U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

April 1, 2015

Exemption No. 11252
Regulatory Docket No. FAA−2014−0763

Mr. Jeffery J. Antonelli
Counsel for Nixon Engineering
Solutions, LLC
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Dear Mr. Antonelli:

This letter is to inform you that we have granted your request for exemption. It transmits our decision, explains its basis, and gives you the conditions and limitations of the exemption, including the date it ends.

The Basis for Our Decision

By letter dated September 24, 2014, you petitioned the Federal Aviation Administration (FAA) on behalf of Nixon Engineering Solutions LLC (hereinafter petitioner or operator) for an exemption. The exemption would allow the petitioner to operate an unmanned aircraft system (UAS) to conduct aerial inspection and photogrammetry services for the mining, oil, and gas industry.

See Appendix A for the petition submitted to the FAA describing the proposed operations and the regulations that the petitioner seeks an exemption.

Discussion of Public Comments:

A summary of the petition was published in the Federal Register on October 17, 2014, (79 FR 62508). Three comments were received. The Small UAV Coalition (Coalition) supported the petition, while the Air Line Pilots Association, International (ALPA) and the National Agricultural Aviation Association (NAAA) opposed it.

In support of the petition, the Coalition stated the petitioner has proposed to abide by stronger safety measures than hobby and modeler groups operating similar aircraft. The Coalition stated that it does not believe that heightened safety measures should be required for the petitioner simply because of the commercial nature of its operations. The Coalition urged the FAA to adopt an evaluation framework for UAS operations under Section 333 of Public Law 112–95 that weighs the relative safety issues and risks of UAS by class and operational circumstances, rather than adopting artificial distinctions among unmanned aerial vehicles based on commercial and noncommercial operations. The petitioner's UAS pose considerably less safety risk than larger UAS. The Coalition asserted that because UAS operations like the petitioner's pose minimal risk to safety, they should be subject to minimal and appropriate regulations.

The Coalition noted the FAA is to consider the seven factors[1] in Section 333 as a minimum. The Coalition stated the petition shows the FAA should consider factors other than those specified in Section 333, such as location, altitude of its UAS, restricted operating areas, proven experience of the sUAS in other countries, and pilot experience. The Coalition maintained that the petitioner's proposed operations satisfy the seven factors in Section 333 and include several additional mitigating factors to ensure the safety and security of the proposed UAS operations. The Coalition emphasized the FAA must evaluate each factor within the context of the petitioner's proposed UAS operations.

The Coalition also commented that the FAA should grant relief from the requirement to hold an airman's certificate. The Coalition further stated that if an airman certificate is required then, at a minimum the, FAA should provide an exception from the training and testing requirements in part 61 in favor of requirements pertinent to the aircraft and operation proposed. The Coalition also asserted that in section 333 Congress intended for the FAA to consider national security with respect to the operation as opposed to addressing it through pilot certification.

The FAA notes that, as discussed in the grant of exemption to Trimble Navigation Ltd. (Exemption No. 11110), neither section 333, nor the FAA's exemption authority[2] allows the FAA to exempt pilots from the statutory requirement to hold an airman certificate as prescribed in 49 USC § 44711.

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[1] Section 333(b) of P.L. 112-95 states, in part: "In making the determination under subsection (a), the Secretary shall determine, at a minimum-- (1) which types of unmanned aircraft systems, if any, as a result of their size, weight, speed, operational capability, proximity to airports and populated areas, and operation within visual line of sight do not create a hazard to users of the national airspace system or the public or pose a threat to national security; …"

[2] 49 USC § 44701(f)

The Coalition commented that a visual observer (VO) should not be required for all small UAS operations. The Coalition further asserted that the presence of one or more VOs may allow the UAS to be operated beyond VLOS of the PIC.

The FAA notes that one of the determinations for operations under section 333 is operation within visual line of sight. The PIC must maintain VLOS while operating the UA. The FAA finds that a VO complements the PIC's capability to see and avoid other aircraft, including when the PIC may be momentarily attending to other flying tasks. The VO provides an additional level of operational safety.

ALPA expressed concern regarding several aspects of the petition. ALPA noted the petitioner does not detail procedures for controlling the airspace or area of operation. Specifically, ALPA stated "there must be means both to ensure that the sUAS remains within the defined airspace and to ensure that the hazard of other aircraft intruding on the operation is mitigated." The FAA believes the limitations under which the petitioner will operate (i.e., VLOS and at or below 400 feet AGL) are sufficient mitigations to this risk so that the operations will not adversely affect safety.

Regarding the petitioner's statement that the PIC and observer will be able to communicate by voice or text, ALPA noted that text messaging could have an unknown latency and extend to several minutes. ALPA also stated voice communication with the pilot is a limited mitigation if both the pilot and observer are not able to maintain a visual observation of both the aircraft and the area. NAAA stated UAS observers must be present and able to communicate with the operator from the most minimal distance possible. The conditions and limitations regarding PIC and VO communications address those concerns.

ALPA asserted the UAS's lithium polymer batteries have numerous associated fire and explosion hazards as outlined in DOT/FAA/AR−09/55, "Flammability Assessment of Lithium-Ion and Lithium-Ion Polymer Battery Cell Designed for Aircraft Power Usage (January 2010)," and that the safe carriage of the batteries and the mitigations in place for known risks should be addressed. The referenced study was primarily conducted to determine how certain battery cells react in a fire situation aboard manned airplanes. Given the size of the battery and the operating conditions of the UAS, the FAA concludes that the use of a lithium polymer battery will not pose an undue safety risk for the proposed operations.

ALPA commented that command and control (C2) link failures are one of the most common failures on a UAS, and that lost link mitigations should require safe modes to prevent fly-aways or other scenarios. The FAA has inserted conditions and limitations in this exemption to mitigate the risk associated with such failures.

ALPA also noted that the petitioner's proposed operations are for "compensation or hire," and therefore contends the pilot must hold at least a current FAA commercial pilot certificate with an appropriate category and class rating for the type of aircraft being flown, as well as specific and adequate training on the UAS make and model intended to be used. Similarly, ALPA asserted a current second-class airman medical certificate should be required. NAAA also commented on pilot qualification, stating—

> Just as manned aircraft pilots are required to undergo a rigorous training curriculum and show that they are fit to operate a commercial aircraft, so too must UAS operators. Holding a commercial certificate holds UAS operators to similar high standards as commercial aircraft operators and ensures they are aware of their responsibilities as commercial operators within the NAS. Medical requirements ensure they have the necessary visual and mental acuity to operate a commercial aircraft repeatedly over a sustained period of time.

The FAA has reviewed the knowledge and training requirements of sport, recreational, private and commercial certificates and concluded that a UAS PIC holding a minimum of a sport pilot certificate, and operating under this exemption, would not adversely affect operations in the NAS or present a hazard to persons or property on the ground..

Regarding the petitioner's request for exemption from § 91.113, ALPA noted the petitioner must specify a means to meet see and avoid requirements in § 91.113 given the absence of an onboard pilot. The FAA notes that all flights must be operated within VLOS of the PIC and VO.

In response to the petitioner's request for exemption from the minimum safe altitude requirements of § 91.119, ALPA stated all aircraft in the NAS must operate to the same high level of safety. ALPA argued this includes maintaining a safe altitude for both airplanes and helicopters.

ALPA commented that the aircraft will not have a barometric altimeter as required by 14 CFR § 91.121. ALPA stated that processes or mitigations must be in place to ensure the UA can accurately maintain altitude including redundant control capability, fail-safe systems, backups and specific, validated procedures for system and equipment failures must be in place. The FAA agrees with ALPA and addresses this concern in its analysis of the exemption from 14 CFR § 91.121, finding that the alternative means of compliance proposed by the petitioner does not adversely affect safety.

Regarding the fuel requirements of § 91.151, ALPA argued that using batteries as the only source of an aircraft's power is a substantial shift from traditional methods of propulsion, and requires further research to determine best safety practices.

ALPA also expressed concern that the petition makes no reference to compliance with, or a request for waiver from, 14 CFR 61.195, Flight instructor limitations and qualifications, which defines the requirements for flight instructors. A certificated flight instructor is authorized to provide the instruction required for the certificates or ratings or currency listed in 14 CFR § 61.193. A person instructing on how to operate the UAS under the petitioner's training program would not need to be a certificated flight instructor because the instruction is not being provided for a certificate or rating listed in § 61.193. We note that none of the UAS operations proposed by the petitioner require such flight instruction because § 61.31(l) allows for operation of the UAS by an airman who is current per 14 CFR § 61.56 without a category and class rating. Instruction provided toward obtaining the pilot certificate required by this exemption would need to be provided by a certificated flight instructor.

ALPA opposed the request for exemption from the transponder requirements of § 91.215. ALPA stated relief from the requirements is already available in § 91.215(d)(3), and noted they object to sUAS not meeting certification and equipage standards.

ALPA expressed concern on whether the petitioner's UAS can comply with the aircraft light requirements for night operations in § 91.209, given its limited electric power. This exemption limits operations to daytime only.

Regarding §§ 91.405(a), 91.407(a)(1), 91.409(a)(2), and 91.417(a) and (b), ALPA opposed the petitioner's attempt to avoid compliance with established aircraft maintenance and recordkeeping requirements. ALPA states the UAS should comply with the same level of safety as other aircraft operated commercially in the NAS. The FAA finds that adherence to the petitioner's operating documents, as required by the conditions and limitations below, is sufficient to ensure that safety is not adversely affected.

ALPA also expressed concern that the petitioner's request is not for a single specific operation or location, but for all operations of the same general type. ALPA stated that this results in a considerable increase in the FAA's oversight tasks. The FAA notes ALPAs concern and in order to minimize potential impact to the NAS, the FAA that requires each operator secure a Certificate of Authorization or COA which covers specific details of the petitioners operation. The FAA recognizes that UAS integration will generate new NAS access demand and will review and adjust accordingly.

NAAA noted that its members operate in low-level airspace, and therefore clear low-level airspace is vital to the safety of these operators. NAAA stated that seeing and avoiding other aircraft and hazardous obstructions is the backbone for agricultural safety, and that agricultural pilots depend on pilots of other aircraft to perform their see-and-avoid functions to prevent collisions. NAAA believes UAS operations at low altitudes will increase the potential for collision with agricultural aircraft.

The FAA recognizes these concerns and has incorporated associated conditions and limitations into this exemption, including: (a) a Notice to Airmen (NOTAM) issued for all operations; (b) operations conducted within VLOS of the pilot in command (PIC) and the VO; and (c) the UAS PIC must always yield right-of-way to manned aircraft.

NAAA stated that FAA airworthiness certification should be a requirement for all unmanned aircraft to operate within the NAS. NAAA recommended UAS be equipped with ADS-B or similar identification and positioning systems, strobe lights, high-visibility markings and registration numbers. NAAA also recommended UAS be operated strictly within the line-of-sight of the ground controller, with the assistance of a VO and clear of any low-flying manned aircraft.

As discussed in greater detail below, Section 333 of the FAA Modernization and Reform Act of 2012 authorizes the Secretary of Transportation to determine, considering a number of factors laid out in the statute, that an airworthiness certificate is not necessary for certain operations. The Secretary has made that determination in this case and therefore the aircraft operated by the petitioner will not need to be certificated by the FAA.

Airworthiness Certification

The UAS proposed by the petitioner is a DJI S800 EVO.

The petitioner requested relief from 14 CFR part 21, C*ertification procedures for products and parts, Subpart H—Airworthiness Certificates*. In accordance with the statutory criteria provided in Section 333 of Public Law 112−95 in reference to 49 U.S.C. § 44704, and in consideration of the size, weight, speed, and limited operating area associated with the aircraft and its operation, the Secretary of Transportation has determined that this aircraft meets the conditions of Section 333. Therefore, the FAA finds that the requested relief from 14 CFR part 21, and any associated noise certification and testing requirements of part 36, is not necessary.

The Basis for Our Decision

You have requested to use a UAS for aerial data collection. The FAA has issued grants of exemption in circumstances similar in all material respects to those presented in your petition. In Grants of Exemption Nos. 11062 to Astraeus Aerial (*see* Docket No. FAA−2014−0352), 11109 to Clayco, Inc. (*see* Docket No. FAA−2014−0507), 11112 to VDOS Global, LLC (*see* Docket No. FAA−2014−0382), and 11213 to Aeryon Labs, Inc. (*see* Docket No. FAA−2014−0642), the FAA found that the enhanced safety achieved using an unmanned aircraft (UA) with the specifications described by the petitioner and carrying no passengers or crew, rather than a manned aircraft of significantly greater proportions, carrying crew in addition to flammable fuel, gives the FAA good cause to find that the UAS operation enabled by this exemption is in the public interest.

Having reviewed your reasons for requesting an exemption, I find that—

- They are similar in all material respects to relief previously requested in Grant of Exemption Nos. 11062, 11109, 11112, and 11213;

- The reasons stated by the FAA for granting Exemption Nos. 11062, 11109, 11112, and 11213 also apply to the situation you present; and
- A grant of exemption is in the public interest.

Our Decision

In consideration of the foregoing, I find that a grant of exemption is in the public interest. Therefore, pursuant to the authority contained in 49 U.S.C. 106(f), 40113, and 44701, delegated to me by the Administrator, Nixon Engineering Solutions, LLC is granted an exemption from 14 CFR §§ 61.23(a) and (c), 61.101(e)(4) and (5), 61.113(a), 61.315(a), 91.7(a), 91.119(c), 91.121, 91.151(a)(1), 91.405(a), 91.407(a)(1), 91.409(a)(1) and (2), and 91.417(a) and (b), to the extent necessary to allow the petitioner to operate a UAS to perform aerial data collection. This exemption is subject to the conditions and limitations listed below.

Conditions and Limitations

In this grant of exemption, Nixon Engineering Solutions, LLC is hereafter referred to as the operator.

Failure to comply with any of the conditions and limitations of this grant of exemption will be grounds for the immediate suspension or rescission of this exemption.

1. Operations authorized by this grant of exemption are limited to the DJI S800 EVO when weighing less than 55 pounds including payload. Proposed operations of any other aircraft will require a new petition or a petition to amend this exemption.

2. Operations for the purpose of closed-set motion picture and television filming are not permitted.

3. The UA may not be operated at a speed exceeding 87 knots (100 miles per hour). The exemption holder may use either groundspeed or calibrated airspeed to determine compliance with the 87 knot speed restriction. In no case will the UA be operated at airspeeds greater than the maximum UA operating airspeed recommended by the aircraft manufacturer.

4. The UA must be operated at an altitude of no more than 400 feet above ground level (AGL). Altitude must be reported in feet AGL.

5. The UA must be operated within visual line of sight (VLOS) of the PIC at all times. This requires the PIC to be able to use human vision unaided by any device other than corrective lenses, as specified on the PIC's FAA-issued airman medical certificate or U.S. driver's license.

6. All operations must utilize a visual observer (VO). The UA must be operated within the visual line of sight (VLOS) of the PIC and VO at all times. The VO may be used to satisfy the VLOS requirement as long as the PIC always maintains VLOS capability. The VO and PIC must be able to communicate verbally at all times; electronic messaging or texting is not permitted during flight operations. The PIC must be designated before the flight and cannot transfer his or her designation for the duration of the flight. The PIC must ensure that the VO can perform the duties required of the VO.

7. This exemption and all documents needed to operate the UAS and conduct its operations in accordance with the conditions and limitations stated in this grant of exemption, are hereinafter referred to as the operating documents. The operating documents must be accessible during UAS operations and made available to the Administrator upon request. If a discrepancy exists between the conditions and limitations in this exemption and the procedures outlined in the operating documents, the conditions and limitations herein take precedence and must be followed. Otherwise, the operator must follow the procedures as outlined in its operating documents. The operator may update or revise its operating documents. It is the operator's responsibility to track such revisions and present updated and revised documents to the Administrator or any law enforcement official upon request. The operator must also present updated and revised documents if it petitions for extension or amendment to this grant of exemption. If the operator determines that any update or revision would affect the basis upon which the FAA granted this exemption, then the operator must petition for an amendment to its grant of exemption. The FAA's UAS Integration Office (AFS-80) may be contacted if questions arise regarding updates or revisions to the operating documents.

8. Any UAS that has undergone maintenance or alterations that affect the UAS operation or flight characteristics, e.g. replacement of a flight critical component, must undergo a functional test flight prior to conducting further operations under this exemption. Functional test flights may only be conducted by a PIC with a VO and must remain at least 500 feet from other people. The functional test flight must be conducted in such a manner so as to not pose an undue hazard to persons and property.

9. The operator is responsible for maintaining and inspecting the UAS to ensure that it is in a condition for safe operation.

10. Prior to each flight, the PIC must conduct a pre-flight inspection and determine the UAS is in a condition for safe flight. The pre-flight inspection must account for all potential discrepancies, e.g. inoperable components, items, or equipment. If the inspection reveals a condition that affects the safe operation of the UAS, the aircraft is prohibited from operating until the necessary maintenance has been performed and the UAS is found to be in a condition for safe flight.

11. The operator must follow the UAS manufacturer's maintenance, overhaul, replacement, inspection, and life limit requirements for the aircraft and aircraft components.

12. Each UAS operated under this exemption must comply with all manufacturer safety bulletins.

13. Under this grant of exemption, a PIC must hold either an airline transport, commercial, private, recreational, or sport pilot certificate. The PIC must also hold a current FAA airman medical certificate or a valid U.S. driver's license issued by a state, the District of Colombia, Puerto Rico, a territory, a possession, or the Federal government. The PIC must also meet the flight review requirements specified in 14 CFR § 61.56 in an aircraft in which the PIC is rated on his or her pilot certificate.

14. The operator may not permit any PIC to operate unless the PIC demonstrates the ability to safely operate the UAS in a manner consistent with how the UAS will be operated under this exemption, including evasive and emergency maneuvers and maintaining appropriate distances from persons, vessels, vehicles and structures. PIC qualification flight hours and currency must be logged in a manner consistent with 14 CFR § 61.51(b). Flights for the purposes of training the operator's PICs and VOs (training, proficiency, and experience-building) and determining the PIC's ability to safely operate the UAS in a manner consistent with how the UAS will be operated under this exemption are permitted under the terms of this exemption. However, training operations may only be conducted during dedicated training sessions. During training, proficiency, and experience-building flights, all persons not essential for flight operations are considered nonparticipants, and the PIC must operate the UA with appropriate distance from nonparticipants in accordance with 14 CFR § 91.119.

15. UAS operations may not be conducted during night, as defined in 14 CFR § 1.1. All operations must be conducted under visual meteorological conditions (VMC). Flights under special visual flight rules (SVFR) are not authorized.

16. The UA may not operate within 5 nautical miles of an airport reference point (ARP) as denoted in the current FAA Airport/Facility Directory (AFD) or for airports not denoted with an ARP, the center of the airport symbol as denoted on the current FAA-published aeronautical chart, unless a letter of agreement with that airport's management is obtained or otherwise permitted by a COA issued to the exemption holder. The letter of agreement with the airport management must be made available to the Administrator or any law enforcement official upon request.

17. The UA may not be operated less than 500 feet below or less than 2,000 feet horizontally from a cloud or when visibility is less than 3 statute miles from the PIC.

18. If the UAS loses communications or loses its GPS signal, the UA must return to a pre-determined location within the private or controlled-access property.

19. The PIC must abort the flight in the event of unpredicted obstacles or emergencies.

20. The PIC is prohibited from beginning a flight unless (considering wind and forecast weather conditions) there is enough available power for the UA to conduct the intended operation and to operate after that for at least five minutes or with the reserve power recommended by the manufacturer if greater.

21. Air Traffic Organization (ATO) Certificate of Waiver or Authorization (COA). All operations shall be conducted in accordance with an ATO-issued COA. The exemption holder may apply for a new or amended COA if it intends to conduct operations that cannot be conducted under the terms of the attached COA.

22. All aircraft operated in accordance with this exemption must be identified by serial number, registered in accordance with 14 CFR part 47, and have identification (N-Number) markings in accordance with 14 CFR part 45, Subpart C. Markings must be as large as practicable.

23. Documents used by the operator to ensure the safe operation and flight of the UAS and any documents required under 14 CFR §§ 91.9 and 91.203 must be available to the PIC at the Ground Control Station of the UAS any time the aircraft is operating. These documents must be made available to the Administrator or any law enforcement official upon request.

24. The UA must remain clear and give way to all manned aviation operations and activities at all times.

25. The UAS may not be operated by the PIC from any moving device or vehicle.

26. All Flight operations must be conducted at least 500 feet from all nonparticipating persons, vessels, vehicles, and structures unless:
    a. Barriers or structures are present that sufficiently protect nonparticipating persons from the UA and/or debris in the event of an accident. The operator must ensure that nonparticipating persons remain under such protection. If a situation arises where nonparticipating persons leave such protection and are within 500 feet of the UA, flight operations must cease immediately in a manner ensuring the safety of nonparticipating persons; and
    b. The owner/controller of any vessels, vehicles or structures has granted permission for operating closer to those objects and the PIC has made a safety assessment of the risk of operating closer to those objects and determined that it does not present an undue hazard.

The PIC, VO, operator trainees or essential persons are not considered nonparticipating persons under this exemption.

27. All operations shall be conducted over private or controlled-access property with permission from the property owner/controller or authorized representative. Permission from property owner/controller or authorized representative will be obtained for each flight to be conducted.

28. Any incident, accident, or flight operation that transgresses the lateral or vertical boundaries of the operational area as defined by the applicable COA must be reported to the FAA's UAS Integration Office (AFS-80) within 24 hours. Accidents must be reported to the National Transportation Safety Board (NTSB) per instructions contained on the NTSB Web site: www.ntsb.gov.

If this exemption permits operations for the purpose of closed-set motion picture and television filming and production, the following additional conditions and limitations apply.

29. The operator must have a motion picture and television operations manual (MPTOM) as documented in this grant of exemption.

30. At least 3 days before aerial filming, the operator of the UAS affected by this exemption must submit a written Plan of Activities to the local Flight Standards District Office (FSDO) with jurisdiction over the area of proposed filming. The 3-day notification may be waived with the concurrence of the FSDO. The plan of activities must include at least the following:
    a. Dates and times for all flights;
    b. Name and phone number of the operator for the UAS aerial filming conducted under this grant of exemption;
    c. Name and phone number of the person responsible for the on-scene operation of the UAS;
    d. Make, model, and serial or N-Number of UAS to be used;
    e. Name and certificate number of UAS PICs involved in the aerial filming;
    f. A statement that the operator has obtained permission from property owners and/or local officials to conduct the filming production event; the list of those who gave permission must be made available to the inspector upon request;
    g. Signature of exemption holder or representative; and
    h. A description of the flight activity, including maps or diagrams of any area, city, town, county, and/or state over which filming will be conducted and the altitudes essential to accomplish the operation.

31. Flight operations may be conducted closer than 500 feet from participating persons consenting to be involved and necessary for the filming production, as specified in the exemption holder's MPTOM.

Unless otherwise specified in this grant of exemption, the UAS, the UAS PIC, and the UAS operations must comply with all applicable parts of 14 CFR including, but not limited to, parts 45, 47, 61, and 91.

This exemption terminates on April 30, 2017, unless sooner superseded or rescinded.

Sincerely,

/s/
John S. Duncan
Director, Flight Standards Service

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U.S. Department of Transportation
Docket Management System
1200 New Jersey Ave S.E.
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September 24, 2014

Re: Request for Exemption under Section 333 of the FAA Reform and Remodernization Act of 2012 and Part 11 of the Federal Aviation Regulations from 14 C.F.R 21(h); 14 C.F.R. 43.7; 14 C.F.R. 43.11; 14 C.F.R. 45.11; 14 C.F.R. 45.21; 14 C.F.R. 45.23; 14 C.F.R. 45.25; 14 C.F.R. 45.27; 14 C.F.R. 45.29; 14 C.F.R. 47.3(b)(2); 14 C.F.R. 47.31(c); 14 C.F.R. 61.113; 14 C.F.R. 91.7(a); 14 C.F.R. 91.9(b)(2); 14 C.F.R. 91.9(c); 14 C.F.R. 91.103(b)(2); 14 C.F.R. 91.105; 14 C.F.R. 91.109; 14 C.F.R. 91.113(b); 14 C.F.R. 91.115; 14 C.F.R. 91.119(b)(c); 14 C.F.R. 91.121; 14 C.F.R. 91.151; 14 C.F.R. 91.203(a) and (b); 14 C.F.R. 215; 14 C.F.R. 91.403; 14 C.F.R. 91.405; 14 C.F.R. 91.407; 14 C.F.R. 409; and 14 C.F.R. 91.417.

Dear Sir or Madam:

Pursuant to Section 333 of the FAA Modernization and Reform Act of 2012 (the Reform Act) and 14 C.F.R. Part 11, Antonelli Law on behalf of Nixon Engineering Solutions, LLC, an operator of Small Unmanned Aircraft Systems ("sUAS") equipped to conduct aerial inspection and photogrammetry services for the mining and oil and gas industry, hereby applies for an exemption from the listed Federal Aviation Regulations ("FARs") to allow commercial operation of its sUASs, so long as such operations are conducted within and under the conditions outlined herein or as may be established by the FAA as required by Section 333. The intended use of the sUAS operations contemplated by this petition is in the public interest because it clearly satisfies the "Four D's" of exemplary uses of UAS: to replace work that is Dangerous, Difficult, Dull, or Dirty, and at the same time provides an equivalent or greater level of safety than approved manned aircraft operations.

For your ease in reviewing this petition please refer to the table of contents which begins on the next page. If we can provide any additional information to assist your understanding or review of this document, please do not hesitate to contact us at 312-201-8310 or via email at Jeffrey@Antonelli-Law.com.

Thank you,

Jeffrey J. Antonelli

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Table of Contents

Exhibit List

I. Publishable Summary

Pursuant to 14 C.F.R. Part 11, the following summary is provided for publication in the Federal Register, should it be determined that publication is needed:

Applicant seeks an exemption from the following rules:

14 C.F.R 21(h); 14 C.F.R. 43.7; 14 C.F.R. 43.11; 14 C.F.R. 45.11; 14 C.F.R. 45.21; 14 C.F.R. 45.23; 14 C.F.R. 45.25; 14 C.F.R. 45.27; 14 C.F.R. 45.29; 14 C.F.R. 47.3(b)(2); 14 C.F.R. 47.31(c); 14 C.F.R. 61.113; 14 C.F.R. 91.7(a); 14 C.F.R. 91.9(b)(2); 14 C.F.R. 91.9(c); 14 C.F.R. 91.103(b)(2); 14 C.F.R. 91.105; 14 C.F.R. 91.109; 14 C.F.R. 91.113(b); 14 C.F.R. 91.115; 14 C.F.R. 91.119(b)(c); 14 C.F.R. 91.121; 14 C.F.R. 91.151; 14 C.F.R. 91.203(a) and (b); 14 C.F.R. 215; 14 C.F.R. 91.403; 14 C.F.R. 91.405; 14 C.F.R. 91.407; 14 C.F.R. 409; and 14 C.F.R. 91.417 to operate commercially a small unmanned aircraft system (sUAS) (15lbs or less).

Approval of exemptions for Nixon Engineering will allow commercial operations of sUASs in the open mine and natural gas well pad inspection industry, enhancing safety by removing the risk of physical harm to surveyors otherwise exposed to dangerous coal piles and heavy equipment in the mine, and dangerous SO2 gases at the well heads. Current inspection operations involve having two men spend several hours inspecting each location in dangerous conditions with the risk of sliding down steep coal piles, inhaling dangerous chemicals, spontaneous fires, and heat related injuries when the temperature in the sites can reach over 100ºF in the summer months. In contrast, a sUAS weighing fewer than 15lbs. and powered by batteries eliminates virtually all of that risk to the two men involved.

The operation of small UASs, weighting less than 15lbs., conducted in the strict conditions outlined below, will provide an equivalent level of safety supporting the grant of the exemptions requested herein, including exempting the applicant from the requirements of Part 21 and allowing commercial operations. These lightweight aircraft operate at slow speeds, close to the ground, and in a low risk, low population environment and, as a result, are far safer than conventional operations conducted with helicopters and fixed-wing aircraft operating in close proximity to the ground and people. The intended use of the sUAS operations contemplated by this petition is in the public interest because it clearly satisfies the "Four D's" of exemplary uses of UAS: to replace work by humans that is Dangerous, Difficult, Dull, and Dirty, and at the same time provides an equivalent or greater level of safety.

Finally, the petitioner requests exemption from the requirement of the PIC possessing a private or commercial pilot's license. Research studies cited by petitioner, sponsored by the FAA and Army Research Laboratory, demonstrate that UAS, even those much larger than the sUAS proposed by Nixon Engineering Solutions LLC, can be safely flown by non-certificated pilots with a small amount of training. However, in the alternative, petitioner requests that if the agency concludes the PIC qualifications proposed in this exemption request do not meet the interim standards it is implementing, it should not deny the application on that ground. Rather, it should grant the exemption subject to Nixon Engineering Solutions LLC meeting whatever interim PIC qualifications the agency has adopted in other Section 333 exemption proceedings, for example the PIC qualification policies established in any of the pending exemption petitions of NextEra Energy, Inc., Oceaneering International, Inc., or Aeryon Labs, Inc.

II. Petitioner's Contact Information

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III. Nixon Engineering Solutions LLC's Operations

A. The sUAS

The requested exemption will permit the operation of small, unmanned multirotor aircraft based on the DJI S800, weighing less than fifteen (15) pounds (inclusive of batteries and technical payload). This rotorcraft operates at a speed of no more than thirty (30) knots and has the capability to hover and move in the vertical and horizontal planes simultaneously.

The sUAS will have the following specifications or equivalent:

Airframe: DJI S800 EVO
Control System: A2
Tx: Futaba 14 SG
Rx: Internal in A2
Motors: DJI 4114
Propellers: Tiger RC 15" Carbon Fiber
Data Link: DJI 2.4 Ghz Data Link
OSD: iOSD Mark II
Gimbal: Zenmuse
Camera: Sony Nex7
Batteries: Glacier from RC Buddy (6000mA 6-cell with EC5 main power connection)

Please refer to Exhibits 3-7, attached to this petition, for further information about the S800 EVO and the A2 control system.

B. Flight conditions

The sUAS will be flown in airspace under 400 feet above ground level ("AGL") and under controlled conditions on restricted, rural, private property. The sUAS will be used to monitor two different types of sites, open pit mines and natural gas well pads.

1. Open Mines

Nixon Engineering Solutions LLC proposes exemption under Section 333 to operate commercially in private, secured-entry open mining operations, including but not limited to, Dolet Hills Lignite Mine in Desoto Parish, Louisiana, and Oxbow Mine in the adjacent Red River Parish. Both mines are privately owned and in extremely rural parishes (a "parish" is Louisiana's equivalent to a county). The surrounding area's primary land use is timber farming, pasture land, and farming. They are between four and ten miles to uncontrolled runways, and are both in class G airspace. Both properties are fenced off and have manned and secured gates which restrict public access.

Nixon Engineering Solutions LLC intends to operate in other, similarly rural areas in the United States, if permitted. Any open mine operations will be guarded and restricted to rural locations in Class G airspace and at least four miles from any controlled and uncontrolled runways, to protect the public from hazardous conditions.

2. Natural Gas Well Pads

Nixon Engineering Solutions LLC proposes exemption under Section 333 to operate commercially at private natural gas well pads including but not limited to the Haynesville Shale Natural Gas play, which encompasses portions of the Desoto, Red River, Caddo, and Bossier Parishes. The surrounding area's primary land use is timber and pasture farming. The well pads will located in rural areas in class G airspace. The properties will be fenced off and secured, which will restrict public access.

Nixon Engineering Solutions LLC intends to expand its natural gas well pads into other, similarly rural areas in the United States if permitted. Any additional operations will be guarded and restricted to rural locations in Class G area space and at least four miles from any uncontrolled runways, to protect the public from hazardous conditions.

C. Flight Operations

The purpose of every sUAS flight will be to safely, accurately, and efficiently create survey maps of open mines and to inspect well pads. The sUAS will collect photogrammetric pictures, survey equipment to set ground control points, and use specialized photogrammetry software to process the data. The survey output will be 3D surface models and high resolution aerial photographs.

Every sUAS flight will use at minimum a two man flight crew, both possessing engineering credentials. The Pilot in Command (PIC) will have substantial prior experience with operating the sUAS, and possess a degree in professional engineering and land surveying. The assistant/spotter will be a licensed engineer intern.

The standard pre-flight and operational procedure will be as follows:

1. Meet at security gate and complete pre-flight security appropriate to each site (described

below).
2. Drive to area to be surveyed.
3. The Pilot in Command begins to ready sUAS for flight.
    a. Set up hand held weather station on tripod.
    b. Check over airframe, connections, and propellers for any damage during transport in vehicle. While the airframe has the ability to disassemble easily for transport, the sUAS will remain fully assembled. The sUAS is transported in the back of a truck which has a camper shell and straps installed to secure the sUAS in place to minimize electrical connection fatigue.
    c. Install and calibrate camera in gimbal.
    d. Turn on and ready lap top on tailgate.
    e. Connect communication antennae to laptop.
    f. Open Ground Station software and pull up pre-planned photogrammetry flight path.
    g. Boot up secondary GPS for tracking and geocoding pictures.
    h. Attach secondary GPS to sUAS.
    i. Remove main flight Tx[1] from case and power up, verify voltage and settings.
    j. Remove gimbal Tx from case and power up, verify voltage and settings.
    k. Remove dual battery pack for flight, measure current voltage, log in battery manual.
    l. Strap batteries securely on to sUAS, do not attached main power.
    m. Move sUAS to take off point, approximately 30 feet from truck and crew.
    n. Attach main power.
    o. Listen to power up sequence of beeps for ESC and motors.
    p. Using Flight Tx cycle through different control modes observing LED lights for good connection and response.
    q. Using Gimbal Tx cycle through all controls making sure the gimbal and camera respond to commands.
    r. Remove secondary GPS and hold in front of camera taking picture to record a time stamp picture.
    s. Reattach secondary GPS.
    t. Set up traffic cones around sUAS with approximately a 20 foot radius. This is the “home” area and the operators are not allowed inside this area while the electrical motor is running.
    u. Walk back to truck with both Tx.
    v. Using Flight Tx activate engine power without moving throttle up. This checks that the automatic throttle kill is working and also records the “home” point.
    w. Using laptop Ground Station now select button connecting laptop to sUAS.
    x. sUAS should appear on the screen, along with a recorded home point, battery voltage, current altitude relative to the ground, and current velocity.
    y. Upload flight path data to sUAS.
    z. Verify good upload and connection.
    aa. Verify weather from portable weather station.
    bb. Record time and weather in Flight Log.
    cc. sUAS is now fully prep and ready to go.

[1] "Tx" represents radio transmitter for command and control. "Rx" represents radio receiver for command and control.

dd. Waits for secondary crew member to return from setting out GCP's.

4. While Pilot in Command is readying the aircraft the second crew member is preparing the Ground Control Points (GPC's) and walking the site.
    a. Power up and calibrates the survey grade GPS equipment.
    b. Begin setting GCP's and shooting center of targets with survey GPS.
    c. While setting out GCP's secondary crew is also making sure area is clear of all people.
5. Typically secondary crew and pilot finish at about the same time. Upon his return, the secondary crew member sets the survey GPS to the side and sits next to the lap top and camera Tx.
6. Pilot double checks take-off area is clear.
7. Pilot takes off flying to the approximate survey altitude.
8. Pilot instructs secondary crew member to initiate preprogrammed flight path.
9. Secondary Crew verifies that the Ground Station has good connection and is tracking the sUAS.
10. Secondary crew then turns on the camera to take pictures at a continuous interval.
11. During entire preprogrammed flight Pilot always has visual line of sight and is prepared to take over flight operations. Pilot's Tx has a flight count down timer which is set to a minimum of 20% battery reserve (Calculated based on prior field experience to safely return the sUAS to safe landing with ample margin of error). The timer begins from the point the throttle is moved out of its start position.
12. During flight secondary crew vigilantly monitors the Ground Station data (Voltage, forward velocity, altitude, and estimated remaining time to complete the mission) and relays any sudden changes or alerts to the pilot.
13. As the mission completes the Pilot informs the secondary crew he is taking back over control.
14. Secondary crew turns off the camera.
15. Pilot begins to land the sUAS.
16. After safely touching down the Pilot immediately goes and unplugs the main power. He then checks the pictures to verify if the pictures are good and the mission was successful.
17. If successful secondary crew leaves to go pick up GCPs.
18. Pilot checks battery voltage and records in battery log.
19. Pilot records flight time in Flight Log.
20. Pilot turns off both Tx, secondary GPS, and camera.
21. Pilot looks over airframe to see if any damage or loose connections happened from the flight.
22. Pilot begins to pack all equipment back up for safe transport.

The flight crew will follow separate safety procedures for open mine surveying and for natural gas well pad surveying.

At the mine sites, the flight crew will check in at the security gate and go through a safety inspection. The crew will meet a mine representative who serves as a liaison in directing any mine personal and will have any dump trucks or bulldozers on the pile clear off before the crew begins its survey. After the flight, the mine representative will inform any trucks and bulldozers that they can begin operations again. (See Exhibit 1)

At the well sites, the flight crew will unlock the security gate upon arrival and put on personal protection equipment, which includes hard hats, safety glasses, flame resistant coveralls, and steel toed boots. The crew then drives around the well pad site to inspect the flight area, set out ground control points, and take land based photographs, and parks just outside of the well pad entrance. (See Exhibit 2)

IV. Privacy

There is little concern that the proposed flights will cause invasions of privacy because all flights will occur over private or controlled access property with the property owner's prior consent and knowledge. In addition, as the overflight areas will be rural, there is little to no chance that there will be inhabited houses in the visual area or other people who have not consented to being filmed or otherwise agreed to be in the area where filming will take place. No attempt will be made to identify any individuals filmed during the flights except in cases where they are trespassing upon or damaging customer property, or interfering with the applicant's or its customers' operations.

V. Aircraft and Equivalent Level of Safety

Nixon Engineering Solutions LLC proposes that the exemption requested herein apply to civil aircraft that have the characteristics and that operate with the limitations listed herein. These limitations provide for at least an equivalent or higher level of safety to operations under the current regulatory structure.

These limitations and conditions to which Nixon Engineering Solutions, LLC agrees to be bound when conducting commercial operations under an FAA issued exemption include:

1. The sUAS will weigh less than 15 lbs.

2. Flights will be operated within line of sight of a pilot and observer.

3. Maximum total flight time for each operational flight will be 12 minutes. Flights will be terminated at 20% battery power reserve should that occur prior to the 12 minute limit.

4. Flights will be operated at an altitude of no more than 400 feet AGL. Despite this limitation, the majority of flights are anticipated to operate at no more than 270 feet AGL.

5. Minimum crew for each operation will consist of the sUAS pilot and the visual observer.

6. A briefing will be conducted in regard to the planned sUAS operations prior to each day's activities. It will be mandatory that all personnel who will be performing duties in connection with the operations be present for this briefing.

7. The operator will file any necessary paperwork in light of the exemptions with the appropriate Flight Standards District Office ("FSDO").

8. The operator will submit a written Plan of Activities to the FSDO at least one day before the proposed operations begin.

9. Pilot and observer will have been trained in operation of sUAS generally and received up-to-date information on the particular sUAS to be operated.

10. Pilot and observer will at all times be able to communicate by voice and/or text.

11. Written and/or oral permission from the relevant property holders will be obtained.

12. All required permissions and permits will be obtained from territorial, state, county or city jurisdictions, including local law enforcement, fire, or other appropriate governmental agencies.

13. The sUAS will have the capability to abort a flight in case of unexpected obstacles or emergencies.

14. If the multirotor and its controller disconnects during flight, the system's failsafe protection will come to the rescue and the multirotor will return to home and land automatically, rather than flying off uncontrollably or landing at an unknown location.

Satisfaction of the criteria provided in Section 333 of the Reform Act of 2012--size, weight, speed, operating capabilities, proximity to airports and populated areas and operation within visual line of sight and national security – provide more than adequate justification for the grant of the requested exemptions allowing commercial operation of applicant's sUAS in the mining, oil, and gas inspection industries pursuant to Nixon Engineering Solutions LLC's rules of operation appended hereto.

VI. Public Interest and Safety

Use of the sUAS will increase ground safety by eliminating ground surveying on the mine floor and help prevent wildfires and exposure to H_2S gas at the well pads, Currently, under safety regulations by the Mine Safety and Health Administration (MSHA), the coal stockpiles are surveyed by employees who walks on the piles with survey grade GPS collection equipment. This task takes two employees several hours to complete.

The surveyors currently face the following challenges:

A. In the stockpiles:

1. The piles are extremely steep and high – up to 100 feet above natural ground. The coal material of the piles is loose and shifts easily, which makes the sides of the piles very hazardous and can lead to unexpected coal slides, which endanger the workers.

2. Inventories of coal piles are collected on a monthly basis. The coal has not been run through a crusher, and the size of the coal can range from dust to 5' chunks, which create a tripping hazard for people walking through the piles. Using the sUAS will eliminate tripping hazards to the surveyors.

3. During August and September, the heat index routinely breaks 100ºF, which can lead to heat related illness and injury. Using the sUAS instead will reduce the risk of heat exhaustion to the surveyors as the time spent by the surveyors on the mine floor will be reduced from up to three hours, to an hour or less.

B. In the well pads:

1. Some of the stacks have the potential for high hydrogen sulfide (H_2S) concentrations, which can be extremely dangerous if inhaled because it is poisonous.

2. There is a small, through real, chance for fires, and surveyors must wear flame resistant coveralls.

3. During August and September, the heat index routinely breaks 100ºF, which can lead to heat related illness and injury. Using the sUAS instead will reduce the risk of heat exhaustion to the surveyors as the time spent by the surveyors on the mine floor will be reduced from up to three hours, to approximately an hour or less.

By flying the sUAS over the coal piles, rather than putting workers on the mine floor, the hazards stemming from these extreme conditions will be removed. Additionally, a sUAS can complete the surveying task in under fifteen minutes, a drastic reduction in the time it takes the two surveyors, who may otherwise spend three or more hours at a time in these conditions. Inspections of the well pads made possible by the sUAS will reveal dangerous conditions, including possible fires which have the potential to spread as wildfires, and may prevent serious injury to employees.

VII. Regulations from Which Exemption is Requested

A. 14 C.F.R. 21(h): Airworthiness Certificates

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 21(h). This exemption meets the requirements for an equivalent level of safety pursuant to Section 333 based on the small size, light weight, relatively slow speed, and use in controlled rural environments on private land, as described previously in this petition.

B. 14 C.F.R. 43.7: Persons authorized to approve aircraft, airframes, aircraft engines, propellers, appliances, or component parts for return to service after maintenance, preventive maintenance, rebuilding, or alteration.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 43.7. This part provides, inter alia, that the holder of a mechanic certificate or a repair station certificate may approve an aircraft, airframe, aircraft engine, propeller, appliance, or component part for return to service. The nature of the sUAS is that of a model aircraft, and the operators of Nixon Engineering Solutions LLC who will maintain and when necessary repair the sUAS have engineering degrees; one is a Professional Engineering and Land Surveyor and the other a licensed Engineer Intern. The operators will conduct inspections and maintenance based on maintenance guidelines provided by the manufacturer of the sUAS, DJI. (See Exhibits 3-7). The capabilities of these operators to maintain and repair the sUAS will meet the requirements for an equivalent level of safety pursuant to Section 333 for the type of sUAS, its intended use, and the rural operating environment.

C. 14 C.F.R. 43.11: Content, form, and disposition of records for inspections conducted under parts 91 and 125 and §§135.411(a)(1) and 135.419 of this chapter.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 43.11. This part provides, inter alia, that maintenance record entries be maintained and for the listing of discrepancies and placards by inspectors. The sUAS, due to its small size, does not have room for placards to be placed in or on it and no inspections for sUAS have been certified by FAA at the present time. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC is willing to keep log books of all maintenance and repairs.

D. 14 C.F.R. 45.11: Marking of products.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 45.11. This part provides, inter alia, that the manufacturers of aircraft, engines, propellers, mark such aircraft, engines, or propellers with an approved fireproof identification plate. The sUAS, due to its small size, does not have room for fireproof placards to be placed in it. Any required placards could become hazardous, due to the additional weight and strain placed on the sUAS.

E. 14 C.F.R. 45.21: General.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 45.21. This part provides, inter alia, that except as provided in §45.22, no person may operate a U.S.-registered aircraft unless that aircraft displays nationality and registration marks in accordance with the requirements of this section and §§45.23 through 45.33. There are no current procedures for obtaining a registration mark for sUASs by the FAA. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC is willing to be assigned a registration number and to display it where practicable as addressed in this petition relative to Parts 23, 27, and 29, below.

F. 14 C.F.R. 45.23: Display of marks; general.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 45.11. This part provides, inter alia, that each operator of an aircraft must display on that aircraft marks consisting of the Roman capital letter "N" (denoting United States registration) followed by the registration number of the aircraft. Moreover, limited, restricted or light-sport category aircraft or experimental or provisionally certificated aircraft, the operator must also display on that aircraft near each entrance to the cabin, cockpit, or pilot station, in letters not less than 2 inches nor more than 6 inches high, the words "limited," "restricted," "light-sport," "experimental," or "provisional," as applicable.

The sUAS, due to its small size, does not have room to display aircraft marks in a conventional size. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC is willing to affix an aircraft mark to one or more of the "arms" of the sUAS. The size of the marking will be determined by the size of the "arm" being used and may be less than 1 inch in size.

The word "Experimental" will be placed on the fuselage in compliance with §45.29(f). However, a partial exemption from this display regulation may be needed as the UAS will have no entrance to the cabin, cockpit or pilot station on which the word "Experimental" can be placed. Given the size of the sUAS, two-inch lettering will be impossible.

The equivalent level of safety will be provided by having the sUAS marked on its fuselage as required by §45.29 (f) where the pilot, observer and others working with the sUAS will see the identification of the UAS as "Experimental." The requested exemption is consistent with the following exemptions to this regulation that the FAA has issued: Exemptions Nos. 10700, 8738, 10167 and 10167A.

G. 14 C.F.R. 45.25: Location of marks on fixed-wing aircraft

The sUAS is a multirotor model aircraft and is not fixed-wing. Therefore, 14 C.F.R. 45.25 is inapplicable.

H. 14 C.F.R. 45.27: Location of marks; nonfixed-wing aircraft

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 45.27. This part provides, inter alia, that each operator of a rotorcraft must display on that rotorcraft horizontally on both surfaces of the cabin, fuselage, boom, or tail the marks required by §45.23. The sUAS, due to its small size, does not have a cabin, fuselage, boom or tail to display the marks required by §45.23.

I. 14 C.F.R. 45.29: Size of marks

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 45.27. This part provides, inter alia, at subpart (3) that the registration marks for rotorcraft must be at least 12 inches high. The sUAS, due to its small size, does not have any surface area large enough to display marks anywhere near 12 inches high. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC is willing to affix an aircraft mark to one or more of the "arms" of the sUAS. The size of the marking will be determined by the size of the "arm" being used and may be less than 1 inch in size.

J. 14 C.F.R. 47.3(b)(2): Registration required

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 47.3(b)(2). This part provides "(b) No person may operate an aircraft that is eligible for registration under 49 U.S.C. 44101-44104, unless the aircraft—(1) Has been registered by its owner; [or] (2) Is carrying aboard the temporary authorization required by §47.31(c)."

There are no current procedures for obtaining a registration mark for sUASs by the FAA. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC is willing to be assigned a registration number provided by FAA and to display it where practicable as addressed in this petition relative to Parts 23, 27, and 29, above.

K. 14 C.F.R. 47.31(c): Application

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R.47.31 (c). This part provides "(c) After compliance with paragraph (a) of this section, the applicant for registration of an aircraft last previously registered in the United States must carry the second copy of the Aircraft Registration Application in the aircraft as temporary authority to operate without registration."

Because FAA currently has no process for registering sUAS, it is impossible to comply with Part 47.31(a), which states, inter alia: "(a) Each applicant for a Certificate of Aircraft

Registration, AC Form 8050-3 must submit the following to the Registry: (1) An Aircraft Registration Application, AC Form 8050-1, signed by the applicant in the manner prescribed by §47.13; (2) The original Aircraft Bill of Sale, AC Form 8050-2, or other evidence of ownership authorized by §47.33, §47.35, or §47.37 (unless already recorded at the Registry)."

L. 14 C.F.R. § 61.113: Private Pilot Privileges and Limitations: Pilot in Command.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 61.113. The PIC (pilot in command) of the sUAS does not possess either a private or commercial license. However, because (i) the sUAS is essentially a model aircraft, weighs less than 15 lbs. including payload, and will not carry any pilot or passengers, (ii) the area of operation is controlled and restricted, (iii) all flights will be planned and coordinated in advance, and (iv) the maximum altitude of the sUAS will not exceed 400 feet AGL, the proposed operations will achieve the equivalent level of safety of current operations by manned aircraft with a private or commercial pilots license.

The level of safety provided by Nixon Engineering Solutions LLC meets or exceeds that provided by an individual possessing a private or commercial pilot's license operating a manned aircraft. For conducting safe sUAS operations it is more important for the PIC of the sUAS be experienced, particularly with the sUAS at issue, than for the PIC to have a pilot's license. The PICs operating under this exemption will be experienced. Nixon Engineering Solutions LLC will have an operator (PIC) who has 1.5 years of radio control aircraft experience and has flown nearly 150 flights on this particular sUAS, and therefore meets or exceeds the present level of safety envisioned under this Section.

Stated another way, the skill set needed to successfully and safely operate the UAS is very different from the set of skills needed by a pilot of manned aircraft. Both FAA and Army Research Laboratory research demonstrate that UAS, even those much larger than the sUAS proposed by Nixon Engineering Solutions LLC, can be safely flown by non-certificated pilots with a small amount of training.

As one Army Research Laboratory study stated:

> **"[T]he specific motor skills needed to control the radio-controlled UAV would have to be learned by aviators independently of the motor skills learned in flying an aircraft. In particular, the somatic and visual cues that pilots use during aircraft landings would not be useful (and perhaps even counter-productive) for the different skill sets and perceptual viewpoint necessary for radio-controlled landings."** Michael J. Barnes, Beverly G. Knapp, Barry W. Tillman, Brett A. Walters & Darlene Veliki, *Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments*, Technical Report ARL-TR-2081, Aberdeen Proving Ground, MD: Army Research Laboratory, page 12 (2000). (See Exhibit 8)

In addition to the above research by the Army Research Laboratory, additional research reports lend further support for the exclusion requested, including one sponsored by the FAA and the other sponsored by the Institute of Aviation, Aviation Human Factors Division, at the University of Illinois at Urbana-Champaign:

1. Kevin W. Williams, *Unmanned Aircraft Pilot Medical Certification Requirements,* Report DOT/FAA/AM-07/3, FAA Civil Aerospace Medical Institute, page 2, (2007), *available at* http://fas.org/irp/program/collect/ua-pilot.pdf.

> **"We know that certain systems, like the U.S. Army Hunter and Shadow systems, are successfully flown by pilots with no manned aircraft experience."**[2]
> (See Exhibit 9).

2. Jason S. McCarley & Christopher D. Wickens, *Human Factors Implications of UAVs in the National Airspace*, Institute of Aviation, Aviation Human Factors Division, University of Illinois at Urbana-Champaign, 13 (2004), *available at* http://www.tc.faa.gov/logistics/grants/pdf/2004/04-G-032.pdf, *citing* Barnes, *supra*.

