1.25
Mission planning	1	3	4	8	1.25
Pilot workload quantification	1	3	5	9	1.63
Handling qualities	1	4	5	10	1.70
Simulation - HILS	2	3	5	10	1.25
Envelope expansion	2	4	5	11	1.25
Pilot display instrumentation	2	4	5	11	1.25
Flight envelope restrictions	2	4	5	11	1.25
Operations workforce	2	5	5	12	1.41

Quantitative Analysis Results (Continued)

Risk	Manned	RPV	Autonomous	Result	St Dev
Lost link	1	4	2	7	1.25
Airframe performance	2	1	4	7	1.25
Pilot situational awareness	1	3	4	8	1.25
Command and control link	1	4	3	8	1.25
Cockpit/Ground control station	1	5	3	9	1.63
Autopilot/Auto throttle/Auto land	1	4	4	9	1.41
Airworthiness process	2	3	5	10	1.25
Flight control - Conventional	1	4	5	10	1.70
Handling qualities	1	4	5	10	1.70
Mission Timeline	1	4	5	10	1.70

Range Restrictions

- **EAFB Instruction 113-100 describes flying and airfield operations**
  - Chapter 14 – Unmanned Aircraft System (UAS) Operations (15 pages)

- **5 UAS type definitions segregate vehicles by sense and avoid and deviation capabilities:**
  - 14.4.1. Type 1: UAS has the **ability to conduct sense and avoid to an equivalent level of capability as a manned aircraft** (cooperative and non-cooperative traffic).
  - 14.4.2. Type 2: UAS **able to detect factor traffic (cooperative only) and take appropriate avoidance action in a timely manner** (usually within a few seconds). The detection to action decision loop only involves the UAS and the operator.
  - *14.4.3. Type 3: UAS **able to detect factor traffic (cooperative only), but unable to react in a timely manner (usually within a few seconds).** This delay may be due to detection method (ATC traffic monitoring, Chase aircraft) and/or latency inherent in UAS system (long link delays, complicated command sequences).*
  - 14.4.4. Type 4: **UAS unable to deviate from flight path for traffic avoidance**. ATC may be able to detect the conflict and direct the conflicting traffic to maneuver (ATC transponder required).
  - 14.4.5. Type 5: **UAS unable to deviate from flight path for traffic avoidance and ATC unable to accurately track a UAS to detect traffic conflicts** (no transponder).

Range Restrictions (Continued)

- **Table 14.1 UAS Mitigation Matrix describes requirements and procedures**

BA: Airspace bubble (2k vertical, 5 NM horizontal, CA are exempt)
CA: Chase aircraft
EUA: Exclusive use airspace
FLG: Limited ground footprint
FS: Sanitized ground footprint
LBL: Lakebed landing
LBT: Lakebed takeoff
LE: Landing exclusion zone
SGC: Safety ground chase vehicle
ST: Sanitized taxi route
RC: Road closure
TA: Traffic avoidance
TE: Takeoff exclusion zone

BA is not required for UAS when CA provides see and avoid

TA: UAS pilot depends on ATC active monitoring to detect traffic and advise UAS pilot of all traffic conflicts and recommended avoidance maneuver
FS: ground area actively cleared of all personnel

Table 14.1. UAS Mitigation Matrix

	Type 1	Type 2	Type 3	Type 4	Type 5
Mature		BA	B A T A	B A T A	EUA or BA/C A TA
Provisional	BA	BA	B A T A	B A T A	EUA or BA/C A TA
Experimental	BA FL FT S	BA FL FT S	BA FL FT S GC	BA/C A FL FT S GC	EU A FL FTS GC
Unproven	EUA or BA/CA FS TE/LE/R C or LBT/LBL or RC/CF FTS ST	EUA or BA/CA FS TE/LE/R C or LBT/LBL or RC/CF FTS ST	EUA or BA/CA FS TE/LE/R C or LBT/LBL or RC/CF FTS G C ST	EUA FS TE/LE/R C or LBT/LBL or RC/CF FTS G C ST	EUA FS TE/LE/R C or LBT/LBL or RC/CF FTS G C ST

Note a '/' indicates all listed mitigating factors on that line of the cell are required -- read as 'and'. Each line in the cell indicates additional mitigating factors required.

Global Hawk / Reaper / Predator

X-47 UCAV

X-45

X-48 BWB (130+ flights), X-56 MUTT

Range Restrictions: Takeaways

- The Sense and Avoid capability of the UAS is a risk reduction metric that impacts the airspace management of the test vehicle.
- Unproven vehicle risk reduction takes into consideration the population, workforce, and high value assets.
- Initial flights of unmanned vehicles would likely occur in sanitized airspace on weekend days (Saturday) only.
- Flight test cancellations common due to weather, instrumentation failures, software, early development problems, and many other issues.
- These realities often affect flight test schedules.

Conclusions

- The aircraft studied during were chosen to demonstrate new approaches for transportation flight efficiency.

- Expert group evaluations from a diverse set of pilots, engineers, and other experts to provide a quantitative result that summarizes and supports the qualitative results.

- An EAFB instruction document was identified that, when implemented, mitigates risk by requiring a new or low flight number vehicle to systematically perform sorties and pass numerous review boards during the testing of the vehicle before being granted further operational flexibilities.

- Overall, this study concluded that a manned aircraft option would be expected to suppress complexity and risk.

Questions?

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