> **"Using the Army's Job Assessment Software System (JASS), Barnes, et al (2000) elicited Hunter UAV operators ratings of the relative importance of various cognitive skills in UAV air vehicle operators. Ratings indicated that outside of communication skills, raters did not consider flight-related skills of great importance to UAV operations, leading the authors to conclude that selection of rated aviators as air vehicle operators would be of little value."**
> (See Exhibit 10).

Finally, if the agency concludes that the PIC qualifications proposed in this exemption request do not meet the interim standards it is implementing, it should not deny the application on that ground. Rather, it should grant the exemption subject to Nixon Engineering Solutions LLC meeting whatever interim PIC qualifications the agency has adopted in other Section 333 exemption proceedings. For example, the pending exemption petitions of NextEra Energy, Inc., Oceaneering International, Inc., and Aeryon Labs, Inc., have already raised the PIC qualification issue. Applicant would be willing to adhere to the PIC qualification policies established in any of those proceedings.

M. 14 C.F.R. 91.7(a): Civil aircraft airworthiness.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.7(a). The regulation requires that no person may operate a civil aircraft unless it is in airworthy condition. As there will be no airworthiness certificate issued for the aircraft should this exemption be granted, no standard will exist for determining airworthiness. Given the size and weight of the aircraft and the requirements contained in Nixon Engineering Solutions LLC's rules of operations, described above, for maintenance and use of safety check lists prior to each flight, an equivalent level of safety will be provided.

N. 14 C.F.R. 91.9(b)(2): Civil aircraft flight manual, marking, and placard requirements.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.9(b)(2). This part provides:

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[2] While the authors speculated that UAV use in populated areas may change this assessment, indicating further research was needed to address this concern, this concern is inapplicable as Nixon Engineering Solutions LLC's flights will be in unpopulated areas.

"(b) No person may operate a U.S.-registered civil aircraft...

(2) For which an Airplane or Rotorcraft Flight Manual is not required by §21.5 of this chapter, unless there is available in the aircraft a current approved Airplane or Rotorcraft Flight Manual, approved manual material, markings, and placards, or any combination thereof."

First, there does not currently exist a method of approving manuals for sUAS. Second, given the size and configuration of the sUAS, there is no space to carry such a flight manual on the aircraft. In addition, carrying the manual on the aircraft would be pointless, since there is no pilot or other person on board who could read or use it. The equivalent – and in fact a greater - level of safety will be maintained by keeping the flight manual at the ground control point where the pilot flying the sUAS will have immediate access to it. The FAA has issued the following similar exemptions to this regulation: Exemption Nos. 8607, 8737, 8738, 9299, 9299A, 9565, 9565B, 10167, 10167A, 10602, 32827, and 10700.

O. 14 C.F.R. 91.9(c): Civil aircraft flight manual, marking, and placard requirements.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.9(c). This part provides: "(c) No person may operate a U.S.-registered civil aircraft unless that aircraft is identified in accordance with part 45 of this chapter."

As stated above, there is no current registration process for sUAS; and the sUAS, due to its small size, does not have room to contain fireproof placard or to display aircraft marks in a conventional size. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC is willing to affix an aircraft mark to one or more of the "arms" of the sUAS. The size of the marking will be determined by the size of the "arm" being used and may be less than 1 inch in size.

P. 14 C.F.R. 91.103(b)(2): Preflight action.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.103(b)(2). This part provides:

"Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight. This information must include—... (b) For any flight, runway lengths at airports of intended use, and the following takeoff and landing distance information: … (2) For civil aircraft other than those specified in paragraph (b)(1) of this section, other reliable information appropriate to the aircraft, relating to aircraft performance under expected values of airport elevation and runway slope, aircraft gross weight, and wind and temperature."

The Nixon Engineering Solutions LLC pilot in command in fact will, before beginning a flight, become familiar with all available information concerning that flight. However, as the flights of the sUAS will not be at airports the information required of Part 91.103(b)(2) does not apply. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC shall perform preflight operations as outlined previously in this Petition.

Q. 14 C.F.R. 91.105: Flight crewmembers at stations.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.105 since this part is not applicable due to the sUAS carrying no flight crewmembers. However, to achieve an equivalent level of safety, Nixon Engineering Solutions LLC will not operate the aircraft unless someone is at the controls at all times.

R. 14 C.F.R. 91.109: Flight instruction; Simulated instrument flight and certain flight tests.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.109. This part provides that no person may operate a civil aircraft (except a manned free balloon) that is being used for flight instruction unless that aircraft has fully functioning dual controls. Remotely piloted aircraft, including the sUAS here, are designed and constructed without dual controls. Flight control will be accomplished through the use of a control box that communicates with the aircraft via radio communications. The FAA has approved exemptions for flight training without fully functional dual controls for a number of aircraft and for flight instruction in experimental aircraft. See Exemption Nos.5778K & 9862A. The equivalent level of safety is provided by the very limited size and speed of the aircraft and by the fact that neither a pilot nor passengers will be carried in the aircraft.

S. 14 C.F.R. 91.113(b): Right-of-way rules: Except water operations.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 113(b) to the extent that it applies to overhead aircraft operating at or above 500 feet AGL as the sUAS will be operating no higher than 400 feet AGL. This part provides:

> "(b): 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."

For example, if another aircraft is operating overhead at 10,000 feet AGL there is no danger posed to that other aircraft if the sUAS is operating under it or ahead of it at or beneath 400 feet AGL. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC will operate its sUAS to see and avoid and give way to other aircraft that should enter airspace at or below 400 feet AGL.

T. 14 C.F.R. 91.115: Right-of-way rules: water operations.

This Part does not apply as Nixon Engineering Solutions LLC does not plan on operations on or over bodies of water in the near future.

U. 14 C.F.R. 91.119(b) and (c): Minimum safe altitudes: General.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.119 subparts (b) and (c). This regulation provides:

> "Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:...
>
> (b) Over congested areas. Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.
>
> (c) Over other than congested areas. An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In those cases, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure."

Nixon Engineering Solutions LLC will not operate the sUAS any higher than 400 feet AGL. Furthermore, while Nixon Engineering Solutions LLC will not be operating over any congested areas, the sUAS will necessarily be flown closer to 500 feet to the structures it will be examining (as well as closer than 500 feet to the ground).

The operations by Nixon Engineering Solutions LLC of the sUAS as set out previously provide for at least an equivalent level of safety of manned aircraft maintaining a distance of at least "500 feet to any person, vessel, vehicle, or structure" due to the small size and relatively light weight of the sUAS; and the close monitoring of the flight by both the pilot in command and the secondary ground crewmember.

V. 14 C.F.R. 91.121: Altimeter Settings

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.121. This Part provides guidelines for altimeter use below 18,000 feet mean sea level ("MSL") in maintaining the cruising altitude or flight level of the aircraft. Nixon Engineering Solutions LLC's operation of the sUAS will not exceed 400 feet AGL and will be operated in a fashion that is not a sustained cruising flight such as a manned aircraft will typically fly. The laptop used in the ground station has live feedback information about the sUAS, including but not limited to the height of the sUAS, its forward velocity, and compass heading. The operator will be able to observe and control the maximum height of the sUAS. Additionally, the sUAS will be operated within the line of sight. Therefore, the equivalent level of safety provided by Section 91.121 will be met.

W. 14 C.F.R. 91.151: Fuel requirements for flight in VFR conditions.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. Part 91.151. This Part provides that:

> "(a) No person may begin a flight in an airplane under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed— (1) During the day, to fly after that for at least 30 minutes; or (2) At night, to fly after that for at least 45 minutes
>
> (b) No person may begin a flight in a rotorcraft under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed, to fly after

that for at least 20 minutes."

The sUAS Nixon Engineering Solutions LLC will fly is electric in nature, using lithium polymer batteries that currently have a flight limit of approximately no more than 15 minutes. Therefore, due to the limitations of the batteries it is currently impossible to comply with Part 91.151. However, the sUAS will be operated in a manner with at least the same equivalent of safety as that of a manned aircraft complying with Part 91.151 because the short distances the sUAS will be operated in, far less than one mile, will allow the sUAS to be flown to a safe landing point within the area of operation within a short period of time and well within the minimum level of reserve capacity of the batteries.

During the entire preprogrammed flight, the operator will always have a visual line of sight and be prepared to take over. Pilot's radio transmitter ("Tx") has a flight count down timer which is set to a minimum of 20% battery reserve defined as allowing an additional 3 minutes of flight time - more than enough to safely fly the sUAS back to the roped off "home" area. This operation procedure adequately complies with ASTM standard F3005 − 14 4.3.1 (Standard Specification for Batteries for Use in Small Unmanned Aircraft Systems (sUAS)). The timer begins from the point the throttle is moved out of its start position.

The battery powering the sUAS provides approximately 15 minutes of powered flight. As a result, the sUAS would never meet the 30 minute reserve requirement. Given the limitations on the sUAS's proposed flight area and the location of its proposed operations within a predetermined area, a longer time frame for flight in daylight VFR conditions is reasonable.

Applicant believes that an exemption from 14 CFR §91.151(a) falls within the scope of prior exemptions. See Exemption 10673 (allowing Lockheed Martin Corporation to operate without compliance with Section 91.151 (a)). Given the limited size and speed of the sUAS, its ability to land safely almost anywhere, that it will be under the operator and the observer's visual observation at all times, and that it will be operating in a tightly controlled area, where all people, other than the operator and the observer, will be removed before flight, permitting its operation with less than 30 minutes of reserve fuel does not engender the type of risks that Section 91.151(a) was intended to alleviate.

Applicant believes that an equivalent level of safety can be achieved by limiting flights to 12 minutes or the time when 20% of battery power remains, whichever happens first. This restriction would be more than adequate to allow the sUAS to reach its planned landing zone. Similar exemptions have been granted to other operations, including Exemptions 2689F, 5745, 10673, and 10808.

X. 14 C.F.R. 91.203(a) and (b): Civil aircraft: Certifications required.

Nixon Engineering Solutions LLC requests an exemption from 14 C.F.R. 91.203(a) and (b). This section provides in part:

> "(a) Except as provided in § 91.715, no person may operate a civil aircraft unless it has within it the following:
>
> (1) An appropriate and current airworthiness certificate…

(2) An effective U.S. registration certificate issued to its owner…

(b) No person may operate a civil aircraft unless the airworthiness certificate required by paragraph (a) of this section or a special flight authorization issued under § 91.715 is displayed at the cabin or cockpit entrance so that it is legible to passengers or crew."

First, there are currently no procedures by the FAA for providing airworthiness certificates for sUAS. However, as a condition to the approval of exemption, Nixon Engineering Solutions LLC will display on the sUAS a registration certificate or equivalent that is issued by FAA pursuant to this petition at the ground point control, where the operator will have immediate access to them.

Second, the sUAS Nixon Engineering Solutions LLC will use the DJI S800 EVO or similar, which has an equivalent level of safety as manned aircraft with an airworthiness certificate. The DJI A2 flight controller provides a number of safety features in addition to acting as the command and control Rx bound to the Futaba brand Tx, including automatic return to home if the radio control link is broken, referred to as a failsafe.

Because of the use of GPS with the sUAS, the operator will set the initial location of flight takeoff ("home position") and if the radio control link is broken, the A2 flight controller will recognize this broken control link and cause the sUAS to automatically return to the home position as recorded by the GPS instrumentation. Additionally, because the sUAS team will mark off an area with traffic cones that has a 20 ft. radius, approximately 30 ft. from the operators that will be used as the "home position" for the sUAS to return, no one will be standing in the way of the path. (See Exhibits 1, 2).

In the restricted environment and under the conditions proposed, operation of the sUAS will be at least as safe as a conventional aircraft (fixed wing or rotorcraft) operating with an airworthiness certificate without the restrictions and conditions proposed. Nixon Engineering Solutions LLC will not accept assignments from clients who are within 5 miles of controlled airspace without first gaining written and/or oral permission from air traffic control.

The sUAS to be operated hereunder is less than 15 pounds inclusive of batteries and technical payload, carries neither a pilot nor passengers, and carries no explosive materials or flammable liquid fuels. The sUASs operating under this exemption will be tightly controlled and monitored by the operator and the observer, and under the requirements and in compliance with local public safety requirements, to provide security for the area of operation. The FAA will have advance notice of all operations. These safety enhancements provide a greater degree of safety to the public and property owners than conventional operations conducted with airworthiness certificates issued under Subpart H. Lastly, application of these same criteria demonstrates that there is no credible threat to national security posed by the UAS, due to its size, speed of operation, location of operation, lack of explosive materials or flammable liquid fuels, and inability to carry a substantial payload.

Y. 14 C.F.R. 91.215: ATC Transponder and Altitude Reporting Equipment and Use

This section requires that installed Air Traffic Control (ATC) transponder equipment must meet specific performance and environmental requirements, and aircraft must be equipped with an operable coded radar beacon transponder.

There are presently no known commercially available ATC transponders that meet the payload requirements of a sUAS and are available at reasonable cost. However, because the sUASs used by Nixon Engineering will not be flying into or near airports, and will fly no higher than 400 feet AGL, there is very low risk of collision with any manned aircraft. In addition, because there will be no need to have contemporaneous communication with Air Traffic Control, due to the short distances, short flight times, and restricted altitude the sUASs will operate within, Nixon Engineering requests an exemption from this section. Additionally, the sUAS is too small to contain ATC transponder equipment in any form factor that is known to be available commercially.

Z. 14 C.F.R. 91.403: General

This section requires that the owner or operator of an aircraft is primarily responsible for maintaining that aircraft in an airworthy condition. Nixon Engineering will adhere to this requirement. However, this Section also limits maintenance to that "prescribed in this subpart and other applicable regulations, including part 43 of this chapter." Because of this limitation, and because of the exemptions under Part 43 requested above, Nixon Engineering Solutions LLC requests an exemption from this Section.

This exemption meets the requirements for an equivalent level of safety pursuant to Section 333 based on the small size, light weight, relatively slow speed, and use in controlled rural environments on private, secured land, as described previously in this petition.

AA. 14 C.F.R. 91.405 (a) and (d): Maintenance Required

This section requires that aircraft be inspected as proscribed by Section E, 14 C.F.R. §§91.401-91.421. As shown below, Nixon Engineering LLC is applying for an exemption for these sections, due to the fact that its operators will inspect the sUAS prior to each flight and keep maintenance records of all parts that are replaced. Because the Sections discussed below are concerned with manned aircraft, and as such have inspection requirements designed for the safety of passengers, they are inapplicable to Nixon Engineering Solutions LLC.

Nixon Engineering Solutions LLC is also applying for an exemption to subpart (d) of this section, which requires a placard to be installed and references §43.11. As noted previously, Nixon Engineering Solutions LLC requests an exemption to the placard requirement, because, due to the small size of the sUAS, there is no room to place the placard. As an alternative and to achieve an equivalent level of safety, Nixon Engineering Solutions LLC will keep logbooks detailing all repairs.

Despite the requested exemption from subparts (a) and (d) of this section, Nixon Engineering Solutions LLC will follow subparts (b) and (c) of this subpart.

BB. 14 C.F.R. 91.407: Operation after maintenance, preventive maintenance, rebuilding, or alteration

This section requires that any aircraft which "has undergone maintenance, preventative maintenance, rebuilding, or alteration unless . . . [i]t has been approved for return to service by a person authorized under § 43.7 of this chapter . . .."

However, Nixon Engineering Solutions LLC has requested an exemption from §§ 43.7 and 43.11 as described previously. The capability of the operators to maintain and repair the sUAS meets the requirements for an equivalent level of safety pursuant to Section 333 for both the type of sUAS, its intended use, and the rural operating environment. Additionally, due to the small size of the sUAS, there is no room to place inspection placards.

Therefore, because Nixon Engineering Solutions has requested an exemption from 43.7 and 43.11, Nixon Engineering Solutions LLC respectfully requests an exemption from 91.407. To achieve an equivalent level of safety, Nixon Engineering Solutions LLC will regularly inspect and maintain its sUASs in accordance with the DJI operator manual, and keep detailed inspection records as described above.

CC. 14 C.F.R. 91.409: Inspections

This section lays out the requirements for inspections of aircraft. Nixon Engineering Solutions LLC respectfully requests an exemption from these requirements because they are intended to maintain the safety of manned aircraft significantly larger and capable of significantly longer flights than the DJI S800.

Nixon Engineering Solutions LLC does have an inspection procedure. Prior to each flight, the operator will conduct an inspection of the sUAS. The steps of this pre-flight inspection include:

- Check the following proponents for damage during transport:
  - Airframe;
  - Connections; and
  - Propellers.
- Calibrate the camera.
- Verify voltage and settings for main flight Tx and the gimbal Tx.
- Measure voltage for dual battery.
- Cycle through different control modes of the Flight Tx observing LED lights for good connection and response.
- Cycle through all controls of the Gimbal Tx making sure the gimbal and camera respond to commands.
- Activate engine power without moving throttle up to check that the automatic throttle kill works.

After each flight, Nixon Engineering Solutions LLC will conduct the following post-flight inspection:

- Blow sUAS with compressed air to remove dirt and dust.
- Wipe down sUAS with a cloth to remove dirt and dust.
- Check each electrical connection to make sure it is still intact.

The pre-flight and post-flight inspections meet or exceed the level of safety achieved by adherence to 14 C.F.R. 91.409.

DD. 14 C.F.R. 91.417: Maintenance records

Nixon Engineering Solutions LLC respectfully requests an exemption from this Section, as it is only applicable for aircraft with an airworthiness certificate. Because Nixon Engineering Solutions LLC will not have an airworthiness certificate, this Section is inapplicable. As an alternative and to achieve an equivalent level of safety, Nixon Engineering Solutions LLC will keep detailed maintenance on every part as it is replaced, including but not limited to propellers, batteries, and electrical components.

Exhibit 1: Mine Procedures

Location:

The Dolet Hills Lignite Mine is located in Desoto Parish, LA. The mine property is approximately 10.5 miles long and nearly 4 miles wide or approximately 24,000 acres, all privately owned. The closest town or city to the property is Mansfield, LA and it is approximately 5 miles as measured from the closest point on Google Earth. This is an extremely rural area. According to the 2010 census, the population density of Desoto Parish is 29 people per square mile and the total population is 32,000. The primary land use of the Parish and more particularly the area in and around the mine is timber farming. The closest airfield is the Mansfield Airfield (an uncontrolled airfield), which is approximately 8.5 miles to the closest point of the mine property. All of the property is in Class G airspace. Finally, all of the property is fenced off and has manned and secured gates which restrict public access.

The Oxbow Mine is located in the adjacent Red River Parish. The Oxbow mine is not quite as large approximately, 3 miles long by 2 miles wide. The closest community is Coushatta, LA and it is approximately 2.5 miles east across the Red River. Again the area is extremely rural; the population density is 25 people per square mile, and the Parish has a total population of 9,091 according to the 2010 census. The topography of Red River Parish is different than Desoto Parish due to the Red River. Therefore the primary land uses around the mine are different and consist primarily of pasture land and farming. The closest airfield is Red River, a small uncontrolled runway approximately 4 miles from the closest point of the mine property. All of the property is in Class G airspace. Similar to the Dolet Hills Mine, the property is fenced off, with restricted access and manned security guards at the gates.

Purpose of Flight:

The primary purpose of the work is to safely, accurately, and efficiently create 3D surface models of stockpiles and the natural ground surface. This is done using a sUAS to collect photogrammetric pictures, survey equipment to set ground control points, and specialized photogrammetry software to process the data.

Flight Crew, Equipment and Typical Flight:

For information regarding the flight crew, equipment, and typical flight, please refer to pages six and seven of the petition, above.

Current Methods:

Currently these stockpiles are surveyed with a man walking around on the piles with survey grade GPS collection equipment. These piles are extremely steep and very high (100ft above natural ground). The coal material of these piles is loose and shifts easily can the sides can be very hazardous. By flying the piles using a sUAS this hazard is removed. Further the sUAS can do the work in under 15 minutes which previously took two men multiple hours to do. In August and September when the heat index routinely breaks 100° this limits the exposure of people to those extreme conditions.

Exhibit 2: Natural Gas Well Pad Procedures

Location:

These locations are spread across the Haynesville Shale Natural Gas play, encompassing Portions of Desoto, Red River, Caddo, and Bossier Parishes. The well pads are all located in rural areas of these parishes. The primary land use in and around all of these wells is farming, pasture and timber. All of the wells we survey are in Class G airspace. Finally, the wells pads are fenced off and secured with no public access.

Purpose of Flight:

The primary purpose of the work is to safely, accurately, and efficiently create as-built survey maps of the completed well heads, tanks, secondary containment walls, compressors and other miscellaneous equipment on the well pad. These as-built maps are comprised of 3D surface models and high resolution aerial photos. The work is done using a sUAS to collect photogrammetric pictures, survey equipment to set ground control points, and specialized photogrammetry software to process the data.

Flight Crew, Equipment and Typical Flight:

For information regarding the flight crew, equipment, and typical flight, please refer to pages six and seven of the petition, above.

Current Methods:

Currently these well pads are surveyed by a surveyor walking and taking shots over the entire pad, along with taking shots on the equipment. Some of these well pads have the potential for high H_2S concentrations around certain areas of the pad. High concentrations of H_2S can be extremely dangerous if inhaled. There is also a small (though real) chance for a well fire. Further the sUAS can do the work in under 15 minutes which previously took two men multiple hours to do. In August and September when the heat index routinely breaks 100° and you are wearing flame resistant coveralls this reduced exposure to the extreme heat is the most appreciated safety mitigation.

Exhibit 3:

Spreading Wings S800 EVO User Manual

Spreading Wings S800 EVO User Manual

V 1.10

February 07, 2014 Revision

Disclaimer

Thank you for purchasing this DJI product. Please regularly visit the S800 EVO web page at www.dji.com, which is updated regularly. Product information, technical updates and manual corrections will be available on this web page. Due to unforeseen changes or product upgrades, the information contained in the manual is subject to change without notice.

Read this disclaimer carefully before using this product. By using this product, you hereby agree to this disclaimer and signify that you have read them fully. Please strictly follow the manual to assemble and use the product. The manufacturer and seller assume no liability for any resulting damage or injury arising from the operation or use of this product.

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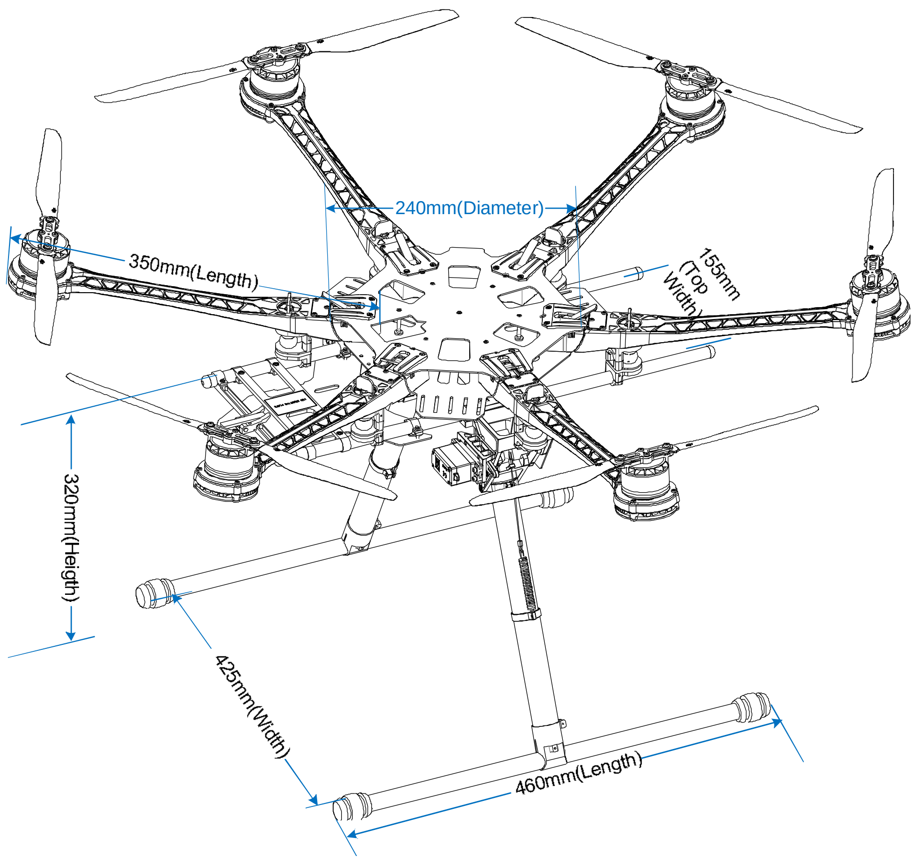
Profile

S800 EVO is a multi-rotor designed for aerial photograph which integrates reinforced mechanical structures, stabilized dynamical system and high-efficiency power supply. Integrated designs make assembly and configuration become especially easy and fast; retractable landing gear, foldable propellers and collapsible GPS Mount are conveniently portable for optimal user experiences. Retractable landing gears and vibration dampers coordinate to create omnidirectional aerial view and high quality photograph. Combined with professional DJI multi-rotor autopilot system S800 EVO will achieve hovering, cruising and other steady flight elements, which can be applied for aerial photography and other aero-modeling activities.



Contents

Product Usage Cautions

When flying, the fast rotating propellers may cause serious damage(s) and injuries. Therefore, please fly with a high safety in mind at all time.

Assembly Cautions

(1) Mount the GPS Module with a bracket, to avoid interference with the power board of center frame.

(2) For IMU mounting, make sure the arrow direction marking on the IMU is pointing to the aircraft nose.

(3) The receiver is strongly recommended to be attached under the bottom board of center frame, and the head of antenna is downward without any obstacle. Otherwise the aircraft may be out of control, since the wireless signal may be lost.

(4) Mount the arms correctly.

a) Center frame ↔ Arm

b) Center frame ↔ Arm

(5) For removing screws in the bottom board, please proceed with cautious, avoiding damages. Do not remove any other screws fixed with glue.

(6) Notice matching the indications is very important, please pay attention to them.

Flight Cautions

(1) With DJI WKM autopilot system, make sure the output signal of WKM F1~F2 and M1~M6 are all normal, to avoid serious damages and injuries.

(2) Keep flying the multi-rotor a distance from people, building, high-voltage lines, tall trees, water, etc.

(3) Make sure to use 6S LiPo battery for power supply.

(4) Do not get close to or touch the working motors and propellers, which will cause serious injury.

(5) Do not over load the multi-rotor.

(6) Make sure the propellers and the motors are installed correctly and firmly before flying.

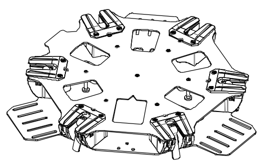
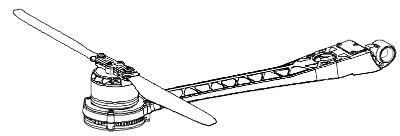
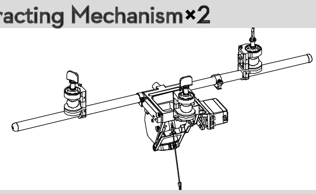
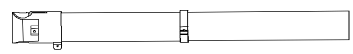
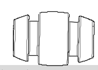
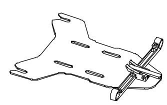
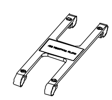
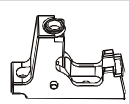
(7) Make sure all parts of product are in good condition before each flight. Do not fly with wore or broken parts.

(8) Strongly recommend you to use DJI parts as much as possible.

Others

(1) If you have any problem you cannot solve, please contact your dealer or DJI customer service.

In The Box

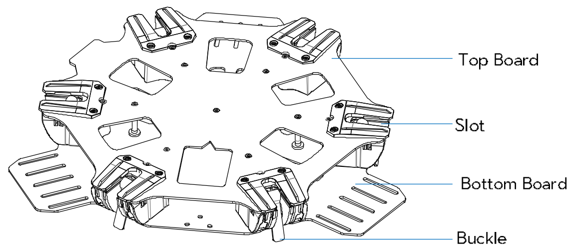
Center Frame×1	**Frame Arm×6**
	
Retracting Mechanism×2	**Landing Gear Support Tube ×2**
	
Base Pipe×2	**H Frame Connection Pipe×1、 Spring×2**
	
Package of 3-PIN Servo Cable ×1	**Silicone Rubber Damper ×4**
	
Package of Battery Tray×1	**Package of IMU Mount×1**
	
GPS Fixed Seat×1	**Screw Package for Frame×1** **Screw Package for Landing Gear×1**
	
Out of The Box Guidance ×2	

Tools Needed

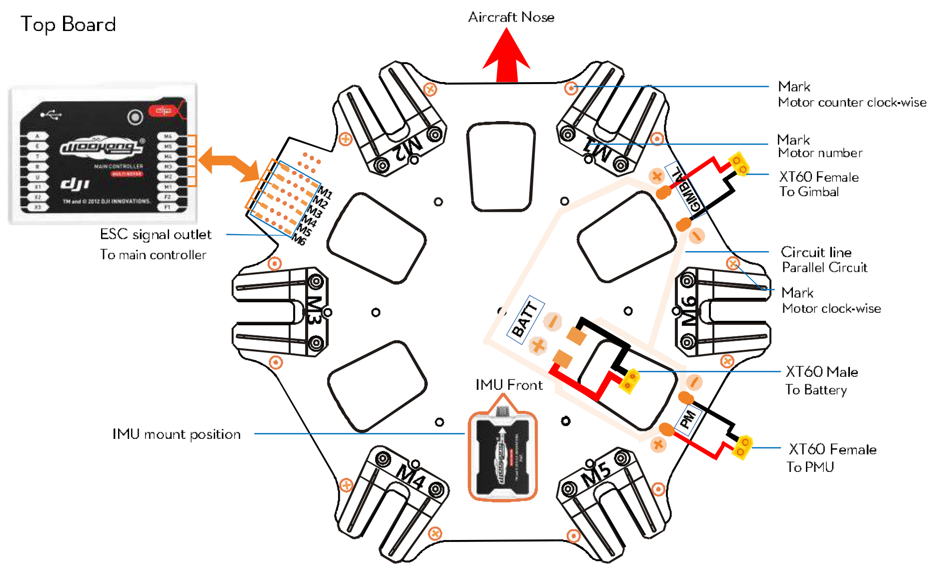
2.0mm Hex Wrench, 2.5mm Hex Wrench	For mounting screws.
Thread Locker	For fastening screws.
Nylon Cable Tie	
Scissors	For binding devices and wires.
Diagonal Cutting Pliers	
Foam Double Sided Adhesive Tape	For fixing receiver, controller and other modules.

Center Frame Wiring

The top board is a power distribution board, and the bottom board is for loading autopilot system components.



Top Board



Notes:

(1) For IMU mounting, make sure the arrow direction marking on the IMU is pointing to the aircraft nose.

(2) Connect the 3-pin connectors (M1~M6) of servo cable from WKM M.C. to ESC signal socket (M1~M6) on center frame markings accordingly.

(WKM M.C. M1↔ESC signal socket M1, ... , WKM M.C. M6↔ESC signal socket M6)

Tips:

(1) The main battery power leads, gimbal and PMU leads are on the bottom surface of the top board.

(2) Markings and stand for the propeller rotation direction. means clock-wise, and means counter clock-wise.

(3) If other lead connector is required, please cut the original connector and solder on the new one. (But NOT Recommend.)

Attach Electric Equipment to Center Frame

1. (Fig.1)Remove the screws in the bottom board.
2. (Fig.2)Attach the IMU module into IMU position in the center frame. Ensure the IMU casing is out of touching the top board edge, as vibration can cause IMU mal-function.
3. (Fig.2)Please attach DJI Autopilot System parts onto the bottom board (not including GPS modules.
4. (Fig.2)Connect the Autopilot System and receiver. Please refer to DJI *WKM User Manual* for details.
5. (Fig.3)Please fix all the screws to bottom board, and use adequate thread locker.
6. (Fig.4)Attach the GPS Fixed Seat to the top board (near to the M3), then mount the GPS Module to the GPS Fixed Seat with a bracket.
7. Configure Autopilot System. Please refer to DJI *WKM User Manual*.

Note:

(1) Make sure to mount the IMU module at the IMU position first, and the mount orientation is correct.

(2) Mount the GPS with a bracket, to avoid interference from center frame power board.

(3) Make sure the USB port of the M.C. is pointing outwards for easy access.

(4) Please wire neatly. Make sure the wires will not be cut by the edge of frames.

(5) Install the screws with appropriate strength to prevent damage threads.

(6) Watch out clamping fingers when folding the GPS Bracket.

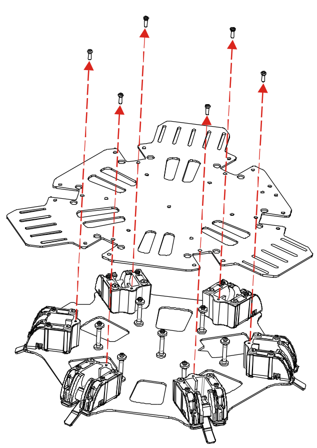


Fig.1 Remove the screws

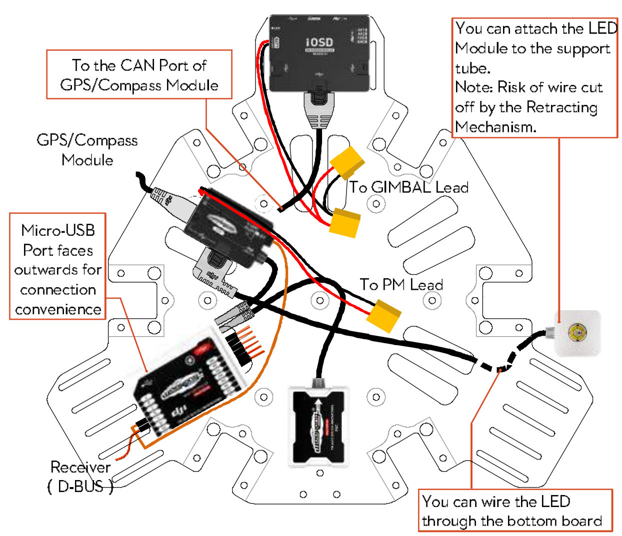


Fig.2 Attach the Autopilot System

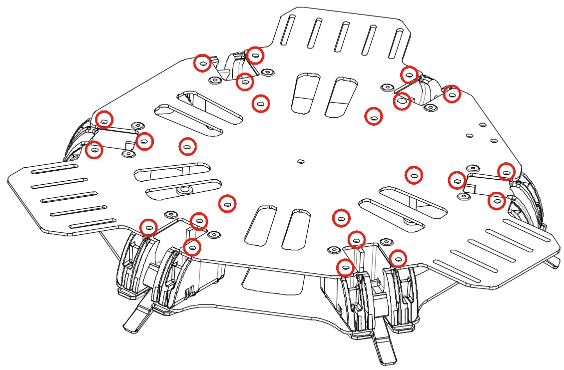


Fig.3 Fix the screws

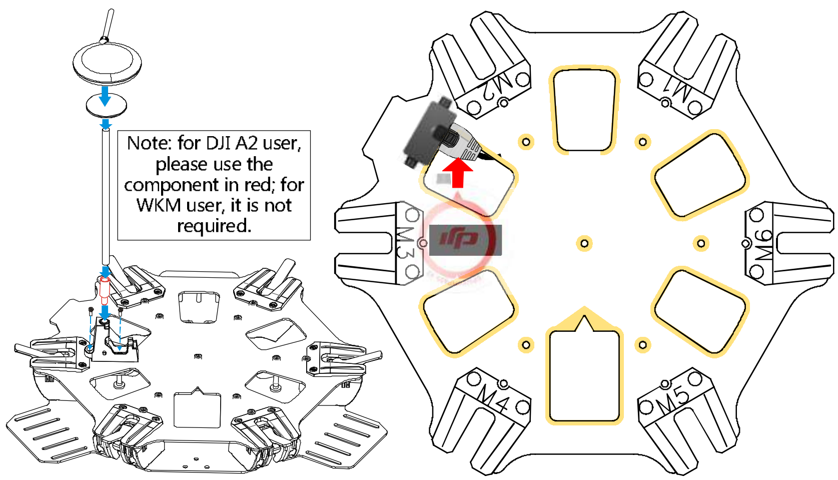


Fig.4 Mount the GPS Fixed Seat and GPS module

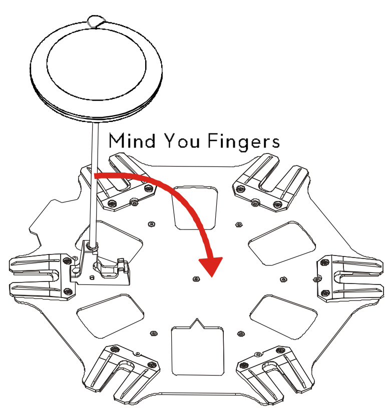
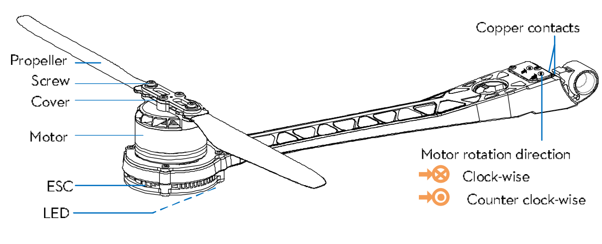


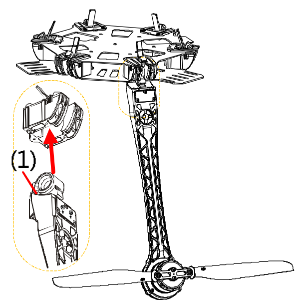
Fig.5 Note of folding the GPS Bracket

Mount Frame Arms

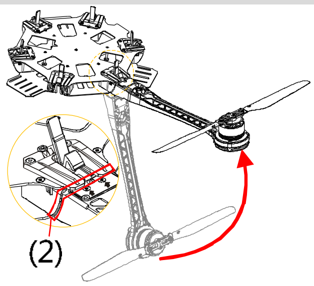
Step 1



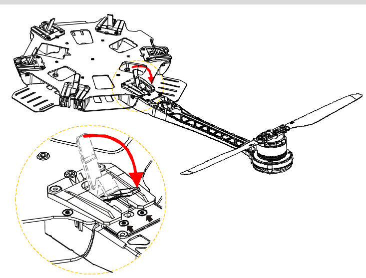
Step 2



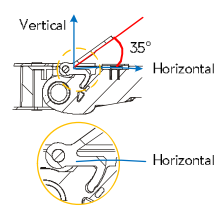
Step 3



Step 4



Step 5



Step1: Check the arms.

(1) Make sure the copper contacts are in good condition without bend or severe wear.

(2) Make sure the propellers are without crack, and screws in propeller cover tight.

(3) Make sure the motors are mounted firmly, and rotate freely.

(4) We recommend you to mount the arms with red propeller cover to M1 and M2 to indicate the nose of aircraft.

(5) Distinguish the marks and on the arms.

Arm ⟷ Center frame

Arm ⟷ Center frame

Step2: Insert the frame arm into center frame vertically.

Step3: Slowly rotate the frame arm upward until positioned completely.

Step4: Press down the buckle to lock the arm. Make sure the arm does not move.

Step5: Make sure the buckle is pressed down correctly, about 35° under normal circumstances.

Notes:

(1) Please add some lubricant at the position (1) if it is hard to press down the buckle.

(2) Slowly rotate the frame arm to prevent from breaking the copper contacts.

(3) Please refer to (2) to make sure the arm is perfectly positioned.

(4) Make sure to use appropriate strength to press down the buckle correctly.

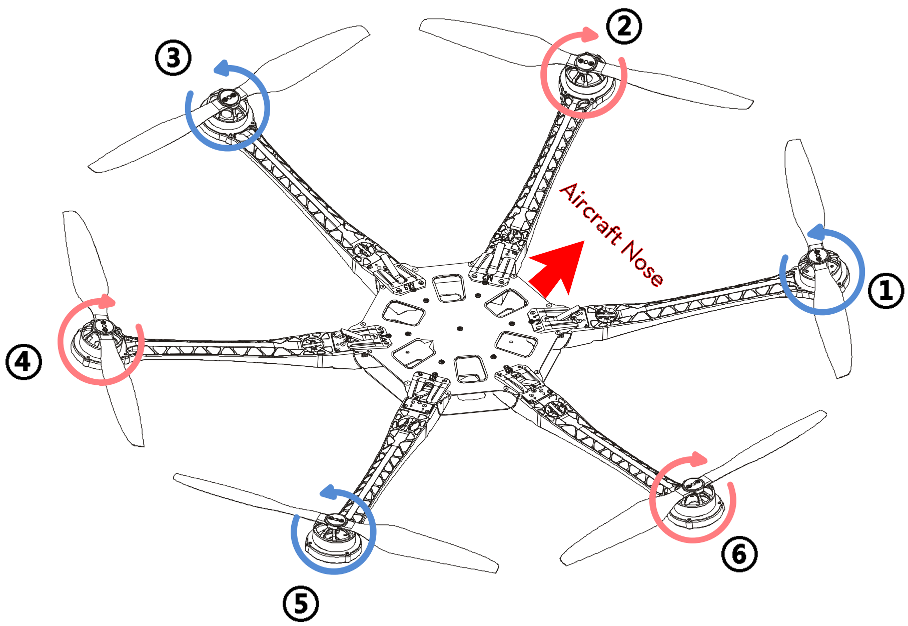
(5) Do not hot plug arms.

Tips:

(1) LED is on after motor start.

Step 6 Double Check

Arms①②are aircraft nose, arms④⑤ are aircraft tail. See from top, motors on arms①③⑤ rotate counter clockwise; motors on arms②④⑥ rotate clockwise.

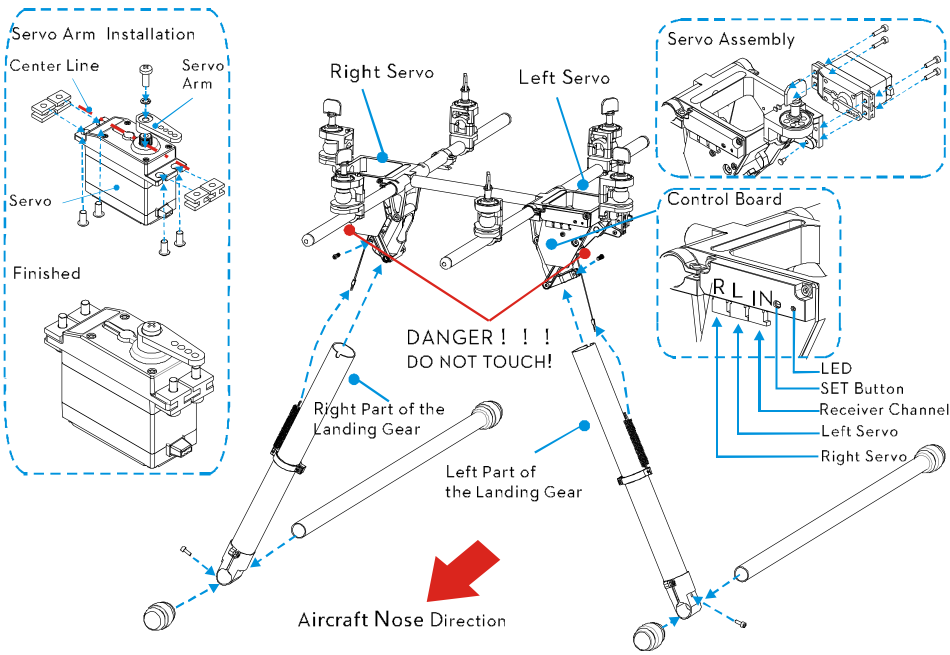


Mount Landing Gear

By using a 2-position switch of R/C transmitter, you can control the landing gear to retract remotely.

1 Assembly & Connection

The part with the control board attached is defined as left, and the other part is right. Make sure to make a distinction between the left and the right servos.



step1:	**Servo Installation** *(If the servos have already been installed, please skip this step.)*

1. (Shown in the Fig) Define and mark the two HS-7954SH servos from Hitec as left servo and right servo.
2. Connect the left servo to the **[L]** port on the control board, and the right servo to the **[R]** port.
3. Keep pressing the SET button with aid of a small tool, and then power on. You will see the yellow LED beside SET button flashes quickly, and then wait until the servos have finished their position initialization.
4. Make sure the servo arm is parallel to the servo's center line.
5. Power off, assemble the left and right servos to the left and the right parts of the landing gear.

Tips: If you use your own servos, it is recommended to use the dedicated programmer from Hitec to enlarge the servo travel from 120° to 150°, and then install servos by the above steps. Servos from DJI have been enlarged servo travel.

step2:	**Mechanical Assembly**

1. Assemble the left and right parts respectively, and then fix the screws at the joints with appropriate thread locker.
2. Connect the left and right parts with connecting rod.
3. For safety reasons, make sure to connect the springs to both parts.

step3: **Electrical Connections**

1. Plug the cables from the servos into the correct ports on the control board. Make sure the right servo is connected to the **[R]** port, and the left servo to the **[L]** port.
2. Connect the required 2-position switch of R/C receiver to the **[IN]** port.

2 Travel Calibration

If the Landing Gear you got has been installed with the servos, please skip this step. Otherwise, calibrate the system using the following procedures.

1. For safety reasons, please keep your hands away from any link mechanism to avoid injury.
2. Make sure the **[R]**, **[L]** and **[IN]** connections are correct and firmly connected.
3. Hang the Landing Gear in the air during calibration, as the landing gear will move.
4. Keep pressing the SET button using a small tool and power on. You can see the LED flashes YELLOW quickly, and then press the SET button once again. The system begins auto calibration with the indication of the LED flashing YELLOW slowly. **DO NOT** obstruct any moving part during auto calibration.
5. The left-part is calibrated, the left link mechanism first moves up then moves down automatically. Then the right-part is calibrated, the right link mechanism first moves up then moves down automatically.
6. After calibration, both left and right parts are in the **[Lower]** position, and the LED is solid GREEN on. Then the landing gear will work normally.

Notes:

(1) If the LED is solid YELLOW on during calibrating, it means that there is something wrong with the calibration, please re-do the Servo Installation of the Assembly & Connection section, since the servo arm might be installed with a wrong angle.

(2) Please avoid any obstruction during calibrating. If the landing gear is blocked from moving, please recalibrate the landing gear by the above steps.

(3) If the **[R]** and **[L]** servo cables are reversed, the travel will not be measured correctly. Please connect correctly and recalibrate the landing gear using the above steps.

3 Transmitter Setting

Select a 2-position switch (default setting is OK) of Transmitter as the control input of the landing gear, and then make sure the corresponding port of receiver is connected to the **[IN]** port on control board.

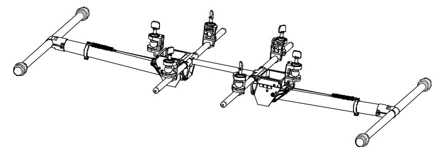
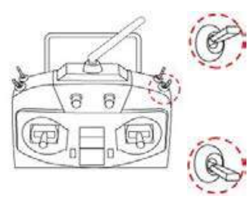


Fig. 1



Retracted：Toggle the switch to this position to retract the landing gear (Fig.1)

Lower：Toggle the switch to this position to lower the landing gear (Fig. 2)

Tips:

(1) If the switch of Transmitter has FailSafe function, set the FailSafe value to the **[Lower]** position, so that the landing gear will be in **[Lower]** status when the receiver enters FailSafe mode, to land the aircraft safely.

(2) To avoid false switch triggering, you can use the slide lever or other trim as the landing gear's control switch.

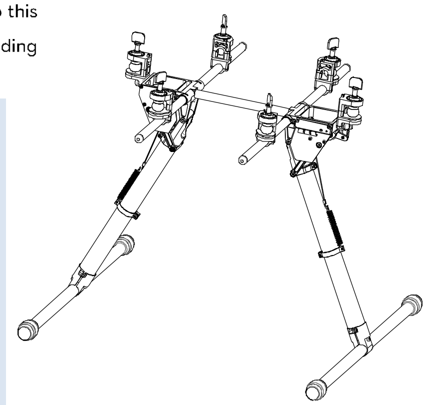


Fig. 2

4 Usage

The landing gear can be used by following the steps below after assembly & connection.

1. Make sure the transmitter & receiver batteries are fully charged.
2. Toggle the switch to the **[Lower]** position, and then turn on the transmitter.
3. Make sure the **[R]**, **[L]** and **[IN]** connections are correct and firmly connected.
4. Make sure the Landing Gear is at the **[Lower]** position, and then power on the system. If the green LED is solid on, then this is a normal start. If the LED flashes GREEN slowly, please re-calibrate the system according to the procedure of Travel Calibration.
5. Make sure to toggle the switch to the **[Retracted]** position ONLY AFTER you takeoff the aircraft.
6. When the aircraft is landing, please toggle the switch to the **[Lower]** position for a safe landing.

Tips

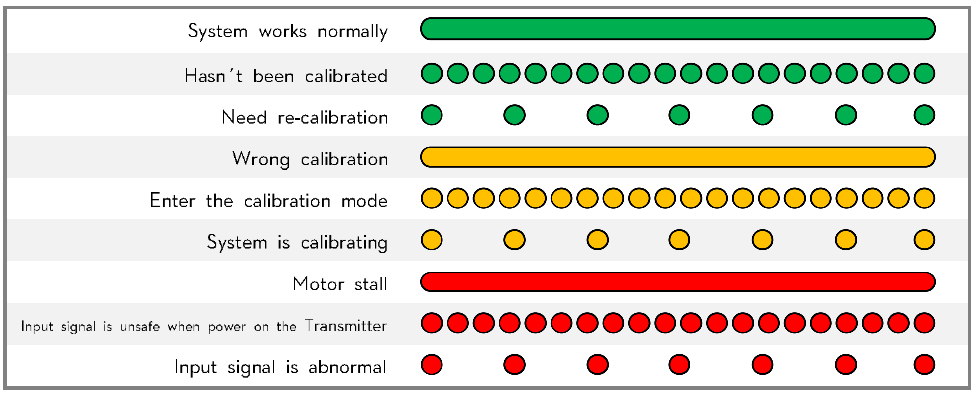
(1) The system will turn off the servo power temporarily within 3 seconds after the landing gear has reached the target position.

(2) When powering on the system, if the Transmitter switch is at the **[Retracted]** position, which is the unsafe signal for the landing gear, the LED will quickly flash RED. Toggle the switch to the **[Lower]** position.

(3) If there is an abnormal signal or no signal input into the **[IN]** port the LED will slowly flash RED. Please check the receiver and the connections.

(4) If the power consumption of servos is too large during usage, the LED will be solid RED on. If this status lasts more than 4 seconds, the landing gear will lower and the LED will flash GREEN slowly. Please re-calibrate the system.

LED Indicator

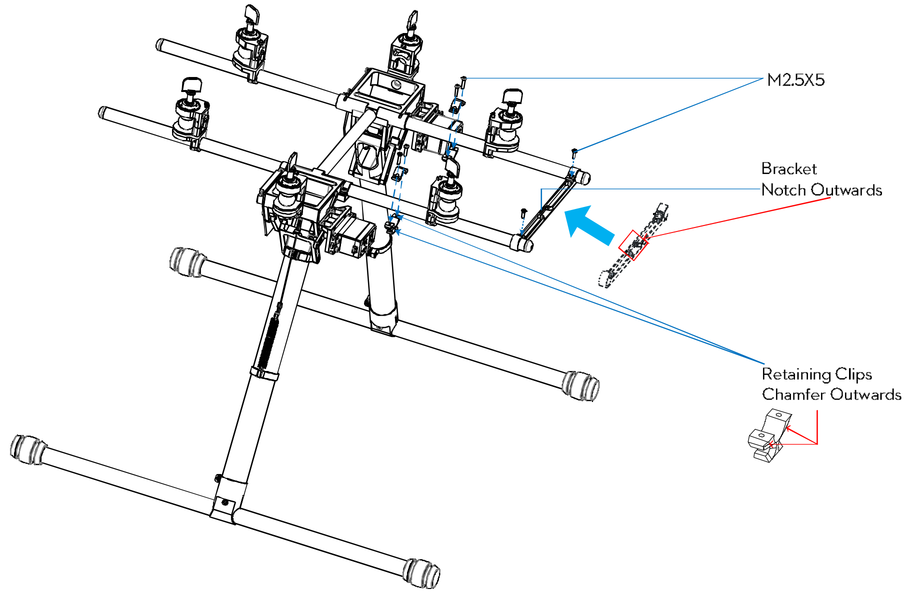


Specifications

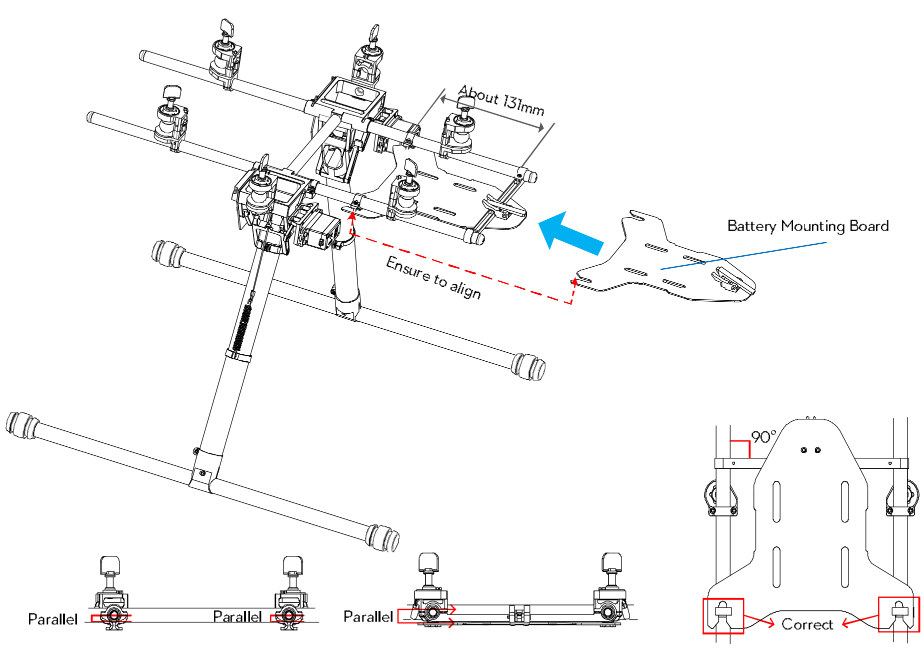
Parameter	Range	Parameter	Range
Working Voltage	3S~6S (LiPo)	Input Signal	PWM (High-Pulse Width 800us~2200us)
Working Current	Max 1A@6S	Output Signal	PWM(Mid Position is 1520us) in 90Hz
Working Temperature	-20~70°C	Output Voltage	6V
Total Weight	875g	Servo Travel	150° (Minimum120°)

5 Mount Battery Bracket

Step1: Mount the retaining clip and the bracket, fix screws (but not tighten).

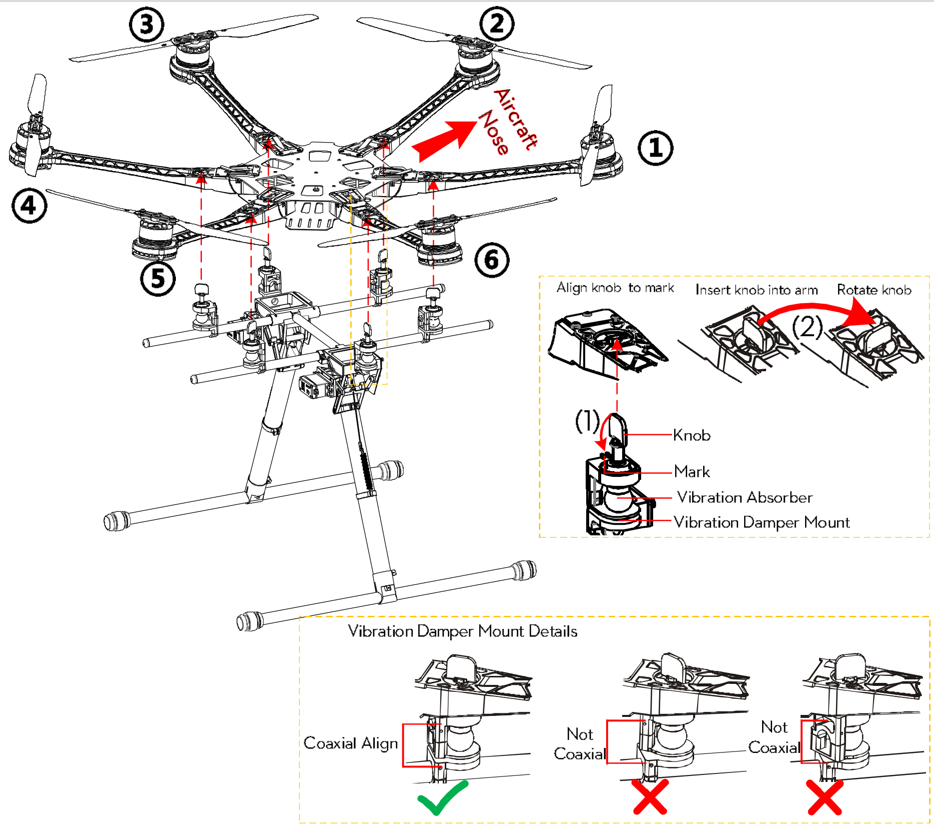


Step2: Place the battery mounting board and adjust its position, and then tighten all screws.



Assembly

Assembly



1. Align all knobs on H frame to the marks; refer to fig (1).
2. Lie frame and Landing Gear horizontally, insert knobs into arms ③ and ⑥ first, and then adjust to insert the others into the arms.
3. Make sure the Vibration Damper Mount is correct, and then rotate the knob to the end, as fig (2) shown.

Notes:

- Ensure all knobs on the H frame aligned to the marks, and they would go through the arms successfully.

Install the IMU Mount (Optional)

If you wish to achieve a smooth and steady fight, carry out the following procedures to install the IMU Mount.

1. (Fig.1) Remove the screws to dismount the Battery Bracket.
2. (Fig.2) Fix the IMU Mount and remount the Battery Bracket.
3. (Fig.3) Adjust the IMU Mount and the Battery Bracket, and then fix all the screws.
4. (Fig.4) Attach the IMU Module; make sure that the arrow on LOGO is pointing to the aircraft nose.

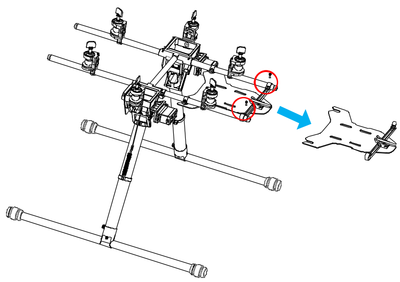


Fig.1

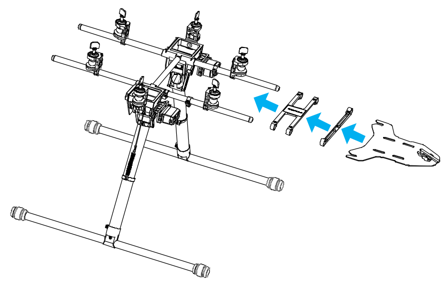


Fig.2

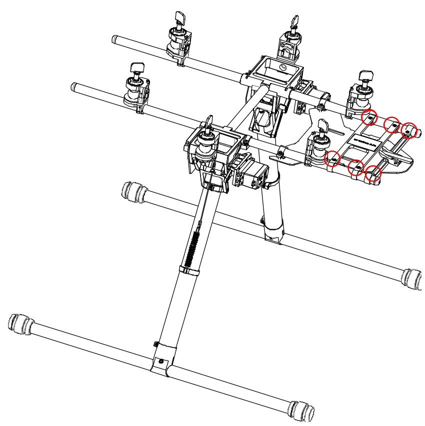


Fig.3

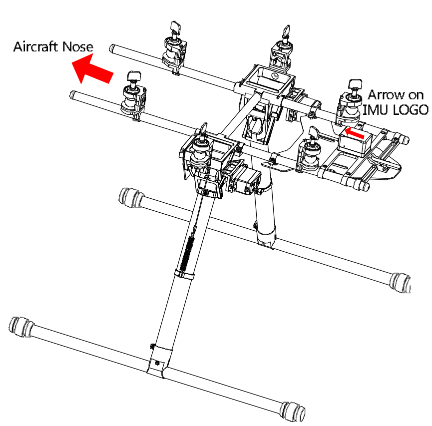


Fig.4

Appendix

ESC Sound

ESC State	Sound
Ready	♪1234567--B--B
Throttle stick is not at bottom	BBBBBB...
Input signal abnormal	B--------B--------B...
Input voltage abnormal	BB---BB---BB---BB...

ESC LED

ESC State	LED
Standby	Off
Motor rotating	Solid Red or Green On
Motor rotating at full throttle position	Solid Yellow On

Tips:

DJI ESCs are specially designed for multi-rotors. When use with DJI autopilot systems, you do not have to setup any parameters or calibrate travel range.

Specifications

Frame	
Diagonal Wheelbase	800mm
Frame Arm Length	350mm
Frame Arm Weight (with Motor, ESC, Propeller)	356g
Center Frame Diameter	240mm
Center Frame Weight	550g
Landing Gear Size	460mm(Length)×425mm(Width)×320mm(Height) (Top width: 155mm)
Retractable Landing Gear Weight (Including Battery Tray)	1050g
Motor	
Stator Size	41×14mm
KV	400rpm/V
Max Power	500W
Weight (with Cooling Fan)	158g
ESC	
Current	40A OPTO
Voltage	6S LiPo
Signal Frequency	30Hz ~ 450Hz
Drive PWM Frequency	8KHz
Weight (with Radiators)	35g
Foldable Propeller (1552)	
Material	Engineering plastic
Size	15×5.2 inch
Weight	13g
Flight Parameters	
Takeoff Weight	6.0Kg ~ 8.0Kg
Total Weight	3.7Kg
Power Battery	LiPo (6S、10000mAh~15000mAh、15C(Min))
Max Power Consumption	3000W
Hover Power Consumption	800W(@ Takeoff Weight 6.7Kg)
Hover Time	Max: 20 min (@15000mAh&6.7KgTakeoff Weight)
Working Environment Temperature	-10 ~ +40 °C

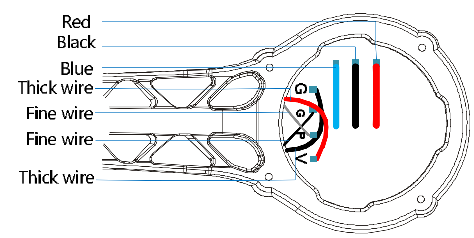
FAQ (Trouble Shooting)

Solder ESC

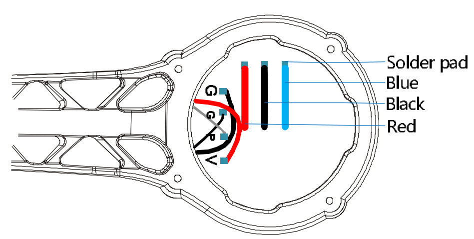
Make sure to solder the thick wires and fine wires correctly, when solder ESC to frame arm.

Clockwise and counter clockwise motor should be soldered to ESC correctly by different color order.

For arms



For arms



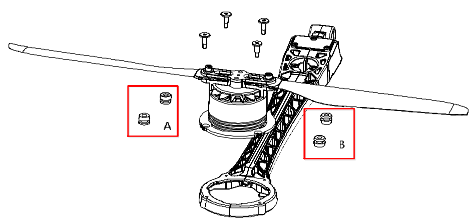
Assemble the Vibration Absorber of Motors

The soft gasket is a part of the Vibration Absorber and it has a thick end and a thin end, it´s important to assemble the soft gaskets in correct approach adhere to the diagram below.

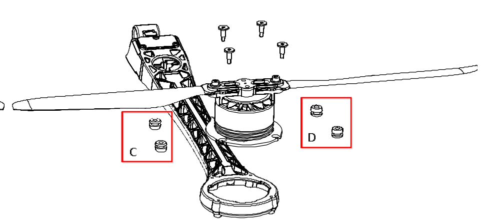
Propeller CCW: the thick ends of the gaskets (A) are upwards, the thick ends of the gaskets (B) are downwards.

Propeller CW: the thick ends of the gaskets (C) are downwards, the thick ends of the gaskets (D) are upwards.

Propeller CCW

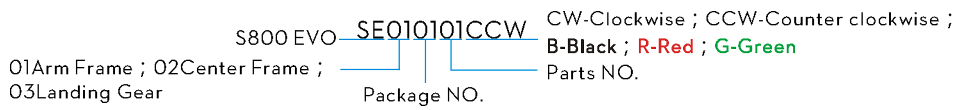


Propeller CW

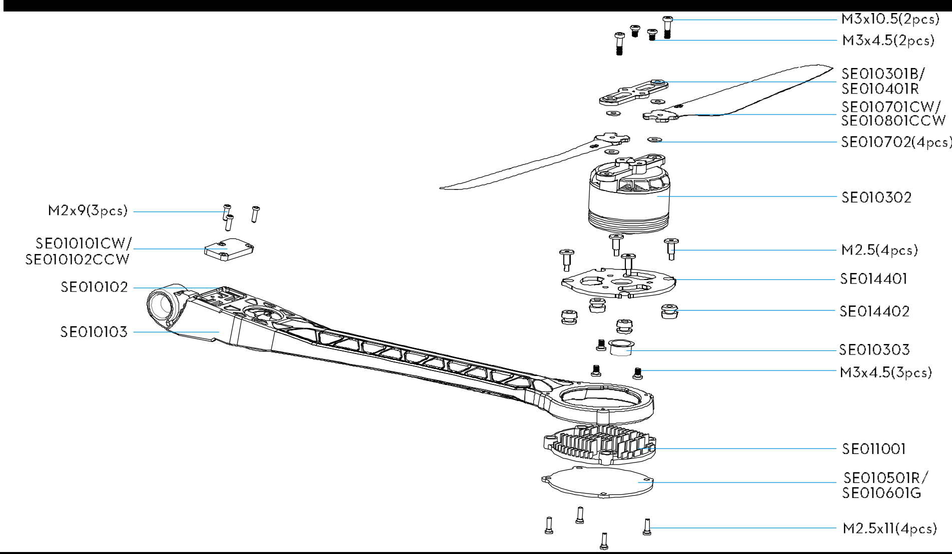


Spare Parts Listing

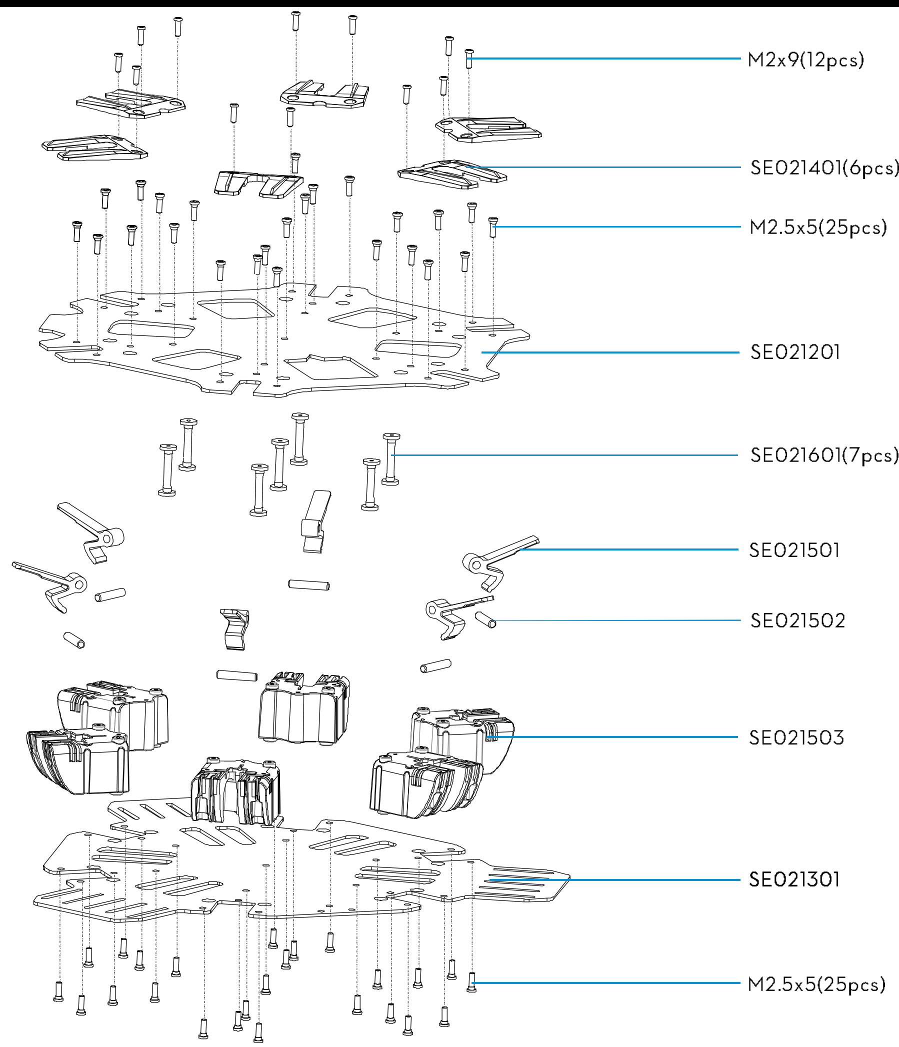
If S800 EVO needs component replaced, please refer to the following diagram to identify the component NO., and then make a purchase of corresponding package. Each package includes screws needed. The Components Number is defined as bellow.



Frame Arm

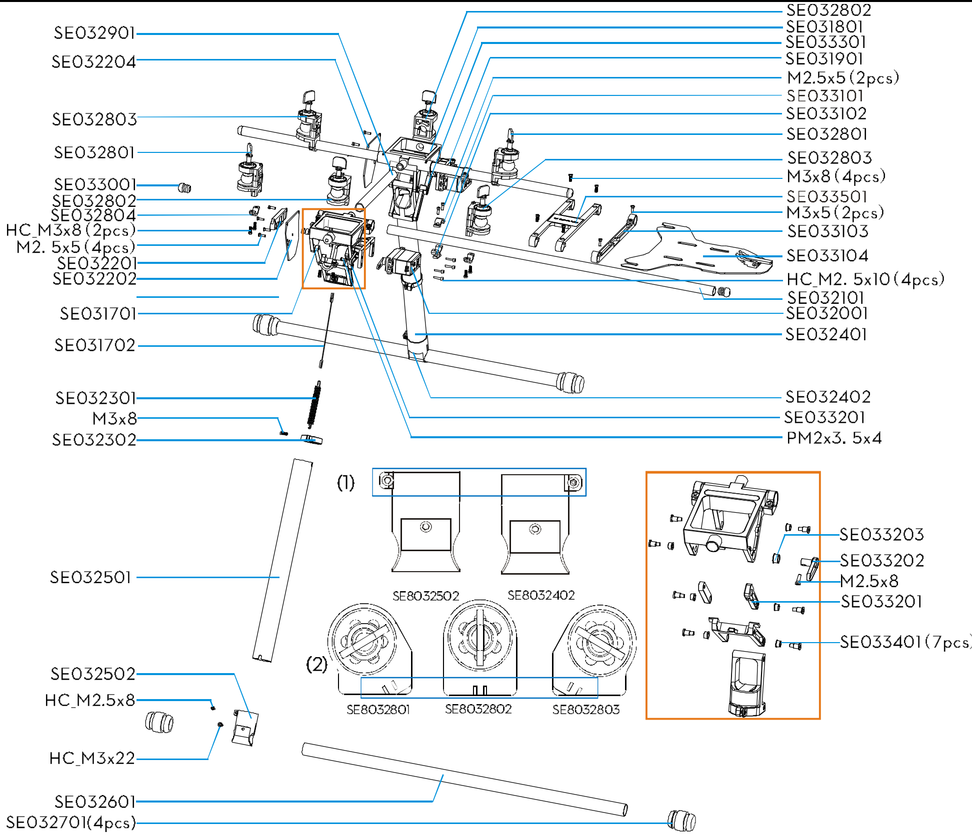


Package NO.	Name	Components Number
1	Frame Arm (Counter Clockwise)	SE010101CCW、SE010102、SE010103、M2x9
2	Frame Arm (Clockwise)	SE010102CW、SE010102、SE010103、M2x9
3	Motor with black Prop cover	SE010301B、SE010302、SE014402、SE014401 、SE010303 、M2.5x5、M3x4.5
4	Motor with red Prop cover	SE010401R、SE010302、SE014402、SE014401 、SE010303 、M2.5x5、M3x4.5
5	ESC with Red Led	SE010501R
6	ESC with Green Led	SE010601G
45	1552 Folding Propellers(both CW&CCW)	SE010701CCW、SE010801CW、SE010702、M3x10.5
9	Washer for Propeller	SE010702
10	ESC Heat Sink	SE011001



Package NO.	Name	Components Number
11	Center Frame	SE021201、SE021301、SE021401、SE021501、SE021502 、SE021503、SE021601、M2x9、M2.5x5
12	Center Frame Top Board	SE021201、M2x9、M2.5x5
13	Center Frame Bottom Board	SE021301、M2.5x5
14	Top Board Cover	SE021401、M2x9
15	Arm Mounting Bracket	SE021501、SE021502、SE021503、 M2x9、M2.5x5
16	Aluminum Brace for Center Frame	SE021601、M2.5x5

Landing Gear

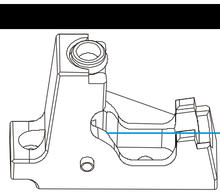


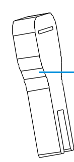
Note1: (1) Left Support Tube right Support Tube are different; (2) Left set, middle set and right set of Damping Unit are different.

Package NO.	Name	Components Number
17	Retract Module(Left)	SE031701、SE031702
18	Retract Module(Right)	SE031801、SE031702
19	HITEC Servo (Right)	SE031901、HC_M2.5x10
20	HITEC Servo (Left)	SE032001、HC_M2.5x10
21	Carbon Tube of H-Frame	SE032101、HC_M2.5x8
22	Control Board	SE032201、SE032202、SE032203、SE032204、M2.5x5
23	Spring	SE032301、SE032302、SE031702、M3x8
24	Support Tube (Right)	SE032401、SE032402、M3x8、HC_M2.5x8、HC_M3x8
25	Support Tube (Left)	SE032501、SE032502、M3x8、HC_M2.5x8、HC_M3x8

26	Base Tube	SE032601、SE032701
27	Silicone Rubber Damper	SE032701
28	Damping Unit (Set)	SE032801、SE032802、SE032803、SE032804、HC_M3x8
29	Aluminum Tube of H-Frame	SE032901
30	Silicone Rubber of H-Frame	SE033001
31	Battery Tray	SE033101、SE033102、SE033103、SE033104、M2.5x5、M3x5
32	Control arm of Retractable Module(Left)	SE033201、SE033202、SE033203、M2.5x8
33	Control Arm of Retractable Module(Right)	SE033301、SE033202、SE033203、M2.5x8
34	Shaft Sleeve of Retract Module	SE033401
35	IMU Mount	SE033501 、 M3x8

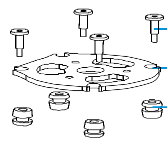
Others





Package NO.	Name	Components Number
36	GPS Holder	SE033601
37	Screws Package	M3x8(10pcs)、HC_M2.5x10(10pcs)、M2.5x5(30pcs)、M2x9(10pcs)、M3x4.5(10pcs)、M2.5x8(5pcs)、M2.5x11(10pcs)、M3x 10.5(15pcs)、HC_M3x8(10pcs)、HC_M2.5x8(10pcs)、HC_M3x22(5pcs)
38	Blade Holder	SE033801

Package NO.	Name	Components Number
39	Battery Mount Board	SE033104、Velcro straps
40	Frame Arm with Prop CCW &Red LED	**Package NO.** 1、4、5、7、10
41	Frame Arm with Prop CW &Red LED	**Package NO.** 2、4、5、8、10
42	Frame Arm with Prop CCW &Green LED	**Package NO.** 1、3、6、7、10
43	Frame Arm with Prop CW &Green LED	**Package NO.** 2、3、6、8、10

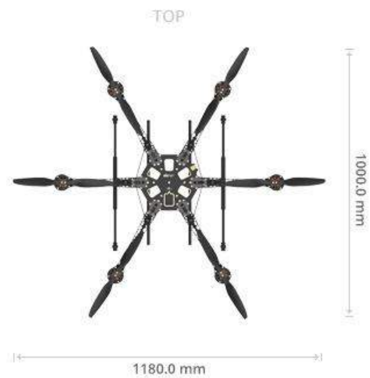


Package NO.	Name	Components Number
44	Vibration absorber of Motor	SE014401、SE014402、M2.5

Exhibit 4:
Spreading Wings S800 Specs

SPREADING WINGS S800 (http://www.dji.com/product/spreading-wings-s800)

Size and Weight



Diagonal Wheelbase: 800mm
Frame Arm Length: 350mm
Center Frame Diameter: 240mm

Bi-pod Size:
500mm(Length)×415mm(Width)×320mm(Height)
(Top width: 145mm)

Frame

Diagonal Wheelbase	800mm
Frame Arm Length	350mm
Frame Arm Weight (Including Motor, ESC, Propeller)	304g
Center Frame Diameter	240mm
Center Frame Weight	365g
Bi-pod Size	500mm(Length)×415mm(Width)×320mm(Height) (Top width: 145mm)
Bi-pod Weight	428g
Total Weight	2.6Kg

Flight Parameters	Takeoff Weight	5.0Kg ~ 7.0Kg
		Load Weight
	0Kg ~ 2.5Kg	
	Power Battery	LiPo (6S、10000mAh~15000mAh、15C(Min))
	Max Power Consumption	2100W
	Hover Power Consumption	720W(@ Takeoff Weight 6Kg)
	Hover Time	Max: 16 min (@10000mAh&6KgTakeoff Weight)
Motor	Stator Size	41×14mm
	KV	320rpm/V
	Max Power	360W
	Weight	147g
ESC	Current	40A OPTO
	Voltage	6S LiPo
	Signal Frequency	30Hz ~ 450Hz
	Drive PWM Frequency	24KHz
	Weight	18g
Propeller	Material	Carbon Fiber
	Size	15×04in
	Weight	15g

Exhibit 5:
A2 Flight Control System User Manual

A2 Flight Control System

User Manual V1.18

June 24th, 2014 Revision

For Firmware 2.2 & Assistant Software V1.3 & DJI Assistant App V1.1.14

Thank you for purchasing DJI products. Please strictly follow these steps to mount and connect this system on your aircraft, install the PC Assistant Software on your computer, as well as installing the DJI Assistant App on your mobile device.

Please regularly check the web page of corresponding products on our website **www.dji.com**, which is updated regularly. Product information, technical updates and manual corrections will be available on this website. Due to unforeseen changes or product upgrades, the information contained in this manual is subject to change without notice.

* This manual is for basic assembly and configuration; you can obtain more details and advanced instructions when using the Assistant Software. To assure you have the latest information, please visit our website and download the latest manual and current software version.

If you have any problems that you cannot solve during usage, please contact your authorized dealer.

Content

Introduction

Product Introduction

The DJI A2 Multi-Rotor stabilization controller is a complete flight system for various multi-rotor platforms for commercial and industrial aerial photography. Based on the technology and design philosophy of DJI's Ace series of high-performance controllers, the A2 offers you a brand new flight experience. Its flight mode provides a seamless transition for current Ace One, WKM AP professionals. A2 features includes:

(1) Integrated with high-precision sensor components and a high-performance GPS Receiver.

(2) Utilizes high quality components precisely calibrated with temperature compensation in all gyros and sensors, industry renowned flight algorithm in autopilot and UAV field.

(3) Designed with built-in vibration absorption, no extra mount frame or vibration absorption pad is required.

(4) Provide high precision control and high performance handling experience.

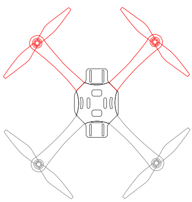
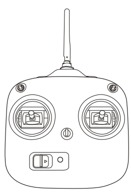
(5) Based on the DESST technology, it has a built-in 16-channel Receiver, and supports DSM2 satellite receiver.

(6) Optional DJI D-BUS Adapter can be used with a traditional Receiver.

In the Box

Controller Unit (Built-in Receiver DR16)	PMU(Power Management unit)	IMU(Inertia Measurement Unit)
		
LED-BT-I	GPS-COMPASS PRO	Accessories
		Micro-USB Cable (1) Servo Cables (2) GPS Bracket Double side sticky pads.

Equipment Prepared by Users

Aircraft (Take Quad-rotor for example: Red is nose, and Black is rear)	Transmitter (Take Mode2 for example)	Others
		Battery DJI D-BUS Adapter Mobile Device

System Introduction

The A2 flight control system uses the Controller Unit at its core, which is connected with the IMU, GPS-COMPASS PRO、LED-BT-I、PMU and ESCs to complete the system. The system can achieve the height-lock and position-lock functions by using the IMU and the GPS, to control the aircraft.

Please carry out the following procedures to finish assembly, configuration and flight-testing.

Mount the A2 flight control system on your aircraft finish connection. → Configure the system using A2 Assistant software. → Basic flying test → FailSafe and Low-voltage settings → Advanced functions: IOC, Gimbal, Gear

Symbol Instruction

General Symbol

	Forbidden(Important)		Cautions		Tips		Reference
	GPS Satellite number		Distance		TX signal good		TX signal lost
	Roll to left		Roll to right		Pitch up		Pitch down

LED Symbol

○(N)	N=1	N=2	N=3	N=4	N=6	N=20	N=∝
Meaning	One Blink	Two Blinks	Three Blinks	Four Blinks	Six Blinks	Twenty Blinks	Continuous Blinks

e.g. (3) means three Red blinks.

(∝)LED blinks yellow and green alternatively.

□ (N)	N=∝
Meaning	Continuous Solid on

e.g. (∝) means Continuous Blue Solid on.

1 Assembly and Configuration

For hardware installation, software configuration and compass calibration please adhere to the following sections.

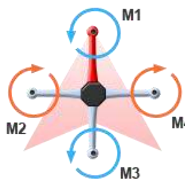
1.1 Hardware Installation and Connection

(1) Please adhere to "1.1.1 Mixer Type Supported" to choose a mixer type and assemble your aircraft.

(2) Please adhere to both "1.1.2 Hardware Connection Diagram" and "1.1.3 Important for Assembly and Connection" to install and connect all units on your aircraft.

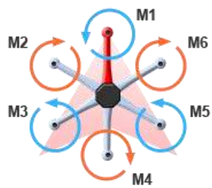
1.1.1 Mixer Type Supported

Following Mixer Types are supported.

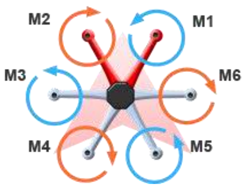


Quad-rotor I

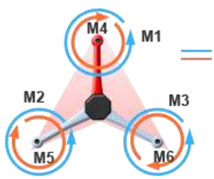
Quad-rotor X



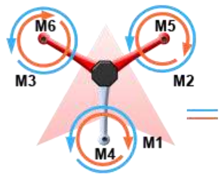
Hexa-rotor I



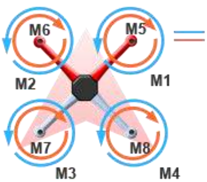
Hexa-rotor V



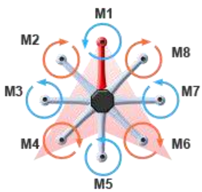
Hexa-rotor IY



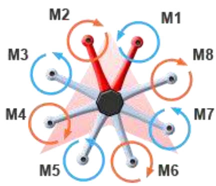
Hexa-rotor Y



Octo-rotor X



Octo-rotor I

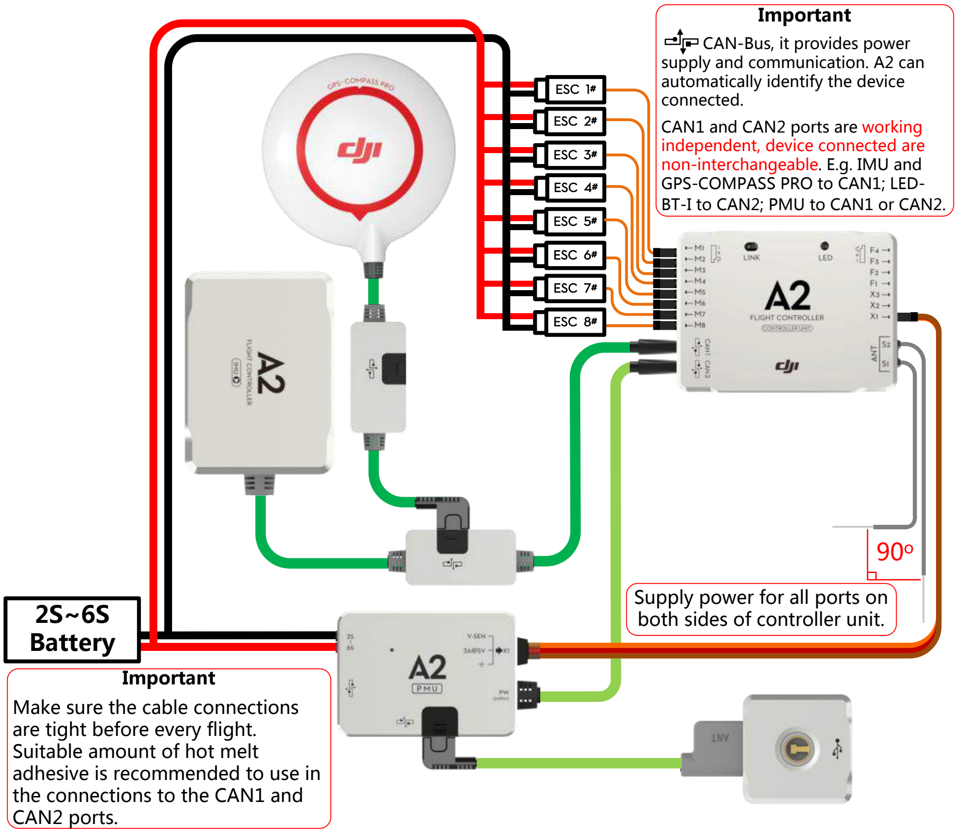


Octo-rotor V

⚠ The direction of the arrow in diagram indicates the rotation direction of the motor/propeller.

For coaxial propellers: Blue propeller is at TOP; Red propeller is at Bottom. Otherwise all propellers are at top.

1.1.2 Hardware Connection Diagram



1.1.3 Important for Assembly and Connection

This section describes all device port functions, assembly requirements, connection requirements and tips during usage. Also the linking procedures between the built-in Receiver DR16 and your Transmitter. Please read all information below carefully, especially if you are a first time user.

(1) Controller Unit

The Controller Unit is the core component of the A2 flight control system:

(1) M1~M8 are used to connect to the ESCs of the aircraft.

(2) The built-in Receiver DR16 is based on DJI DESST technology, which can be used with the Futaba FASST series and DJI DESST series Transmitter.

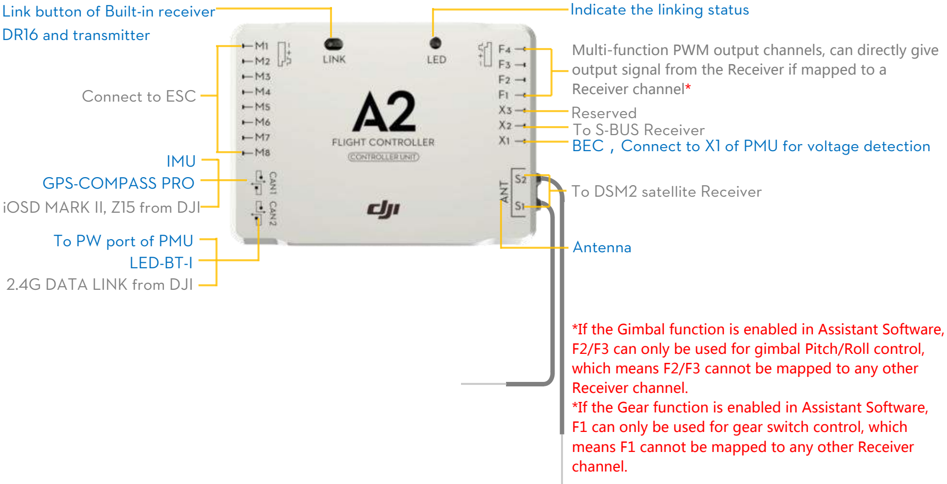
(3) CAN1 and CAN2 ports are working independently and should connect to different modules.

(4) 4 independent and configurable outputs.

(5) It is compatible with the external Receiver, e.g. DSM2 satellite Receiver.

(6) Use the optional DJI DBUS Adapter to support the traditional receiver.

Port Description



Mounting Requirements:

Install the Controller Unit in the proper position to make sure the ports are accessible. No specified direction is required.

Place the antennas in an open space under the aircraft, DO NOT block them. Position the heads of two antennas at a 90-degree angle. DO NOT bend or wind them.

Receiver System

The A2 flight control system can use its own built-in Receiver, and also can support external receivers. Whatever type of Receiver is used, please make sure that the Receiver and Transmitter is linked correctly before use.

A. Built-in Receiver

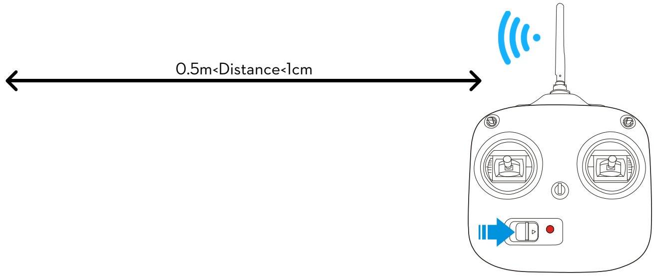
For enhancing the system integration and reliability, the A2 is integrated with a 2.4G receiver based on frequency hopping technology. The built-in Receiver can be used with the Transmitter of Futaba FASST series or DJI DESST series after linking. For users, you are only asked to carry out the link procedures, no extra requirement for connection.

Please carry out the following procedures to finish the Link process, and the configuration in the **A2 Assistant software->Basic ->R/C ->Receiver Type**. Select the **DR16** option.

During use, you may see the following LED indication, please do the operation according to the table below.

LED	Description	Operation
Green (∝)	Signal from Transmitter has been detected by the Receiver, but not matched.	Link operation required
Red (∝)	No Transmitter signal is received, e.g. the flight control system is powered on but the Transmitter is powered off.	Switch on
Green (∝)	The Receiver and Transmitter have been linked to each other successfully.	Can work normally

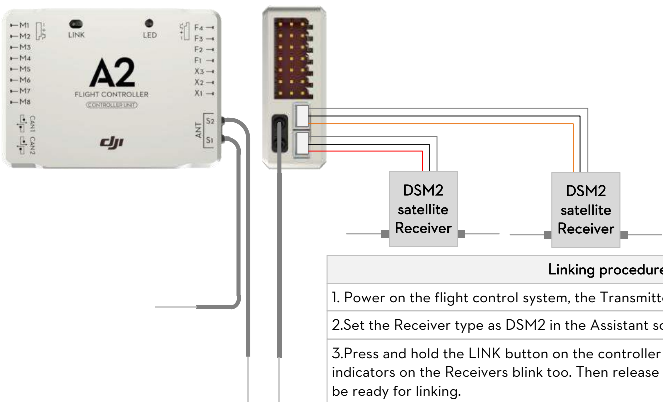
Link Procedures
1. Turn on the transmitter, it begins to send signals after 1.5secs.
2.Power on the flight control system, configure the Receiver type as DR16 in the Assistant software.
3.Press the LINK button, hold for 2secs, wait until the LED blinks Red ● .
4.Release the LINK button, the LED turns Green on after successfully linking.



⚠ The DR16 Receiver is compatible with the Futaba transmitters which have optional FASS MODE MULT, MLT2 or 7CH. Users can find out more available Futaba transmitters and configuration requirements refer to the FAQ->The Transmitter setup of FUTABA.

B. DSM2 Satellite Receivers

If using DSM2 satellite Receivers, please follow the diagram for connection, set the Receiver referring to your Receiver manual, and select the Receiver type as **DSM2** in the **Assistant software->Basic->R/C-> Receiver Type**.



Linking procedures
1. Power on the flight control system, the Transmitter should be turned off.
2.Set the Receiver type as DSM2 in the Assistant software.
3.Press and hold the LINK button on the controller unit the LED blinks red ● and the indicators on the Receivers blink too. Then release the LINK button the Receiver will be ready for linking.
4.Press and hold the linking button on the Transmitter then turn on the Transmitter to start linking, release the button after the Transmitter is displayed Linked or the indicators on the Receivers are solid on.
5.The LED on the controller unit will be solid green on after linking successfully.

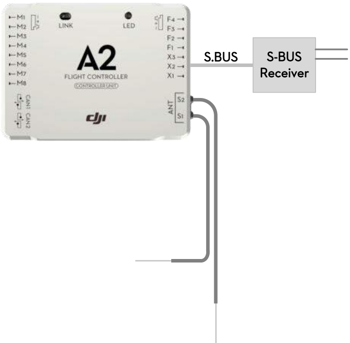
⚠ Notes for the DSM2 users:

- There is no need to enable the FailSafe function in the Transmitter. If the Receiver loses the signal from the Transmitter, the controller unit will enter into FailSafe automatically, and the aircraft will hover or Go-home as configure in the FailSafe in the Assistant software.

- When using the dual-mode Transmitter, please set the transmiting mode as DSM2 in SYSTEM SET UP->FRAME RATE ->MODE, which should not be DSMX.
- Support DSM2 satellite Receivers used with all SPEKTRUM Transmitters, e.g. DX6I DX7S DX8 DX18 etc., as well as JR Transmitters, e.g. DXS9II DXS11.

C. S-BUS Receivers

If using S-BUS Receivers please follow the diagram for connection, set the Receiver referring to your Receiver manual, and select the Receiver type as **D-BUS** in the **Assistant software->Basic->R/C-> Receiver Type**.

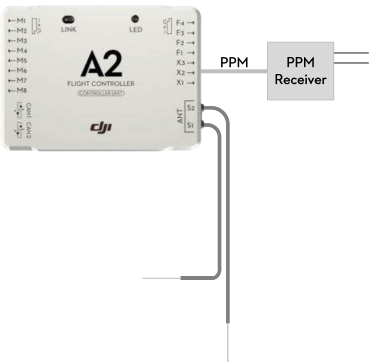


Notes for the S-BUS users:

- It is no need to enable the FailSafe function in the Transmitter. Once the Receiver loses the signals from the Transmitter, the controller unit will enter into FailSafe automatically, and the aircraft will hover or Go-home as configurations of the FailSafe in the Assistant software.

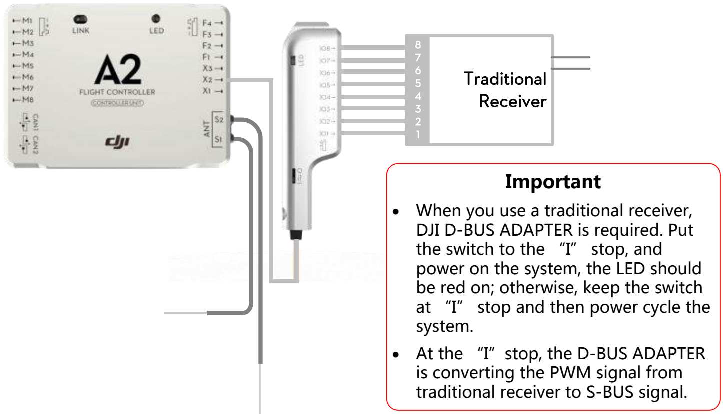
D. PPM Receivers

If using PPM Receivers please follow the diagram for connection, set the Receiver referring to your Receiver manual, and select the Receiver type as **PPM** in the **Assistant software->Basic->R/C-> Receiver Type**.



E. Traditional Receivers

If using Traditional Receivers, the DJI D-BUS Adapter is required. Please follow the diagram for connection, set the Receiver referring to your Receiver manual, and select the Receiver type as **D-BUS** in the **Assistant software->Basic->R/C-> Receiver Type**.



Notes for the traditional receiver users:

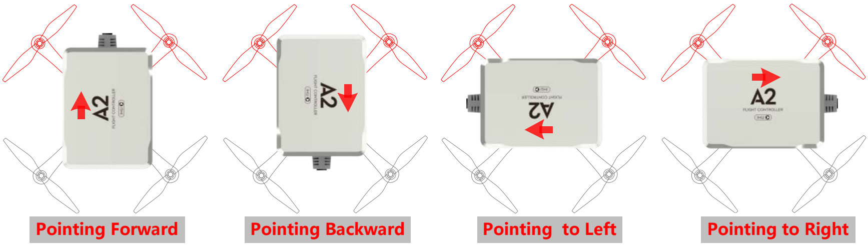
- When using the traditional receiver which doesn't have endpoint adjustment operations to set FailSafe in the U channel, the Go-Home switch is recommended and users can use it to trigger the FailSafe.
- Configure the FailSafe function of your transmitter and receiver according to its instructions, set the FailSafe position of the Go-Home switch in the position triggering the FailSafe function. If it is configured correctly as mentioned above, the FailSafe function will be activated automatically if the receiver loses the signal from the transmitter.
- Users can get more information about the FailSafe function referring to 3.1 FailSafe in this manual and the help text in the Assistant software.

(2) IMU (Inertial Measurement Unit):

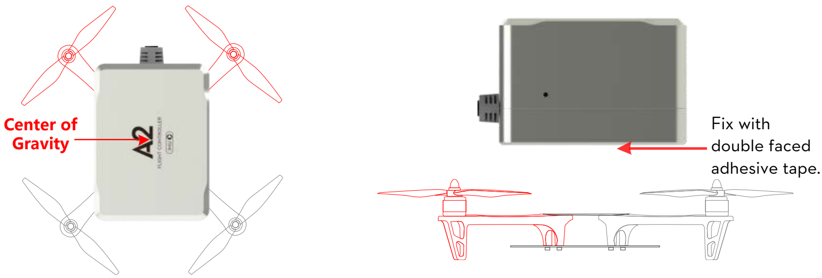
Built-in inertial sensors, for the measurement of aircraft attitude; built-in pressure sensor for the detection of aircraft altitude. Should be connected to the CAN1 port of the Controller Unit, and be mounted according to the required location and orientation. The IMU has been calibrated before delivery, it should be used under the specified temperature; otherwise the temperature may have an effect on the IMU performance.	
Working environment temperature: -5°C ~60°C	Storage environment temperature:<60°C

Orientation Requirements:

Please mount the IMU as one of the following options. Configure in the **A2 Assistant software ->Basic ->Mount -> IMU**, and select the matched option.



Location Requirements:



🚫	(1)	The top side should be facing up. DO NOT mount upside-down.
	(2)	DO NOT cover the ventilation holes, keep them unblocked and clean.
	(3)	Take heat preservation measures if working in cold weather.
⚠	(1)	Mount the IMU at a low vibration position and the sides of the IMU should be precisely parallel to the aircraft body. Based on our experience, there is less vibration near the aircraft's center of gravity.
	(2)	NOT water-proof or oil-proof.
	(3)	Check the double faced adhesive tape regularly to make sure that the IMU is fixed firmly.

There is a CAN-Bus connector, which can be used to connect to the GPS-COMPASS PRO or other DJI product.

(3) GPS-COMPASS PRO

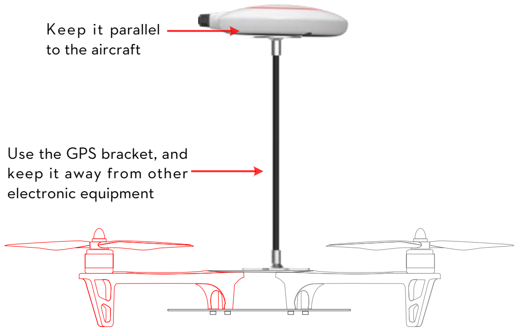
GPS-COMPASS PRO module has a built-in GPS and compass. The compass is used for geomagnetic field measurement. It should be mounted according to the required location and orientation. Compass calibration is required before use. DO NOT use and store the compass in the ferromagnetic material environment.

Mounting Procedure:

a) Use the epoxy resin AB glue to assemble the GPS bracket first. The longest one is recommended.

b) Mount the bracket on the aircraft first, and then fix the GPS-COMPASS PRO on the plate of the bracket (using the 3M sticky pads provided).

Mount Requirements:



Usage Requirements

(1) The DJI logo should be facing the sky, with the orientation arrow pointing directly to the nose direction; otherwise it may lead to take off failure.

(2) Fly the aircraft in an open space without buildings or trees; otherwise it may have an effect on the GPS.

(3) The compass is sensitive to magnetic interference, should be far away from electronic devices, otherwise it may lead to abnormal flying.

(4) Please always keep the compass module away from magnet fields. Otherwise it may damage the compass module and lead the aircraft to work abnormally or even be out of control.

(4) PMU (Power Management Unit)

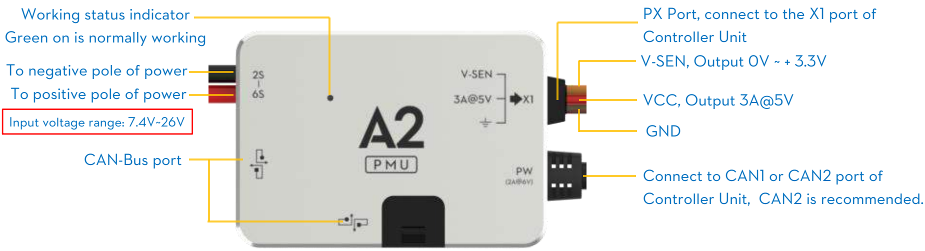
The PMU provides dual BECs (Battery Eliminator Circuit):

(1) PW port outputs power for the whole Flight Control System with current no more than 2A.

(2) PX port outputs power (3A@5V) and V-SEV signal using the low voltage protection function.

In addition, there are two CAN-Bus ports for LED-BT-I connection and other DJI products (e.g. DJI 2.4G Data Link).

Port Description



Mounting Requirements:

Choose a ventilated place to mount the PMU for cooling, no mounting orientation requirement.

(5) LED-BT-I

The LED-BT-I has integrated LED Indicator, Bluetooth and USB port:

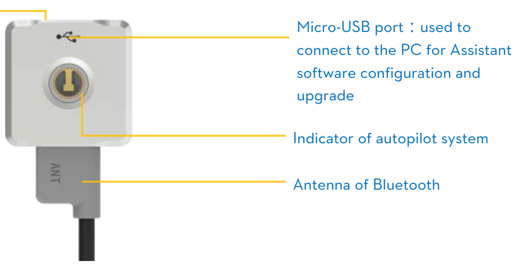
(1) The LED is mainly for flight control system status indication during flying (e.g. Control Mode).

(2) Bluetooth is used for real-time communication with your mobile device (e.g. iPhone), to realize parameter configuration on a mobile device. For parameter configuration using a mobile device, it is required to install the DJI Assistant App on the mobile device. When you mount the LED-BT-I, please make sure the side with ANT LOGO is unsheltered after mounting.

(3) In addition, there is a Micro-USB port, make sure it is mounted for convenient connection.

Port Description:

Bluetooth status indicator	
(solid red)	Normal
(green blinking ●●●●)	Communicating
(solid grey)	Abnormal



Mounting Requirements:

Mount in a good place to make sure the LED is visible during flying. Antenna of Bluetooth should be unobstructed.

1.2 Software Installation and Configuration

Please configure the A2 flight control system in the Assistant Software according to the following instructions. Users are required to configure every item within the "Basic" page when use the A2 flight control system for the first time.

1.2.1 Installing Driver and Assistant Software

Installing and running on Windows

1. Download driver installer and Assistant Software installer in EXE format from the download page of A2 on the DJI website.
2. Connect the A2 flight control system to a PC via a Micro-USB cable. The Micro-USB port of the A2 flight control system is on the LED-BT-I module.
3. Run the driver installer and follow the prompts to finish installation.
4. Next, run the assistant software installer and follow the prompts to finish installation.
5. Double click the A2 icon on your Windows desktop to launch the software.

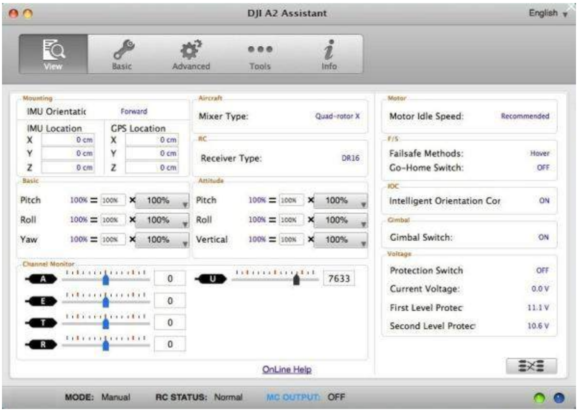
⚠ The installer in EXE format only supports Windows operating systems (Win XP, Win7, Win8 (32 or 64 bit)).

Installing and running on Mac OS X

1. Download the Assistant Software installer in DMG format from the download page of A2 on the DJI website.
2. Run the installer and follow the prompts to finish installation.

3. When launching for the first time if use Launchpad to run the A2 Assistant software, Launchpad won' t allow access because the software has not been reviewed by Mac App Store.

4. Locate the A2 icon in the Finder, press the Control key and then click the A2 icon (or right-click the A2 icon using a mouse). Choose Open from the shortcut menu, click Open in the prompt dialog box and then the software will launch.
5. After the first successful launch, direct launching of the software can be achieved by double-clicking the A2 icon in the Finder or using Launchpad.



Installer in DMG format supports only Mac OS X 10.6 or above.

Usage of A2 Assistant software on Mac OS X and Windows are exactly the same. The Assistant software pages appear in other places of this manual are on the Windows for example.

1.2.2 Configure using Assistant Software on a PC

A2 flight control system can takes power via the USB port during configuration, no additional battery is required. Note that the USB port can supply power no more than 500mA, an additional battery is necessary if connection failure or intermittent working.

Run the assistant software, and follow the built-in guide to carry out the configuration. Note that you may be asked to register for first time use.

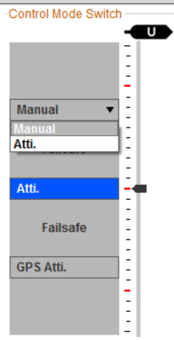
1. View	2. Restore &Upgrade	3.Set	4.Check
Click "Info" to view user information and software version etc.	Enter "Tools" to restore default settings. And check whether the firmware is the latest.	Enter "Basic" page. Set the Aircraft, Mounting, RC, Gain" in each tab.	Enter "View" page to check all basic settings.

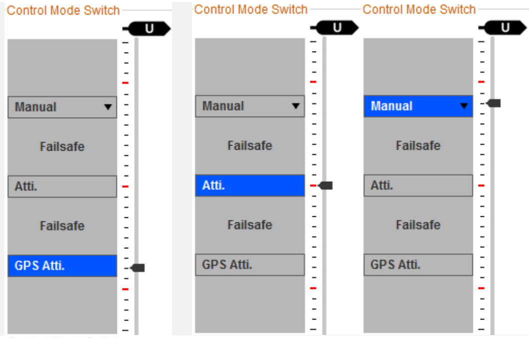
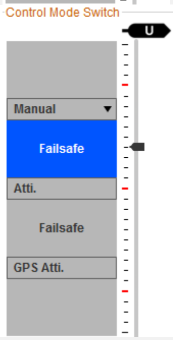
	"RC STATUS" description	**Normal:** the transmitter and receiver are linked and communicating well.
		Disconnect: the A2 Flight Control System is powered on, but the transmitter is powered off.
		RC-LOST: RC signal is lost (e.g. the transmitter is turned off after power on) or the receiver is sending F/S signals (e.g. the aircraft flies out of the range which transmitter is controllable).

!	The firmware version and the Assistant Software version should be matched when using the software to configure the A2 flight control system, otherwise the software will not work. It's recommended to keep the firmware version and Assistant Software version up to date to avoid this issues.

1.2.3 Configure the control mode switch

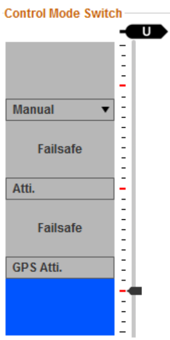
Users should configure the control mode switch in the Assistant software in the following page. Only the control mode switch has been set correctly, the control mode displayed in the left bottom corner will be the same to the control mode pointed by the cursor on the channel U.

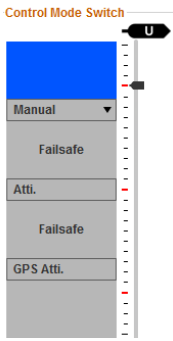
Configuration steps	**Exambles**
Step 1. Power on your Transmitter, map a 3-position switch on the transmitter to the U channel of Controller Unit as the control mode switch, of which two positions are default as Atti. Mode and GPS Atti. Mode and the third position is optional, users can set as Atti. Mode or Manual Mode.	

<table>
<tr>
<td>Step 2.
Toggle the control mode switch to its three positions, accordingly the cursor will move to some control mode.</td>
<td>
</td>
</tr>
<tr>
<td>Step 3.
Power off the Transmitter, the FailSafe will be enabled and the cursor will point to any area out of the control modes.</td>
<td>
</td>
</tr>
<tr>
<td>Step 4.
If all steps above are realized, that indicates the control mode switch is set successfully.</td>
<td></td>
</tr>
</table>

Important

In step 2, if the cursor doesn't point to the correct control mode area (e.g. the following figures), that indicates abnormal control mode switch configuration. Users must re-configure the Endpoint and FailSafe functions in the Transmitter to make the cursor point to the right control mode and the according areas become blue.





1.2.4 Configuration Checking

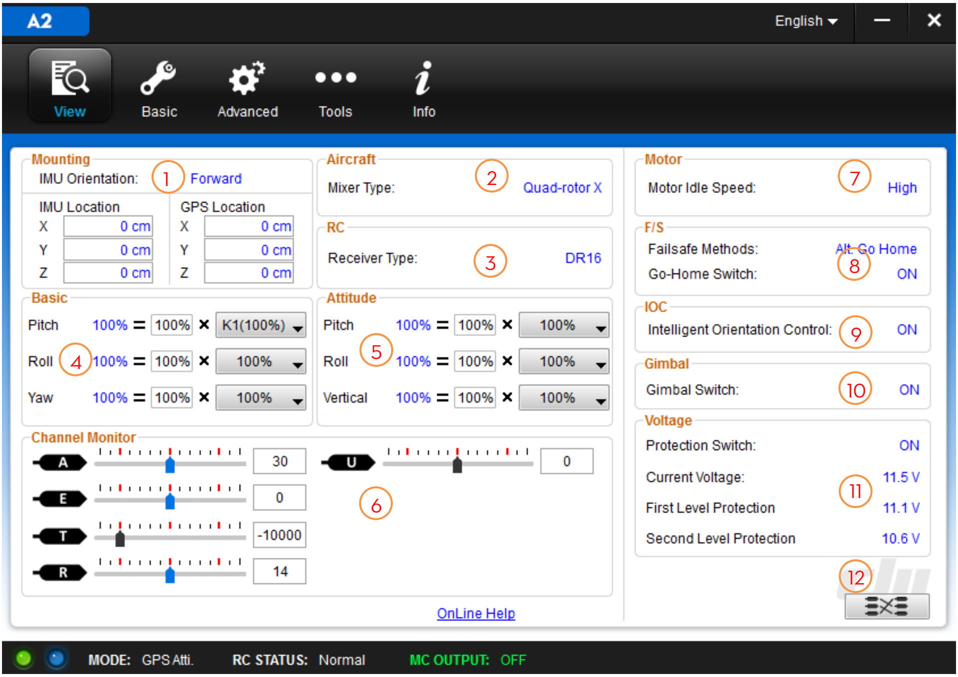
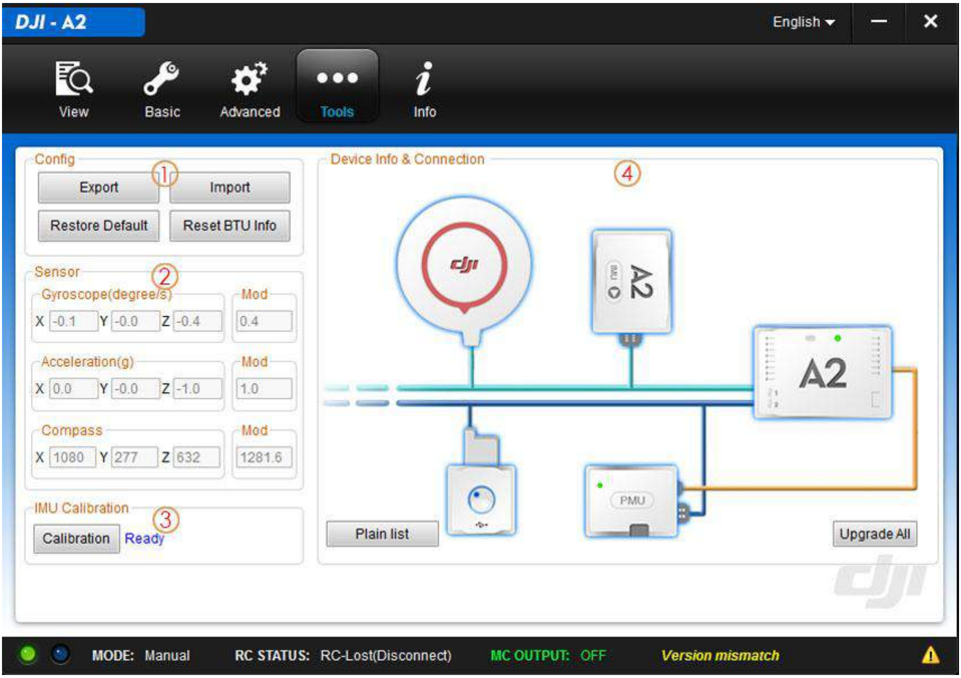


*Fig. above for reference only, please adhere to actual GUI.

Check List	**Description**
①	Check the IMU orientation direction.
②	Check the Mixer Type of aircraft. Make sure the motors are rotating normally, and propeller installation is in correct direction.
③	The Receiver type is correct.
④、⑤	Check the basic and attitude gains.
⑥	Move the sticks to test whether the cursors moves following the sticks. Toggle the "U" switch to test the control mode setting.
⑦~⑪	Advanced configuration, users can configure it according to their requirements after reading the manual.
⑫	Check the Channel Map between the Transmitter and A2 flight control system.

1.2.5 Tools



① Config

Export or import the tuning parameters and restore the default setting and reset the BTU module.

② Sensors

Read gyroscope, acceleration and compass sensor value.

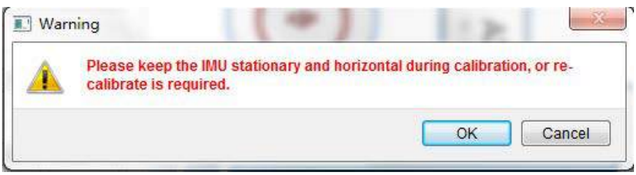
③ IMU Calibration

Calibrate IMU based on the gyroscope and acceleration sensor readings from Assistant. Calibrate is needed, when:

- Gyroscope Mod value exceeds 1.5.
- Acceleration Mod value below 0.98 or exceeds 1.02.

Steps to follow when calibrating IMU:

1. Go to IMU Calibration section after powering on A2, wait until A2 enters "Ready" status.
2. Click "**Calibration**", take note of the following warning message:



Place the IMU on a stationary and horizontal surface and ensure A2 logo faces upward.

3. Click "**OK**" to proceed.

④ Device Information and Connection Status

All devices that connected to the A2 flight controller are highlighted, however, disconnected devices appear grey. Single click a highlighted device to upgrade its firmware. You can also upgrade all firmware by clicking the "**Upgrade All**" button.

1.3 Compass Calibration

The Compass can assistant the GPS to position the aircraft, which is very important during flight. As we know, the compass is very sensitive to electromagnetic interference, which will cause abnormal compass data, and lead to poor flight performance or even flight failure. Compass Calibration MUST be done for first time use.

It is recommended to calibrate the compass outdoors after the Controller Unit finds 7 or more GPS satellites. Regular calibration enables the compass to keep optimal performance.

Calibration Cautions

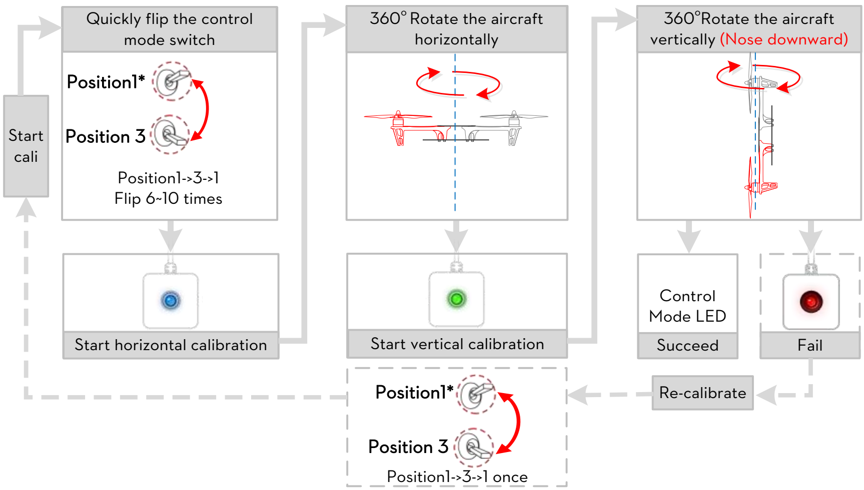
(1) DO NOT calibrate your compass where there is strong magnetic interference, such as magnetite, car park, and steel reinforcement under the ground.

(2) DO NOT carry ferromagnetic materials with you during calibration, such as keys or cell phones.

(3) Compass Calibration is very important; otherwise the flight control system cannot work.

Calibration Procedures

Choose an open space to carry out the following procedures.



Situations that require recalibration

Situations	Descriptions
Compass Data abnormal	LED blinks yellow and green alternatively(🟡🟢(∝)).
Flying field altered	Flying field has changed over a long distance.
Mechanical alteration	The mounting position of GPS-COMPASS PRO module changes. Electronic units such as Controller Unit, CAN-HUB, battery etc. have been added, removed, remounted or other alterations. Mechanical structures of the aircraft has changed
Drifting during flying	Evident drifts occurred in flight such as the aircraft doesn't fly straight
Attitude errors	LED often blinks error indicator when the aircraft turns around.

2 Basic flying

Read this section before basic flight testing.

2.1Control Mode Instruction

The aircraft performs differently when using different control modes. Please read the following table to know the different control modes, which may help you to achieve a more involved flight experience.

Control Mode	GPS ATTI. Mode	ATTI. Mode	Manual Mode
Command Linearity	YES		
Yaw	Control the aircraft to rotate in clockwise and counter clockwise direction. Maximum rudder angular velocity 150°/s		
Roll and Pitch	Aircraft attitude control; Mid point of stick is for 0° attitude, and its endpoint is 35°.		Max-angular velocity is 150°/s. No attitude angle limit.
Throttle	Aircraft height control. Maintain the altitude best above 1 meter from ground when the throttle stick is in mid position.		No altitude locking when the throttle stick is in mid position.
All Sticks Released	Lock position if GPS signal is adequate.	Only attitude stabilizing. No position locking.	Keep original attitude.
GPS Lost	Once GPS signal lost the flight control system will enter ATTI. Mode automatically. Return to GPS ATTI. Mode after GPS signal has recovered for 2 seconds.	---	---
IOC Supported	CL/HL/POI	CL	None

Assign a 3-position switch of the transmitter as the control mode switch. The position-1 is defaulted as "GPS ATTI. Mode" and the position-2 is "ATTI. Mode". The position-3 can be set as "Manual Mode" or "ATTI. Mode" in A2 assistant software.

Control Mode Switch	 position-1	 position-2	 position-3	
Configurable Control Mode	GPS ATTI. Mode	ATTI. Mode *	ATTI. Mode *	Manual Mode
FailSafe Protection	The flight control system will enter FailSafe Mode if the Transmitter signal is lost and no matter if Transmitter signal recovers or not, system will not exit FailSafe mode automatically.		The flight control system will enter FailSafe Mode if the Transmitter signal is lost and the system will exit FailSafe once the signal recovers.	

GPS Involved	YES		NO
Low-voltage Protection	LED alert with Descending or Go Home & Landing precautions		Only LED alert
Environment recommended	Open flying field; Good GPS signal	Narrow Space; GPS signal bad	Regain control in emergency

The difference between ATTI. Mode of position-2 and ATTI. Mode of position-3 is that they are working differently in protection situations.

2.2 Flying Environment Requirements

(1) Before use of the product, please accept some flight training (Using a simulator to practice flying, getting instruction from a professional person, etc.).

(2) DO NOT fly in bad weather, such as rain or wind (more than moderate breeze) or fog.

(3) The flying field should be open without tall buildings or other obstacles; the buildings of steel structure will interfere with the compass.

(4) Keep the aircraft away from obstacles, crowds, power lines, trees, lakes and rivers etc.

(5) Try to avoid interference between the remote control Transmitter and other wireless equipment. (No base station or cell tower around)

(6) The flight control system can't work at the South Pole and the North Pole.

(7) All parts must be kept out of the reach of children to avoid CHOKE HAZARD; if a child accidentally swallows any part you should immediately seek medical assistance.

2.3 Check List before Flying

Double check the following list, otherwise, if any one of the following items is wrong it may lead to flight accident.

(1) All parts are in good condition, no ageing or damaged components

(2) Motor rotating direction

(3) Propeller mounting direction

(4) Mixer Type set in assistant software

(5) IMU and GPS-COMPASS PRO mounting direction

(6) Transmitter channel mapping and sticks movement direction correct

(7) Compass calibration

(8) ESC connection

(9) IMU and GPS-COMPASS PRO firmly mounted

In addition, check the following items to make sure the system can work.

(1) The Transmitter battery is fully charged.

(2) The aircraft battery is fully charged.

(3) Do not over load the aircraft.

2.4 Power on and Check

(1) Control mode LED indicator

Power on the Transmitter then the flight control system. Toggle the control mode switch to different positions.

Control Mode LED indicator			
Control Mode Switch	GPS ATTI. Mode	ATTI. Mode	Manual Mode
LED	● (Stick not in midpoint ●(2))	● (Stick not in midpoint●(2))	No LED indicator
Set	Put the Control Mode switch to GPS position for basic flying test. **Note:** when the GPS signal LED indicator is bad or worst (●(2) or ●(3)) and lasts for more than 3secs, the flight control system will enter into ATTI. Mode.		

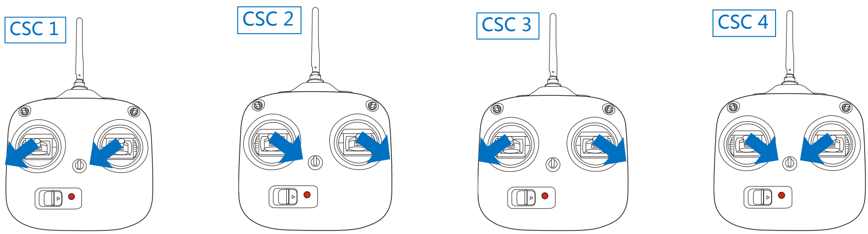
(2) GPS signal LED indicator

GPS signal indication blinks after every Control mode indication. We suggest flying when GPS satellites are more than 5.

GPS signal LED indicator			
Worst (GPS < 5)： ●(3)	Bad (GPS = 5)： ●(2)	Well (GPS = 6)： ●(1)	Best (GPS > 6)：No indicator

2.5 Start Motors Methods

CSC (Combination sticks commands) is used to start motors instead of just pushing the throttle stick. One of the following methods can be used to start/stop motors.



Under the conditions stated below, the motors will stop in ATTI. Mode/GPS ATTI. Mode:

(1) The throttle sticks is under 10% for more than 3secs after motors start.

(2) The throttle sticks is under 10% for more than 3secs after landing.

(3) The throttle sticks is under 10% for more than 3secs and the inclined angle of aircraft exceeds 70°。

If motors fail to start, please refer to the following list for trouble shooting.

(1) The Controller Unit fails to obtain the firmware version of IMU and GPS, please check the connection or upgrade the IMU and GPS.

(2) The firmware version of IMU and Controller Unit is mismatched; please upgrade the firmware of IMU or Controller Unit.

(3) The firmware version of GPS and Controller Unit is mismatched; please upgrade the firmware of GPS or Controller Unit.

(4) The transmitter calibration has exited abnormally, please recalibrate.

(5) The transmitter calibration results with big bias, please recalibrate.

(6) The transmitter calibration results with big mid point bias, please recalibrate.

(7) Incorrect channel mappings, please make sure the basic channels A/E/T/R/U are mapped correctly.

(8) Invalid SN or SN error; please contact your dealer or DJI custom service.

(9) The Controller Unit is locked, please unlock the Controller Unit and reconfigure all the parameters in the Assistant software.

(10) IMU disconnected, please check the connection.

(11) Compass data abnormal, please eliminate magnetic interference and recalibrate the compass.

(12) When Flight limit function is enabled, if the aircraft fly out of the max-radius in ATTI. mode and the motors are stalling, the motors will fail to spool up in GPS ATTI. mode cause the Flight limit function works.

(13) The attitude status is bad and the LED indicator blinks white, the motors will fail to spool up.

(14) The Transmitter disconnected, the motors will fail to spool up.

(15) The A2 flight control system is connecting and communicating with the Assistant software, the motors will fail to spool up.

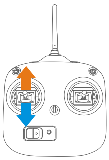
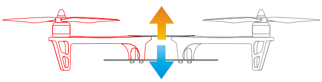
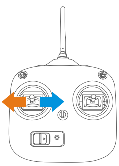
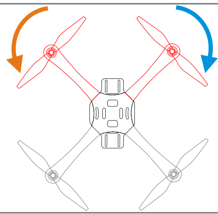
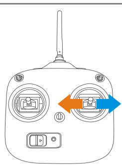
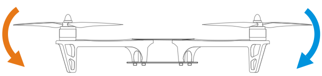
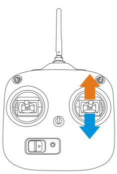
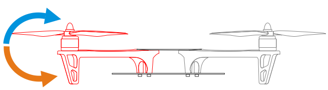
2.6 Basic Flying Test

Carry out the following procedures to complete the basic flight test.

1. Wait the GPS signal to be well	LED
Place the aircraft away from you and others at least 3 meters and wait the  ≥6 (about 30 seconds).	or no Red LED

2. Start motors and takeoff aircraft.	LED
Execute CSC to start motors; all sticks back to midpoint as soon as motors start, then push the throttle stick to take off the aircraft, meanwhile the home point is recorded. NOTE: 36secs after power on; 10secs after  ≥6; Motors have been started, auto-record the position as home point at the first time the throttle stick is raised	(∝)
After the home point is recorded successfully and the distance from aircraft is less than 8m, LED indicator will blink 6 violet continually. Note: only when GPS signal is good (no Red LED) LED indicator will blink 6 violet continually.	(6)

3.Operate sticks to control the flying attitude of the aircraft during flight

Transmitter (Mode2)		Aircraft	Operations
Throttle Stick			Push Throttle sticks to control the aircraft to elevate and descend. The aircraft can lock to an altitude when the throttle stick is at midpoint.
Yaw Stick			Push the yaw stick to rotate the aircraft in clockwise or counter clockwise direction.
Roll Stick			Push roll stick to control the aircraft left or right, pitch stick to control forward or backward. When both roll and pitch sticks are at midpoint： (1) GPS ATTI. Mode: the aircraft will be stabilized and locked in horizontal position. (2) ATTI. Mode: the aircraft will be stabilized but unlocked in horizontal position.
Pitch Stick			

4.Hover
In GPS ATTI. Mode， the aircraft will hover when the throttle/yaw/roll/pitch sticks are all released at mid-point.

5.Landing
Use the throttle stick to control the landing speed, try to land your aircraft gently to avoid shock or crash.

⚠	Please refer to the next section "Protection Functions Setting" to take precautions. (1) Low voltage alert: yellow quick flashes or red quick flashes. (2) FailSafe: LED indicator blinks blue.
⚠	Moreover, you may come across the following abnormal situation, please carry out the operation below. (3) Compass data is abnormal; the LED blinks yellow and green alternatively. Please re-calibrate the Compass. (4) IMU data is abnormal, the LED blinks four green. Please contact your dealer.

3 Protection Functions Setting

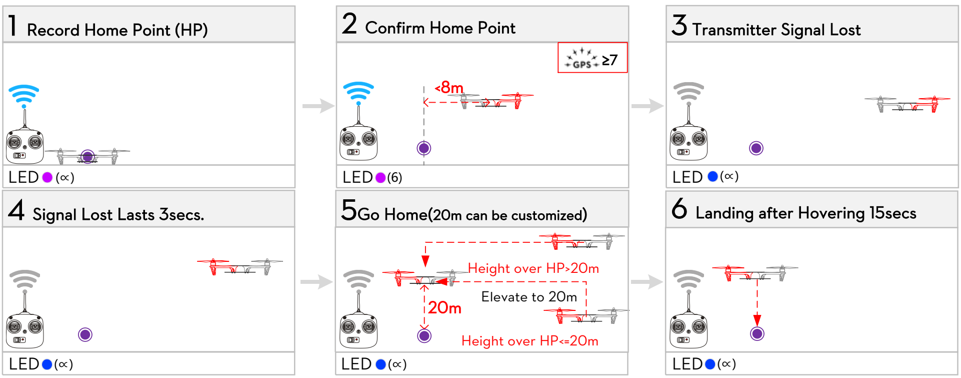
Set protection in the Assistant software ->Advanced page. FailSafe and Low voltage protections are required.

3.1 FailSafe

FailSafe works when the Transmitter (TX) signal is lost, the flight control system will automatically control the aircraft to reduce injuries or damage.

	TX signal	GPS	Descriptions
Home Point (HP)		GPS ≥ 6	30secs later after power on; 10secs later after GPS ≥6(or no Red LED); Motors have been started; auto-record the position as home point at the first time the throttle stick is raised.
FailSafe			Flight control system can automatically control the aircraft after Transmitter signal is lost. It should be set in **Assistant software->Advanced->F/S**, while Hover, Go-Home or Alt Go-Home is optional. Additionally, a Go-Home switch can be enabled.
One-Key Go Home			Go Home switch can be used to trigger a "go home" without FailSafe. If One-Key Go Home is enabled during flying, you no longer have control of the aircraft, the LED blinks in its Control Mode. If One-Key Go Home is disabled, you regain the control at once. If already in a FailSafe condition, then the switch will not work.

FailSafe and Go Home procedures



(1) The aircraft will not go home (only attitude stabilizing) in the condition that GPS <6 or GPS is not working, even if Transmitter signal is lost or Go Home switch is triggered.

(2) It is recommended to set the Go Home switch in the Assistant software. Users are suggested to enter FailSafe and go home by using the Go Home switch rather than turning off the Transmitter in emergency situations.

(3) Make sure there are no obstacles during aircraft go home and users are familiar with the methods to regain control.

How to regain control in FailSafe

3-position Switch	Position-1	Position-2	Position-3	
	GPS ATTI. Mode	**ATTI. Mode**	**ATTI. Mode**	**Manual Mode**
Regain control	You have to toggle the control mode switch once to regain control if the signal recovers.		Regain control as soon as signal recovers.	

3.2 Low Voltage Protection

Low voltage protection is used to alert low battery voltage during flight; in this case, users should promptly fly back the aircraft and land to avoid unexpected damages.

To use this function please set in **Assistant software->Advanced->Voltage** page to configure two voltage levels.

Protections		Option Selected	Conditions	LED	Aircraft
	First level	LED	----	Yellow (∝)	None
		GH & Landing	Make sure the home point is recorded and no obstacles in going home and landing path.	Yellow (∝)	Go-Home & Landing
	Second level	LED	----	Red (∝)	None
		Descending	----	Red (∝)	Descending directly

Go-Home & Landing Usage Tips

(1) The home point recorded is the same in both FailSafe and Low voltage protection. The aircraft will not go home in the following cases :

a) Control mode switch is at the position-3 (Manual Mode or ATTI. Mode)

b) GPS signal is bad (GPS<6)

c) The distance between aircraft and the home point is less than 25m, and the height over the Home point less than 20m.

Descending Usage Tips

The aircraft will not hover when the throttle stick is at the mid point. Push the throttle stick to 90% of its endpoint, the aircraft will still ascend slowly if you continue to pull the throttle stick, and the control of Pitch, Roll and Yaw are the same as before.

(1) Please pay attention to the LED alert of low voltage and make sure the power is enough for go home and landing. Insufficient power reserve will cause the aircraft to crash as well as other consequences.

(2) If the second level low voltage alert occurs in below procedures, the aircraft will descend automatically.

a) When the aircraft is in FailSafe and Go Home process。

b) When the aircraft is controlled by the Ground Station.

4 Advanced Functions

IOC and Gimbal functions of A2 and how to use A2 Assistant app via a mobile device.

4.1 IOC (Intelligent Orientation Control) function

IOC	Help users to set the Flying direction; Should be enabled in Assistant software.
Flying direction	The flying direction of aircraft when pushing the Roll and Pitch sticks.
Forward direction	The flying direction of aircraft when the pitch stick is pushed forward.
Normal flying	IOC is disabled. Forward direction is pointing to the nose direction and changes along with the nose.
CL flying	Course Lock. Its forward direction is pointing to the nose direction when recording, which is fixed until you re-record it or exit from CL.
HL flying	Home Lock. Record a Home Point (HP), push Pitch stick to control the aircraft far from or near to the HP.
POI flying	Point of Interest. Record a point of interest (POI), the aircraft can circle around the POI, and the nose always points to the POI.

Conditions of IOC function

Flying	IOC Setting	Control Mode	GPS-COMPASS PRO Required	GPS Satellites	Distance Limits
Normal	----	----	----	Basic to control mode	None
CL	Enabled	Not Manual Mode	Compass	None	None
HL	Enabled	GPS ATTI. Mode	GPS	GPS ≥6	Aircraft ←≥10m→ HP
POI	Enabled	GPS ATTI. Mode	GPS	GPS ≥6	Aircraft ←5m~500m→ POI

Step 1 IOC switch setting

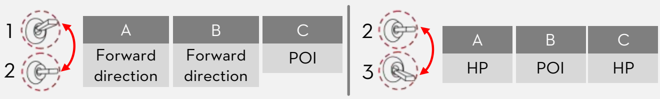
Please enable the IOC function in **Advanced->IOC** page of Assistant software. Then choose a 3-positon switch on the Transmitter to set as IOC switch, which is used to select the different IOC modes and manually record the Forward direction, HP and POI recording.

Below are the three options of IOC switch setting which may be configured in the Assistant software.

Switch positions		A	B	C
1		OFF	OFF	OFF
2		CL	CL	POI
3		HL	POI	HL

Step 2 Forward Direction, HP and POI Recording

After you enable the IOC in assistant software, the flight control system will record the forward direction and home point automatically after power on, if the recording conditions are met. You can Manually re-record the forward direction, home point and POI during flying. Read the following table for the recording method details.

	CL	HL	POI
Aims	Record a direction as Forward direction	Record a position as HP	Record a position as POI
Conditions	36secs after power on	10secs later after GPS≥6; Motors have been started.	10secs later after GPS≥6.
Automatically	Automatically record at 36secs after power on	Automatically record at the first time you push the throttle stick	No Automatic record method
Manually	According to any option of IOC switch setting, quickly toggle the switch between adjacent positions 3-5 times to record manually. 		
Successful	●(20)	●(20)	●(20)

⚠

(1) DO NOT toggle the switch between the position 1 and 3 frequently, which may re-record the position 2.

(2) The new Home Point and Forward Direction can be set only after one has already been recorded automatically.

(3) HP is not only used in IOC, but also in FailSafe and Low voltage as go home and landing destination. The flight control system will automatically record the HP even if IOC function is disabled in Assistant software but Forward direction and POI can be recorded only after IOC is enabled.

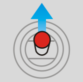
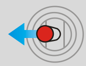
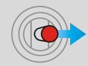
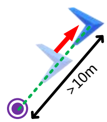
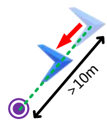
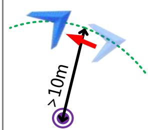
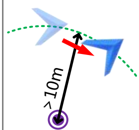
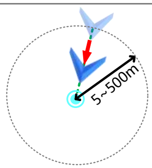
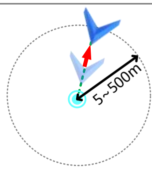
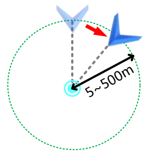
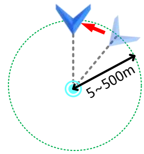
(4) Once the Home Point is recorded successfully, LED will blink ●(6) continually under the following conditions. All conditions must be true.

1. GPS≥7.
2. Distance between aircraft and the recorded home point is less than 8m.
3. Current control mode is in GPS ATTI. Mode or ATTI. Mode of switch position-2.

Step 3 IOC flying test

Please study the following diagram then make an IOC flying test. IOC LED indicator blinks ●(●(2) means not all stick(s) at the midpoint)

HP POI Flying direction Forward direction Route Auxiliary line

Flying	IOC switch	Record	Pitch stick control of aircraft		Roll stick control of aircraft	
						
Normal	OFF	None				
CL	CL					
HL	HL					
POI	POI					

DO NOT toggle the IOC switch frequently in HL flying to avoid re-recording the HP unwittingly.

IOC function is available only when all the required conditions are satisfied. If any condition is omitted the flight control system will exit IOC. Please keep an eye on the LED to know the current control mode.

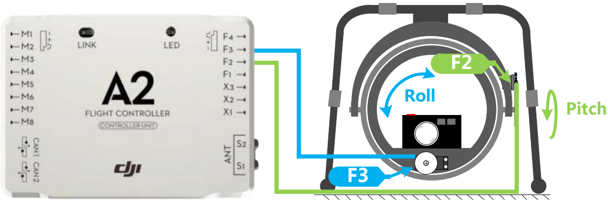
(1) It' s recommended to start the HL flight when the aircraft is >10m away from the HP. If starting the HL when the distance between aircraft and HP is less than 10m and it' s the first time you start HL after power on, then the flight control system will only enter HL after flying out of the 10m range.

(2) During HL flying if one of the following conditions occur, the flight control system will exit HL and enter into CL: the aircraft is within of 10m from HP; the control mode is changed to ATTI. Mode; GPS<6(LED (2) or (3)).

4.2 Servo Gimbal function

Connect the servos of your gimbal to the Controller Unit as the fig. below，roll servo connects to F3 port and pitch servo connects to F2, and configure in **Advanced->Gimbal** page in the Assistant software. No Receiver channel is asked to be mapped for the F2 or F3 port if gimbal function is enabled in the Assistant Software.

Note: Even you map Receiver channels to F3 and F2 (Which are shown as D3 and D2 in the Assistant Software -> Channel Mapping), the F3 and F2 will not give output signals from the mapped Receiver channels.



4.3 Gear function

Once enable the Intelligent Gear function, the gear is default down on the ground or in case of emergency (e.g. motor failure tolerance, auto landing); you can control it to be up or down by a switch when the aircraft altitude is above 5m during flight.

Please configure in the **Advanced->Gear** page in the Assistant software. Connect the landing gear of S800 EVO to the Controller Unit as fig. below.

(1) Make sure to enable and configure the Intelligent Gear function in the Assistant software first, and then connect the gear to the F1 port.

(2) The Gear channel is required to be mapped with a channel on Receiver if the Intelligent Gear function is enabled in Assistant Software, and the F1 port will give outputs for retracting control.

(3) Once you map the Gear channel, F1 port will give output signals from the controller for retract control. Otherwise, even the Intelligent Gear function is enabled; F1 will give output from D1 (it's necessary to map the D1 channel with a channel on Receiver as your demands).

4.4 Attitude Control When One Motor Output Fails

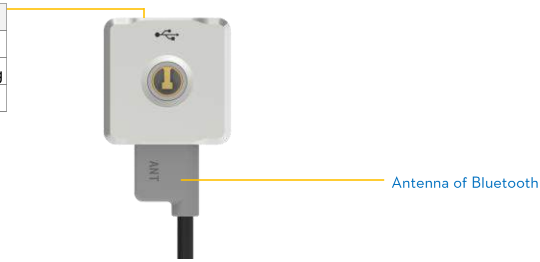
For Hexa-rotor, including Hexa-rotor I, Hexa-rotor V, Hexa-rotor IY and Hexa-rotor Y, the aircraft with A2 flight control system is attitude controllable when one motor output fails.

Select Course lock or home lock mode for flying the aircraft into a safe area to land when the aircraft is far away or the attitude can't be recognized.

4.5 DJI Assistant App Usage

There is a built-in Bluetooth in the A2 LED-BT-I module. With a DJI Assistant App installed on your mobile device, remote parameter configuration can be obtained via Bluetooth communication between the A2 Flight Control System and the mobile device.

Bluetooth status indicator	
(red bar)	Normal
(four green dots)	Communicating
(grey bar)	Abnormal



Supported iOS devices

iPhone 4s, iPhone 5, iPhone 5s, iPod Touch 5, iPad 3, iPad 4, iPad air, iPad mini,

iOS6.1 or above is required. Bluetooth version is required to be 4.0 or above.

Required versions of DJI Assistant App & Firmware

Require DJI Assistant App version 1.1.14 or above and the firmware of A2 Controller Unit version 2.1 or above, as well as the firmware of LED-BT-I module version 2.0 or above.

Specifications

Bluetooth version	4.0	Environment temperature	-10℃~+50℃
Communication distance	50m	Consumption	240mw(0.04A@6V)

DJI Assistant App Usage

Step 1 Download and installation

1. Search the **DJI Assistant** in App store on mobile device and install it.

Step 2 Connect the A2 Controller Unit and the DJI Assistant App

1. Prepare an iOS device supported 4.0 Bluetooth, and then enable the Bluetooth function on the mobile device.
2. Power on the transmitter and the A2 Flight Control System, make sure the Bluetooth Status Indicator is solid Red.
3. Run the DJI Assistant App. You may be asked to register through internet when first login (the account of PC Assistant software is OK for login); follow the tips to set Main Controller name and password.
4. Observe the indicators on the left bottom of the software. (connection indicator and communication indicator) On the DJI Assistant App, if the communication indicator is, please double check the connections and driver installation; otherwise if the indicator is blinking, go to next step.

5. Select the "Basic" option. Please follow step-by-step for your first-time-configuration. Basic configuration is necessary. Click the icon ⓘ to get the configuration details.
6. You can click the "Advanced" option for more parameter settings. Advanced setting is optional. There are Motor, F/S, IOC, Gimbal, Voltage, Limits, Gear, etc.
7. Check all parameters in the View page.
8. Select "More" to obtain more details. Including: Restore MC default settings, Accounts, Main Controller List, Information, wiki, Rate DJI Assistant, FAQ, Feedback, About.

1. Make sure to upgrade the LED-BT-I module to the latest firmware via the PC Assistant software on a PC before you use the DJI Assistant App with the A2 Flight Control System.
2. Every time you run the DJI Assistant App, the App will search the Controller Unit automatically.
3. The gain value displayed on Mobile Device and PC may be a little different, that is OK for use.

Step 3 Flying Test Procedures

1. Get the aircraft ready, run the DJI Assistant and make sure it is connected with the main controller. (The indicators on the DJI Assistant are )
2. Start the motors.
3. The "View" page shows the relative parameters real-time when flying.
4. Go to the "Basic" and click into the "Gain" page to set the values of all gains real-time during flying.
5. Go to the "Basic" and click into the "Tool" page to view the values of IMU & Compass real-time during flying.
6. Finish the flying and land your aircraft.

Only the parameter referred above can be changed during flying. Others can be configured after landing.

Appendix

LED indicator descriptions

Control mode	GPS signal
Manual Mode: No indicator	Best (GPS > 6): No indicator
ATTI. Mode: (1) (sticks not in mid-point (2))	Good (GPS = 6): (1)
GPS ATTI. Mode: (1) (sticks not in mid-point (2))	Bad (GPS = 5) : (2)
Ground Station: (1)	Worst (GPS < 5): (3)

Flight Attitude	
Attitude good: No indicator	Attitude status bad: (3)
IMU data lost, calibrate IMU needed：(4)	

Compass calibration			
Horizontal calibration	(∝)	Calibration Failed	(∝)
Vertical calibration	(∝)	Abnormal Compass Data	(∝)

Low voltage alert			
First level alert	(∝)	Second level alert	(∝)

FailSafe mode		
During the FailSafe	(∝)	

Errors			
System Error	(4)	Compass Abnormal after power on	(∝)

IOC Recording	
Record home-point successfully	(20)
Aircraft is in the 8m range of HP	(6)
Record forward direction successfully	(20)
Record a Point Of Interest successfully	(20)

Bluetooth	
A2 Assistant is connected / disconnected to the flight control system	(∝)

When the LED blinks (3), please hover or land the aircraft and wait for the white LED to go off.

When the LED blinks (3), it is not recommended to fly.

When the LED blinks (4), please contact your dealer.

Specifications

General		
Built-In Functions	• Built-in Receiver	• External Receiver Supported
	• Multiple Control Modes	• 9 Types of Supported Multi-rotor
	• 2-axle Gimbal Supported	• Other DJI Products Supported
	• Enhanced FailSafe	• Low Voltage Protection
	• Intelligent Orientation Control	• 4 Configurable Outputs
	• Dynamical Systems Protection	• Sound Alarm
	• PC & Bluetooth Ground Station	• Configure Parameters Via Bluetooth

Peripheral	
Supported Multi-rotor	• Quad-rotor: I4, X4 • Hexa-rotor: I6, V6, Y6, IY6 • Octo-rotor: X8, I8, V8
Supported ESC output	400Hz refresh frequency.
Supported Transmitter for Built-in Receiver	Futaba FASST (MULT, MLT2, 7CH) Series and DJI DESST Series
External Receiver Supported	Futaba S-Bus, DSM2, PPM
Recommended Battery	2S ~ 6S LiPo
Other DJI Products Supported	Z15, iOSD Mark II, D-BUS Adapter, S800 EVO, 2.4G Data Link, H3-2D

Electrical & Mechanical	
Power Consumption	MAX 5W (Typical Value: 0.3A@12.5V)
Operating Temperature	-5°C to +60°C
Total Weight	<= 224g (overall)
Dimensions	• MC: 54mm x 39mm x 14.9mm • IMU: 41.3mm x 30.5mm x 26.3mm • GPS-COMPASS PRO: 62 mm (diameter) x 14.3 mm • PMU: 39.5mm×27.6mm×9.8mm • LED-BTU-I：30mm x 30mm x 7.9mm

Flight Performance (can be effected by mechanical performance and payloads)	
Hovering Accuracy (In GPS ATTI. Mode)	• Vertical: 0.5m • Horizontal: 1.5m
Maximum Wind Resistance	<8m/s (17.9mph / 28.8km/h)
Max Yaw Angular Velocity	150deg/s
Max Tilt Angle	35°
Ascent / Descent	6m/s

FAQ

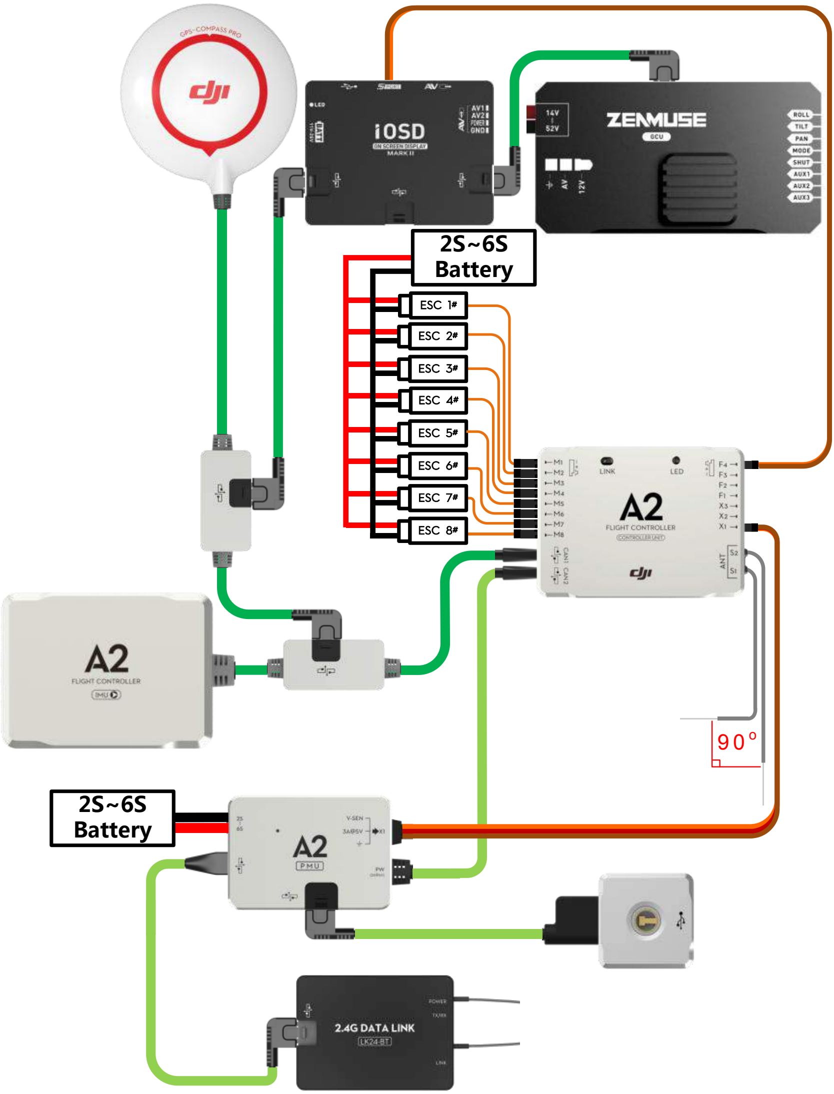
Use with other DJI products

The A2 can be used with other DJI products such as iOSD Mark II, Z15 series gimbals, S800 EVO and 2.4G Data Link(iPAD Ground Station function), H3-2D, etc. Users should connect them to the correct CAN-Bus port.

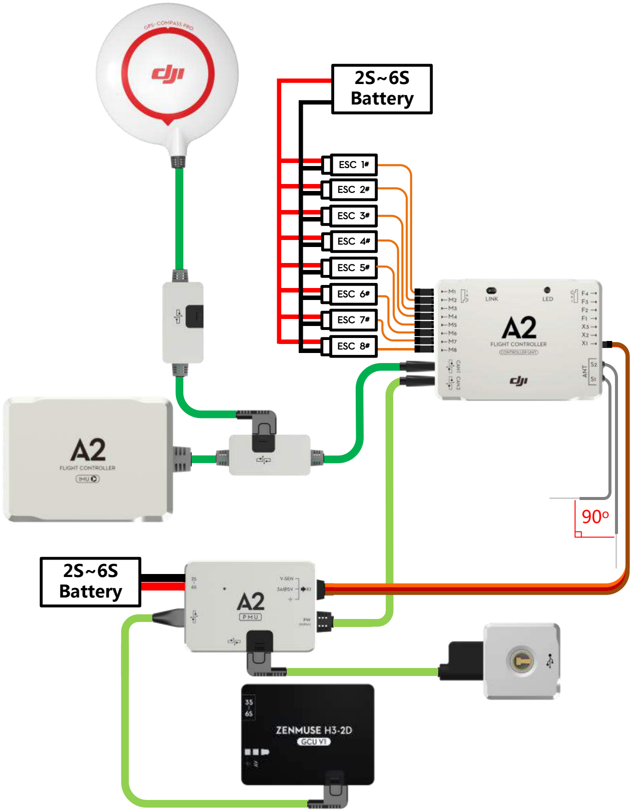
CAN1: iOSD Mark II, Z15 series.

CAN2: 2.4G Data Link (iPAD Ground Station function), H3-2D.

The following 2.4G Data Link connection diagram is the connection for your reference.



The following H3-2D connection diagram is the connection for your reference.

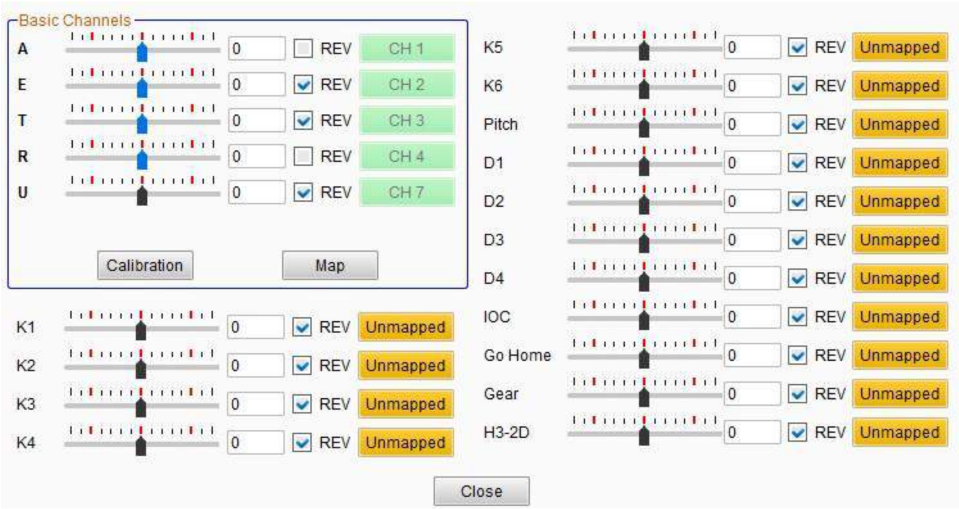


⚠	(1)	H3-2D users should upgrade the firmware to the latest version (GCU V1.6& IMU V1.6 or above).
	(2)	If the 2.4G Data Link and H3-2D are used at the same time, a CAN-HUB module is required.

When using the A2 flight control system firmware version V2.1, the firmware of other DJI products used in conjunction must be matched with the requirements in the table below.

Other DJI Products	Firmware/Software Version (or above)	Assistant Software(use to upgrade)
iOSD Mark II	V3.0	iOSD V4.0 & OSD Viewer V4.0
Zenmuse H3-2D	GCU V1.6 & IMU V1.6 & CMU1.0	H3-2D V1.02
Z15-GH3	GCU V0.12 & IMU V1.4	Z15-GH3 V1.00
Z15-5D	GCU V0.12 & IMU V1.4	Z15-5D V1.00
Z15-5N/7N/GH2/5R	GCU V0.0.12 & IMU V1.0.18_beta	Z15 V1.4
2.4G Bluetooth Datalink	The Ground end V1.0.1.5 & The Air End V1.0.1.1 & BTU V1.0.1.2	2.4G Bluetooth Datalink V1.0.0.6
iPAD Ground Station	V1.3.56	

Channel Mapping Instructions for PC Assistant Software



Basic Channel	Default Settings	Usage Descriptions
A	Roll Control of the Controller Unit, mapped to the Channel 1 of Receiver	During Assistant Software usage, please click the "Calibration" button, to calibrate the Transmitter sticks travel. During calibrating, make sure to operate strictly following the prompts; otherwise may lead to calibration failure. Click the "Map" button, then you can re-do mapping for A/E/T/R/U.
E	Pitch Control of the Controller Unit, mapped to the Channel2 of Receiver	
T	Throttle Control of the Controller Unit, mapped to the Channel3 of Receiver	
R	Yaw Control of the Controller Unit, mapped to the Channel4 of Receiver	
U	Control Mode Switch of the Controller Unit, mapped to the Channel7 of Receiver	
Others	Default Settings	Usage Descriptions
K1~K6	Remote Gains Adjustment of the Controller Unit, unmapped.	Click "Unmapped" button to map K1~K6 to the channels of Receiver.
Pitch	Gimbal Pitch Control of the Controller Unit, unmapped.	Click "Unmapped" button to map Pitch to a Receiver channel for the gimbal servo control.
D1~D4	Direct Channels (The corresponding ports are F1~F4 on the Controller Unit) of Controller Unit, unmapped.	Click "Unmapped" button to map D1~D4 to the Receiver channels. If you enable the Gimbal functions in Assistant Software, then the F3/F2 are used for gimbal control; even D3/D2 are mapped to channels of Receiver,

		and the signals from the mapped Receiver channels will be ignored. You can use F4 for switching the video channel of iOSD Mark II, then map D4 to a Receiver channel.
IOC	IOC function of the Controller Unit, unmapped.	Click "Unmapped" button to map IOC to a Receiver channel. It is recommended to use a 3-position switch channel.
Go Home	One-Key Go Home function of the Controller Unit, unmapped.	Click "Unmapped" button to map Go Home to the Receiver channel. It is recommended to use a 2-position switch channel.
Gear	Intelligent Gear function of the Controller Unit, unmapped.	If you enable the Gear function in Assistant Software, then the F1 is used for the gear control of S800 EVO landing.
H3-2D	H3-2D function of the Controller Unit, unmapped.	Click "Unmapped" button to map H3-2D to a Receiver channel. It is recommended to use a Knob switch channel, which is only used for H3-2D pitch control.

The Pitch and the H3-2D channels can be used at the same time. The Pitch is for the pitch control of servo gimbal, and the H3-2D is for the pitch control of H3-2D gimbal

Recommended Mapping for Futaba Transmitter (Mode 2) User

Controller Unit Channel	Receiver Channel	Recommended Transmitter Switch
A	Channe 1 (AIL)	Joystick J1
E	Channe 2 (ELE)	Joystick J2
T	Channe 3 (THR)	Joystick J3
R	Channe 4 (RUD)	Joystick J4
U	Channe 7 (AUX5)	3-Position switch, e.g. SG
K1~K6	Channe 5 (GEAR)	Knob switch, e.g. LD, RD
Pitch	Channe 6 (Vpp)	Knob switch, e.g. LD, RD
D1/D3/D2	----	----
D4	Channe 9 (AUX1)	2-Position switch, e.g. SF
IOC	Channe 10 (AUX2)	3-Position switch, e.g. SG
Go Home	Channe 11 (AUX3)	2-Position switch with spring back function, e.g. SH

Gear	Channe 8 (AUX4)	2-Position switch, e.g. SF
H3-2D	Channe 12（AUX5）	Knob switch, e.g. LD、RD

Settings of gain values for Your Reference

To set the value of basic gain and attitude gain you can refer to the following diagram. These values are only for reference and may vary in practice.

Aircraft	Configuration Information					Basic			Attitude		
	Motor	ESC	Propeller	Battery	Weight	Pitch	Roll	Yaw	Pitch	Roll	Vertical
F450	DJI-2212	DJI-30A	DJI-8 Inch	3S-2200	890 g	150	150	135	150	150	140
F550	DJI-2212	DJI-30A	DJI-8 Inch	4S-3300	1530 g	170	170	150	160	160	150
S800 EVO+Z15	DJI-4114	DJI-40A	DJI-15Inch	6S-15000	7000g	140	140	130	140	140	130

The Transmitter setup of FUTABA

Please configure the Frequency item on your Transmitter adhere to the table below. (The names of FASST modes here are based to the Transmitter FUTABA T8FG, please ensure to select the most similar mode as the names differs for different Transmitters)

Transmitter type	AREA	FASST
FUTABA 18MZ	Default	FASST-MULTI\FASST-7CH
FUTABA 14MZ with TM-14	Default	MULT\7CH
FUTABA 14SG	FRANCE\GENERAL	FASST-MULTI\FASST-7CH
FUTABA 12Z 2.4G FASST with TM-14	Default	MULT\7CH
FUTABA 12FG 2.4G FASST with TM-14	Default	MULT\7CH
FUTABA 10CG or 10C with TM-10	Default	7CH
FUTABA 9C SUPER with TM-7 or TM-8	Default	7CH
FUTABA 8FG SUPER	FRANCE\GENERAL	MLT2\MULT\7CH
FUTABA 8FG	FRANCE\GENERAL	MULT/7CH
FUTABA 7C 2.4G	Default	Default
FUTABA 6EX FASST	Default	Default

Disclaimer

Please read this disclaimer carefully before using this product. By using this product, you hereby agree to this disclaimer and signify that you have read it fully.

THIS PRODUCT IS NOT SUITABLE FOR PEOPLE UNDER THE AGE OF 18.

A2 flight controller is designed for experience multi-rotor enthusiasts providing excellent self-leveling and altitude holding, which completely takes the stress out of flying RC multi-rotors for both professional and hobby applications. Despite the product having a built-in flight control system and our efforts in making the operation of the controller as safe as possible when the main power battery is connected, we strongly recommend users to remove all propellers when calibrating and setting parameters. Make sure all connections are good, and keep children and animals away during firmware upgrade, system calibration and parameter setup. DJI Innovations accepts no liability for damage(s) or injuries incurred directly or indirectly from the use of this product in the following conditions:

1. Damage(s) or injuries incurred when users are drunk, taking drugs, drug anesthesia, dizziness, fatigue, nausea and any other conditions no matter physically or mentally that could impair your ability.
2. Damage(s) or injuries caused by subjective intentional operations.
3. Any mental damage compensation caused by accident.
4. Failure to follow the guidance of the manual to assemble or operate.
5. Malfunctions caused by refit or replacement with non-DJI accessories and parts.
6. Damage(s) or injuries caused by using third party products or fake DJI products.
7. Damage(s) or injuries caused by mis-operation or subjective mis-judgment.
8. Damage(s) or injuries caused by mechanical failures due to erosion, aging.
9. Damage(s) or injuries caused by continued flying after low voltage protection alarm is triggered.
10. Damage(s) or injuries caused by knowingly flying the aircraft in abnormal condition (such as water, oil, soil, sand and other unknown material ingress into the aircraft or the assembly is not completed, the main components have obvious faults, obvious defect or missing accessories).
11. Damage(s) or injuries caused by flying in the following situations such as the aircraft in magnetic interference area, radio interference area, government regulated no-fly zones or the pilot is in backlight, blocked, fuzzy sight, and poor eyesight is not suitable for operating and other conditions not suitable for operating.
12. Damage(s) or injuries caused by using in bad weather, such as a rainy day or windy (more than moderate breeze), snow, hail, lightning, tornadoes, hurricanes etc.
13. Damage(s) or injuries caused when the aircraft is in the following situations: collision, fire, explosion, floods, tsunamis, subsidence, ice trapped, avalanche, debris flow, landslide, earthquake, etc.
14. Damage(s) or injuries caused by infringement such as any data, audio or video material recorded by the use of aircraft.
15. Damage(s) or injuries caused by the misuse of the battery, protection circuit, RC model and battery chargers.
16. Other losses that are not covered by the scope of DJI Innovations liability.

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Exhibit 6:
A2 Flight Controller Features


MC


IMU


GPS


PMU

click and drag

9 TYPES OF MULTI-ROTOR AND A CUSTOMIZED MOTOR MIXER

It's a UAS that's targeted at commercial and industrial multi-rotor platforms with simple configuration, easy installation and stable performance. It also supports customized motor mixing, which greatly meets the demands of particular users.

The A2 supports 9 types of traditional motor mixer:

INTELLIGENT ORIENTATION CONTROL (IOC)

Usually, the forward direction of a flying multi-rotor is the same as the nose direction. By using Intelligent Orientation Control (IOC), wherever the nose points, the forward direction has nothing to do with nose direction:

In course lock flying, the forward direction is the same as a recorded nose direction. See the following figures

In home lock flying, the forward direction is the same as the direction from home point to the multi-rotor. See the following figures

POINT OF INTEREST (POI)

A2 has a POI function: Point of Interest. When the GPS signal is good, users can record the current position of the aircraft as a point of interest by a preset switch on the remote control. The aircraft can achieve a circling flight around the point of interest with the nose pointing at the POI in an area of 5 meters to 500 meters radius, when the roll command is given. This function is easy to set and simple to operate, it is suitable for all-round shooting of a fixed scenic spot.

POINT OF INTEREST

Click to play video

(//www.youtube.com/embed/HRF8lCtmb3Q)

point of interest

INTELLIGENT LANDING GEAR FUNCTION

Once you enabled the Intelligent Landing Gear function in the assistant software, the landing gear is default at the Lower position when the aircraft is on the ground; and the system will lower the landing gear in emergency, motor failure or auto landing, to protect the aircraft and gimbal; you can control to lower or retract the landing gear by a switch when the aircraft altitude is over 5m from the ground.

AUTO RETURN-TO-HOME /ONE-KEY GO-HOME

If the multirotor and its controller disconnects during flight, the system's failsafe protection will come to the rescue and if the signal is good enough, the multirotor will return to home and land automatically.

You can also setup a One Key Go Home function to activate this feature manually.

MULTI-ROTOR ONE-MOTOR FAIL PROTECTION

This function means that when the aircraft is in attitude or GPS attitude mode, and one of the motors stops, the aircraft will retain good attitude and rotate around the frame arm with the stopped motor. In this condition, the aircraft is still under control and returns home safely and highly reducing the risk of a crash.

MULTI-ROTOR
ONE-MOTOR FAIL PROTECTION

Click to play video

(//www.youtube.com/embed/HQ7wa5cBT_w)

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Exhibit 7:
A2: A New Standard in Flight Control

IMPOSSIBLY PRECISE

A NEW STANDARD IN FLIGHT CONTROL

Main Controller

- Dual CAN-Bus system
- 12 output channels

- Built-in 2.4GHz DR16 receiver which supports Futaba FASST series transmitters.
- Reserved JR and SPEKTRUM satellite

IMU

- High sensitive built-in damper IMU module

GPS

- High gain antenna
- High precision satellite receiver

PMU

- Voltage detection and alarming
- An extendable CAN BUS port

LED

- Equipped with an LED Bluetooth indicator(LED-BT-I) adjusting parameters is more convenient than ever
- Internet connection to your smartphone will still be available when one is adjusting parameters via LED-BT-I module

Our Most Advanced Multirotor Stabilization Controller Ensures Total Ease Of Flight, Reliability And Stability In Any Situation.

Total Solution
For Aerial Photography

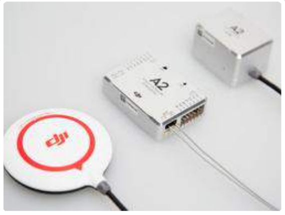
- Supports all multirotor platforms.
- Ideal for DJI video downlink, iOSD, Ground Station, Zenmuse gimbals. Compatible with future products.
- All modules can be upgraded online through Assistant to offer more functionalities.

Gallery

EXPAND


(/uploads/product_photo/image /108/a2_photo_01.jpg)


(/uploads/product_photo/image /109/a2_photo_02.jpg)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A2 Features

- 9 TYPES OF MULTI-ROTORAND A CUSTOMIZED MOTOR MIXER
- INTELLIGENT ORIENTATION CONTROL (IOC)
- POINT OF INTEREST (POI)
- INTELLIGENT LANDING GEAR FUNCTION
- AUTO RETURN-TO-HOME /ONE-KEY GO-HOME
- MULTI-ROTOR ONE-MOTOR FAIL PROTECTION

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Exhibit 8:
Michael J. Barnes, Beverly G. Knapp, Barry W. Tillman, Brett A. Walters & Darlene Veliki, *Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments*, Technical Report ARL-TR-2081, Aberdeen Proving Ground, MD: Army Research Laboratory (2000)

ARMY RESEARCH LABORATORY

Crew Systems Analysis of Unmanned Aerial Vehicle (UAV) Future Job and Tasking Environments

Michael J. Barnes
Beverly G. Knapp
Barry W. Tillman
Brett A. Walters
Darlene Velicki

ARL-TR-2081 JANUARY 2000

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Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

ARL-TR-2081 January 2000

Crew Systems Analysis of Unmanned Aerial Vehicle (UAV) Future Job and Tasking Environments

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Abstract

The purpose of the research project was to understand the future crew environments for developing unmanned aerial vehicle (UAV) systems. A variety of human engineering tools (job assessment software system [JASS], enhanced computer-aided testing [ECAT], and MicroSaint™) were used to address crew issues related to the utility of having rated aviators as crew members, supplementing current crews with imagery and intelligence specialists, and the use of automation to improve systems efficiency. Data from 70 soldiers and experts from Fort Huachuca, Arizona, Fort Hood, Texas, and Hondo, Texas, were collected as part of this effort. The general finding was that the use of cognitive methods and computerized tool sets to understand future crew environments proved to be cost effective and useful. Specifically, no evidence was found to support a requirement for rated aviators in future Army missions, but the use of cognitively oriented embedded training simulators was suggested to aid novices in developing the cognitive skills evinced by experts. The efficacy of adding imagery specialists to 96U crews was discussed, and specific recommendations related to automation were derived from the workload modeling.

CONTENTS

TABLES

CREW SYSTEMS ANALYSIS OF UNMANNED AERIAL VEHICLE (UAV) FUTURE JOB AND TASK ENVIRONMENTS

INTRODUCTION

Future battle spaces will be exploited by a variety of aerial and ground platforms to help U.S. forces achieve information dominance. The unmanned aerial vehicle (UAV) family of platforms will increase the range, survivability, and effectiveness of this effort. The purpose of this ongoing research is to understand the crew environment and soldier performance issues related to future UAV systems. Specifically, three major issues were addressed: (a) the importance of using rated aviators for piloting positions for the UAV, (b) the use of imagery specialists and intelligence analysts (96D and 96B military occupational specialty [MOS]) as adjunct crew members, and (c) the potential use of automation to assist in future crew functions. The variety of questions asked required the use of numerous human engineering and human performance data collection methods.

A secondary motivation was to investigate the effectiveness of available tool sets and methodologies to understand human job and mission environments for developing systems. The best way to test the mettle of these approaches was by attacking important problems of developing systems rather than by investigating laboratory problems of dubious validity. The UAV was an ideal candidate because of its crew-intensive mission profiles (Barnes & Matz, 1998) and the need to investigate the crew issues perceived by the Training and Doctrine System Manager (TSM). The TSM's cooperation was absolutely essential in completing this study; in providing direction, expertise, and a sense of priorities; and because a significant investment of the TSM personnel's own time and effort was required during the data collection and analysis portions. The overall study was extensive, including the efforts of more than 70 participants representing expertise from the aviation, intelligence, and UAV communities of Fort Huachuca, Arizona, Fort Hood, Texas, and the contractors in Hondo, Texas, who engineered the Outrider UAV.

RATED AVIATORS

The use of rated aviators as part of the UAV crew was deemed the most crucial issue addressed. The problem is complicated because of the safety, training, and selection issues involved. In the UAV crew, two flight positions were examined: the internal pilot (designated air vehicle operator [AVO]) and the external pilot (EP). The AVO for current Hunter UAV configuration resides in the ground control station (GCS) seated next to the mission payload operator (MPO). The AVO coordinates with the mission commander to do mission planning, assumes flight control of the air vehicle after take-off, and sets the course to the various way points. The AVO must be able to read flight instruments and understand the current flight status but does not usually fly the air vehicle in the sense that a fixed or rotary wing aviator does. Instead, the AVO directs the UAV to a target location and upon arrival, coordinates with the MPO who executes the best search pattern over the target area. The AVO also responds to flight emergencies and makes course changes for tactical or safety reasons. However, most of the initial "hands-on" control of the air vehicle is done by the EP who flies the UAV during take-off and landing using a control device similar to that used for radio-controlled model airplanes. It is important to note that most flight safety problems occur during the EP's watch; this is not a result of any characteristic of the EP; rather, it reflects the dangers associated with take-off and landing for any air vehicle.

Method

Procedure

Four analyses were performed to determine the important cognitive skills required for the AVO and EP positions and to relate them to safety-of-flight issues. Although data were collected for all flight functions for both categories, the main focus was on flight functions clearly related to air vehicle accidents and incidents.

Using the job assessment software system (JASS), the authors collected ratings from UAV AVOs and EPs regarding the importance of an array of cognitive skills to their jobs and tasks. Data were collected from flight-rated U.S. Army aviators to contrast the cognitive skills they reported as particularly important with skills reported by the UAV EPs.

Subsequent analysis indicated that JASS data painted an incomplete picture; it became obvious that more was needed to be known about the relationship between reported cognitive skill levels and actual mishaps. One source of information concerning the relationship of performance and skill level was the training experiences at the UAV Flight School at Fort Huachuca. JASS data were supplemented with enhanced computer-aided testing (ECAT) data from a pilot study collected by Hopson (1995). This study correlated the ECAT scores on one- and two-handed tracking scores with failure rate for the EP training course. In addition, the UAV flight incident report results were compared to the JASS flight tasks, which permitted us to focus our analysis on critical flight functions (TSM, 1998).

Finally, data interpretation proved to be a difficult problem. Besides the relationship of tasks to skill levels, there were operational, programmatic, and experiential issues as well as similar investigations by other services to consider in attempting to forge a position on rated aviators from the raw data. To address these issues, a subject matter expert (SME) working session was convened on 15 October 1998 at Fort Huachuca in order to help interpret the data (see list of participants in Appendix A).

Participants

For the JASS data collection, a total of 30 96U soldiers or Hunter-trained contractors was tested during the exercise. There were 21 MPO and AVO designations, 11 of whom provided JASS data from a primarily AVO task structure and 10 from a primarily MPO task structure for this part of the data analysis. The AVO task list consisted of AVO tasks associated with flight and navigation functions, excluding tasks involved with take-off and landing. In addition, nine certified EPs were tested using the external pilot task structure for the JASS testing. Further, because of the difference in EP experience levels, those with a year or less of experience were considered the low experience group (4) and those with more than 1 year of experience (5) were designated the high experience group. The EP task list consisted of functions related to take-off and landing an air vehicle. This same list of EP functions was administered to 16 currently rated U.S. Army aviators. The aviators characterized themselves as primarily fixed wing (10) or rotary wing (6) when they answered JASS.

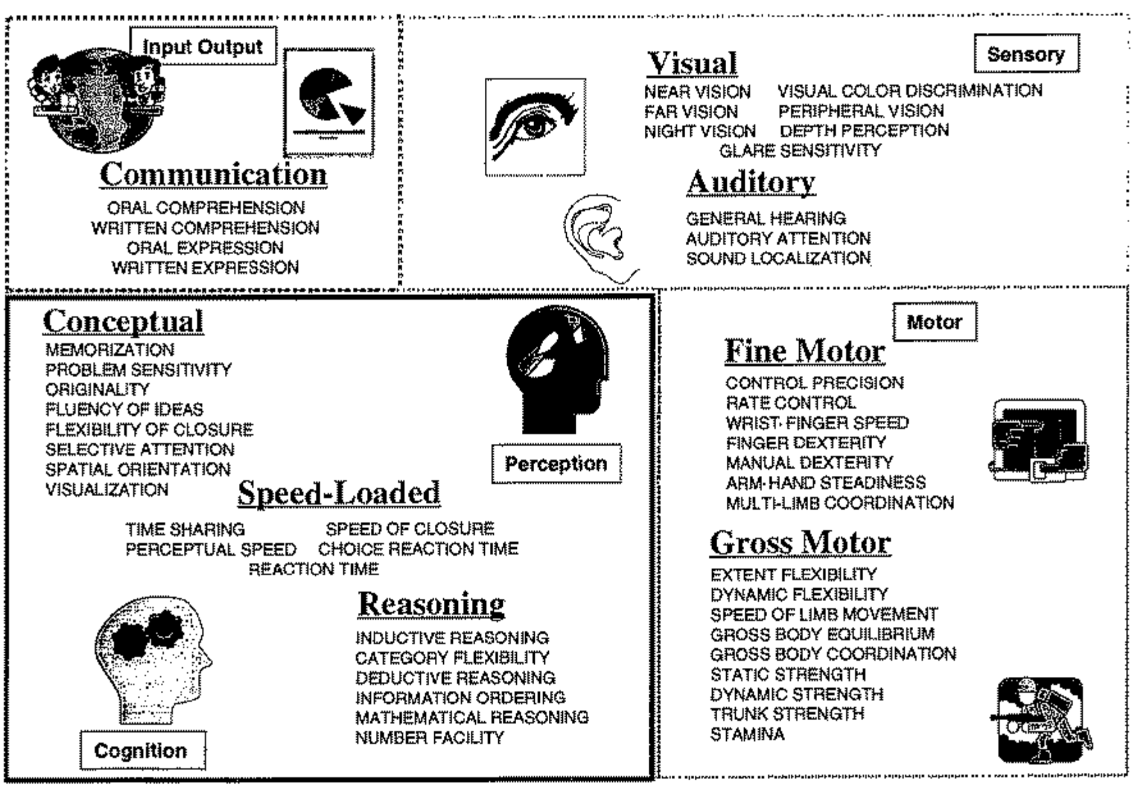
Data from the ECAT selection test battery were used in this analysis as well. The two sub-tests used were the one- and the two-handed tracking tasks. This test was administered in 1995 and used a sample of 28 students from both the Pioneer and Hunter external pilot classes held at Fort Huachuca, including six participants who failed the external pilot course. Finally, a

SME group consisting of 12 members was used to help interpret the data. The group was comprised of military, contractor, and civilian personnel with operational and human engineering backgrounds related to the UAV crew issues.

Test Instruments

Job Assessment Software System (JASS)

JASS is a test instrument developed to elicit from soldiers the relative importance of 50 skills and abilities for specific task functions defining various MOSs. The computerized test is designed to allow the soldiers to rate each skill designation on a seven-point scale for each specified military task. The itemized skills and abilities are illustrated in Figure 1, broken into functional areas: communication, speed-loaded, reasoning, visual, auditory, and psychomotor (fine and gross motor skills). The test is based on validated psychometric investigations performed by Fleishman and his colleagues (Fleishman & Quaintance, 1984) and broken into the underlying cognitive, perceptual, and psychomotor skills that would constitute any human work activity.



Fleishman, E. A. & Quaintance, M. K. (1984). Taxonomies of human performance: The description of human tasks. Orlando: Academic Press.

Figure 1. Job assessment software system – 50 skills and abilities.

This version of JASS was tailored for military applications and was developed using a number of MOS test cases to validate further the basic concepts in an operational context (Knapp & Tillman, 1998). The JASS software was administered to the soldier participants on a laptop computer and required approximately an hour of each soldier's time. Test administrators were present to answer queries about test or procedural matters related to JASS.

Enhanced Computer-Aided Testing (ECAT)

The ECAT battery was developed jointly by the U.S. Army Research Institute and the U.S. Naval Personnel Research and Development Center. It consists of nine sub-tests that were designed to supplement the Armed Services Vocational Aptitude Battery (ASVAB) now used by the Department of Defense for initial selection and training purposes. For this effort, data were collected using only two of the nine sub-tests. These particular tests measured one- and two-handed tracking performance, respectively. The tests were computer administered and lasted approximately 20 minutes each.

Results

The AVO JASS data were investigated to determine whether the requirement for high levels of cognitive skills was pertinent to the flight issues discussed. Figure 2 summarizes the results and indicates that the AVO raters did not consider their flight-related functions (except for communications) to be overly demanding for any of the skill clusters. The complete skill profiles are presented in Appendix B and basically show the same trend. These data are supported by both the accident reports reported next and the feedback from SMEs; the AVO cognitive skill level requirements do not seem to be related to flight issues.

The EP data were more complicated, and both anecdotal and empirical information suggest an important relationship between the EP's skill levels and safety (the data summary is given in Appendix C). Figure 3 is a bar graph plot of the skill categories as a function of skill rating. When the EP's job is compared with the AVO data, it can be seen that this job is rated as requiring higher skill and ability levels across all eight skill clusters.

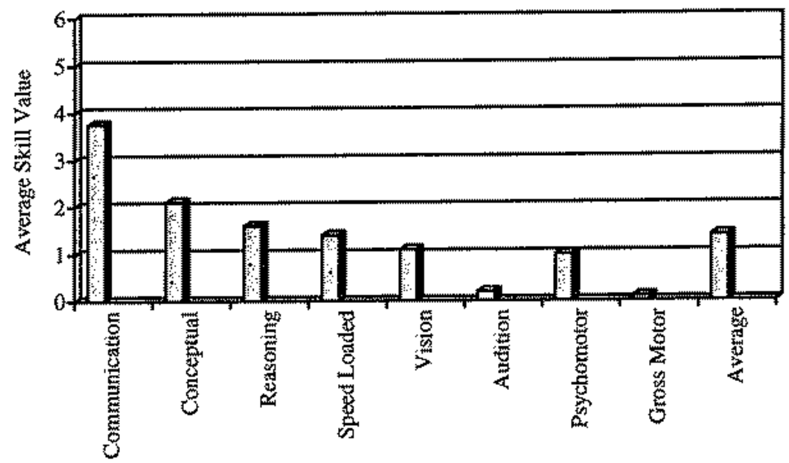


Figure 2. Skill cluster ratings for air vehicle operators.

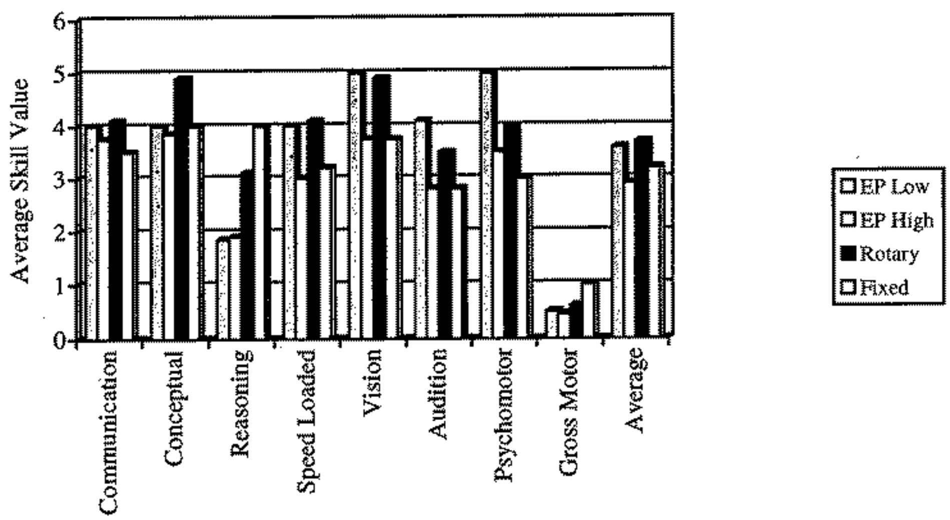


Figure 3. Skill cluster ratings of external pilots (both high and low experience levels) and rated aviators (both rotary and fixed wing).

The data are decomposed further into four job categories: EP low experience, EP high experience, rotary wing aviators, and fixed wing aviators. The main difference was in the reasoning factor, with both aviator groups showing slightly increased importance attached to reasoning skills, compared to the EP groups. There is evidence of relatively heavy loadings on conceptual, vision, and psychomotor components for all groups. The EP low experience group seems to give high ratings to the vision, audition, and psychomotor skill clusters. This suggests that the initial training may have been particularly weighted toward developing these skills.

The ECAT results obtained in a previous study support the particular importance of psychomotor skills during training. As Table 1 indicates, the one- and two-handed tracking scores were nearly perfect indicators of failure rate during the EP training at Fort Huachuca. Five of the six students who failed the course had scores on both the tracking tasks near the bottom of the performance scores of the sampled students. The EP designated "x" who also failed had a severely impaired hand, making his failure to complete the course difficult to interpret.

The data were further analyzed to understand precisely the relationship between flight safety and skill clusters for the four job categories. First, only the task data related to emergency conditions were examined (emergency landings, etc.). Next, identification was made of which of the 50 skills (see Figure 1 for the full listing) were ranked in the top 10 for each of the emergency condition tasks. Finally, determination was made as to how many of these skills were in each skill cluster, and these data were plotted as a function of what percentage of each cluster was represented in the top 10. Based on previous research, it was felt that the importance rankings were a better indicator of the usefulness of each skill cluster in performing crucial task functions vice using simple average skill values (Knapp & Tillman, 1998). The results are plotted in Figure 4, which shows a very different relationship between experience level and the type of skills required in emergency conditions. The experienced EP used mostly conceptual skills in emergency situations, whereas the inexperienced EP reported relying heavily on visual and psychomotor skills during these conditions. These findings are consistent with the results of the ECAT tracking tasks reported (which indicated how important the student's perceptual and motor skills were in passing the EP portion of the UAV training regimen). A surprising finding was that the aviators used speed-loaded skills for emergencies, whereas speed-loaded skills were rated as relatively unimportant by both EP groups.

The UAV accident and air safety report (TSM, 1998) indicated that both the Pioneer and the Hunter UAVs historically had high accident rates of an average of one incident per every 269 and 158 operational hours, respectively. Not surprisingly, almost all of the incidents involved EPs because take-off and landing are the most dangerous parts of the mission for flight safety. However, since 1996, the Hunter EP incident rate has fallen dramatically to 1,201 hours per incident, which compares favorably to the Predator (current Air Force UAV) rate of 1,247 hours per incident. One possibility for this improvement is the maturing of the Hunter EP cadre. Data discussed later support this hypothesis.

Table 1

Ranking of 28 Students on the One-Handed Tracking Test Portions of the ECAT Inventory

System or branch of service	EP	Two-handed tracking	One-handed tracking
Hunter-Army	b	2729	2212
Pioneer-USMC	r	4067	2348
Hunter-Army	d	2829	2353
Pioneer-USN	n	3537	2407
Hunter-USMC	f	3738	2488
Pioneer-USMC	t	3696	2491
Hunter-USMC	e	3512	2545
Pioneer-USMC	q	3208	2605
Pioneer-USMC	v	3271	2632
Hunter-USMC	a	2852	2652
Pioneer-USMC	z	3892	2674
Hunter-USMC	g	3634	2730
Pioneer-USN	u	3123	2796
Pioneer-USMC	I	3656	2800
Pioneer-USN	l	3880	2837
Pioneer-USMC	w	3953	2837
Pioneer-USN	x	3969	2846
Pioneer-USMC	j	3786	2853
Pioneer-Army	p	3902	2923
Pioneer-USN	s	3560	2961
Pioneer-USN	y	3705	2993
Pioneer-USN	k	3782	3002
Pioneer-USN	o	4045	3068
Pioneer-USN	aa	4304	3183
Pioneer-USN	m	4111	3229
Pioneer-USN	ab	4282	3297
Hunter-Army	c	4209	3462
Hunter-Army	h	4895	3756

Shaded area indicates student did not finish course.

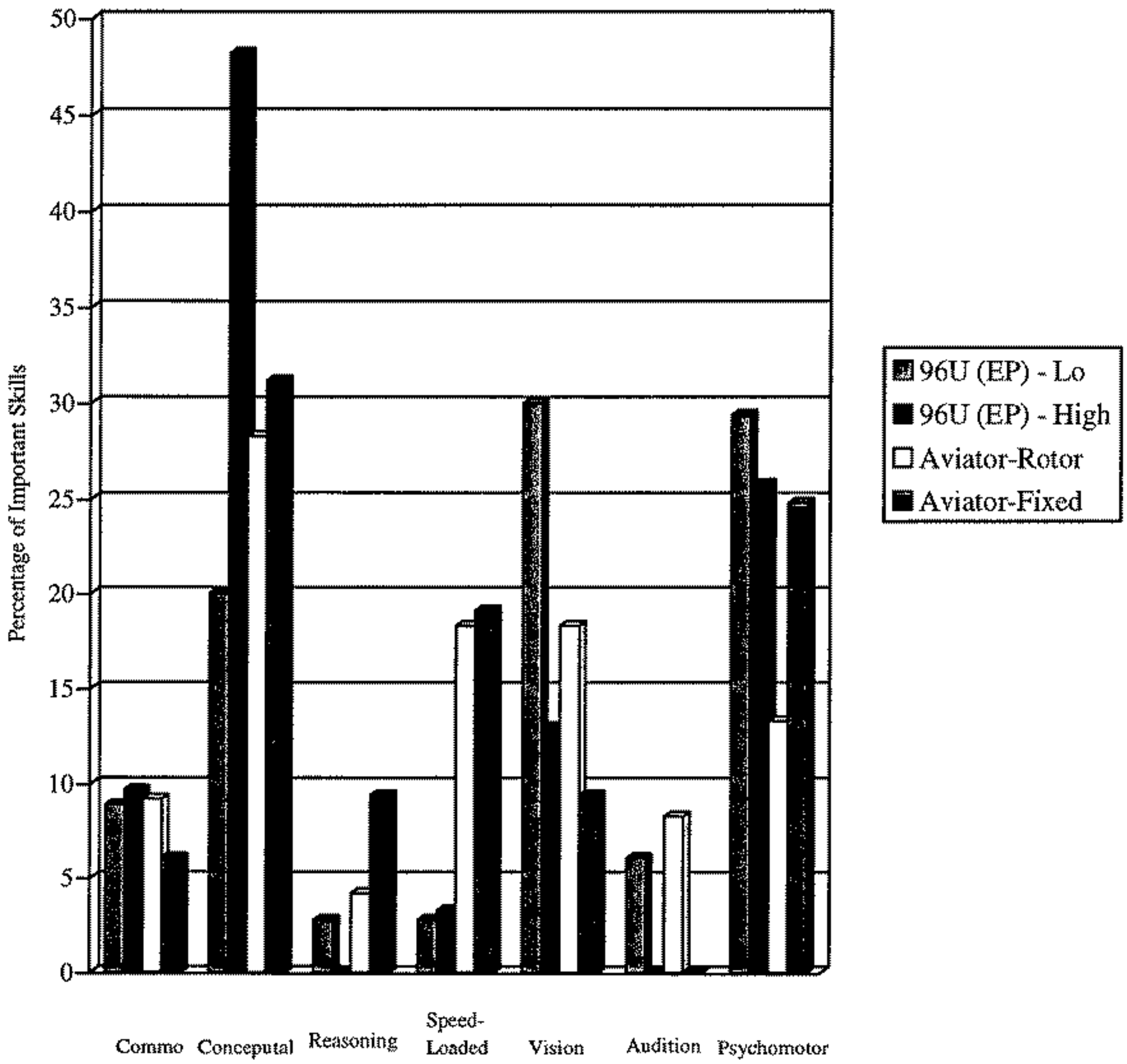


Figure 4. Percentage of important skills used during emergencies, shown by job category.

Discussion

Scant evidence was found for the need of rated aviator skills for the AVO. The JASS list of critical skills, accident data, and the consensus of the SME deliberations suggest that the current skill level of the AVO community is sufficient for piloting responsibilities. The EP situation is more complex. There was a marked difference between experienced and inexperienced EPs in the inventory of skills the two groups used during emergency situations. Apparently, the experienced EPs were able to visualize and anticipate problems before they occurred; an experienced UAV operator described the process as "getting ahead of the air vehicle." With experience, the operator is able to devote his or her attentional resources to future problems while attending to the immediate perceptual and motor tasks in an automatic mode. In effect, the operator crosses a cognitive threshold as expertise increases and the problem domain becomes more cognitive and less psychomotor intensive. This agrees with the psychological literature regarding both automatic processing (Shiffrin & Schneider, 1977) and the development of expertise (Rasmussen, 1983). If this interpretation is correct, using rated aviators would have little effect on the accident rate during landing and take-off. Expertise tends to be task specific. Therefore, the specific motor skills needed to control the radio-controlled UAV would have to be learned by aviators independently of the motor skills learned in flying an aircraft. In particular, the somatic and visual cues that pilots use during aircraft landings would not be useful (and perhaps even counter-productive) for the different skill sets and perceptual viewpoint necessary for radio-controlled landings. This is not to say that there would not be some transfer of training, only that the transfer would be transitory, and the more cost-effective solution would be to develop expertise in the EP corps.

The improvement in the Hunter accident rate gives at least some preliminary assurance that the EP performance record will improve with the maturing of the operator population. This does not address the question of how to turn novices into experts. Fortunately, innovative research funded by the Israeli Air Force offers some promise in addressing this issue. Gopher, Weil, and Bareket (1994) developed a computer game to help train Israeli Air Force cadets before flight training. The computer game simulation was not high fidelity and did not stress motor skills; instead, the game emphasized the higher level conceptual skills (such as the ones identified in the JASS for the experienced EPs) necessary to anticipate and plan in a combat aviation environment. The simulation group was able to generalize these skill sets to actual training. Students practicing the computer game were twice as likely to graduate from advanced flight training as the no-game control groups. The Israeli Air Force has since adopted the computer game as part of their training program. The UAV program would very likely benefit from a similar computer training project. The software would be cost effective because air vehicle fidelity is not an issue; the simulation would need to emphasize attentional and visualization skills. These skills could be developed in parallel to the psychomotor and other flight skills currently being developed in the training program.

A number of related issues were discussed with the SMEs during the consensus exercise held at Fort Huachuca. The greater use of speed-loaded skills by the aviators at first seemed counter-intuitive to the SME group. However, further discussion suggested that the underlying cause was related to the demands of the different aircraft flown by the two communities. The controls and displays that both fixed and rotor wing aviators use are extremely complex, especially compared to the relatively simple EP interface. Thus, the EPs could concentrate on future aircraft states, whereas the aviators had to respond to the more complex interface environment as well as anticipate future problems.

The question of using rated aviators in either the AVO or EP positions was specifically addressed by the group after the data were presented. The group consensus was that UAV operators do not need to be rated aviators for Army applications. In particular, neither the Air Force nor the Navy representatives believed that the EP or AVO should necessarily be aviator rated. The Navy's solution was to have the equivalent of the mission commander be aviator rated when possible. This solution had the advantage of freeing the AVO and EP to concentrate on UAV-related issues, while the mission commander handled the mission planning and air space coordination, giving the crew the benefit of his or her aviation expertise in a supervisory role. The Air Force representative pointed out that the Predator (a current Air Force UAV) was a different air vehicle than those employed by the Army. The Predator was designed to be flown like a standard aircraft and as such, the transfer of skills from the aviator to the UAV community was a natural solution. According to this representative, no firm decision had been made concerning the use of rated aviators for future Air Force UAVs such as Dark Star.

In summary, there was no evidence that would lead to the conclusion that either the AVO or the EP should be rated aviators. In particular, the EPs' landing and take-off functions require motor and cognitive skills that are unique to their mission profiles and job environment. However, the greater use of cognitive skills by the experienced EPs suggests that greater emphasis should be placed on developing these skills during training. The use of computer games was offered as an innovative and cost-effective solution to accomplish this end. Finally, the utility of having military aviators or personnel with equivalent experience as part of the decision chain for UAV crews seems to be both a cost-efficient and a tactically effective method to introduce aviator skill sets into the UAV program.

IMAGERY AND INTELLIGENCE SPECIALISTS AS COMPONENTS OF THE UAV CREW

As mentioned, two 96U operators reside in the GCS during a typical mission. The MPO works with the AVO to search the target area and make preliminary recognition and detection decisions regarding potential targets in the locations designated by the intelligence staff as named areas of interest (NAI). However, MPOs are not imagery or intelligence analysts, and their reporting requirements in this regard are minimal. In light of the specialized skills of the UAV crews, the possibility of adding operators from MOSs with skills and abilities that complement the MPOs' skill set was the focus of this portion of the study. The two MOSs investigated were the 96B, Intelligence Analyst, and the 96D, Imagery Analyst.

Method

Procedure

The JASS computer-based job assessment system was used as in the rated aviator section work. Data analysis proved to be fairly complicated because 96B and 96D MOSs have distinctly different task structures and would therefore bring different skill sets to the 96U crew. In order to assess the commonalities as well as the differences among the three jobs, separate task structures had to be derived for each of the MOS positions. From the task lists, it was then possible to derive an overall ranking of the importance of the JASS skill sets for each task structure.

The actual comparison was done in three steps: (a) the top 20 JASS skills (see Figure 1) for each of the 16 tasks that the MPO performed were rank ordered; (b) the top 20 skills for both the 96B and 96D distinct skill sets were ranked separately; and (c) the resulting ranks of the JASS skills from the 96B and the 96D were compared to the ranks of the JASS skills for the 96U operators for each of the 16 tasks evaluated in the initial step. Kendall's rank order correlation test was used to evaluate rank concordance.

Participants

The comparison was made for the tasks to which the 21 96Us responded on the JASS inventory. Scores from nine 96B analysts and eight 96D imagery specialists were collected on the JASS in order to compare the skill sets of these two MOSs to those of the UAV GCS operators. All soldiers were stationed at Fort Huachuca.

Results and Discussion

Table 2 matches the UAV crew task duties to the skill rankings for the 96B and 96D operators. Kendall's rank order correlation test was used to assess the commonalities among the JASS results. The columns in Table 2 labeled "MOS" indicate the degree of correlation between the 96D and 96B skill rankings and the rankings on each of the duties listed in the first column. The 96D skill rankings were significantly correlated to two of the UAV crew duties ($p < .05$). In contrast, the 96B showed a significant Kendall rank correlation to 14 of the 16 duties the UAV crew engaged in during their missions (again, $p < .05$). Interpretation of the data was that the 96D was a possible candidate to complement the skill profiles of the UAV crews because of the difference in the skill sets used by these two MOS groups. In terms of information theory, the lack of redundancy between the two MOSs implies a higher information transmission rate. The authors' interpretation was given credibility by the SME discussions that indicated the importance of enhancing the imagery interpretation skills of the MPO in particular. It was felt, especially by the 96U operator participants, that the 96D skills would be a very useful addition to the UAV crew. This does not imply that MPO requires the in-depth imagery understanding of the 96D; the 96D skills could be employed remotely at the brigade or division tactical operations center (TOC). For many or perhaps even most missions, the detection and recognition reporting skills of the MPO would suffice to meet the commander's goals. The 96D skills would be necessary for particularly difficult interpretations or specialized missions when in-depth target analyses are required. Another possibility would be to incorporate the 96D skills into the mission command module by enhancing the skill set of the data exploitation operator (DEO) with additional imagery training. The DEO resides in the command module and performs the function of a senior analyst but is not currently required to have 96D training. In summary, the principal conclusion is that additional imagery support using 96D specialists should enhance the overall operational versatility and capabilities of the UAV crews. On the other hand, the role of the 96B as now configured seems to be a satisfactory adjunct to the UAV crews' intelligence-gathering function.

Table 2

Statistical Comparison of Skill Commonalities Using
the Kendall Rank Order Correlation Test

96U duties	96D highest overall skills	96B highest overall skills
Create air vehicle mission plan on display		**
Perform air reconnaissance		**
Perform air vehicle navigation		**
Prepare air vehicle mission plan		**
Detect targets of military significance		**
Identify target type and number		**
Operate remote video terminal		**
Perform mission payload terminal		**
Recognize targets; place in context		**
Transfer control of air vehicle		
Prepare intelligence reports		**
Disseminate mission results	**	**
Coordinate airspace requirements		**
Coordinate with higher headquarters		**
Coordinate with support and external elements	**	**
Conduct launch and recovery operations		

**Significance level: $p < .05$

AUTOMATION AND WORKLOAD MODELING FOR FUTURE UAV PLATFORMS

An important consideration in designing the future crew interfaces is the degree and type of automation required in future UAV applications. The UAV operator has to perform multiple functions, often simultaneously during a typical mission profile (Barnes & Matz, 1998). In order to understand automation requirements in this environment, the MicroSaint™ modeling environment was used to investigate the workload for one potential future UAV platform, the Outrider. The Outrider was a good candidate to investigate incipient crew workload issues (i.e., high workload may suggest a need to automate tasks) because the Outrider was in the process of completing an advanced combat technology development (ACTD) during these data collection efforts. MicroSaint™ was chosen because it is a relatively mature instrument and has been used successfully in a number of human engineering applications. (A detailed description of MicroSaint™ is given in Appendix D.) However, the general findings of this report should generalize to a larger class of PC workload modeling environments; in particular, the underlying workload model residing in MicroSaint™ is shared with other test instruments such as the Improved Performance Research Integration Tool (IMPRINT).

Method

Procedure

First, a model of the Hunter UAV system was developed by using MicroSaint™ and a database that contained most of the GCS operator tasks and functions related to the Hunter system, which range from setting up the equipment, route planing, internal flight procedures, and intelligence gathering to actually landing the UAV. The Hunter model was based mainly on a Hardman III workload task analysis[1] done for the Joint Tactical UAV Program Office as part of a previous project. In addition to task time data and the task sequence logic, the database contained the visual, auditory, cognitive, and psychomotor workload values for each task. This model served as a foundation for the design of the Outrider model.

The Hunter model was then modified according to information from SMEs and data collected during an observation of the Outrider training simulator. The scenario chosen to be used in the model included four stationary targets, no malfunctions, and no in-flight modifications. After the model was executed, two sets of data were produced: the workload values for each operator throughout the scenario and the number of steps required to perform each task.

Participants

The number of SMEs available to assist in building the Outrider model was small; however, the scarcity of the subject pool was mitigated by drawing upon an existing network model of the Hunter UAV, which had been validated during a number of simulation exercises (Barnes & Matz, 1998). The first iteration of knowledge elicitation was done at Fort Huachuca with two experienced UAV operators who were familiar with the Outrider and a human factors specialist familiar with the previous workload model developed for the Hunter in the 1993-1995 time frame. The next iteration was completed at Fort Hood using two 96U soldiers who had

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[1]Test battery developed by ARI

been trained the month before in the Outrider training simulator in Hondo, Texas. The last iteration took place in Hondo with two SMEs whose job was to develop lesson plans for the training simulator and to teach 96U operators to use the Outrider simulator. Both operators had been flight-qualified Hunter operators before being employed in their current positions.

Workload Scales

The visual, auditory, cognitive, and perceptual (VACP) workload theory implemented in this work is discussed in detail in an Army Research Institute report (McCracken & Aldrich, 1984).

Workload theory is based upon the idea that every task a human performs requires some effort or work. Usually, a task is composed of several different types of work, such as visual or cognitive. For example, consider a task such as steering a car. This task will have some visual work (watch where you are going), some cognitive work (decide if you are turning enough), and some psychomotor work (rotate the steering wheel). The workload theory implemented in this effort assigns values representing the amount of effort that must be expended in each channel in order to perform the task. Table 3 scales are taken directly from Bierbaum, Szabo, and Aldrich (1989).

This theory also hypothesizes that when two tasks are performed at once, the workload levels are additive within channels, across tasks. For example, if two tasks are being done at once, one with a psychomotor load of 2.6 and one with a psychomotor load of 4.6, then a psychomotor score of 7.2 (2.6 + 4.6) would be recorded for the time that the two tasks were being performed together.

Results

Four different categories of data were collected to help determine which tasks should be candidates for automation. These categories were based on the model output and data taken from interviews with the SMEs. Besides the two model-based data sources, the SMEs provided a list of tasks that were critical to the mission, and they indicated which additional tasks they would like to see automated.

Table 3

Workload Scale Values

Scale	Scale value	Descriptor
		Auditory scale
	0.0	No auditory activity
	1.0	Detect or register sound (detect occurrence of sound)
	2.0	Orient to sound (general orientation or attention)
	4.2	Orient to sound (selective orientation or attention)
Auditory workload	4.3	Verify auditory feedback (detect occurrence of anticipated sound)
	4.9	Interpret semantic content (speech)
	6.6	Discriminate sound characteristics (detect auditory differences)
	7.0	Interpret sound patterns (purse rates, etc.)
		Cognitive scale
	0.0	No cognitive activity
	1.0	Automatic (simple association)
	1.2	Alternative selection
Cognitive workload	3.7	Sign or signal recognition
	4.6	Evaluation or Judgment (consider single aspect)
	5.3	Encoding or decoding, recall
	6.8	Evaluation or judgment (consider several aspects)
	7.0	Estimation, calculation, conversion
		Psychomotor scale
	0.0	No psychomotor activity
	1.0	Speech
	2.2	Discrete actuation (button, toggle, trigger)
	2.6	Continuous adjustive (flight control, sensor control)
	4.6	Manipulative
Psychomotor workload	5.8	Discrete adjustive (rotary, vertical thumb wheel, lever position)
	6.5	Symbolic production (writing)
	7.0	Serial discrete manipulation (keyboard entries)
		Visual scale
	0.0	No visual activity
	1.0	Visually register or detect (detect occurrence of image)
	3.7	Visually discriminate (detect visual differences)
Visual workload	4.0	Visually inspect or check (discrete inspection or static condition)
	5.0	Visually locate or align (selective orientation)
	5.4	Visually track or follow (maintain orientation)
	5.9	Visually read (symbol)
	7.0	Visually scan, search, or monitor (continuous or serial inspection, multiple conditions)

Automation is generally suggested for tasks (a) that have high workload, (b) that require multiple operator actions, (c) that are mission critical or life threatening, and (d) the operator feels are auxiliary or bookkeeping, which could be automated easily. The four categories of data (workload, steps per task, critical tasks, and operator suggestions) were analyzed to identify which tasks might be automated. Tasks that appear in multiple categories were then reviewed for a final recommendation about the requirement for automation.

Workload

Each task within the Outrider model has corresponding visual, auditory, cognitive, and psychomotor workload values. Tasks that have workload values of 5.2 or higher in at least two of the workload components were viewed as high workload tasks and are listed next:

- Enter way points
- Verify system settings
- Monitor video, telemetry, and systems
- Check AV and navigation systems
- Enter way points and prepare flight plan

Steps Per Task

Each task within the Outrider model is performed in one or more steps. The tasks with three or more steps involved are

- Set up equipment
- Perform off-line mission planning
- Enter way points
- Analyze and modify mission planning
- Verify system settings
- Perform engine start procedures
- Perform verifications
- Monitor video, telemetry, and systems
- Check AV and navigation systems
- Monitor flight and search parameters
- Enter way points and prepare flight plan
- Monitor landing
- Modify landing

- Perform checks after landing

Critical Tasks

The functions that must be performed in order for the mission to be completed are

- Set up equipment
- Set up map system
- Create mission plan
- Preflight
- Verify indicators
- Start engine
- Perform take-off procedures
- Fly to way points
- Perform area search
- Recover AV

Tasks that operators suggested are

- Analyze and modify mission plan
- Perform pre-flight functions

The tasks that appear in two or three of the categories are listed next. No tasks appeared in all four categories. Tasks from the function "set up equipment" were removed because they cannot be automated. Tasks from the function "perform off-line mission planning" were also removed because it is a non-critical function that is usually performed only during training and because the UAV operators already perform mission planning "on line".

- Enter way points
- Analyze and modify mission plan
- Perform pre-flight procedures
- Verify system settings
- Perform engine start procedures

- Monitor video, telemetry, and systems
- Check AV and navigation systems
- Enter way points and prepare flight plan
- Monitor landing
- Modify landing
- Perform checks after landing

Discussion

The results indicate that the candidates for automation include pre- and post-flight procedures and checks, verification of system settings, and computer checks for the mission plans. This corresponds with the suggestions provided by the SMEs who stated that although the Outrider system does provide some error messages, it does not check to see if the mission plan or system settings are within range or engineering limits. In addition, the results indicate that monitoring is another task that could be automated. However, monitoring the aircraft is one reason why human operators are involved in the "loop". Still, this task can be partially automated (e.g., warnings or voice commands can be given by the system when certain parameters are no longer within specified values). In particular, when system safety is involved, having both the human and the system computer monitor for possible safety issues is essential. The task "modify landing" addresses the issue of unsafe landings and would entail extensive analyses to determine the optimal mixture of human and computer control during dangerous landing situations. In general, the operators were not asking for fully automated systems; instead, they preferred the decision making to remain with the operator and the workload reduction to be accomplished by making the computer interface faster and more efficient as well as having the computer become another set of "eyes" to check for safety problems.

It is also important to determine how operators react when the system behaves unexpectedly and which corrective tasks should be automated or computer aided. Areas for future work include expanding the model to simulate more scenarios, such as instances of dynamic targets and system malfunctions, and to collect human performance to extend the model's capabilities to predict mission and task outcomes. Further investigation is also needed to examine the human cognitive profile related to search tasks and to assess the utility of automated search and target detection algorithms. Finally, the model should be improved so that it is possible to examine how fatigue and possibly stress factors affect operator performance and overall mission safety in future UAV operational tempos.

GENERAL DISCUSSION

The use of a variety of human engineering tools has helped in our understanding of future crew environments. Most of the results were generic and can be used to help guide the design process for any UAV configurations involved in tactical Army missions. For example, the MicroSaint™ model generated a number of hypothetical task structures for possible automation, which should generalize to most future tactical UAV environments. These tasks can be narrowed further by design considerations, and realistic soldier-in-the-loop simulation experiments can then be designed to focus on a small set of pre-selected tasks. The results of the JASS study for the rated pilots were supplemented by performance data from both training and accident data that indicated the ability of these techniques to combine easily with empirical methods. Another feature of the analyses was the reliance on the SME team for interpretation. This is probably inevitable in a developing system because no one person could possibly understand the tactical, programmatic, and engineering issues of a system that is yet to be developed. The backgrounds of the SMEs involved were broad enough to cover many of these facets, thus laying a firm foundation for further analyses. Also, the combination of modeling techniques and expert input helped to curtail the shortcomings of both approaches by constraining the experts' tendency to tell "war stories" and by giving the results of the modeling efforts face validity and an operational context.

The preliminary suggestions for the UAV program, which were derived across the three sets of analyses, are

1. It is not cost efficient to require flight certification for either the AVO or EP operator positions.

2. Computerized training (especially embedded training) should be an effective means for developing operator flight skills. These efforts should concentrate on the cognitive components of the flight tasks.

3. Aviator-rated personnel (or personnel with equivalent expertise) should be involved in the decision chain to aid the UAV crew in mission planning, air space coordination, and general liaison with the other services.

4. Imagery interpretation skills drawn from the 96D training program would be a useful addition to the UAV targeting and reporting process. These skills do not have to be present in UAV ground control stations.

5. Automation requirements for the UAV operator should focus on computer assistance (e.g., quickly change way points) and system monitoring rather than on acquiring fully automated sub-systems. (Note. The utility of automated landing and take-off was not addressed in this study because the status of this feature on the Outrider was not clear at the time the workload data were collected.)

6. Future modeling efforts should include human performance (particularly in the search domain) and fatigue and stress data to predict mission performance during future UAV operational tempos more effectively.

The basic premise of this effort is that by using a variety of human engineering methods, a set of tools and methods could be created, which will mutually reinforce each other. The authors deliberately chose to investigate methods that were both cost and time efficient, thus avoiding methods that required large-scale simulations or field exercises. MicroSaint™ was chosen in part because it is available on personal computers and its software is relatively inexpensive and easy to use. The overall goal is to improve the human engineering design process by introducing methods (particularly computerized ones) that encourage early human system integration (HSI) analysis before the traditional materiel acquisition process begins. Too often, especially early in the acquisition process, the amount of HSI analysis is determined by cost and timeliness considerations. Tools such as JASS, ECAT, IMPRINT, and MicroSaint™ are being continually refined and validated to be more efficient and scientifically valid. The strategy adapted here is to combine these methods for a synergistic approach that can be used to investigate a complex and changing HSI environment early in the design process.

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APPENDIX A

PARTICIPANTS IN SUBJECT MATTER EXPERT WORKING GROUP

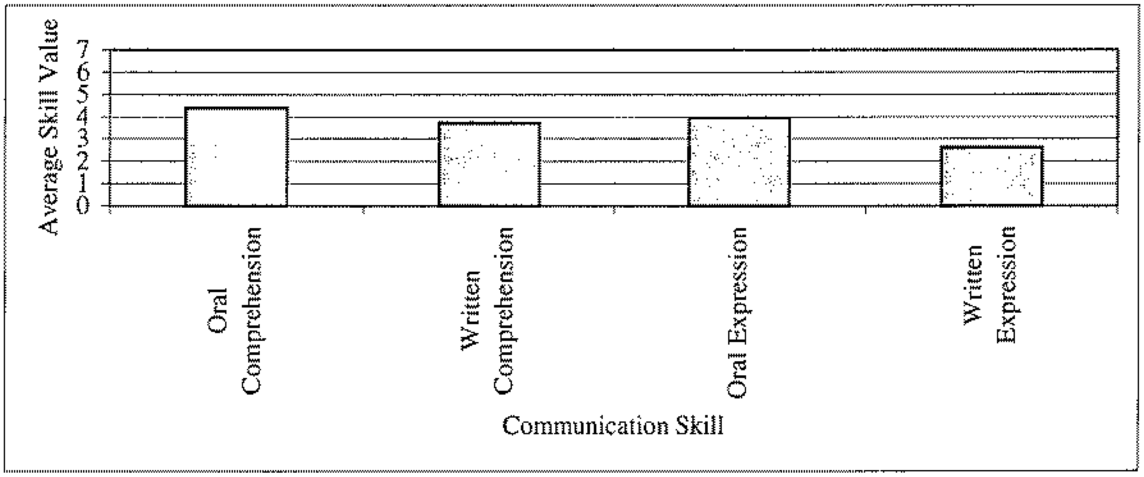
PARTICIPANTS IN SUBJECT MATTER EXPERT WORKING GROUP

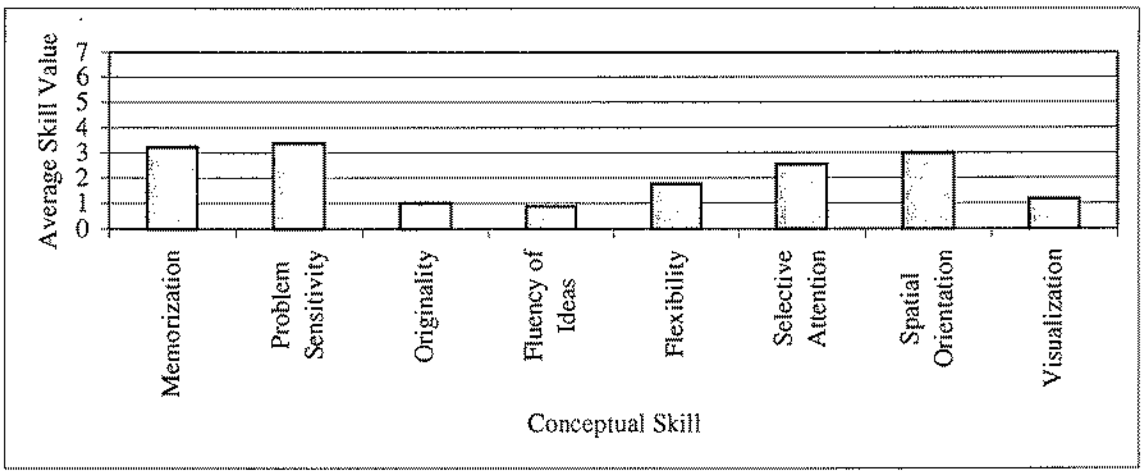
Michael J. Barnes	Army Research Laboratory (ARL)
Dr. Beverly G. Knapp	ARL
Brian Schreiber	Lockheed Martin
LT Henry Williams	Navy Aero-Medical Laboratory
Dr. Joseph L. Weeks	Air Force Research Laboratory
Barbara Karbens	Joint Tactical Program Office
Brett Walters	Micro Analysis & Design
SFC Ronald Miller	Joint Program Office Coordinator
SFC Edward Bradley	Fort Huachuca
SFC Allen Ruggles	Fort Huachuca
SSG Perry Coleman	Fort Huachuca
SSG Daryl Gorff	Fort Huachuca

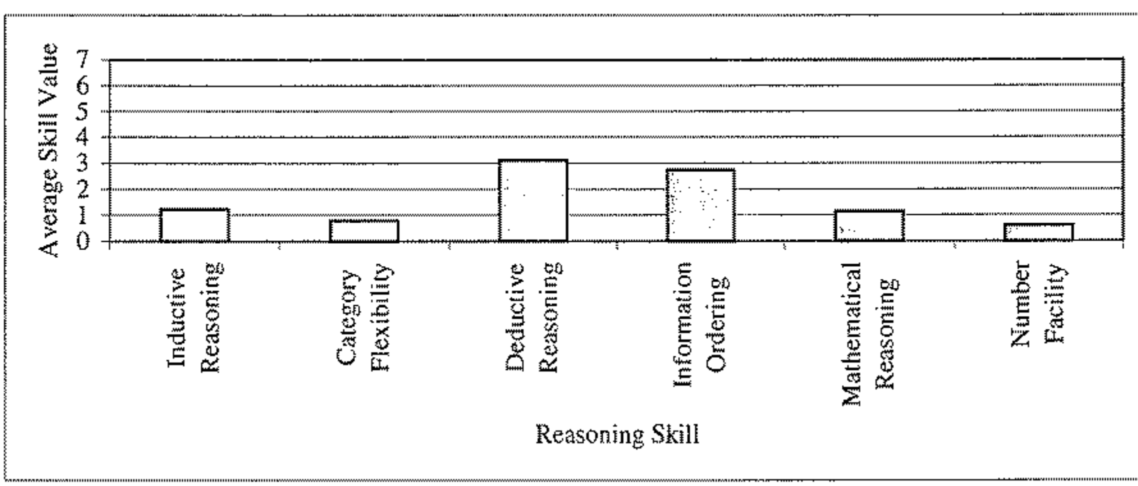
APPENDIX B

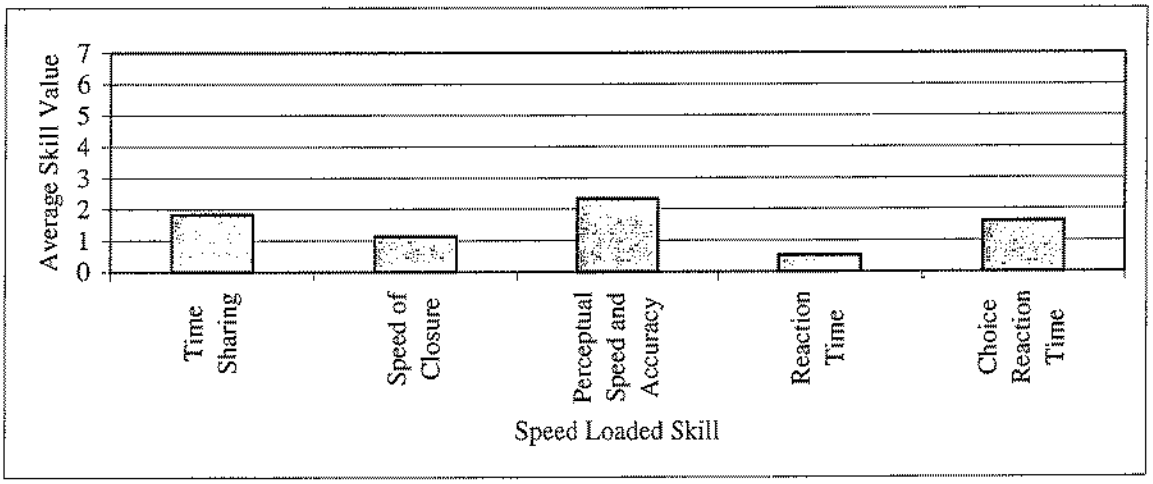
JASS AVERAGES FOR AVO POSITION ACROSS DUTIES

JASS AVERAGES FOR AVO POSITION ACROSS DUTIES








Average Skill Value
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6
5
4
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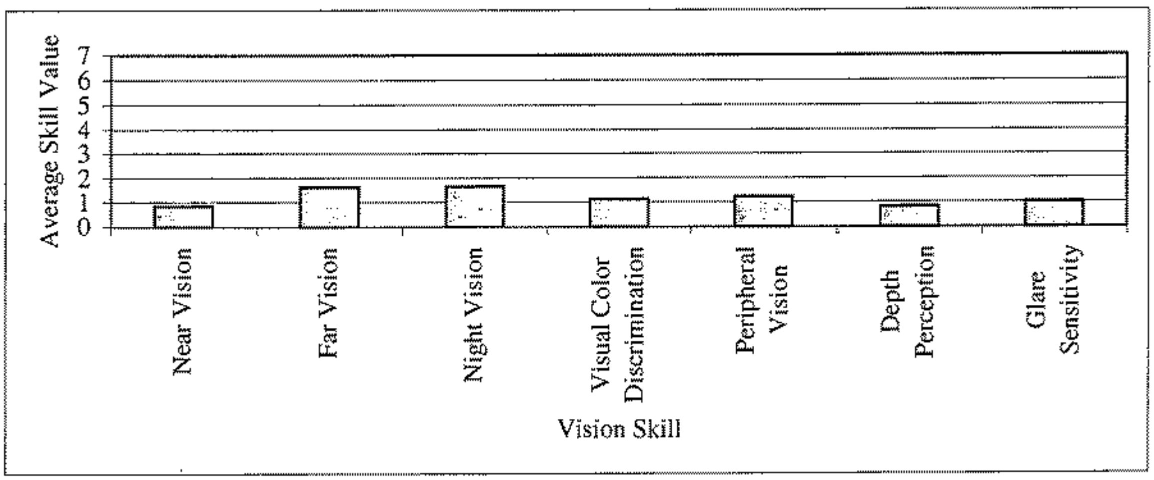
Time Sharing
Speed of Closure
Perceptual Speed and Accuracy
Reaction Time
Choice Reaction Time
Speed Loaded Skill


Average Skill Value
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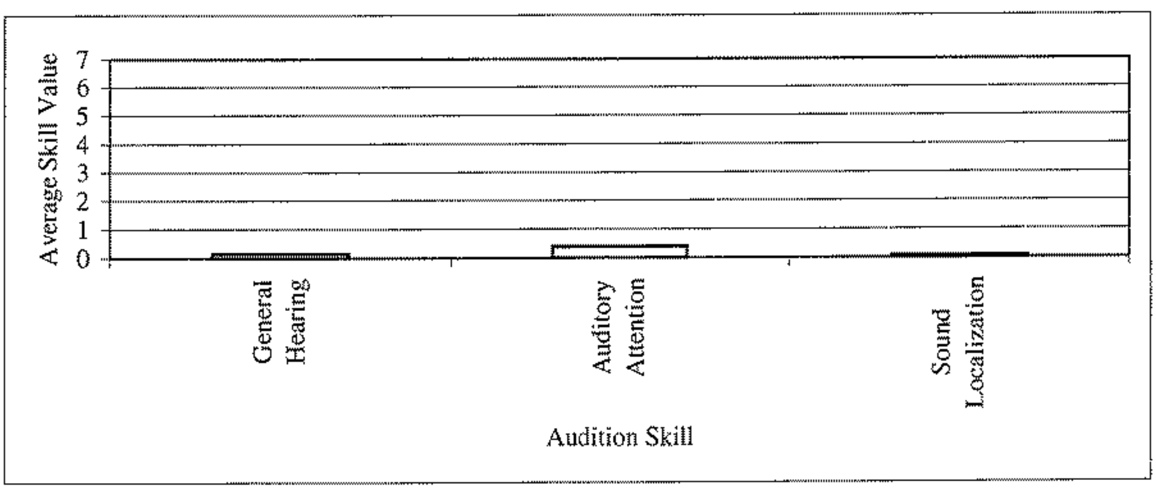
6
5
4
3
2
1
0
Near Vision
Far Vision
Night Vision
Visual Color Discrimination
Peripheral Vision
Depth Perception
Glare Sensitivity
Vision Skill


Average Skill Value
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6
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4
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1
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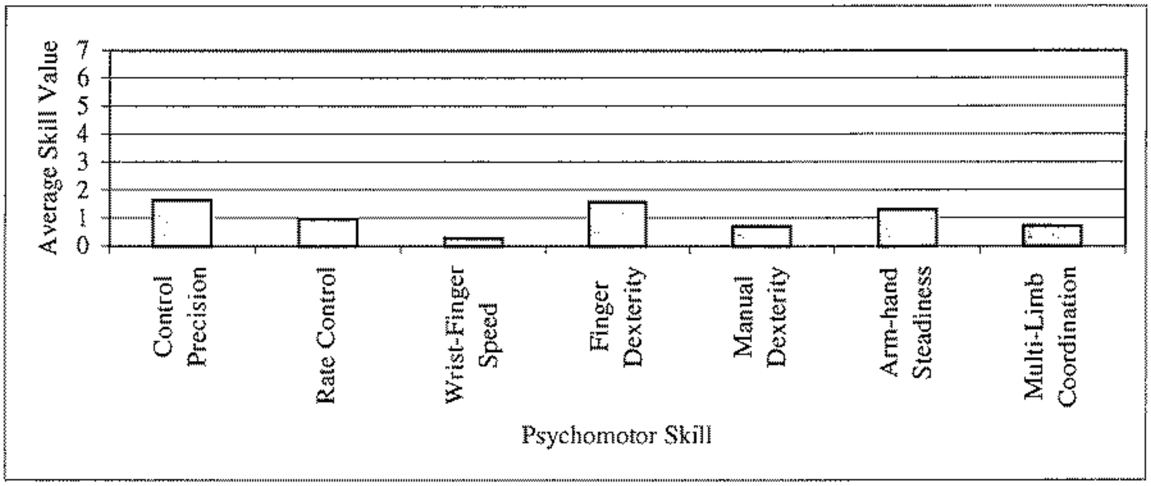
General Hearing
Auditory Attention
Sound Localization
Audition Skill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3
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Rate Control
Wrist-Finger Speed
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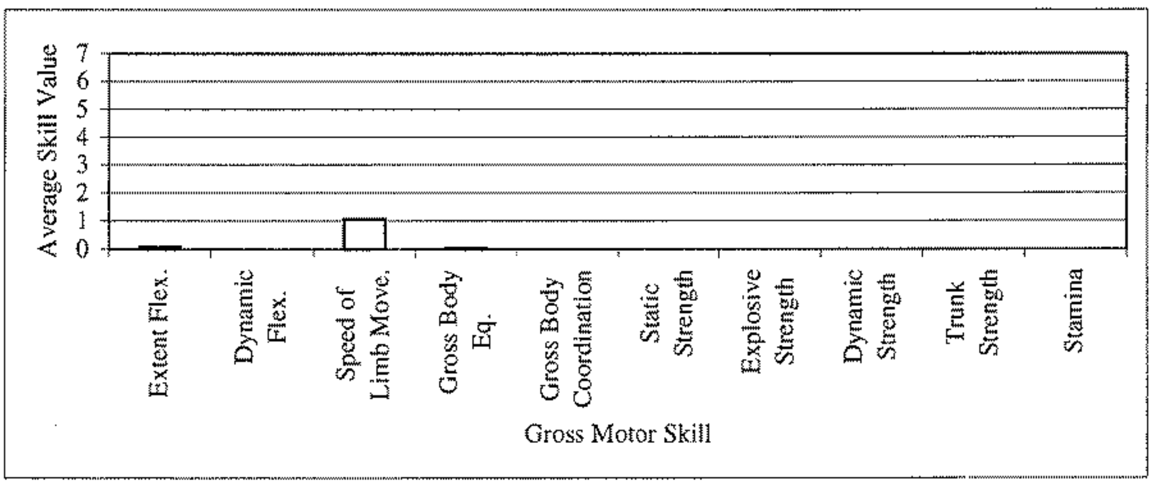
Arm-hand Steadiness
Multi-Limb Coordination
Psychomotor Skill


Average Skill Value
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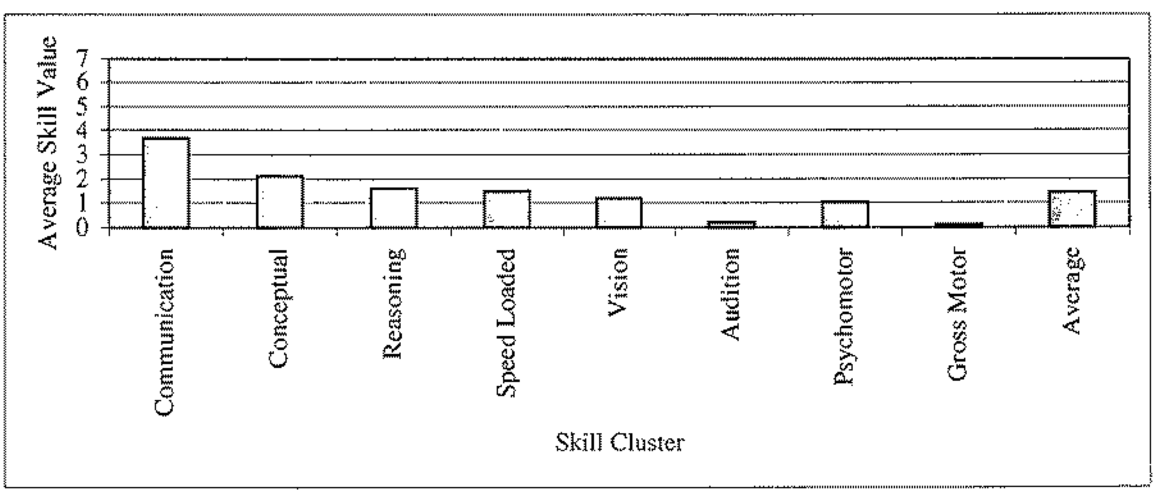
5
4
3
2
1
0
Extent Flex.
Dynamic Flex.
Speed of Limb Move.
Gross Body Eq.
Gross Body Coordination
Static Strength
Explosive Strength
Dynamic Strength
Trunk Strength
Stamina
Gross Motor Skill


Average Skill Value
7
6
5
4
3
2
1
0
Communication
Conceptual
Reasoning
Speed Loaded
Vision
Audition
Psychomotor
Gross Motor
Average
Skill Cluster

Average score within each skill cluster across 16 duties for the AVO

Communication	**AVO**
Oral Comprehension	4.41
Written Comprehension	3.72
Oral Expression	3.96
Written Expression	2.61
AVERAGE	3.68

Conceptual	**AVO**
Memorization	3.24
Problem Sensitivity	3.40
Originality	1.02
Fluency of Ideas	0.89
Flexibility	1.78
Selective Attention	2.53
Spatial Orientation	3.00
Visualization	1.18
AVERAGE	2.13

Reasoning	**AVO**
Inductive Reasoning	1.23
Category Flexibility	0.79
Deductive Reasoning	3.13
Information Ordering	2.75
Mathematical Reasoning	1.14
Number Facility	0.62
AVERAGE	1.61

Speed-loaded	**AVO**
Time Sharing	1.84
Speed of Closure	1.14
Perceptual Speed and Accuracy	2.33
Reaction Time	0.53
Choice Reaction Time	1.62
AVERAGE	1.49

Vision	AVO
Near Vision	0.87
Far Vision	1.64
Night Vision	1.66
Visual Color Discrimination	1.13
Peripheral Vision	1.23
Depth Perception	0.82
Glare Sensitivity	1.02
AVERAGE	1.20

Audition	AVO
General Hearing	0.16
Auditory Attention	0.40
Sound Localization	0.07
AVERAGE	0.21

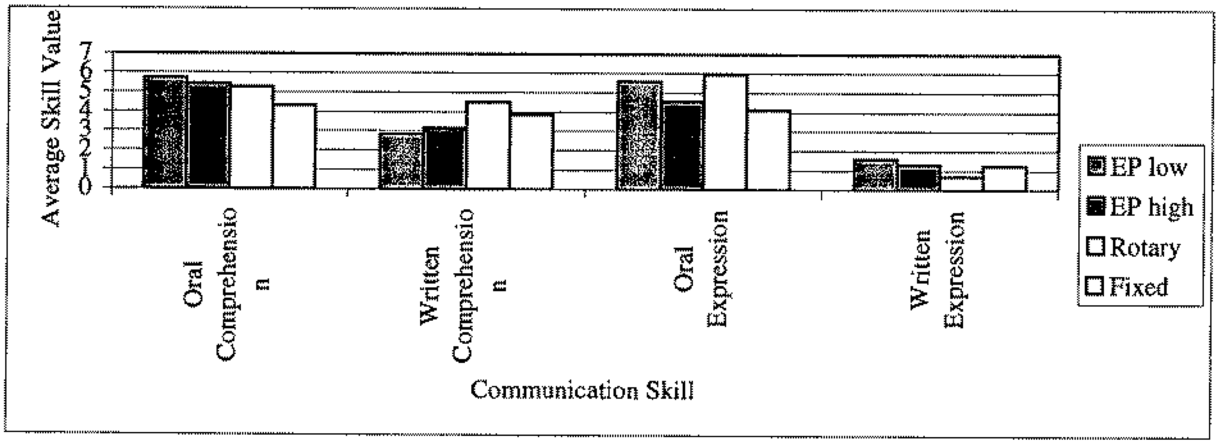
Psychomotor	AVO
Control Precision	1.65
Rate Control	0.97
Wrist-Finger Speed	0.29
Finger Dexterity	1.58
Manual Dexterity	0.71
Arm-hand Steadiness	1.31
Multi-Limb Coordination	0.72
AVERAGE	1.03

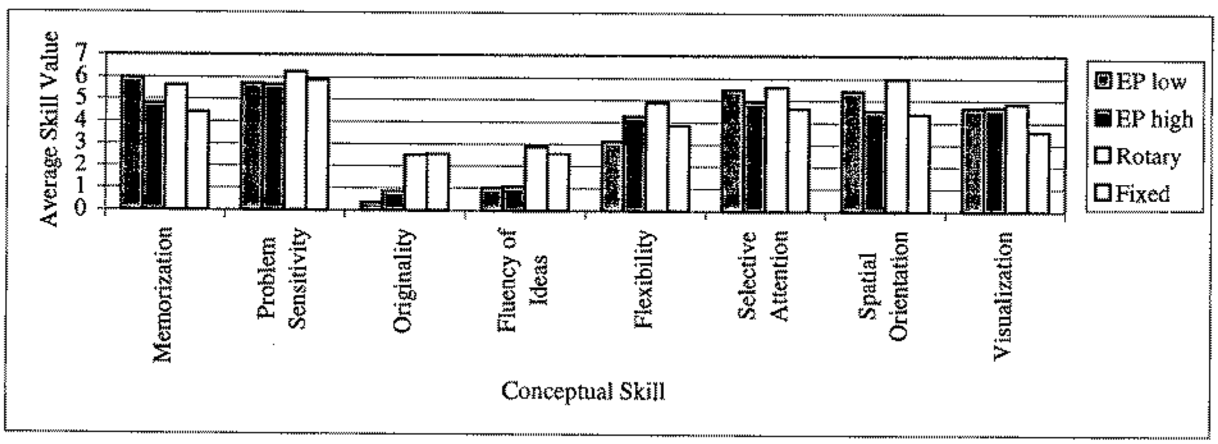
Gross Motor	AVO
Extent Flexibility	0.08
Dynamic Flexibility	0.00
Speed of Limb Movement	1.06
Gross Body Equilibrium	0.05
Gross Body Coordination	0.00
Static Strength	0.00
Explosive Strength	0.00
Dynamic Strength	0.00
Trunk Strength	0.00
Stamina	0.00
AVERAGE	0.12

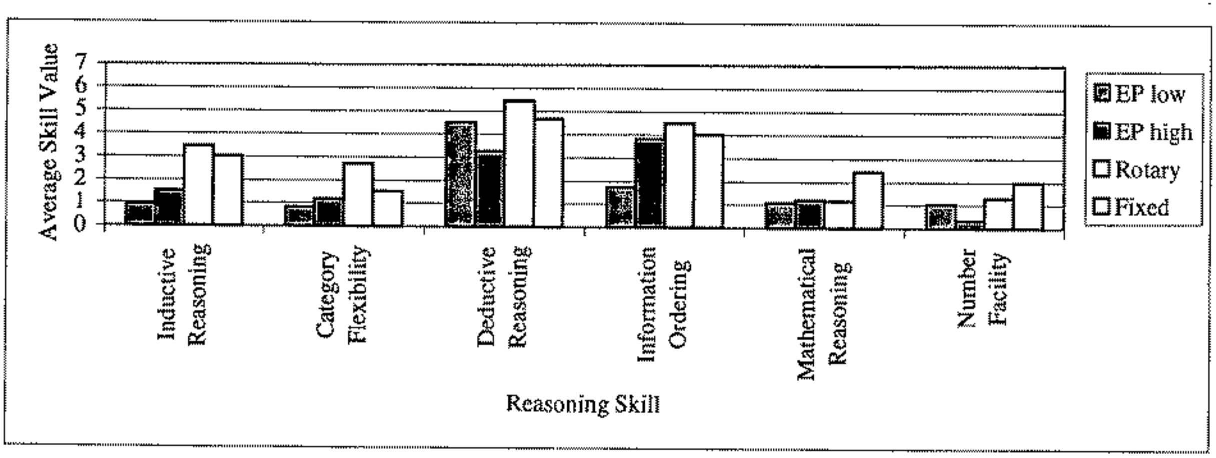
APPENDIX C

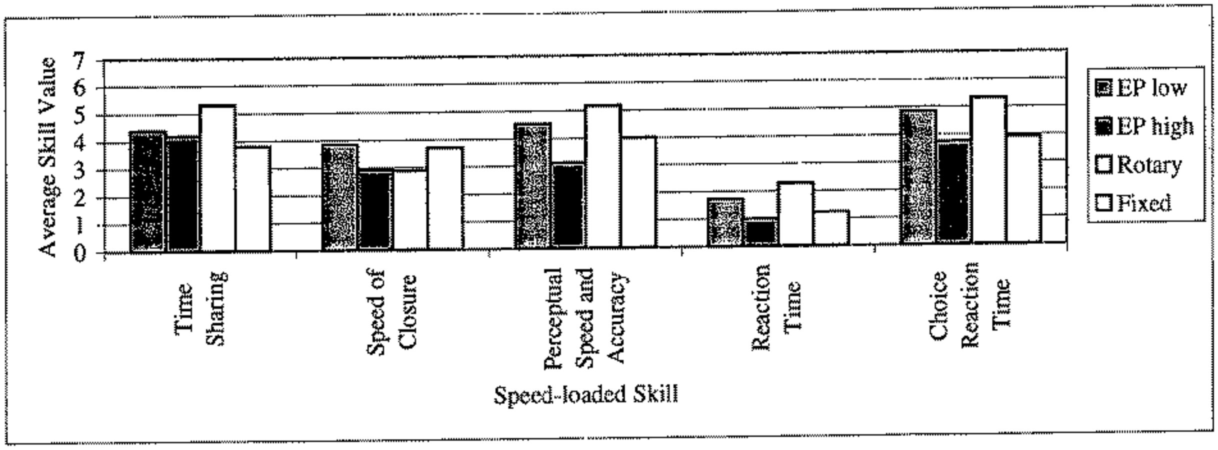
JASS DATA AVERAGES FOR EP (LOW AND HIGH EXPERIENCE) AND FIXED AND ROTARY WING AVIATORS' POSITION ACROSS DUTIES

JASS DATA AVERAGES FOR EP (LOW AND HIGH EXPERIENCE) AND FIXED AND ROTARY WING AVIATORS' POSITION ACROSS DUTIES








Average Skill Value
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6
5
4
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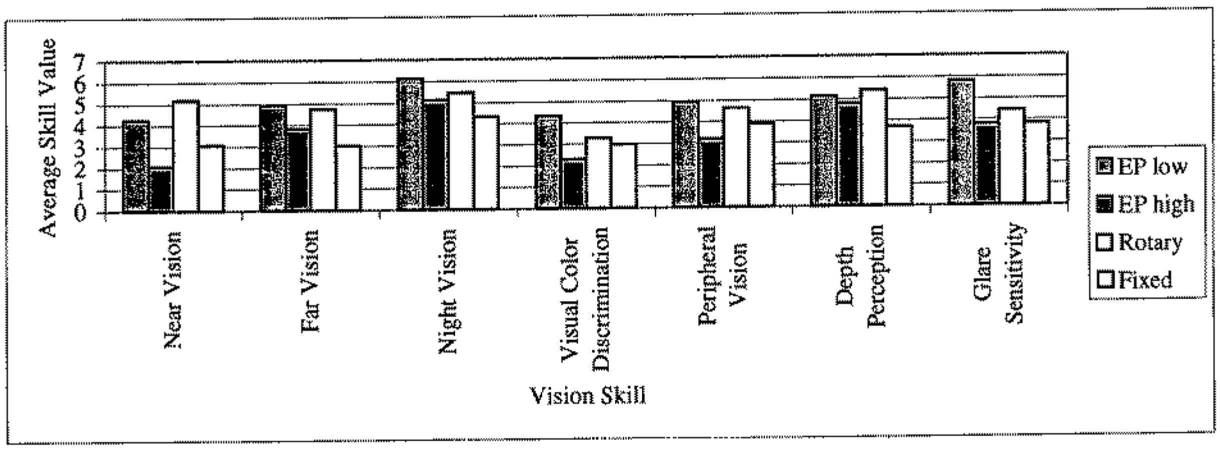
Time Sharing
Speed of Closure
Perceptual Speed and Accuracy
Reaction Time
Choice Reaction Time
Speed-loaded Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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6
5
4
3
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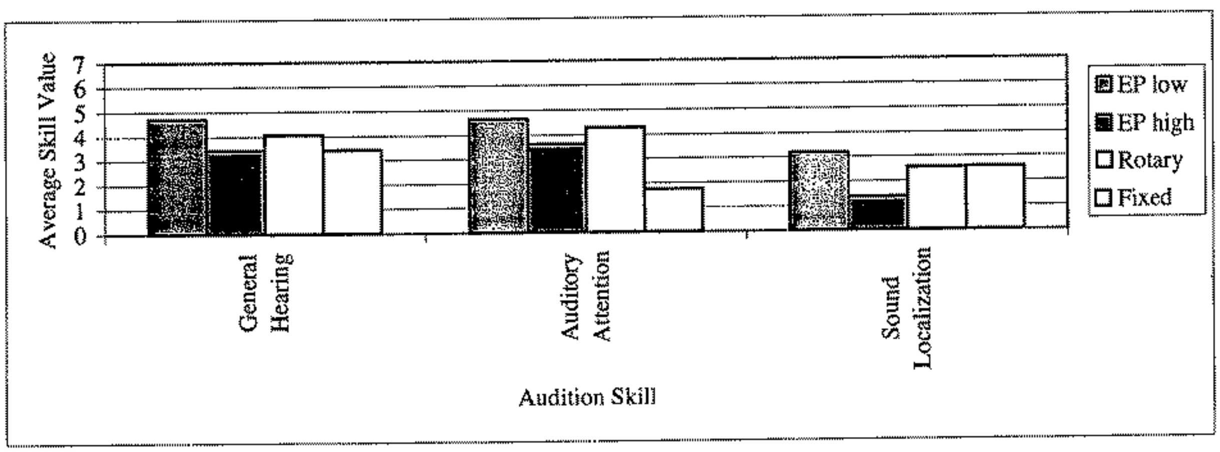
Near Vision
Far Vision
Night Vision
Visual Color Discrimination
Peripheral Vision
Depth Perception
Glare Sensitivity
Vision Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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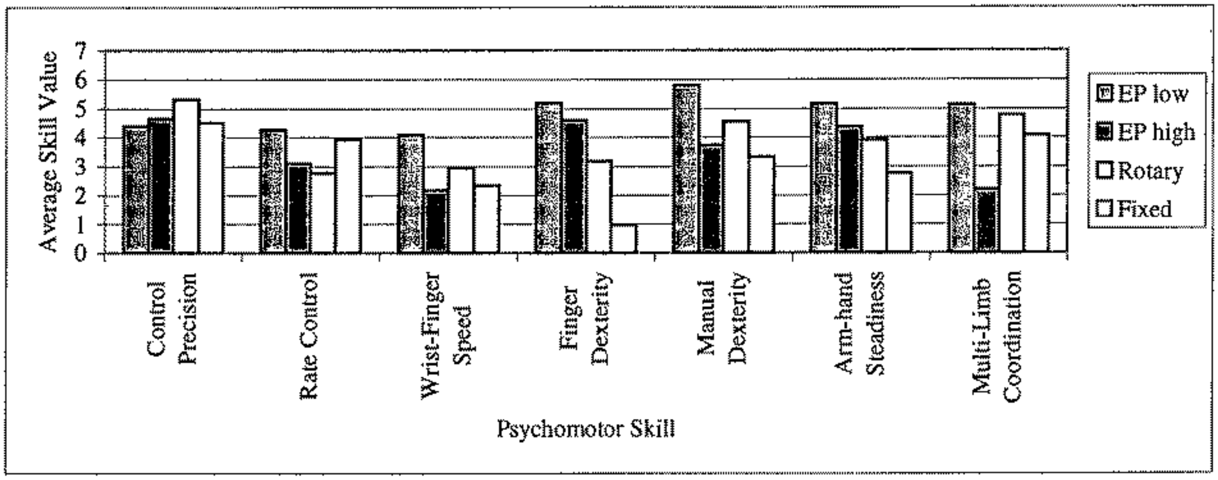
4
3
2
1
0
General Hearing
Auditory Attention
Sound Localization
Audition Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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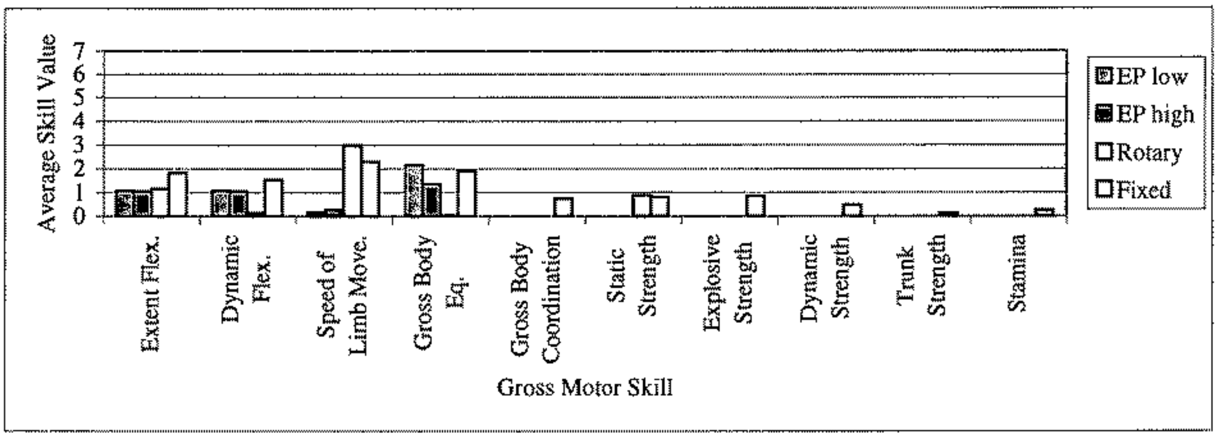
Control Precision
Rate Control
Wrist-Finger Speed
Finger Dexterity
Manual Dexterity
Arm-hand Steadiness
Multi-Limb Coordination
Psychomotor Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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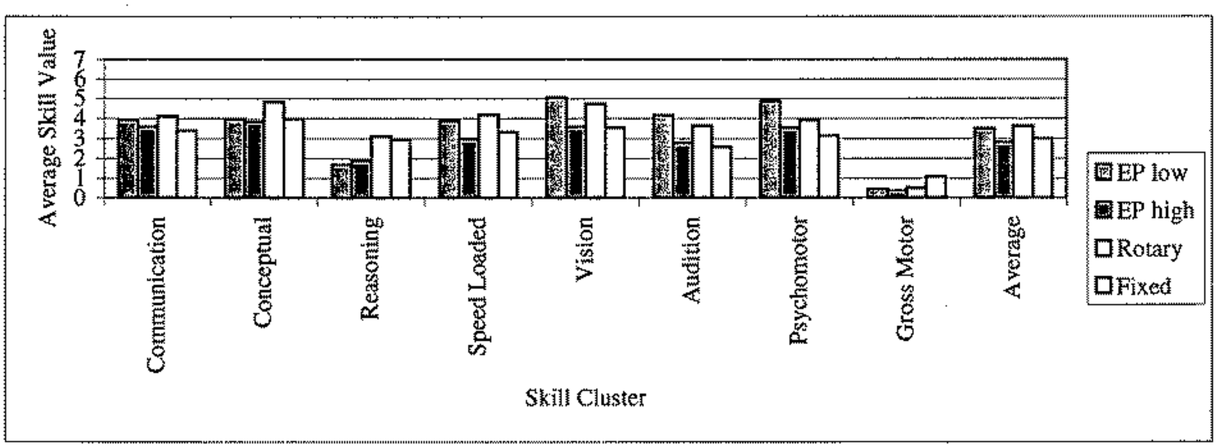
Extent Flex.
Dynamic Flex.
Speed of Limb Move.
Gross Body Eq.
Gross Body Coordination
Static Strength
Explosive Strength
Dynamic Strength
Trunk Strength
Stamina
Gross Motor Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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Communication
Conceptual
Reasoning
Speed Loaded
Vision
Audition
Psychomotor
Gross Motor
Average
Skill Cluster
EP low
EP high
Rotary
Fixed

Average score within each skill cluster across nine duties

Communication	Group			
	EP inexperienced (low)	**EP experienced (high)**	**Rotary**	**Fixed**
Oral Comprehension	5.69	5.41	5.25	4.31
Written Comprehension	2.83	3.12	4.49	3.86
Oral Expression	5.57	4.54	5.95	4.12
Written Expression	1.59	1.30	0.71	1.25
AVERAGE	3.92	3.59	4.10	3.39

Conceptual	Group			
	EP inexperienced (low)	**EP experienced (high)**	**Rotary**	**Fixed**
Memorization	5.97	4.81	5.62	4.40
Problem Sensitivity	5.72	5.67	6.23	5.88
Originality	0.36	0.87	2.50	2.55
Fluency of Ideas	1.00	1.06	2.89	2.56
Flexibility	3.13	4.26	4.88	3.86
Selective Attention	5.46	4.93	5.60	4.63
Spatial Orientation	5.42	4.54	5.98	4.38
Visualization	4.65	4.69	4.84	3.60
AVERAGE	3.96	3.85	4.82	3.98

Reasoning	Group			
	EP inexperienced (low)	**EP experienced (high)**	**Rotary**	**Fixed**
Inductive Reasoning	0.92	1.52	3.44	3.03
Category Flexibility	0.81	1.15	2.71	1.52
Deductive Reasoning	4.51	3.26	5.45	4.67
Information Ordering	1.75	3.82	4.53	4.01
Mathematical Reasoning	1.07	1.19	1.16	2.44
Number Facility	1.03	0.33	1.28	1.98
AVERAGE	1.68	1.88	3.10	2.94

Speed-loaded	Group			
	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Time Sharing	4.39	4.19	5.30	3.77
Speed of Closure	3.83	2.91	2.88	3.68
Perceptual Speed and Accuracy	4.53	3.09	5.16	4.00
Reaction Time	1.72	0.98	2.29	1.23
Choice Reaction Time	4.83	3.74	5.30	3.90
AVERAGE	3.86	2.98	4.19	3.32

Vision	Group			
	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Near Vision	4.23	2.09	5.17	3.07
Far Vision	4.90	3.82	4.72	3.02
Night Vision	6.13	5.13	5.46	4.33
Visual Color Discrimination	4.31	2.31	3.28	2.98
Peripheral Vision	4.92	3.19	4.62	3.87
Depth Perception	5.14	4.80	5.42	3.68
Glare Sensitivity	5.81	3.78	4.42	3.81
AVERAGE	5.06	3.59	4.73	3.54

Audition	Group			
	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
General Hearing	4.70	3.42	4.06	3.42
Auditory Attention	4.64	3.59	4.28	1.75
Sound Localization	3.17	1.36	2.54	2.57
AVERAGE	4.17	2.79	3.63	2.58

Psychomotor	Group EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Control Precision	4.38	4.64	5.32	4.51
Rate Control	4.26	3.11	2.77	3.93
Wrist-Finger Speed	4.08	2.18	2.95	2.35
Finger Dexterity	5.20	4.59	3.18	0.96
Manual Dexterity	5.79	3.72	4.54	3.32
Arm-hand Steadiness	5.17	4.36	3.90	2.76
Multi-Limb Coordination	5.13	2.20	4.77	4.07
AVERAGE	4.86	3.54	3.92	3.13

	Group			
Gross Motor	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Extent Flexibility	1.07	1.04	1.15	1.84
Dynamic Flexibility	1.07	1.04	0.14	1.52
Speed of Limb Movement	0.15	0.26	2.97	2.30
Gross Body Equilibrium	2.16	1.35	0.04	1.91
Gross Body Coordination	0.00	0.00	0.00	0.73
Static Strength	0.00	0.00	0.87	0.81
Explosive Strength	0.00	0.00	0.00	0.85
Dynamic Strength	0.00	0.00	0.00	0.47
Trunk Strength	0.00	0.00	0.00	0.12
Stamina	0.00	0.00	0.00	0.24
AVERAGE	0.45	0.37	0.52	1.08

APPENDIX D

DISCRETE EVENT SIMULATION USING MICROSAINT™

DISCRETE EVENT SIMULATION USING MICROSAINT™

Discrete event simulations (DES) use a computer model to describe a process that can be expressed as a sequence of events, each with a distinct beginning and end. Events can be any part of the process, such as scheduled activities or tasks that represent the flow of the process. The tasks are displayed schematically on a diagram called the task network diagram, which is the basis of the model.

MicroSaint™ is a simulation software package for constructing models that simulate real-life processes. In this section, the basic DES components that comprise the MicroSaint™ software tool are described. Models can be relatively simple or complex. A simple, functional model can be built just by creating a network diagram and entering task timing information for each task in the network. More complex models can be built, which include dynamically changing variables, probabilistic and tactical branching logic, conditional task execution, and extensive model data collection—all of which can be specified by choosing menu commands or providing expressions for MicroSaint™ to execute during specific circumstances.

Whether the model is simple or complex, the process of executing a MicroSaint™ model and generating statistics and graphs from the collected data is mostly automatic. The software uses random numbers to generate specific task times from a pre-established distribution and routing choices specific to the current execution. After the model has been run, statistic charts, scatter plots, line or step graphs, bar charts, and frequency distributions can be used to analyze the data collected during model execution. In addition, the results files can be opened in spreadsheets or statistical packages for further analysis.

This section is designed to provide sufficient information about MicroSaint™ so that the Outrider UAV modeling presented in this report can be understood. This is not meant to provide a complete understanding of how MicroSaint™ can be used for modeling in general. For questions and a more detailed understanding of MicroSaint™, refer to the MicroSaint™ 3.0 manual.

User Interface

MicroSaint™ uses a standard Windows™-style graphical interface. The standard point-and-click method is used to select MicroSaint™ tools and to define and move objects. Double-clicking an object with the mouse opens a description dialog box where information specific to the object can be entered. Figure D-1 shows the task network diagram window of MicroSaint™. The window contains a sample network diagram of four nodes labeled 1 through 4, with a probabilistic decision node after Node 2.

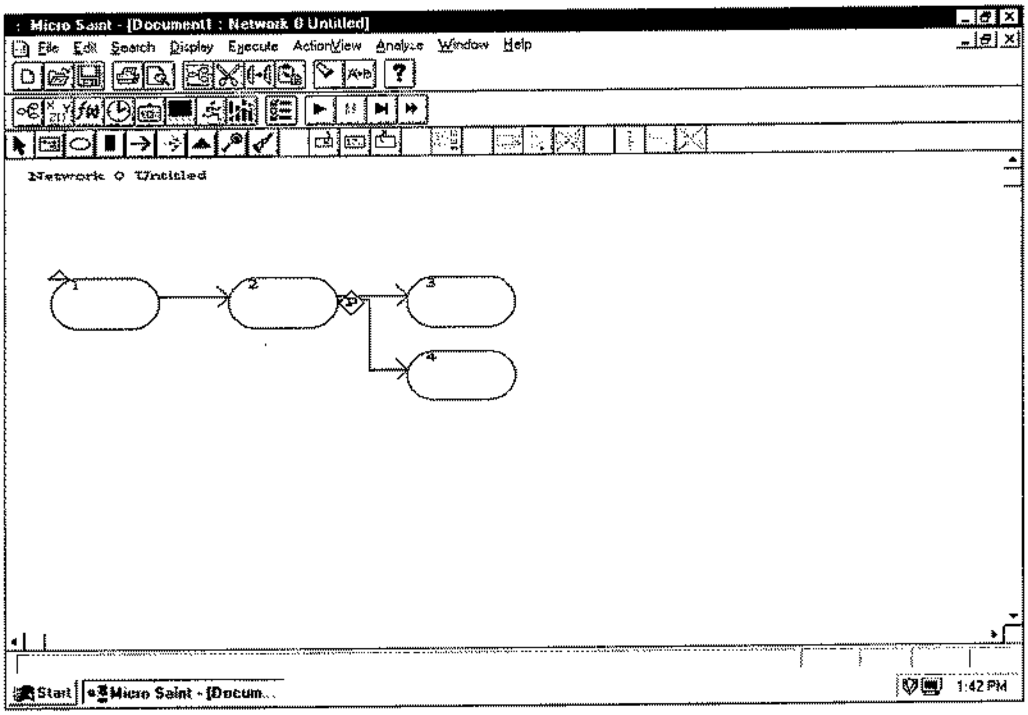

Figure D-1. The MicroSaint™ user interface and an example of a task network diagram.

Task Network Diagram

The task network is a graphical representation of the process that is being modeled. Tasks are represented in a diagram that shows the order of task execution within the process. A task network diagram is composed of nodes representing tasks that are connected by arrows. A rounded rectangle or oval sbape represents each task. Sub-networks are represented by a rectangle. The arrows between the nodes indicate the possible sequences in which the tasks can be performed. Figure D-1 is an example of a task network. The "P" in the diamond-shaped node represents the type of decision (probabilistic) that is used to determine which path is taken.

Task and network nodes are created in MicroSaint™ with the task and network tools. Users click on the network diagram with one of the tools to place a task or network and then continue clicking to place subsequent tasks (or networks). The path tool is used to draw a path from each task or network to any other task or network that can follow it, and it indicates the direction of task execution. MicroSaint™ also uses symbolic animation during execution. When a particular task in the network has been reached, the rounded rectangle for that task is highlighted. The animation shows entities (items, people, etc.) as they move through the network. This type of animation is particularly useful in debugging a model and when verifying a model with SMEs.

Task Description

Tasks are the lowest level in a model network hierarchy and are described by specific parameters such as task timing information, release condition, and beginning and ending effect, which relate the task to other system activities. An example of the task description dialog box is displayed in Figure D-2. The description is for Task Number 1 (this number is inside the MicroSaint™ software and does not affect or reference the process being modeled); a name for the task can be entered into the name field. Expressions for each of the task parameters can be entered in the labeled fields.

Task Timing Information

Task timing information consists of the mean time for the task, the standard deviation, and a type of time distribution. In Figure D-2, the task mean time is 10 time units (hours, minutes, seconds, etc.), the standard deviation is one time unit, and the time distribution is normal.

The mean time is the average time required to complete a task. For example, if the task represents an activity such as "enter way points," then the mean time to execute the task is the average time that it takes an operator to enter the way points. The mean time is used in conjunction with the standard deviation and time distribution to determine the simulated task execution time for each execution of the task. The standard deviation is used in conjunction with the time distribution and controls the spread of a distribution

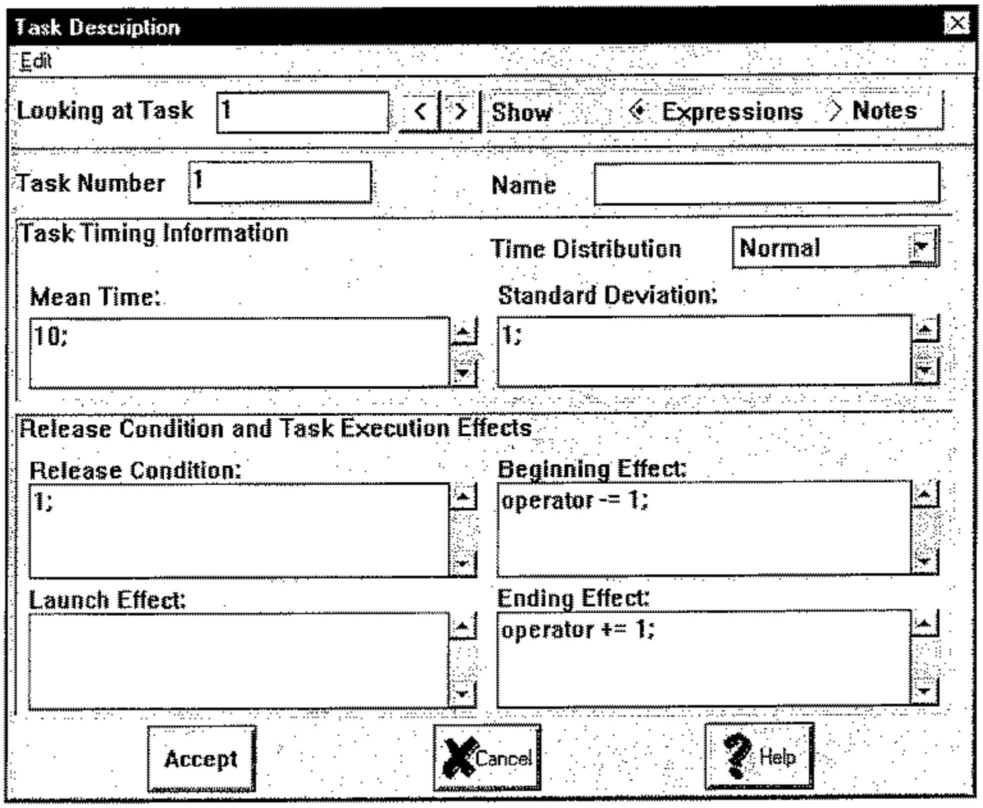

Figure D-2. Task description dialogue box.

The time distribution indicates the function used by MicroSaint™ to randomly generate execution times for a task. The mean time and standard deviation are used in conjunction with the probability distribution to determine the task execution time. In most cases, the execution time is not constant, but instead, the execution time is variable within a range of values that can be represented by a probability distribution. MicroSaint™ supports more than 21 probability distribution types, including normal, rectangular, exponential, gamma, Wiebull, Poisson, triangular, and others.

Release Conditions

Situations often occur when a task cannot begin executing until certain conditions are met. A task can have resource requirements such as availability of an operator or other constraints such as time of day or availability of part type that controls when the task can begin. In MicroSaint™, the expression in the "release condition" field can prevent a task from executing until certain conditions in the model are met (e.g., the availability of a resource, the completion of another task). The release condition expression can be as simple as the value 1 for tasks that execute as soon as the previous task completes, or it may be a complicated expression in which several conditions are evaluated. Entities moving through the network cannot be released into a task for processing until the release conditions for the task are met.

Task Execution Effects

An execution effect defines how the task performance affects other aspects of the system. For instance, the current state of the system may change when a task begins and then change again when the task ends. These changes are made using expressions in the beginning and ending effects of a task description. In the example in Figure D-2, the expression in the beginning effect of the task reduces the number of available operators by one. The expression in ending effect increases the number of available operators by one.

Controlling Process Logic

The arrows that are displayed between nodes define the basic order in which tasks are executed. Alternatives are indicated when more than one path is displayed, which originated from a single node. Task sequences can also be affected by conditions outside the network diagram. For example, a task can be started as a function of time. A diamond-shaped "decision node" automatically displays on the network diagram when more than one path follows a task. These decision points can be used to represent real-world decisions or to control aspects of how the model works, which may have little to do with the process being modeled.

The conditions that control the branching must be entered as expressions. MicroSaint™ provides the following decision types to ensure that real-world situations can be represented in the model:

1. In a probabilistic decision type, the next task to execute is determined by the relative probabilities of all tasks listed. Probabilistic decisions allow only one of the following tasks to execute.

2. In a multiple decision type, all the tasks with conditions that evaluate to non-zero will execute. This allows for one or more tasks to begin execution, based on rules that determine execution tasks.

3. In a tactical decision type, the next task to execute is the task with the condition that evaluates to the highest value. This allows for rule-based decisions. A tactical decision type differs from the multiple type in that only one following task is executed.

Variables and algebraic expressions can be used in the branching logic, and the value of the variables can be changed by conditions in the model. This allows complete control and manipulation of the network flow.

Simulation Clock

The simulation clock tracks the simulated time as the model executes. Time can be advanced in the simulation either in *fixed* or *variable* time intervals. In a *fixed* interval simulation, the simulation clock is advanced in fixed time intervals; the simulation is referred to as clock driven. Examples of clock-driven simulations are chemical processes and weather models. In a *variable* interval simulation, events are used to advance the clock in initial value and type (integer, real, array of integers, array of real numbers).

Expressions

An expression can be a calculation, formula, function, or statement that supplies a value or performs an operation. Expressions are used to supply numerical values such as mean times or true or false values such as those used in release conditions. They are used to make changes in the state of the model, such as beginning effects and ending effects. Each expression in MicroSaint™ must end with a semi-colon and can include any of the following elements:

- Constants
- Variables
- Functions (groups of expressions that can be referred to or called)
- Comments

- Mathematical operators (+, -, *, /, ^, %, ( ))
- Assignment operator (:=)
- Adjustment operators (+=, -=, *=, /=)
- Logical operators (>, >=, <, <=, &, ==, |, <>)
- If-then-else and while-do statements

Scenario Event

A scenario event is scheduled to occur at a specific time (in simulation time) during model execution. Scenario events are also used to change variable values, thereby changing the state of the model. These can be one-time events or they can repeat at regular intervals. An example of a one-time event would be setting a variable at simulation time zero, indicating the number of alarms that will sound during a nuclear plant disturbance. Scenario events are defined by supplying the following information for each event in the event description dialog box:

1. Time of occurrence.
2. Whether the event should repeat and at what interval.
3. Time when you want the event to stop repeating, if applicable.
4. The expressions you want executed at the specified time(s).

Model Execution

When the model execution is started, an entity begins at the first task node in the model. If the release condition for that task is evaluated to "true," then the task executes. The effect(s) that the task has on the system are evaluated, based on the expressions defining the task description. The changes are expressed in variables that can be used in other tasks in the model. Once the task is completed, the entity proceeds to the next task in the network diagram. When more than one path is available, the branching logic is used to determine the path the entity will follow. In general, the entire network diagram is traversed by the entity and the model is completed when the entity reaches the end of the last task in the network. Models can have conditions that send entities through the network until a specified simulation time or until a pre-determined number has completed the simulation.

Data Collection During Model Execution

The output data for a simulation are specific values of model variables recorded at specific times during the execution of the model. The data recorded are used to answer the questions about the system being modeled. The output is similar to the results of an experiment. Data output can include measures of system effectiveness or can be used for system diagnostics. Some examples of useful output are resource use, cost, and errors initiated.

Data are collected during the execution of a MicroSaint™ model using a feature called "snapshots". Snapshots provide a way to collect values of variables at specified points during model execution. They can be programmed to occur at specific clock times, when a task begins or ends, or when a model execution ends. Snapshots are defined by providing the following information in the snapshot description dialog box:

1. A name for the document where the data are stored.
2. The "trigger types" for the snapshot (end of run, clock, begin task, end task).
3. The number of the triggering task, if applicable.
4. The start time, stop time, and repeat interval, as applicable, if the snapshot has a clock trigger.
5. The names of the variables for which you want to record values.

Once the snapshots have been defined, they can be set to "on" or "off" during model execution. When they are turned "on," the variable values are stored in a results file with the extension "**.res**". After the file is opened, the analyze commands in MicroSaint™ can be used to generate statistics and create graphs from the data. The data can also be imported into other statistical analysis packages.

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The purpose of the research project was to understand the future crew environments for developing unmanned aerial vehicle (UAV) systems. A variety of human engineering tools (job assessment software system [JASS], enhanced computer-aided testing [ECAT], and MicroSaint™) were used to address crew issues related to the utility of having rated aviators as crew members, supplementing current crews with imagery and intelligence specialists, and the use of automation to improve systems efficiency. Data from 70 soldiers and experts from Fort Huachuca, Arizona, Fort Hood, Texas, and Hondo, Texas, were collected as part of this effort. The general finding was that the use of cognitive methods and computerized tool sets to understand future crew environments proved to be cost effective and useful. Specifically, no evidence was found to support a requirement for rated aviators in future Army missions, but the use of cognitively oriented embedded training simulators was suggested to aid novices in developing the cognitive skills evinced by experts. The efficacy of adding imagery specialists to 96U crews was discussed, and specific recommendations related to automation were derived from the workload modeling.

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Unmanned Aircraft Pilot Medical Certification Requirements

Kevin W. Williams
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

February 2007

Final Report

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16. Abstract

This research study was undertaken to create recommendations for unmanned aircraft pilot medical certification requirements. The effort consisted of the convening of a panel of subject matter experts and interactions with groups engaged in the process of establishing unmanned aircraft pilot guidelines. The results of this effort were a recommendation and justification for use of the second-class medical certification.

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EXECUTIVE SUMMARY

This research addressed the medical requirements necessary for unmanned aircraft (UA) pilots for successful flight in the National Airspace System (NAS). Given that an existing medical certification was recommended, the question of which class of certification to propose was based on the perceived level of risk imposed by the potential incapacitation of the UA pilot. A second-class medical certification was judged to be the most acceptable, considering that there were several factors that mitigated the risk of pilot incapacitation relative to those of manned aircraft. First, factors related to changes in air pressure could be ignored, assuming that control stations for non-military operations would be on the ground. Second, many of the current UA systems have procedures that have been established for lost data link. Lost data link, where the pilot cannot transmit commands to the aircraft, is functionally equivalent to pilot incapacitation. Third, the level of automation of a system determines the criticality of pilot incapacitation because some highly automated systems (e.g., Global Hawk) will continue normal flight whether a pilot is or is not present.

Unmanned Aircraft Pilot Medical Certification Requirements

INTRODUCTION

The rapidly expanding commercial Unmanned Aircraft (UA) industry presents a challenge to regulators whose task it is to ensure the safety of the flying public, as well as others who might be injured as a result of an aircraft accident. The military has used unmanned aircraft for several decades with varying levels of success. Within the last few years, commercial UA operations have increased dramatically. Most of these operations have concentrated on surveillance and advertisement, but several companies have expressed an interest in using unmanned aircraft for a variety of other commercial endeavors.

Although the term "unmanned aircraft" suggests the absence of human interaction, the human operator/pilot is still a critical element in the success of any unmanned aircraft operation. For many UA systems, a contributing factor to a substantial proportion of accidents is human error (Williams, 2004). The Federal Aviation Administration (FAA) needs guidance to assist in deciding who will pilot UA and the training required. Research may be required to investigate the effects on pilot performance of different types of console display interfaces; how UA flight mission profiles affect pilot workload, vigilance, fatigue, and performance; and to determine whether prior flight experience is important in both training and operation of UA. Also, it is important to determine whether new opportunities present themselves in terms of the inclusion of handicapped persons previously excluded from piloting aircraft but not expected to have difficulty with piloting a UA, and to investigate medical and physiological standards required to operate UA.

To assist in developing guidance, a research effort was begun to produce recommendations regarding UA pilot medical qualifications. The approach consisted of three steps. First, a literature review of existing research on UA pilot requirements was conducted. Second, an analysis of current and potential UA commercial applications and an analysis of current and potential UA airspace usage was completed. The third step in the process involved assembling a team of subject matter experts to review proposed UA pilot medical and airman certification requirements and make recommendations regarding how those requirements should be changed or expanded. This paper is a summary of that effort.

UA PILOT REQUIREMENTS LITERATURE REVIEW

The first task was to review the literature related to the development of UA pilot requirements. Appendix A presents a bibliography of research related to the development of UA pilot requirements. The literature fell into a few basic categories. Many of the papers were recommendations regarding the development of requirements (e.g., DeGarmo, 2004; Dolgin, Kay, Wasel, Langelier, & Hoffman, 2001; Reising, 2003). The paper by Weeks (2000) listed current crew requirements for several different military systems. Finally, some of the papers reported actual empirical research addressing some aspect of pilot requirements (Barnes & Matz, 1998; Fogel, Gill, Mout, Hulett, & Englund, 1973; Schreiber, Lyon, Martin, & Confer, 2002).

The research by Fogel et al. (1973) was especially interesting because it was one of the earliest attempts to address the issue of UA pilot requirements. In the study, three groups of pilots were recruited to fly a simulation of a Strike remotely piloted vehicle. The first group consisted of Navy Attack pilots with extensive combat aircraft experience. The second group consisted of radio-control aircraft hobbyists. The third was composed of non-pilots with no radio-control aircraft experience. The results showed that, even though the Navy pilots scored better than either of the other two groups, the non-pilot groups showed significant improvement in flight control across the sessions, leading the authors to state, "It is hypothesized that a broader segment of relatively untrained personnel could be brought up to the required level of skill with short time simulation/training provided they meet some minimum selection criteria" (Fogel et al., p. 75).

In the study, the control interface consisted of a joystick for controlling the aircraft (but no rudder pedals), with very little in the way of automation for simplifying the control task. However, the researchers did compare two types of flight control systems, with the joystick either directly controlling (simulated) aircraft surfaces or a more sophisticated control system where the joystick commanded the aircraft performance (bank and pitch) directly. The authors concluded that the performance control joystick was superior for aircraft control, regardless of the level of pilot experience.

The research by Schreiber et al. (2002) looked at the impact of prior flight experience, both Predator and manned aircraft, on learning to fly the Predator unmanned aircraft system (UAS). Seven groups of participants were used in the study, ranging from no flight experience to prior Predator flight experience. Results showed that the group with no flying experience performed significantly worse than the other groups, while the group with previous Predator experience performed significantly better. This finding was expected. However, an unexpected finding from the study was that participants with various levels and types of non-Predator flight experience all performed at relatively the same level on the Predator system. The authors concluded that any type of flight experience with an aircraft with similar handling characteristics to the Predator was beneficial for flight training on the Predator system. They pointed out, though, that the study looked only at stick and rudder skills and not at more general types of flight skills such as communication and airspace management. In addition, the study did not address whether other types of training, such as simulator training, would also transfer to the Predator.

While it might be possible to establish whether a certain type of training or experience is more effectively transferred to a particular UA system, such as the Predator, these studies have not answered the question of whether manned aircraft time is required to be a successful pilot of an unmanned aircraft. We know that certain systems, like the U.S. Army Hunter and Shadow systems, are successfully flown by pilots with no manned aircraft experience. However, once these systems begin flying in populated airspace, there is a question of whether a lack of manned aircraft experience within the airspace might degrade the effectiveness of the pilot and the safety of the flight. Research is needed to address this issue.

Finally, in regard to pilot medical qualifications, the literature review failed to find any research that was relevant. While it might be possible to make the argument that studies showing the benefit of manned aircraft experience for the piloting of certain systems suggest that medical qualifications should be similar to manned aircraft qualifications, the more reasonable conclusion is that no research is available to guide the decision on medical qualifications.

UA APPLICATIONS AND AIRSPACE USAGE

After completion of the literature review, the second task was an assessment of current and near-term UA applications, along with an assessment of the types of airspace usage that would be required for the applications. It is of critical importance that we anticipate the types of activities that will be accomplished using UA. The activities that they will perform will determine the kinds of systems required, the types of airspace that will be flown through, the level of automation that will be used, and the pilot skills and abilities needed to perform the task. The airspace requirements will, in turn, determine the expected degree of interaction with air traffic control and with other aircraft that will occur during typical flights.

The potential applications to which UA can be employed is expansive. However, they all fall into just a few basic categories, based on the type of payload that is carried and its function. The primary purpose for unmanned aircraft stems from the need to place a payload of some type in an aircraft. These needs fall into the categories of 1) Sensor/Surveillance, 2) Payload Delivery, 3) Orbiting, and 4) Transport.

Sensor/Surveillance

By far, the largest category of current applications for UA, both military and civilian, is Sensor/Surveillance. The placement of a camera or other type of sensor on an aircraft has a great many uses. The types of applications vary widely in regard to the type of sensor employed, the level of detail required, and what is being surveilled.

Within the category of sensor/surveillance, we can distinguish between moving and stationary targets. We can also distinguish between the need for real-time download of data or the collection of information that can be analyzed later.

A few current sensor/surveillance applications include logging inspection, pipeline and power line inspection, border patrol, and crop analysis. Potential applications include those involving law enforcement, agriculture, construction, media, the petroleum industry and public utilities (James, 1994), as well as data collection for archaeologists, surveyors, and geologists (Aerospace Daily, 1994). Other applications include monitoring wildfires, floods, and crops (Dino, 2003).

Payload Delivery

Payload delivery applications refer to the use of a UA to deliver a non-reusable payload. For military UA, this refers to ordnance delivery such as air-to-air or air-to-ground missiles. Civil applications of payload delivery would be crop dusting or fire fighting. Air-to-air refueling is also an example of payload delivery. For each of these applications, the payload is expendable and is not intended to return with the aircraft. This aspect distinguishes the payload delivery category from other categories.

Orbiting

Orbiting applications require that the aircraft maintain position at a particular location for reasons other than surveillance. At least three applications present themselves in this category. One is the use of UA at high altitudes to act as communication satellites. Telecommunications companies could use UA to relay signals for mobile phones, for example. Another application is the use of UA for advertising purposes; banner towing, for example.

Transport

Transport applications refer to the carrying of goods and/or people from one location to another. Express mail delivery to small towns is one potential transport application (Aerospace Daily, 1994). For this category, the payload is not expendable and is expected to survive the flight intact. In addition, the payload is intended to be moved from one location to another, as opposed to those applications where the payload is returned to the point of origin.

Airspace Usage

It is important that we anticipate how these various applications will impact the airspace. Table 1 lists various types of UA applications, organized by the type of airspace that will be utilized. The airspace categories are listed (from top to bottom) in terms of the criticality of sense-and-avoid technology required to fly in that airspace. The term "transition" in the table refers to the fact that the aircraft might take off from a public use airport (Class B, C, or D airspace) and have to transit through this airspace before getting to the location where the focal activity will occur.

We have differentiated between two types of Class G airspace, depending on whether the area underlying that airspace is populated or not. Flight in Class G airspace sometimes originates from a public use airport, depending on the size of the aircraft or its ability to land and takeoff vertically or without a runway. These factors led to the differentiation of four separate categories that deal with Class G airspace. The category called "high altitude flight" refers to flight above FL430 (43,000 feet above mean sea level), which is still within Class A airspace but is rarely used by air carriers. Flight within Class E airspace was considered more critical than flight within Class A airspace in regard to the sense-and-avoid issue because Class A is positively controlled airspace and because equipage requirements for aircraft within Class A are more stringent than equipage requirements for Class E.

RTCA Scenarios

In an effort to gauge the types of applications and systems that are expected, a review was made of 63 unmanned aircraft flight scenarios that were developed by members of RTCA Special Committee 203 on Unmanned Aircraft Systems. These scenarios are posted on their limited-access Web site.

The scenarios describe systems that range in weight from 200 grams up to 96,000 pounds. Many of the scenarios use existing military systems. Sometimes these scenarios are military in nature, but more often the scenarios involve civilian use of a military system. After

Table 1. Listing of applications by airspace requirements.

Airspace\Application	Surveillance	Payload	Orbit	Transport
Class G only unpopulated	RC apps, crop inspection			
Transition to Class G unpopulated	Pipeline inspection	Crop dusting		
Class G only populated	Building fire inspection			
Transition to Class G populated	Powerline inspection		Advertisement	
Transition to high altitude flight	Environmental imaging		Pseudo satellite	
Transition to Class A	Crop surveys	Air refuel		Cargo/people
Transition to Class E	Law enforcement		Banner towing	Cargo

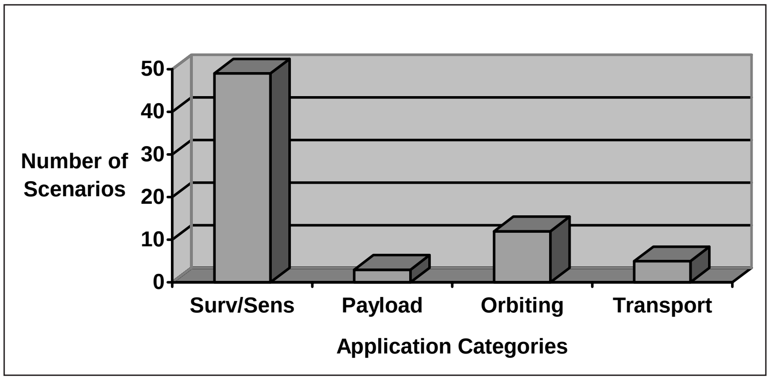

Figure 1. Breakdown of RTCA scenarios by application category

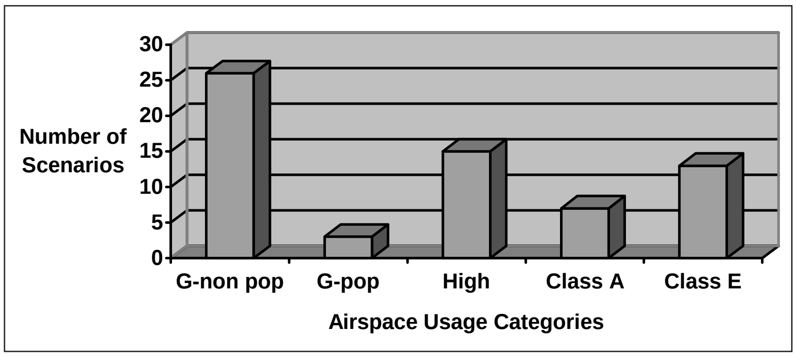

Figure 2. Breakdown of RTCA scenarios by airspace usage category.

reviewing each of the scenarios, the following figures were constructed to categorize the types of applications proposed and the types of airspace that will be used. Figure 1 shows how the scenarios fall into the four basic types of applications described above.

As can be seen from Figure 1, most scenarios, 49 (78%), fell into the Sensor/Surveillance category. The Orbiting category was a distant second, although it should be pointed out that test flights were placed into this category. The Transport applications included the delivery of mail and the transportation of donor organs. Finally, the Payload applications included two in-flight refueling scenarios and a military strike mission.

Figure 2 shows the breakdown of scenarios according to how they would use the airspace. Airspace usage categories are those referenced earlier. It should be noted that the numbers in Figures 1 and 2 add to greater than the number of scenarios because some of the suggested scenarios included more than one application and more than one type of airspace being used.

Figure 2 does not show two of the airspace usage categories because there were no scenarios associated with those categories. Those categories were *transition to non-populated Class G* airspace and *transition to populated Class G* airspace. That these categories were not included in the scenarios suggests that the types of systems expected to fly in Class G airspace would be able to take off and land without the need for a runway. All of the scenarios occurring within Class G airspace assumed that the aircraft would be launched and recovered within Class G airspace. Scenarios occurring within a military operational area (MOA) were classified as Class G airspace over a non-populated area. Scenarios occurring within Class G airspace over a populated area (G-pop in the figure) involved monitoring automobile traffic, transporting donor organs to hospitals, and police surveillance. It is interesting to note that the majority of scenarios used airspace in a manner that minimized the need for sense-and-avoid technologies. One conclusion that was evident from reviewing the RTCA scenarios is that a distinction can be made between systems that remain within the line-of-sight of the pilot and those that do not. This distinction could prove useful when it comes to specifying airworthiness and pilot classifications.

SUMMARY OF A MEETING ON UA PILOT MEDICAL REQUIREMENTS

On July 26, 2005, a meeting was held at the FAA Civil Aerospace Medical Institute (CAMI) in Oklahoma City, OK, of a diverse group of subject matter experts from industry, academia, the FAA, and the military to discuss UA pilot medical requirements. Table 2 lists the attendees and contact information.

Attendees included representatives of several groups currently working on the development of standards and guidelines for UA. There were representatives from the National Aeronautics and Space Administration (NASA) Access 5, the FAA, ASTM F38, RTCA SC-203, and SAE-G10 at the meeting. In addition, Dr. Warren Silberman represented the FAA Aerospace Medical Certification Division in regard to the medical certification requirements.

Given that the meeting encompassed only a single day, an attempt was made to focus the discussion as much as possible by providing to the group a draft standard that was developed by the FAA Flight Standards Division (AFS-400). In particular, one paragraph from the draft UA standard (shown below) was reviewed and discussed extensively during the meeting.

Table 2. Attendee listing.

Name	Organization	E-mail	Phone
Adams, Rich	FAA AFS-430	rich.adams@faa.gov	202-385-4612
Beringer, Dennis	FAA/CAMI AAM-510	dennis.beringer@faa.gov	405-954-6828
Berson, Barry	Lockheed Martin/Access 5	barry.berson@lmco.com	661-572-7326
Eischens, Woody	MTSI/Access 5	weischens@mtsi-va.com	703-212-8870 x133
Goldfinger, Jeff	Brandes Associates/ASTM F38	jgoldfinger@brandes-assoc.com	775-232-1276
Johnson, Marca	Access 5	marca@direcway.com	410-961-3149
McCarley, Jason	U of Illinois Institute of Aviation	mccarley@uiuc.edu	217-244-8854
Silberman, Warren	FAA/CAMI AAM-300	warren.silberman@faa.gov	405-954-7653
Swartz, Steve	FAA AFS-430	steven.swartz@faa.gov	202-385-4574
Tvaryanas, Anthony	USAF (311 HSW/PE)	anthony.tvaryanas@brooks.af.mil	210-536-4446
Williams, Kevin	FAA/CAMI AAM-510	kevin.williams@faa.gov	405-954-6843

6.14 Pilot/Observer Medical Standards. Pilots and observers must have in their possession a current third class (or higher) airman medical certificate that has been issued under 14CFR67. The provisions of 14CFR91.17 on alcohol and drugs apply to both UA pilots and observers.

Current pilot medical requirements are separated into three classes. Table 3 lists the requirements for each class.

The first topic discussed was whether the agency should create a new medical certification category for UA pilots or use an existing certification. The rapid consensus by the group was that the creation of a new certification would be prohibitive for a number of reasons related to the difficulty, expense, and time of initiating any new rulemaking activity.

The next topic addressed which existing medical certification(s) to use. Several suggestions were generated by the group, including the use of the Air Traffic Controller (ATC) medical certification and the use of an automobile driver's license. Regarding the ATC medical certification, the argument presented was that the activity of a UA pilot was, in some ways, closer to that of an air traffic controller. However, it was pointed out that there was very little difference between the ATC medical requirements and the second-class medical certification requirements. The real question, then, could be reduced to whether or not a second-class medical was required.

The discussion regarding the use of an automobile driver's license, as is done in Australia and in the United States for the Sport Pilot Certificate, centered on the idea of accountability and professionalism. Some of the group maintained that there was a need to instill at least a minimal level of accountability and professionalism upon UA pilots, and that the use of a driver's license would not accomplish this goal. Others, however, suggested that the pilot certification process could be used to instill professionalism and accountability and that a stronger rationale, using medical reasons, should be established before discarding the use of a driver's license for medical requirements.

As a follow-up to the meeting, Anthony Tvaryanas provided a useful summarization regarding the establishment of occupational medical standards. Basically, there are two separate reasons to establish medical standards for occupations. The first is predicated on the need within individual organizations to establish medical standards that comply with the Americans with Disabilities Act. The procedure includes an analysis of the job requirements (knowledge, skills, and abilities) for a particular position. Because the analysis is for each individual job, there is no generalizable medical standard. After the job requirements are established, the medical examiner, as described by Tvaryanas, "typically receives a list of the job essential tasks (stand for 2 hrs, lift 25 lbs, etc.). The examiner determines and reports whether the individual can or cannot perform the essential tasks outlined by the employer. If they cannot, the organization has a duty to attempt to accommodate the individual (redesign the job), unless it poses an undue burden on the organization, or the individual poses an undue hazard to the safety of self or others. This approach is fraught with the potential for litigation" (Tvaryanas, personal communication).

The second reason for establishing medical standards is to protect the public from occupations where public safety is potentially at risk, such as transportation (including air transport) and the nuclear industry. Medical standards for these occupations are not based on an analysis of the specific tasks but, instead, are focused on the risk of impairment or incapacitation due to the pathology of any preexisting medical conditions. These standards also usually stipulate provisions for drug and alcohol testing. The establishment of medical standards for unmanned

Table 3. Pilot medical certification standards.

Certificate Class Pilot Type	First-Class – Airline Transport	Second-Class – Commercial	Third-Class - Private
Distant Vision	20/20 or better in each eye separately, with or without correction.		20/40 or better in each eye separately, with or without correction.
Near Vision	20/40 or better in each eye separately (Snellen equivalent), with or without correction, as measured at 16 in.		
Intermediate Vision	20/40 or better in each eye separately (Snellen equivalent), with or without correction at age 50 and over, as measured at 32 in.		No requirement.
Color Vision	Ability to perceive those colors necessary for safe performance of pilot duties.		
Hearing	Demonstrate hearing of an average conversational voice in a quiet room, using both ears at 6 feet, with the back turned to the examiner or pass one of the audiometric tests.		
Audiology	Audiometric speech discrimination test (Score at least 70% discrimination in one ear): 500Hz 1,000Hz 2,000Hz 3,000Hz Better Ear 35Db 30Db 30Db 40Db Worse Ear 35Db 50Db 50Db 60Db		
Ear, Nose & Throat	No ear disease or condition manifested by, or that may reasonably be expected to be manifested by, vertigo or a disturbance of speech or equilibrium.		
Blood Pressure	No specified values stated in the standards. 155/95 Maximum allowed.		
Electrocardiogram	At age 35 & annually after age 40.	Not routinely required.	
Mental	No diagnosis of psychosis or bipolar disorder or severe personality disorders.		
Substance Dependence & Substance Abuse	A diagnosis or medical history of substance dependence is disqualifying unless there is established clinical evidence, satisfactory to the Federal Air Surgeon, of recovery, including sustained total abstinence from the substance(s) for not less than the preceding 2 yrs. A history of substance abuse within the preceding 2 yrs is disqualifying. Substance includes alcohol and other drugs (i.e., PCP, sedatives and hypnotics, anxiolytics, marijuana, cocaine, opiods, amphetamines, hallucinogens, and other psychoactive drugs or chemicals.)		
Disqualifying Conditions **Note: Pilots with these conditions may still be eligible for "Special Issuance" of a medical certificate.**	Examiner must disqualify if the applicant has a history of: (1) diabetes mellitus requiring hypoglycemic medications; (2) angina pectoris; (3) coronary heart disease that has been treated or, if untreated, that has been symptomatic of clinically significant; (4) myocardial infarction; (5) cardiac valve replacement; (6) permanent cardiac pacemaker; (7) heart replacement; (8) psychosis; (9) bipolar disease; (10) personality disorder that is severe enough to have repeatedly manifested itself by overt acts; (11) substance dependence; (12) substance abuse; (13) epilepsy; (14) disturbance of consciousness without satisfactory explanation of cause; and (15) transient loss of control of nervous system function(s) without satisfactory explanation of cause.		

aircraft pilots clearly falls under the second reason. Thus, the suggestion by Tvaryanas and others in the group (e.g., Eischens) was that it is important to identify the factors associated with the risk of pilot incapacitation for unmanned aircraft in deciding on the appropriate level of medical certification. In addition, it is important that we understand these factors as they relate to manned aircraft to obtain an objective assessment.

Ultimately, the primary driver of the decision of which certification level to use was the current perception of risk for these aircraft. One member of the group offered the following comment in regard to the definition of acceptable risk:

I think the core issue is defining acceptable public risk from UA operations and applications. This has historically driven (at least in part) the evolution of the current stratified pilot and medical certification systems for manned aviation. This cut-point (acceptable versus unacceptable risk) is not defined by the medical, scientific, or engineering communities, but rather by the policy community (e.g., our political/regulatory institutions). For example, the current '1% rule' (derived from European civil aviation standards) for risk of incapacitation in commercial aviation is a policy threshold. It could just have easily been a '2% rule' or a '5% rule.' The point is that it is a completely arbitrary boundary. The function of the medical/scientific community is to then quantify an individual's risk to determine whether they may exceed this arbitrary threshold. This is accomplished in part by setting certification standards. It is inherently futile for the medical and scientific communities to try to set standards without the policy community first defining 'acceptable risk.' I would urge the FAA to consider this core issue early, and then return to a discussion of standards setting. Once 'acceptable public risk' is defined, setting medical standards becomes more an academic exercise rather than a policy debate (A. Tvaryanas).

Regarding the risk of pilot incapacitation, at least a few factors distinguish this risk from manned aircraft. First, factors related to changes in air pressure can be ignored, assuming that control stations for non-military operations will always be on the ground. Second, it was pointed out by one participant that many of the current UA systems have procedures established for lost data link. Lost data link, where the pilot cannot transmit commands to the aircraft, is functionally equivalent to pilot incapacitation (Goldfinger, personal communication). For those systems with an adequate procedure for handling a lost data link, pilot incapacitation does not compromise safety to the same extent as it would in a manned aircraft. Third, the level of automation of a system determines the criticality of pilot incapacitation, since some highly automated systems (e.g., Global Hawk) will continue normal flight whether a pilot is present or not (Tvaryanas, personal communication).

In the end, it was decided that not enough was known about these aircraft to make an accurate assessment of all of the risks involved. Because of this, the decision was reached by the group that the original suggestion of a third-class medical certification was adequate, with use of the existing medical waiver process (also called "Authorization of Special Issuance") for handling exceptions (e.g., paraplegics). This decision was also supported by the factors identified above that mitigate the severity of pilot incapacitation. However, there was additional discussion that some applications might require a second- or first-class medical certification because of the increased risks involved. Imposing different certification requirements, though, would require a clearer specification of pilot certification levels and UA classes. The third-class medical certification statement was believed to apply to many, if not all, existing commercial and public UA endeavors (e.g., border patrol applications). The question then arose as to what types of pilot certification would require stricter medical certification. Because the document was viewed as sufficient for present needs, no wording changes were suggested for paragraph 6.14.

Since the meeting, the FAA Office of Aerospace Medicine has suggested that a second-class medical certification might be more appropriate for UA pilots. The main reasons for this recommendation are that some UA pilots are required to maintain visual contact with the aircraft and a third-class medical certification requires only 20/40 vision, with or without correction. On the other hand, second-class medical certification requires 20/20 vision, with or without correction. A second reason for a second-class medical is that there are currently no commercial pilots that have less than a second-class medical. A replacement paragraph has been drafted that will change the medical certification requirement to second-class. The paragraph is as follows:

> Pilot/Observer Medical Standards. Pilots and observers engaging in flight operations for compensation or hire who will, in the course of their duties, perform visual collision avoidance duties IAW[1] paragraph 6.20 of this policy, must have in their possession a current Second-Class airman medical certificate that has been issued under 14 CFR 67, Medical Standards And Certification. Pilots and observers engaged in flight operations of other than a commercial nature will possess a current Class Three medical certification. The provisions of 14 CFR 91.17, Alcohol or Drugs, applies to both UA pilots and observers. The Department of Defense will establish guidelines for medical fitness that, in the judgment of the services, provides a similar standard.

[1] In accordance with (IAW)

SUMMARY AND CONCLUSIONS

The goal of the research was a recommendation of the medical requirements for UA pilots. The recommendation for the level of medical class for UA pilots was based on an analysis of the method for establishing the medical requirements of other occupations, including manned-aircraft pilots. Rather than suggesting the creation of a new medical class for UA pilots, the group decided to recommend an existing pilot medical certification. There were several reasons supporting this decision, including the difficulty of establishing a new certification level and the problems associated with training medical examiners that would be asked to assess whether UA pilots successfully met the new requirements.

Given that an existing medical certification was recommended, the question of which class of certification to propose was based on the perceived level of risk imposed by the potential incapacitation of the UA pilot. The original recommendation of a third-class medical certification was replaced with the implementation of a second-class medical in the standards. The decision was based on the idea that there were several factors that mitigated the risk of pilot incapacitation relative to those of manned aircraft. First, factors related to changes in air pressure could be ignored, assuming that control stations for non-military operations would always be on the ground. Second, many of the current UA systems have procedures that have been established for lost data link. Lost data link, where the pilot cannot transmit commands to the aircraft, is functionally equivalent to pilot incapacitation. Third, the level of automation of a system determines the criticality of pilot incapacitation because some highly automated systems (e.g., Global Hawk) will continue normal flight whether a pilot is or is not present.

Against these mitigating factors was the fact that most UA operations were anticipated to be public use, such as border patrol flights or commercial activities. Manned-aircraft pilots in these instances are required to have a second-class medical certification. In addition, there is very little difference between a second- and third-class medical certification. The major differences are the vision requirements (20/20 vs. 20/40 correctable) and how often they must be renewed.

Finally, the waiver process available to pilots provides that handicapped persons can still receive a medical certification. All that is required is a demonstration of their ability to pilot the aircraft effectively. This process gives individuals who might not be able to fly manned aircraft an opportunity to receive medical certification for flying an unmanned aircraft. However, issues with pilot airman certification must still be resolved before this can occur.

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APPENDIX A

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Exhibit 10: Jason S. McCarley & Christopher D. Wickens, Institute of Aviation, Aviation Human Factors Division, University of Illinois at Urbana-Champaign, *Human Factors Implications of UAVs in the National Airspace* (2004)

Human Factors Implications of UAVs in the National Airspace

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INTRODUCTION

Unmanned aerial vehicles (UAVs) are quickly becoming a part of the national airspace system (NAS) as they transition from primarily military and hobbyist applications to mainstream flight applications such as security monitoring, satellite transport, and cargo hauling. Before the full potential of UAV flight in the NAS can be realized, however, FAA standards and regulations for UAV operations must be established. Given the experience of the U.S. military that mishap rates for UAVs are several times higher than for manned aircraft (Williams, 2004)—over thirty times higher, in some cases (Department of Defense, 2001)—the importance of carefully designed standards and regulations is clear.

Issues related to human factors are likely to be of particular concern in establishing guidelines for UAV flight. As noted by Gawron (1998), UAV flight presents human factors challenges different from and in some ways greater than those of manned flight. These arise primarily from the fact that operator and aircraft are not co-located. As discussed in more detail below, the separation of operator and vehicle imposes a number of barriers to optimum human performance, including loss of sensory cues valuable for flight control, delays in control and communications loops, and difficulty in scanning the visual environment surrounding the vehicle. Unmanned flight also allows the possibility that a single operator might control multiple vehicles simultaneously, a task likely to impose unique and heavy workload demands.

The goal of the current work was to examine the existing research literature on the human factors of unmanned flight, and to delineate issues for future research to address. The topics discussed below are divided into the categories *Automation*; *Perceptual and Cognitive Aspects of Pilot Interface*; *Air Traffic Management Procedures*; and *Crew Qualifications*. As will be clear, however, the issues covered within the various categories are highly interrelated. Answers to questions about crew complement, for example, will be contingent on the nature and reliability of automation provided to support UAV operators. Likewise, decisions about interface design will depend on the extent to which flight control is automated, with manual flight mode demanding traditional stick-and-rudder controls and automated flight mode allowing for point-and-click menu-based control or other forms of non-traditional interface.

It is also important to note that unmanned aircraft will likely serve a range of purposes in civilian airspace, and that the demands placed on human operators will vary with characteristics of the flight mission. Proposed uses for UAVs include agricultural, geological, and meteorological data collection; border surveillance; long distance transport; search and rescue; disaster monitoring; traffic monitoring; and telecommunications relay. Furthermore, military UAVs will increasingly be required to transition through civilian airspace en route to their missions. In some of these cases, the vehicle is likely to operate solely within line-of-sight communications range and only over relatively short periods of time (i.e., on the time scale of several hours or less). In other cases, the vehicle will operate at distances demanding over-the-horizon communications, and will potentially remain airborne for many days on end. These mission characteristics will modulate concerns about communications delays between ground control station and vehicle, and about the need for transfer of vehicle control between crews. For some applications, additionally, operators will likely be required to make frequent control inputs, adjusting flight parameters or selecting new waypoints "online" in response to changing task demands or conditions. For other applications, flight path will be predetermined and less susceptible to modification, reducing the immediacy and frequency with which operators are required to intervene in flight control and allowing for a heavier reliance on automated vehicle guidance.

TECHNICAL APPROACH

Our technical approach involved three parallel efforts. (1) We acquired a large body of literature, both in published sources and in technical reports, that addressed any aspects of human factors in UAVs. This literature is documented in an annotated bibliography in Appendix A. (2) We identified laboratories where UAV human factors work is in progress. These laboratories, and points of contacts, are listed in Appendix C. (3) We became acquainted with UAV human factors issues in civilian airspace by familiarizing ourselves with Access 5 documents. (4) We applied our own subject-matter expertise of both aviation human factors in general, and UAV operations in particular, to identify 18 key human factors research topics, that we believed were **relatively unique** to UAV operations. This uniqueness constraint is critical. There are for example numerous human factors issues that should be applied equally to manned as well as to unmanned aircraft, relating to topics such as display legibility, CRM and communications, checklist design, etc. We did not include these in our effort, but note their enduring importance for UAV certification. Research topics are described in the text below, and in Appendix B are cross-indexed with relevant sources from the research literature described in Appendix A.

Having identified issues, and examined written documents that described human factors research, our final product was to map research needs against existing research documents, where such documents contained empirically valid findings. This material, contained in table 1 of the report below, provides an identification of the key research areas that we believe should be funded, in order to proceed on the path toward safe certification of UAVs in civilian airspace. We have not explicitly prioritized these areas in terms of their importance.

AUTOMATION ISSUES

1. To what extent should en route flight control be automated?

Current UAV systems vary in the degree to which en route flight control is automated. In some cases the aircraft is guided manually using stick and rudder controls, with the operator receiving visual imagery from a forward looking camera mounted on the vehicle. In other cases control is partially automated, such that the operator selects the desired parameters or behaviors through a computer menu or rotary dial interface in the ground control station. In other cases still control is fully automated, such that an autopilot maintains flight control using preprogrammed fly-to coordinates. At least one system (Pioneer), finally, allows the operator to switch between full manual, hybrid, and full automation control modes.

These various modes of flight control each present benefits and drawbacks (Mouloua, et al, 2003). Full manual control would seem to impose the highest and most continuous level of cognitive workload on UAV operators. Moreover, manual control will be degraded by communication delays between UAV and GCS (see #8, #13). Conversely, fully automated control can prevent an operator from rapidly intervening when necessary, (e.g., upon loss of communications) and by leaving the operator largely "out of the loop" (Wickens & Holland, 2000), can produce degraded situation awareness (e.g., noticing a change of handling qualities due to icing). Flight planning can also be excessively time consuming for fully automated systems, sometimes requiring many weeks (Williams, 2004).

For reasons like those described above, Mouloua, et al (2003) recommended hybrid manual/automated control systems for military UAVs. A blanket recommendation, however, may not be appropriate for UAV flight in civilian airspace. Rather, the optimal flight control system seems likely to vary with the characteristics of the flight operation, either within or across flights. UAV operations that entail primarily long-endurance station-keeping (ACCESS 5, 2003), for example, are not likely to impose especially high demands on operator situation awareness. Fully automated control might therefore be more appropriate for such operations that either hybrid or manual automation. The optimal level of automation may also depend on the number of UAVs that a single operator is required to control, the communication delays between operator and UAV, and the quality of visual imagery and other sensory information provided to the operator from the UAV.

A number of questions related to the method of UAV flight control thus remain to be addressed. Research is recommended to:

- Determine the circumstances under which various modes of UAV flight control—fully automated, partially automated, manual—are appropriate.
- Determine whether or not the level of automated flight control should be reconfigurable, such that the operator can alternate between levels of control when he/she deems appropriate.
- Determine whether the reconfiguration of flight control should itself be adaptively automated, such that the UAV system adjusts the level of automated flight control to match the current circumstances (e.g., the current communications delay between UAV and GCS).
- Determine how and when the UAV operator will be allowed to override the automated flight control system.

The output of this work would be a set of rules advising what level of automation should be available/required, during what phases of flight and types of operations.

2. What are the consequences of degraded reliability of automated UAV functions for performance of the automated task and of concurrent tasks?

As the discussion in #1 above makes clear, UAV operations are likely to be highly automated. It is widely acknowledged, however, that often the effect of automation is not to reduce the human operator's task demands but rather to change them, imposing new forms of cognitive workload and modifying the operator's performance strategies (Parasuraman, 2000). Such changes, and occasional increases in cognitive workload, often result in circumstances when automation is imperfect. This imperfection does not refer to issues such as software reliability (e.g., "10^{-5} requirements"), but rather, to circumstances where correctly functioning automation is incapable of perfectly carrying out the functions asked of it. Examples include on-board conditions (e.g., icing) for which stability control cannot fully compensate, diagnostic systems based on imperfect cues, or conflict detection/avoidance algorithms based upon future trajectory estimates in a probabilistic environment (Xu, et al, 2002; Kuchar, 2001). Past work has indicated that imperfect automation at a reliability level greater than around 0.80 can continue to support performance on the automated task as well as concurrent tasks (Dixon and Wickens, 2004; Wickens & Dixon, 2005), although this "threshold" estimate remains far from an absolute value, and other factors, such as the nature and priority of the automated task, appear to modulate pilot tolerance for imperfection. To allow the optimal design of automated support systems for UAV operators, research is thus recommended to:

- Determine the minimum acceptable reliability levels for automated functions that relatively unique to UAV operations.
- Anticipate potential forms of system failure, and delineate their likely consequences.
- Estimate the means and standard deviations of operators' response times to various failures.

Techniques such as Failure Modes Effects Criticality Analysis can be used in these endeavors.

3. How will see and avoid requirements be addressed in UAV flight? Can automated detect, see, and avoid (*DSA*) technology allow a UAV operator to maintain acceptable levels of separation? What are the consequences of imperfectly reliable DSA automation on conflict detection and on performance of concurrent tasks?

The ability to maintain adequate separation between aircraft is a prerequisite for the safe integration of unmanned vehicles into the NAS. While safe separation from other aircraft can generally be assured through standard ATC operations in operations under IFR and IMC (but see issue #13 below), there will be times in which UAVs may be flying under VFR (or a corresponding designation) in which detect, see and avoid (DSA) capabilities are essential. In such circumstances, separation may often be maintained through emerging CNS (communications, navigation, surveillance) technology supported by GPS navigation and ADS-B communications. However, these conditions do not accommodate unequipped (non-cooperating) air vehicles that are unable to accurately transmit (or transmit at all) their position and trajectory through the 3D airspace, and which may be uncooperative or non-responsive in negotiating conflict avoidance maneuvers. It is for this reason that automated DSA functions are required. The need for such functions raise two critical human factors concerns.

First, operators will be asked to interact with error prone systems. It is likely that automatic target recognition capabilities will be fallible, particularly if they are asked to generate early alerts (i.e., at sufficient distance that avoidance maneuvers are possible). As a consequence, this form of automation will be imperfect (see # 2 above; Thomas, Wickens, & Rantanen, 2003), leading to either misses (late alerts) or false alerts. Given the high costs of misses, and low base-rate of events (Parasuraman, Hancock, and Obofinbaba, 1996), the false alarm rate will be potentially quite high (Krois, 1999). The effects of such automation errors will have to be considered in designing DSA systems. Second, operators will be required to interact with the imperfectly reliable DSA system while also maintaining responsibility for airframe and payload control. These concurrent responsibilities will determine the degree to which the operator can be expected to oversee the DSA, monitoring the raw data of the UAV sensor images of the 3D airspace upon which the DSA algorithms are based. In light of these concerns, research is recommended to:

- Determine how operators will respond to alert imperfections in DSA.
- Delineate the conflict geometries and visibility conditions that are likely to degrade the reliability of DSA automation.
- Establish procedures by which the output of human perception and automated target analysis can be combined to maximize the sensitivity of the two component (pilot and algorithm) system given the pilot's concurrent responsibility for flight control.

4. To what extent should takeoff and landing be automated?

Current UAV systems differ in their manner of takeoff and landing. Some (e.g., the Hunter and Pioneer) are controlled by an on-site external pilot. Others (e.g., the Predator) are controlled by an air vehicle operator within the GCS. For others still (e.g., the Global Hawk) takeoff and landing are fully automated. These differences appear to be consequential; takeoff and landing errors constitute a higher proportion of human factors-related accidents for the Hunter (67%) and Pioneer (78%) systems, both of which are controlled by an external pilot, than for other systems (Williams, 2004). Research is therefore recommended to:

- Determine what method of UAV control during takeoff and landing is appropriate for aircraft in civilian airspace.
- Delineate the responsibilities that the human operator can and will be expected to assume in the case of automation failure.
- Establish guidelines to for how and how will the human operator will be allowed to override automated control systems.

<u>PILOT INTERFACE: PERCEPTUAL AND COGNITIVE ISSUES</u>

5. Through what form of control interface should internal and external pilots manipulate a UAV?

As noted above, UAV systems will vary in the degree to which airframe control is automated either en route or during takeoff and landing. For any system that is not fully automated—including systems that allow for a human operator to intervene in vehicle control by overriding automation—it will be necessary to provide operators with a control interface through which to manipulate the vehicle. The form of this interface will differ for internal pilots, those who interact with the vehicle through an interface of sensor displays and controls inside a ground control station, and external pilots, those who interact with the vehicle while in visual contact with it at the site of takeoff or landing. In the case of full manual control by an internal pilot, the seemingly obvious choice of control design is a stick and rudder interface like that used for control of manned aircraft. In cases of partially automated flight control, or of fully automated flight control where the pilot is provided authority to override the automation when deemed necessary, the optimal design of control interface is less clear. Current UAV systems vary in control design, with some systems allowing interaction through knobs or position switches and others through mouse-driven point-and-click computer menus (Williams, 2004). Alternative designs may be possible, however, and should be explored. Additionally, it is important to ensure that any interface be tailored according to established human factors guidelines; data suggest that some existing UAV system interfaces are poorly designed for human interaction.

Similarly, research is necessary to assess and improve the design of controls for external pilots. Currently, an external pilot manipulates the UAV using joystick controls similar to those used by radio-controlled aircraft hobbyists (Williams, 2004). These designs are problematic, however, in that the mapping of vehicle movement to control input varies depending on the heading of the vehicle relative to that of the EP. When the heading of the vehicle and pilot are the same, a rightward input to the joystick control produces rightward motion from the aircraft relative to the pilot. When the heading of the aircraft and pilot deviate, however, this is no longer true. In the most extreme case, where the heading of the UAV and pilot differ by 180°, a rightward input on the joystick produces leftward motion of the vehicle relative to the pilot. Joystick controls for external pilots are thus not designed to conform consistently to the well-established human factors principle of *motion compatibility* (Wickens & Holland, 2000; Wickens, Vincow, & Yeh, 2005). Not surprisingly, this violation appears to be contributing factor in a high number of UAV mishaps (Williams, 2004). Quigley and colleagues (Quigley, Goodrich, & Beard, 2004) have designed and tested a variety of control interfaces to address this problem. Further is now necessary to:

- Explore and optimize the design of control interfaces for internal and external pilots' control of UAVs.
- Delineate the performance benefits and drawbacks of various forms of UAV control interface so as to determine which design should be adopted.

6. What compromises should be adopted between spatial resolution, temporal resolution, time delay, and field-of-view (FOV) in the display of visual imagery for flight control and/or conflict detection?

A UAV operator generally relies on imagery from onboard sensors for manual control of vehicle and payload and for visual target detection. The quality of this visual information, however, may be degraded due to datalink bandwidth limits and transmission delays. Specific degradations include poor spatial resolution, limited FOV, low update rates, and delayed image updating (Van Erp, 2000). These conditions will impair both vehicle control and the visual detection of air traffic. For example, low image update rates will degrade perception of motion information that is useful for drawing attention to air traffic in the visual field. Low update rates and long communication delays, likewise, will produce discontinuous and slow visual feedback in response to operator control inputs, leading to instability of manual UAV control or camera image control and encouraging operators to adopt a “go-and-wait strategy” in manual control (Van Erp & Van Breda, 1999). Poor spatial resolution, obviously, will impair detection of objects that occupy only a small visual angle within an image, reducing stand-off distance in detection of potential traffic conflicts (see 4 above). A small field of view (FOV) will not only eliminate ambient visual information useful for assessing ego-motion necessary at low level flight (Gibson, 1979; Wickens & Holland, 2000), but will also impose a demand for greater amounts of camera scanning for successful traffic detection. A well-designed system for display of sensory imagery will be required to balance the benefits and costs of temporal resolution, spatial resolution, and FOV. To guide the design of visual information displays, research is recommended to:

- Determine what information is "task-critical" in manual airframe control, payload sensor control, and visual traffic detection (Van Breda, 2000).
- Establish the optimal compromise between spatial resolution, temporal resolution, and FOV in the display of visual imagery.

As part of this work, it will be important to establish a catalogue of mission payload requirements that may compromise the quality of visual information for flight, and establish the minimum necessary information (time delay and image quality) for manual control. For different functions, sensitivity curves should be established to show performance quality or function degradation as a function of spatial and temporal resolution.

7. Can augmented reality displays or synthetic vision systems successfully compensate for the degraded visual imagery provided by onboard sensors?

As noted above (#6), low temporal resolution and delayed updating of visual imagery received from onboard sensors will degrade manual control of airframe and payload tasks. The judicious choice of spatial and temporal image parameters may attenuate these effects, but is unlikely to mitigate them in full. An alternative approach to improving visual information display may be through the use of "augmented reality" (Milgram & Colquhoun, 1999) or "synthetic vision" (Draper, et al, 2004), in which the real-world imagery provided by a sensor is embedded within a display of computer-generated landmarks or objects representing the same scene. The virtue of augmented reality in the context of UAV flight is that the computer-generated component of a display can be updated immediately in response to control inputs from a UAV operator, providing rapid feedback to improve manual tracking. For example, Van Erp & Van Breda (1999) provided subjects in a simulated payload sensor control task camera imagery overlaid by a computer-generated grid of perpendicular lines, oriented so as to conform to the imaged scene. The synthetic grid shifted in real time following input from the operator, giving visual feedback as to the direction and magnitude of camera movement. As compared to a control condition with no virtual grid, augmented displays significantly improved target tracking at low camera update rates (i.e, long sensory delays). A study by Veltman and Oving (2002) produced similar benefits by embedding current and predicted camera footprints within a larger map (either 2D or 3D) of the terrain to be scanned. A still more sophisticated form of display is a fully virtual synthetic vision system, in which terrain information is stored in databases and rendered based on GPS position. An important issue here concerns the degree of realism with which synthetic imagery should be presented, whether minimalist (e.g., the grid used by Van Erp and Van Breda), or highly realistic, such as employed in current SVS systems (Prinzel et al, 2004). The danger of the latter is that pilots may place undue trust in the imagery, leading to cognitive tunneling and neglect of information not available within such a high imagery display (e.g., a "transponder off" aircraft; Thomas and Wickens, 2004). Augmented displays thus present a promising method of enabling good UAV operator performance, but are not without potential costs. Research is thus recommended to:

- Further develop and test predictive augmented displays to improve airframe and payload sensor control.
- Determine the effects of display format/fidelity on the UAV operator's level of trust in the automated system.

8. Can multimodal display technology be used to compensate for the dearth of sensory information available to a UAV operator?

One of the primary consequences of the separation between aircraft and operator is that the operator is deprived of a range of sensory cues available to the pilot of a manned vehicle. Rather than receiving direct sensory input from the environment in which his vehicle is embedded, the UAV pilot receives only that information provided by onboard sensors via datalink. As noted above, this consists primarily of potentially degraded visual imagery covering a relatively small FOV. Sensory cues that are lost thus include ambient visual input, kinesthetic/vestibular information, and sound, all of which are valuable in maintaining operator awareness of the environmental and system conditions (e.g., turbulence, icing). As compared to the operator of a manned aircraft, therefore, a UAV operator can be said to function in relative "sensory isolation" from the aircraft under his control. It is critical in light of this for UAV system developers to design displays and alarms to keep operators well-informed of system status and aware of potential system failures.

Visual displays provide one method of presenting a UAV operator with sensor information beyond that conveyed by imagery from a vehicle-mounted camera. Data suggest, however, that UAV operators may not optimally modify their visual scanning strategies to compensate for the absence of multisensory cues (Tvaryanas, 2004). Moreover, the task of creating an "ecological", intuitively-interpreted visual representation for such information is often difficult. An alternative way to compensate UAV operators for the lack of direct sensory input from the vehicle's environment could be through the use of multimodal (e.g., tactile or auditory) information displays. For example, fly by wire controls have long been equipped with augmented force feedback mimicking the forces experienced on the air surfaces of manned aircraft, and roughly capturing the changes in handling quality. Ruff, et al (2000) examined the value of haptic displays for alerting UAV operators to the onset of turbulence. Their data revealed that haptic alerts, conveyed via the UAV operator's joystick, could indeed improve self-rated situation awareness during turbulent conditions in a simulated UAV approach and landing task. Interestingly, this was true despite the fact that the haptic signals were not designed to closely simulate or mimic the veridical haptic information experienced by the pilot of a manned vehicle. The benefits of haptic displays, however, were obtained only under limited circumstances (specifically, only when turbulence occurred far from the runway), and were offset by an increase in the subjective difficulty of landing. These results suggest some value of multi-modal displays as a method of compensating for sensory cues typically denied to a UAV operator, but also indicate that such displays may not be universally valuable and may carry costs as well as benefits.

A related point is that multimodal displays may be useful not simply as a means to compensate for the UAV operator's impoverished sensory environment, but more generally to reduce cognitive-perceptual workload levels. Studies by Calhoun, et al

(2002), Sklaar and Sarter (1999), and Wickens and Dixon (2002; Dixon & Wickens, 2003; Wickens, Dixon, & Chang, 2003), for example, have found that auditory and tactile displays can improve aspects of flight control and system monitoring.

In sum, research is necessary to:

- Further develop techniques for multimodal information display.
- Assess the value of multimodal displays in countering UAV operators' sensory isolation.
- Assess the more general value of multimodal displays in distributing workload optimally across cognitive-perceptual channels.

9. To what extent can displays and controls be standardized across UAV systems? What level of standardization should be mandated? (Basic T instrument panel? HUD overlay?)

We anticipate a tendency for vendors to produce novel designs for the interface, particularly, given the diversity of specialized payload missions for which UAVs may be designed. It is essential to establish certain commonalities across all interfaces. Exactly what these should be remains a question for research. Questions to be considered include, but are not limited to:

- Should the "basic T" always be maintained?
- Is an inside-out attitude display necessary, given that the pilot is no longer inside the vehicle?
- Should certain information always be visible (never hidden to be retrieved by menu navigation)?
- Should all aspects of the payload display be kept spatially separated from the primary flight display, or are HUD overlays advisable?
- Should certain controls (e.g., a joystick) be mandatory for certain functions, and should others be prohibited (e.g., mouse for flight control)?

Identification of these issues recognizes that no single display layout or control assignment is optimal for all tasks, but also recognizes that certain cases of inconsistency can lead to negative transfer and pilot error, as pilots transfer from one interface to another. Similar issues have been addressed in assigning common type ratings and differences training in commercial manned aircraft.

10. What are the consequences for system safety of pilot judgment when the pilot no longer has a "shared fate" with the vehicle? Will there be subtle shifts in risk taking that might affect overall airspace safety?

UAV pilots will not be at risk for injury or death if their aircraft crashes, in contrast to the circumstances of manned aircraft pilots, who "share fate" with their aircraft. This difference could, in theory, impose a substantial difference in risk taking tendencies, in such areas as the decision to carry out a flight into bad weather (Goh & Wiegmann, 2001; Weigmann, Goh, & O'Hare, 2002). Such differences may be further amplified by the sensory isolation described previously. Research is thus recommended to:

- Determine how the UAV operator's risk perception and risk taking behavior are affected by absence of shared fate with his/her vehicle.

- Determine how the UAV operator's risk perception and risk taking behavior are affected by the absence of sensory/perceptual cues.

AIR TRAFFIC MANAGEMENT PROCEDURAL ISSUES

11. How will hand-offs between crews be accomplished during long-endurance flights?

Long-distance and/or long-endurance UAV flight will require the frequent transfer of control between operators, generally taking one of three forms (Kevin Williams, personal communication). First, control may be passed from one ground control station to another. Second, control may be passed from one crew of operators to another within the same ground control station. Finally, control may be passed from one operator to another within a crew. The transfer of control will likely constitute a critical and high-workload phase of UAV operations. Indeed, a number of military UAV accidents have occurred during transfer of control from one team of operators to another, generally because the station receiving control was not properly configured (Williams, 2004). Research is necessary to establish procedures for the safe handoff of control between UAV crews. More specifically, this work should:

- Develop and test formal procedures for handoff of UAV control between teams of operators.
- Develop and test displays, automation, and procedures to ensure that the operators receiving UAV control are adequately informed of system status and are alerted to discrepancies in system configuration between control stations relinquishing and assuming vehicle control.

12. What are the effects of variable total loop time delays on response to ATC instructions?

Datalink delays may be expected to add as many as several seconds to the communications loop between UAV operators and ATC. The magnitude of these delays, however, will be variable, and may not always be predictable to human operators. Thus, controllers may have greater difficulty in compensating for these delays than they do in compensating for the fixed response characteristics of a given class of aircraft. Potential compensatory responses to communication delays are changes in the timing with which ATC commands are issued and acted upon, and changes in the communications flow between ATC and UAV operators (Kiekel, Gorman, & Cooke, 2004; Rantanen McCarley & Xu, 2004). To anticipate and accommodate the effects of communications delays, it will be necessary to understand and take account of these compensatory behaviors and their consequences for system performance. Research should thus be conducted to:

- Determine what compensatory behaviors, if any, air traffic controllers' and UAV operators' adopt in response to communication delays.
- Determine the effects of communications delays on the flow of air traffic.

Computer simulation models of communications may be particularly effective tools here, so long as such models are based on empirically validated estimates of human response time, variability, and reliability (probability of communications error).

13. What form of predictable autonomous behavior should a UAV adopt following a loss of ground-to-air communications? How should the UAV operator be alerted to a loss of ground-to-air communications?

One particularly disruptive scenario of UAV automation failure is a total severing of the GC-UAV control loop. It is important that the vehicle behave predictably under such circumstances. This is a human factors issue because such default rules are of critical importance to the ATC/ATM who must manage traffic based on the knowledge of these rules (Shively, 2004). It is also important, clearly, that the UAV operator become aware of the communications loss as rapidly as possible. Research is therefore necessary to:

- Determine what behavior UAV be programmed to adopt by default in case of a total communications loss with ground control station (Continue to fly on a straight path? Descend? Fly toward the nearest equipped airfield?).
- Develop displays, automation, and/or procedures by which the UAV operator can be made aware of a communications loss, and be provided estimates of its potential causes and consequences.

<u>CREW QUALIFICATIONS</u>

14. How many members will each crew comprise, and what will be each crewmember's responsibilities? Can an operator supervise multiple UAVs simultaneously while maintaining an acceptable level of performance?

Military UAV crews for reconnaissance missions typically include both an air vehicle operator and a mission payload operator (Draper, et al, 2000; Mouloua et al, 2003). Such crew structure is reasonable in light of findings that the assignment of airframe and payload control to the same operator can substantially degrade performance (Van Breda, 1995, cited in Van Erp & Van Breda, 1999). For UAV flight in civilian airspace, however, the size of the crew complement necessary for each vehicle is likely to be contingent on the nature and goals of the flight task (e.g., surveillance vs. long-distance transport vs. station keeping for telecommunications). Although some research has demonstrated possibility of single pilot-multiple UAV (1-to-many) control (Cummings and Guerlain, 2004; Galster, et al, 2001; Wickens, et al, 2003), these successes pre-suppose three circumstances: (1) closely coordinated and correlated activities among the multiple UAVs (Cummings & Guerlain, 2004), (2) operation in a disturbance free (closed) environment, such as very high altitudes, (3) high levels of reliable automation (Dixon and Wickens, 2004). When any of these three characteristics are not in force, and, in particular, when one UAV enters a failure mode, the ability of the pilot to monitor others in a 1-to-many configuration is severely compromised. Furthermore, even in a 1-to-1 configuration, performance of concurrent tasks is dramatically degraded when heavy demands are imposed on the single operator by complex payload operations (e.g., manipulating camera imagery) (Dixon and Wickens, 2004). In light of this, research is necessary to:

- Delineate circumstances under which multiple responsibilities (e.g., flight control, conflict detection, payload control) be safely assigned to a single UAV operator, and circumstances under which such responsibilities should be distributed across two or more crew members.

And, by extension:

- Delineate circumstances under which a single operator can safe hold responsibility for multiple UAVs simultaneously.

It is crucial that such research consider circumstances under which automation is imperfect (#2), and that it address the potential cost of communications and teamwork between multiple operators (Kiekel, et al, 2004).

15. What are the core knowledge, skills, and abilities (KSAs) that should be required for UAV pilot certification? What KSAs should be required for certification to fly particular UAV systems or classes of systems?

Research is necessary to:

- Determine the general KSAs that will be required of all UAV operators.
- Determine KSAs required for certification to operate specified classes or systems of UAV.

16. How should UAV operators be trained? What constitutes an appropriate regimen of ground school, simulator, and flight experience for UAV flight certification?

Safe flight of unmanned vehicles in the national airspace will demand effective procedures for UAV pilot training. Ryder, et al (2001) note that because the task demands of operating a UAV from a ground control console are similar during simulated and real flight, simulator experience is likely to constitute a greater portion of training for pilots of unmanned vehicles than for pilots of manned aircraft. As noted below (#17), furthermore, experience piloting manned aircraft appears to produce positive but imperfect positive transfer to UAV flight (Schreiber, et al, 2002). Research is needed to:

- Optimize simulation systems for UAV pilot training and test their adequacy
- Establish requirements for flight training outside the simulator.
- Determine to what extent manned pilot experience should offset training requirements for UAV certification.

17. Should experience piloting a manned aircraft be prerequisite for UAV pilot certification?

Past research has come to conflicting conclusions as to whether UAV operators will benefit from experience piloting a manned aircraft. Schreiber, et al (2002) examined the effects of prior flight experience on novice operators' skill acquisition and transfer in a Predator UAV simulation. In general, flight experience reduced the number of training trials required for operators to reach a criterion level of performance on a set of basic maneuvering and landing tasks, and improved operator performance on a subsequent reconnaissance task. Other findings, however, have suggested that UAV operators need not be rated aviators. Using the Army's Job Assessment Software System (JASS), Barnes, et al (2000) elicited Hunter UAV operators ratings of the relative importance of various cognitive skills in UAV air vehicle operators. Ratings indicated that outside of communication skills, raters did not consider flight-related skills of great importance to UAV operations, leading the authors to conclude that selection of rated aviators as air vehicle operators would be of little value.

The apparent discrepancy in the conclusions reached by Schreiber, et al (2002) and Barnes, et al (2000) may be due, at least in part, to differences in the operation of the UAV systems under consideration; while the Predator is piloted manually via a stick and rudder interface similar to that of a manned aircraft, the Hunter is guided by automation that allows the operator to select flight parameters using knobs on the GCS console. The value of prior flight experience to a UAV operator, that is, may depend in part on similarity between the manned and unmanned systems. Research is necessary to:

- Determine whether and how much experience piloting a manned system should be required for UAV pilot certification.
- Determine whether prerequisite levels of flight experience, if any, should vary across UAV platforms.

18. What medical qualifications should a UAV operator be required to meet?

Although issues of high altitude physiology and medication induced vestibular disruption are not relevant to UAV pilots, some forms medical qualifications are likely to remain necessary. Research is necessary to:

- Determine whether medical standards for UAV operators should be in any ways less or more strict than for pilots of manned aircraft.
- Establish special duty limits for long duration missions.

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Appendix A

Bibliography

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The paper uses an ACT-R model to examine expert/novice differences and effects of control strategy on Predator UAV flight. Three models were developed. Model P (performance only) lacked the knowledge of control instrument settings that is characteristic of expert pilots, and therefore could only rely on performance indicators in maneuvering the aircraft. Model CP (Control + Performance) had knowledge of control and performance settings needed to achieve aircraft behavior, and therefore could rely on a control and performance strategy. However, the model did not remain focused on control indicator after making adjustment to it, but continued with normal crosscheck and checked to see if manipulation had its intended when attention eventually returned to the indicator. Model CFP (Control Focus & Performance) was similar to model CP, except that it remained focus on control instrument until it was properly set. This was in addition to normal crosscheck.

To examine expert/novice differences, the authors compared Model P to Model CP. To examine strategic effects, they compared Model CP to Model CFP.

Results
Performance was better for Model P than for Model CP on 6 of 7 maneuvers. Model P was better on the most complex (three-axis) maneuver, though its not clear why. Performance was better for Model CFP than for Model CP on 5 of 7 maneuvers. Performance on other two maneuvers was similar. Overall, Model CFP performed the most like human subject matter experts.

2) Barnes, M.J., Knapp, B.G., Tillman, B.W., Walters, B.A., Velicki, D. (2000). ***Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments (Technical Report ARL-TR-2081).*** **Aberdeen Proving Ground, MD: Army Research Laboratory**.

<u>Experiment 1</u>
Assessed the importance of using rated aviators for air vehicle operator (AVO) and external pilot (EP) positions in the Hunter UAV. The AVO tasks are to design mission plans in collaboration with commander, fly the UAV after take-off, and set course to waypoints. The AVO must be able to read the instruments, understand flight status, coordinate with the mission payload operator (MPO) when reaching target area, and

respond to emergencies and make course changes when necessary. However, the AVO does not fly the vehicle using stick-and-rudder controls, in the manner of a typical pilot. The EP is responsible for take-off and landing, using a controller similar to that for model airplanes. Most flight safety problems occur during the times that the EP is in control, primarily because take-off and landing are inherently difficult.

The study used the Army's Job Assessment Software System (JASS) to determine what cognitive skills are important for the AVO and EP positions. JASS collects ratings about the degree to which various skills and abilities are necessary to perform a given task. The skills/abilities rated by JASS fall into six categories: communication, speed-loaded, reasoning, visual, auditory, and psychomotor. JASS data were supplemented with enhanced computer-aided testing (ECAT) data from an earlier study. The ECAT data were one- and two-handed tracking scores, which were correlated with failure rates for EP training.

21 subjects were AVO & MPO designated; 11 gave ratings of AVO task structure, 10 gave ratings of MPO task structure. 9 subjects were certified EPs, and gave ratings of EP task structure. 16 fixed- or rotary-wing Army aviators also rated EP skills. ECAT data came from a sample of 28 students in Pioneer and Hunter UAV EP training courses. Six of these failed the course.

Results
AVO raters did not rate flight-related tasks as overly demanding on any of the six skill sets except communication. The EP task was rated as more demanding than AVO task on all skill sets. EP subjects were broken into 4 groups: EP low experience, EP high experience, fixed-wing aviators, and rotary-wing aviators. Aviators gave slightly higher ratings to reasoning skills than did EPs. The EP low experience group gave especially high ratings to vision, audition, and psychomotor skills. Experienced EPs reported using mostly conceptual skills during emergency situations. Inexperienced EPs reported relying on visual & psychomotor skills.

ECAT tracking data were correlated with EP course success rates; 5 of the 6 students who failed had tracking data near bottom of sample distribution. These findings are consistent with the finding (noted above) that inexperienced EPs find visual and psychomotor skills to be particularly important.

Experiment 2
Examined the potential value of imagery and intelligence analysts as components of the UAV. The method used was to measure overlap between JASS ratings for imagery analysts, intelligence analysts, and UAV crew task duties. Imagery analyst skill rankings were significantly correlated with those for 2 out of 16 UAV crew duties, intelligence analyst skill rankings were correlated with those for 14 out 16 UAV crew duties. Results suggest that imagery analysts would complement UAV crew skill sets.

Experiment 3

Used a computational model of human cognition (Micro Saint) to investigate workload throughout the course of a simulated Outrider UAV flight mission. Also considered remarks from subject matter experts (SMEs). Results suggest that candidate tasks for automation included pre- and post-flight procedures & checks, verification of system settings, and computer checks of mission plans. SMEs reported that they did not want full automation, but preferred instead to retain decision making authority themselves. To reduce workload, they suggested making the computer interface faster and letting the automation provide backup check for safety problems.

3) Bell, B., & Clark, J.G. (2002). Bringing command and control of unmanned air vehicles down to earth. *Proceedings of the 21st Digital Avionics Systems Conference (DASC)*, Irvine, CA.

Describes an automated system to assist in UAV search area planning. System is called the Automated Search Area Planning System (ASAPS), and is meant to reduce search area by modeling terrain and target mobility then helping operator to plan a search route focusing on areas where target is most likely to be found.

4) Calhoun, G.L., Draper, M.H., Ruff, H.A., & Fontejon, J.V. (2002). Utility of a tactile display for cueing faults. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 2144-2148.

Subjects performed a compensatory tracking task in conjunction with a monitoring task. Study compared the value of visual, tactile, and combined visual/tactile alerts for identifying which of four scales exceeded normal range in the monitoring task. In the visual condition, subject was required to monitor the scales. In the tactile condition, subject received pulse train alert of fault, with location and frequency of train indicating which scale was beyond normal range of values.

Results

Response time to faults was faster and RMS tracking error was reduced with tactile cues compared to visual cues. Subjective ratings also strongly preferred the tactile cues.

5) Calhoun, G.L., Fontejon, J.V., Draper, M.H., Ruff, H.A., & Guilfoos, B.J. (2004). Tactile versus aural redundant alert cues for UAV control applications. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 137-141.

<u>Experiment 1</u>

Examined the value of aural and tactile alerts, presented redundantly with visual cues, to signal warnings during a simulated UAV control task. Subjects performed a continuous

UAV control task. While doing this, they were required to respond to occasional (3-4 per minute) data entry tasks. Two kinds of data entry task were used:
1) Warning response task Subject determined whether warning level was caution (20-24 per trial) or critical (3 per trial), then responded by entering an appropriate sequence of keys.
2) Radio frequency task Subjects heard call signs, followed by a combination of color & number. On events with call sign Eagle, subject was required to select the appropriate color/number coordinate on the HDD using a mouse. On low auditory load trials, only the call sign Eagle events were used. On high auditory load trials, distractors events with different call signs were interposed.
3) Data query task Simultaneous visual/voice commands specified data for subject to retrieve from HDD and enter via keypad.

Primary manipulation of interest was in the warning response task. In baseline condition, caution signals were specified by yellow visual cue and redundant Type I aural cue, critical signals were specified by red visual cue and the Type I aural cue. In +2nd aural condition, caution signals were specified by yellow visual cue and redundant Type I aural cue, critical signals were specified by red visual cue and the Type 2 aural cue. In +Tactile condition, caution signals were specified by yellow visual cue and redundant Type I aural cue, critical signals were specified by red visual cue and tactile cue.

Results
+2nd aural and +Tactile conditions produced shorter RTs than baseline condition ($p < .05$ and $p < .10$). Baseline was also subjectively rated as less salient than the other two conditions. +2nd aural and +Tactile were not significantly different. +2nd aural and +Tactile improved performance in the radio frequency task under high auditory load conditions. Flight performance was not affected by alert condition.

<u>Experiment 2</u>
The second experiment was conducted to examine the interaction of cue format and auditory load more closely. Method was similar to that the Experiment 1, except that 1) no auditory cue was used in the baseline condition, 2) only critical cues (no caution cues) were used, 3) high auditory load was more difficulty, 4) aural and tactile cues were matched for salience by a pilot study, 5) a visual IFF status probe task was added.

Results
+Aural and +Tactile conditions produced shorter RTs than baseline condition, and were rated as more salient. No differences obtained between +Aural and +Baseline conditions. Baseline condition also produced higher subjective workload. Low auditory load in general produced better self-rated SA and task performance and lower workload, but did not interact with cue format, contrary to findings of Experiment 1.

6) Cooke, N.J., & Shope, S.M. (2004). Synthetic task environments for teams: CERTT's UAV-STE. *Handbook on human factors and ergonomics methods*. Taylor Francis.
Details steps involved in creating a synthetic task environment, and illustrates the process by describing the development of CERTT's Predator UAV STE.

7) Cummings, M.L. (2004). Human supervisory control of swarming networks. *Paper presented at the Second Annual Autonomous Intelligent Networked Systems Conference*.
Discusses issues related to supervisory control of swarming UAVs, i.e., groups of UAVs with some level of autonomous inter-vehicle collaboration. Collaboration between UAVs introduces another layer of automation into UAV control task. At the minimum level of of network autonomy, there is no collaboration between UAVs. At the maximum level, vehicles are in full collaboration and there is no need for human intervention in emergent situations.

Increasing inter-vehicle collaboration does not necessarily increase automation level for the system as a whole. At the lowest level of inter-vehicle collaboration, automation can range from SV levels 1-10. At highest levels, it can range from levels 7-10. The effects of automation of full system and of inter-vehicle communication must be considered in system design.

DOD recognizes the need for a standard UAV interface that provides critical SA and location data to support airspace integration. Swarming UAVs will be tasked to optimize multi-objective cost functions, and central issue in maintaining SA will be to provide visualization tools that communicate cost function info to UAV operator. It will also be necessary to provide interactive sensitivity analysis tools to determine how human adjustments of variables could change overall cost function.

8) Cummings, M.L., & Guerlain, S. (2004). *Developing operator capacity estimates for supervisory control of autonomous vehicles*. Manuscript under review.
An experiment assessed operators' ability to control multiple autonomous aircraft. Subjects performed a supervisory task that required them to control and occasionally re-target multiple Tomahawk missiles. Commands and occasional queries were presented in an onscreen chat box. Chat box responses served as a secondary task measure of workload. Retargeting was done with a decision matrix (looks like a spreadsheet) that allowed subjects to view information on all retargetable missiles, including how long it would take missiles to get to target and the time remaining for the operator to retarget the missile. Available missiles were listed in rows, potential targets were listed in columns. Cell at the intersection of a given row and column gave info about that missile/target

pairing. Retargeting commands arrived at two tempos, low (one event every 4 minutes) and high (one event every 2 minutes). Difficulty of task scenarios was easy, medium, or hard.

Dependent variables were decision time for retargeting; Figure of Merit (FOM), a weighted measure of overall performance; utilization, an objective workload measure given by % busy time; and NASA-TLX ratings. Participants were 42 active and retired duty Navy personnel.

Results

Decision time, FOM, and utilization scores were similar with 8 and 12 missiles, but were degraded with 16 missiles. The effect of number of missiles on decision time was larger as the scenario became more difficult. Subjective workload scores were not affected by number of missiles. Results suggest that operators can manage up to 12 missiles with no degradation. See papers by Galster, et al (2001) and Hilburn, et al (1997) for similar conclusions from ATC domain.

9) de Vries, S. C. (2001). *Head-slaved control versus joystick control of a remote camera (TNO-report TM-01-B008)*. Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Experiment compared benefits of head-slaved HMD control of UAV camera vs. joystick control. Camera joystick was either passive, active (force feedback), or combined with UAV control joystick. Dynamics of the joystick were either position or velocity control. In some conditions, reference marks were included to aid perception of camera orientation.

Results

Analysis of joystick manipulations indicated that best performance came from a passive joystick providing position control without vehicle references. Performance on almost all measures was superior with joystick control relative to head-slaved control.

10) de Vries, S.C., & Jansen, C. (2002). Situational awareness of UAV operators onboard moving platforms. *Proceedings HCI-Aero 2002*.

An experiment examined spatial awareness of operators controlling a UAV from onboard a moving helicopter. Displays presented a 2-D electronic map of terrain including the UAV, helicopter, football stadium, and a column of tanks. In some conditions, a 3-D map was presented to provide self-motion info from perspective of operator inside the helicopter. 2-D maps varied in their center (heli-centered vs. UAV centered) and orientation (north up vs. helicopter heading up vs. UAV heading up). The subject's task was to monitor displays through a 40-60 s automated flight period then answer questions about locations of various items. Questions could ask about either absolute (world-centered) orientation or relative positions of the four items onscreen.

Results

North-up displays were better for absolute orientation questions, as assessed by angular judgment errors and by RTs. In general, absolute judgments were slower than relative judgments, except in case where map is north-up and there was no 3-D self-motion. 3-D self motion increased errors in most conditions (perhaps producing an SAT in some cases) but improved judgments of relative direction from helicopter, and had no effect on judgments relative to the UAV.

11) Wickens, C.D., & Dixon, S. (2003). *Imperfect automation in unmanned aerial vehicle flight control (Technical report AHFD-03-17/MAD-03-2)*. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Employed the single-UAV task of Wickens & Dixon (2002) to examine the effects of imperfect automated aids for detecting system failures and controlling UAV flight path. Subjects flew simulated UAV missions to a command target (CT) locations while concurrently searching for targets of opportunity (TOOs) and monitoring a set of gauges for system failures (SFs). In a baseline manual condition, subjects flew without automated aids. Three groups of subjects were provided an aid to signal system failures. For one group, aid was perfectly reliable. For another group, aid was 67% reliable and prone to committing false alarms. For the third group, aid was 67% reliable and prone to committing misses. Two additional groups were provided an autopilot to control UAV flight path. For one group, autopilot was perfectly reliable. For the other group, autopilot was 67% reliable (i.e., prone to going off-course). A final group was provided both forms of automation, with both being perfectly reliable.

Results

Data indicated that perfectly reliable aids improved performance relative to baseline, and that even the imperfect autopilot was beneficial. Furthermore, automated flight control improved performance on the concurrent TOO search task. In contrast, imperfectly reliable aids for SF detection produced no gains relative to baseline, and even perfectly reliable SF detection failed to improve TOO detection. Results suggest that the benefits of later stage automation (i.e., automation of task execution) may be greater and more robust than the benefits of early stage automation.

12) Dixon, S.R., & Wickens, C.D. (2004). *Reliability in automated aids for unmanned aerial vehicle flight control: Evaluating a model of automation dependence in high workload (Technical report AHFD-04-05/MAAD-04-1)*. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Employed the single-UAV task of Wickens & Dixon (2002) to examine the effects of an imperfect automated aid for detection of system failures. Subjects flew simulated UAV missions to a command target (CT) locations while concurrently searching for targets of opportunity (TOOs) and monitoring a set of gauges for system failures (SFs). In A80 condition, automated aid was 80% reliable and was equally likely to commit a miss or a false alarm. In A60f condition, aid was 60% reliable and was 3x more likely to commit a false alarm than a miss. This should have encouraged high reliance/low compliance. In A60m condition, aid was 60% reliable and was 3x more likely to commit a miss than a false alarm. This should have encouraged low reliance/high compliance. In a baseline condition, subjects performed with no automated aid.

Results
Tracking error was unaffected by automation condition.

The number of instruction refreshes (presented visually) was higher in the A60m (M = 8.5) condition than in the baseline (M = 3). The number of refreshes for A80 (M = 5.57) and A60f (M = 5.25) conditions were marginally lower than in A60m condition, and were non-significantly higher than in baseline condition.

TOO detection rate was higher in the A80 condition than in baseline. No other differences in detection rate between groups were significant. TOO detection times were higher in the A60f and A60m conditions than in baseline. Data showed a non-significant trend toward larger decrement in A60f condition, suggesting that a high false alarm rate induced subjects to invest more visual resources in inspecting gauges in response to an alarm than a high miss rate did.

CT detection times were significantly and substantially (2 seconds) longer in A60f and A60m conditions than in the baseline and A80 conditions.

SF detection rates were higher when workload was high (i.e., during loitering/inspection), but this did not interact with automation condition. SF detection times were also higher when workload was high, and showed an interaction with condition, reflecting the fact that load increased detection times in A60f condition more than in any other condition. Effects of load were similar on all other conditions. Comparison of A60f and A60m conditions showed that in both cases, detection times were increased when automation missed the SF. Detection times when the automation detected the failure were longer in the A60f condition than in the A60m, reflecting greater compliance with alarms in the later condition.

A computational model accounted for the data well. Results of the modeling suggest that compliance and reliance are linearly related to the automation's FAR and HR, respectively, and are largely independent of one another.

13) Dowell, S.R., Shively, R.J., & Casey, D.P. (2003). UAV ground control station payload symbology evaluation. *Paper presented at the Annual AUVSI Conference*, July 15-17, Baltimore, MD.

Compared the effects of floating compass rose and heading tape symbology on mission payload operators' ability to respond to change commands and SA queries. Symbology formats also differed in their representation of sensor pitch: compass rose displays gave pitch as a digital readout, heading tape displays depicted it with a wedge representation indicating the angle of declination. Commanded changes could be to sensor heading, sensor pitch, sensor heading relative to air vehicle (sensor bearing angle), or to AV heading. MPO did not perform AV heading changes, but called them out to confederate pilot. Subjective measures of workload (NASA-TLX) and SA (SART) were also collected.

Results

Changes to sensor heading and sensor bearing angle were more accurate with heading tape than with compass rose symbology, with no SAT. Unexpectedly, changes to sensor pitch were more accurate with compass rose symbology. Post-experiment interviews with subjects suggest this might be due to size and gradient of marked increments on heading tape symbology. Control reversals were more frequent with compass rose than with heading tape. SA probes didn't show much, and no differences were found in subjective ratings.

14) Draper, M., Calhoun, G., Ruff, H., Williamson, D., & Barry, T. (2003). Manual versus speech input for unmanned aerial vehicle control station operations. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting*, 109-113.

Employed a UAV simulation to examine benefits of manual (keyboard) and speech input modalities for intermitted data entry tasks during a continuous flight/navigation control task. A manual command comprised a series of button presses. A voice command comprised a single word or short phrase. Subjects received intermittent signals to perform data entry tasks during flight task. A response to each alert was required within 10 seconds, and the task was required to be completed within an allotted amount of time thereafter. A failure to acknowledge alert was considered a miss, and a failure to complete the task was considered a time-out.

Results

Task completion times were on average 40% shorter with voice commands. Benefits ranged in magnitude from 3.14 to 21.43 seconds. Number of time-outs was almost 10 times higher with manual entry (M = .95 vs. M = .1), and the number of tasks completed incorrectly was approximately 23 times greater. Response time to alerts was faster for manual entry mode, but difference was less than 1 second. RMS airspeed error, path error, and altitude error were all smaller in speech entry conditions. Subjective data also favored speech entry.

As study was devised, speech entry mode generally required fewer commands than manual entry. Data do not indicate if speech entry would still be superior if modalities were equated for number of steps required to execute commands.

15) Draper, M.H., Geiselman, E.E., Lu, L.G., Roe, M.M., & Haas, M.W. (2000). Display concepts supporting crew communications of target location in unmanned air vehicles. *Proceedings of the IEA 2000/ HFES 2000 Congress*, 3.85 - 3.88.

UAVs for intelligence, reconnaissance, and surveillance (ISR) usually have two operators, a sensor operator (SO) and an air vehicle operator (AVO). The AVO controls the airframe, monitors subsystems, and communicates with the ground control station (GCS). The SO searches for targets using a UAV-mounted camera.

The AVO generally views scene with a larger FOV than the SO, and can therefore assist in target detection by directing the SO's attention to targets outside the SO's current FOV. Usually, the AVO attempts to communicate the target location verbally. The goal of paper was to assess a pair of display concepts meant to facilitate AVO/SO communication about target location. Two kinds of advanced displays were tested:

- Compass rose overlay on the SO's camera display Allows AVO to give direction in world-centered references (N, S, E, W), and should make translation to screen-centered references easier for the SO
- Telestrator Allows AVO to designate target location on his display using a mouse, then presents a locator line on the SO's display indicating the direction and distance in which SO should shift camera to find target

Four conditions were tested: baseline (control), compass rose, telestrator, compass rose + telestrator

Results

Telestrator reduced the time necessary to designate the target, improved camera path efficiency improved, and reduced workload. Compass rose was of little benefit.

16) Draper, M.H., Nelson, W.T., Abernathy, M.F., Calhoun, G.L. (2004). Synthetic vision overlay for improving UAV operations.

The authors discuss potential benefits of synthetic vision systems (SVSs) for UAVs. These include:

- SVS could improve SA by highlighting items of interest in camera image.
- SVS could allow operator to maintain SA if visual datalink is lost.
- SVS could facilitate communications between users who are not co-located.

17) Draper, M.H., Ruff, H.A., Fontejon, J.V., & Napier, S. (2002). The effects of head-coupled control and a head-mounted display (HMD) on large-area search tasks. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 2139-2143.

Compared effects of various head-coupled and manually-controlled camera/display configurations on ability to locate targets in a 360-degree search task in a simulated UAV. Target acquisition was better with manual joystick/stationary CRT combination than with head-coupled HMD configurations. Workload ratings, SA ratings, and simulator sickness data also generally favored the non-HMD configurations.

18) Draper, M.H., Ruff, H.A., & LaFleur, T. (2001). The effects of camera control and display configuration on teleoperated target search tasks. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 1872-1876.

Subjects performed forward-field and rear-field search tasks in a UAV simulation using either A) joystick controlled camera with stationary CRT display, B) 1.0x gain head coupled camera with HMD, C) 1.5x gain head coupled camera with HMD, or D) 1.0x gain head coupled camera with HMD in conjunction with combined with manual joystick control.

Results

Configuration A produced best performance for forward-field search. Data showed no significant differences between configurations for rear-field search.

19) Fong, T., & Thorpe, C. (2001). Vehicle teleoperation interfaces. *Autonomous Robots, 11*, 9-18.

Paper discusses various forms of interfaces for vehicle teleoperation. These include:

- <u>Direct</u> Operator manually controls aircraft, typically using controls that are similar to those of a manned vehicle. This form of control/interface is appropriate when 1) real-time human control or intervention is required, and 2) the control station and vehicle are connected by a high-bandwidth, low-delay communications link.
- <u>Multimodal/multisensor</u> Multimodal interfaces "provide the operator with a variety of control modes (individual actuator, coordinated motion, etc.) and displays (text, visual, etc.)...Multisensor displays combine information from several sensors or data sources to present a single integrated view."
- <u>Supervisory control</u> Operator specifies subtasks which the vehicle then performs on its own. This is appropriate when datalink bandwidth is low or communications are delayed.
- <u>Novel</u> These include psychophysiologically-driven control, gesture-based control, web-based interfaces, PDA-based interfaces.

20) Fontejon, J., Calhoun, G., Ruff, H., Draper, M. & Murphy, K. (2004). Tactile alerts for monitoring tasks in complex systems.

An earlier study (Calhoun, et al, 2002) found that tactile alerts could speed detection of system faults in a multi-task environment. In that experiment, subjects were required to detect & identify system faults while also performing a manual tracking task. Two tactors were used to signal four possible system faults: combination of tactor location and vibration frequency signaled which of four system parameters was in fault. Performance was best (RT shortest) when one tactor was located on each arm. When both were on a single arm, performance was better with the right than the left arm.

In the study described above, all participants were right-handed. Additionally, manual tracking was performed with the right hand. The current study was conducted to determine if similar results would obtain for A) left-handed subjects, and B) when subject performed the tracking task using the left hand.

Results

RTs were shortest when tactors were located on different arms. When they were on the same arm, there was no significant difference in RTs for left & right arms. Hand used for tracking did not have any affect on RT to faults.

21) Gawron, V.J. (1998). Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles. *AUVSI '98: Proceedings of the Association for Unmanned Vehicle Systems International*, 431-438.

The author discusses a number of unique human factors concerns unique to UAV flight. These include:

- Data link drop outs may be difficult for operator to notice.
- UAV mission times may exceed human vigilance capability.
- Humans can attend to/inspect only one stream of images at a time, while some UAVs may provide multiple image streams.
- Operators are sometimes given with unprioritized lists of multiple of targets to search for. This may be especially problematic when the operator is asked to control multiple UAVs simultaneously.
- Crew coordination depends on appropriate communications flow between crew members, which can be difficult when crew is large or when crew members are not co-located.
- Visual imagery is difficult to obtain during rocket launching or UAV, and during net or cable arrest. Workload is also high during launch and recovery. Finally, small sensor FOV can reduce SA and make navigation, target acquisition, and traffic detection difficult.
- Manual control of vehicles with time delays is difficult.
- Control interface on some systems is poorly designed.
- Software is not standardized, even between instances of the same UAV system.

Proposed military uses for UAVs include special operations; point reconnaissance, cued surveillance, and target acquisition. Non-military uses are possible in the fields such as law enforcement, fire fighting, agriculture, construction, archaeology, geology, and postal delivery.

22) Gluck, K.A., Ball, J.T., Krusmark, M.A., Rodgers, S.M., & Purtee, M.D. (2003). A computational process model of basic aircraft maneuvering. *Proceedings of the Fifth International Conference on Cognitive Modeling*, 117-122.

Paper presents an ACT-R model of Predator UAV flight. The model is based on simulation used to train Air Force Predator operators. The simulation involves three tasks: basic maneuvering, landing, and reconnaissance. The modeling effort presented in this paper focuses on basic maneuvering. Pilot is required to make constant-rate changes in airspeed, altitude, and heading. A total of seven maneuvers are involved. The first three require pilot to change one flight parameter and hold the other two constant. The second three maneuvers require pilot to change two flight parameters and hold third constant. The seventh maneuver requires the pilot to change all three flight parameters simultaneously.

The model uses a flight strategy called "Control and Performance Concept". First, the operator establishes appropriate control settings for desired performance. Next, the operator cross checks instruments to determine if the desired performance is being achieved. The rationale is that control instruments have a first-order effect on aircraft behavior, which shows up only as a second-order effect in performance instruments.

Results

RMSD for airspeed, altitude, and heading were normalized and summed to provide an overall measure of performance. Grand mean performance on this measure over 20 runs of the model was almost identical to grand mean performance of 7 subjects. Across maneuvers, r-squared for predicting human performance from model was .64. The model was also sensitive to maneuver complexity in the same way that human subjects were, showing better performance for one-axis maneuvers than for two axis-maneuvers and better performance for two-axis maneuvers than for three-axis maneuvers.

23) Gorman, J.C., Foltz, P.W., Kiekel, P.A., Martin, M. J., & Cooke, N. J. (2003). Evaluation of latent-semantic analysis-based measures of team communications. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting*, 424-428.

The authors used Latent Semantic Analysis to develop methods of assessing communications content between team members in a Predator UAV simulation. Measures used were communications density (CD), the average task relevance of the team's communications, and lag coherence (LC), a measure of task-relevant topic-shifting. Data came from two experiments in which teams of three-operators (air vehicle operator, payload operator, and navigator) flew simulated Predator UAV reconnaissance missions. In the second experiment, workload levels were manipulated (low vs. high) and some teams of operators were distributed rather than colocated.

Results

Communications density

Team performance in Experiment 1 was related to CD by a quadratic function, indicating that beyond some point performance declined with additional communication. Similar results were found for co-located and low-workload teams in Experiment 2. Under high-workload conditions, performance continued to increase as CD increased, showing no evidence of a quadratic trend or an optimal CD level. Data from distributed team conditions was too noisy to interpret clearly.

Lag coherence

Coherence was positively correlated with team performance, indicating that low-performing teams tend to shift topics more within a short window than high-performing teams.

24) Gugerty, L. & Brooks, J. (2004). Seeing where you are heading: Integrating environmental and egocentric references frames in cardinal direction judgments. *Journal of Experimental Psychology: Applied, 7*, 251-266.

Navigational tasks often require operators to make cardinal direction judgments, which data suggest are difficult. The goal of the experiments reported here was to examine the strategies by which people make cardinal direction judgments.

Experiment 1

Subjects performed a static judgment task. Stimuli each trial were A) a north-up map showing their aircraft and a footprint of a forward-facing vehicle-mounted camera, and B) a 3-D view of the terrain as seen through the vehicle-mounted camera. The view presented each trial contained a building with a parking lot on each side (N, S, E, W). One of the parking lots contained vehicles while the others were empty. The subjects' job was to indicate the cardinal direction of the occupied parking lot, relative to the building.

Results

Three noteworthy effects were evident in both the error rate and the RT data. The first was a misalignment effect, whereby performance declined as camera heading deviated from north-up. The second was a south-advantage effect, whereby performance was substantially better when camera was oriented south than when it was at nearby orientations. The third was cardinal-direction advantage effect, whereby judgments were more slightly accurate when the camera was oriented east or west than when it was at nearby orientations.

Experiment 2

The goal of experiment 2 was to determine if dynamic spatial information, such as that provided by controlling a vehicle, improves cardinal direction judgments. The dynamic task used was a simulated UAV mission. Subjects were provided three visual channels, A) a north-up map similar to that used in Experiment 1, B) a 3-D view of terrain from a rotatable vehicle-mounted camera, similar to that used in Experiment 1, and C) a standard flight display. The subjects' task was to pilot the UAV to a 10 target objects and answer questions about each one. Three of the 10 questions required cardinal direction judgments.

Subjects also performed a static judgment task identical to that of Experiment 1.

Results
Static judgment task replicated the results of the first experiment. Cardinal-direction judgments in the dynamic task showed effects similar to those of the static task, though the cardinal direction advantage was weaker.

Experiment 3
Subjects performed the cardinal direction task of Experiment 1 and 2 while providing verbal protocols.

Results
Protocols gave evidence for final strategies. The first was a mental rotation strategy, whereby subjects mentally transformed images to be in alignment with one another and north-up. The second was a heading referencing strategy, whereby subjects assigned the current heading to the forward view in the camera, then making judgments relative to that heading ("If forward is northeast, then this is north [pointing to the upper left lot], and this is east [pointing to the upper right lot]." The third was a south-reversal strategy, whereby subjects noted that camera heading was south and then reversed the answers they would have given for a northward heading (this was possible only when camera was oriented toward the south, obviously). The final strategy was a north-heading strategy, whereby subjects noted that camera was oriented to the north and then simply made judgments within a canonical north-up frame.

25) Gunn, D.V., Nelson, W.T., Bolia, R.S., Warm, J.S., Schumsky, D.A., & Corcoran, K.J. (2002). Target acquisition with UAVs: Vigilance displays and advanced cueing interfaces. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 1541-1545.
The authors note that UAV operators will probably spend much of their time in supervisory control mode, but will be required to switch to manual control suddenly in response to system malfunctions, target acquisition, enemy actions, and other intermittent events. As such, UAV operation will be a form of vigilance task. The goals of study were A) to examine value of display type (cognitive or sensory) on performance in a vigilance task and in subsequent manual control mode, B) to compare the effects of visual, auditory, and haptic cueing of target location in a 360 degree target acquisition task.

Subjects flew simulated UAV missions. In supervisory control mode, they were required to monitor a stream of digit pairs for a threat warning indicating the presence of an enemy aircraft. In the sensory task, the threat warning was signaled by a size difference between the two digits. In the cognitive task, the threat warning was signaled by an even-odd digit pairing. After detecting a threat warning, the subject was required to target the hostile aircraft with a joystick-controlled crosshair. In the visual cueing condition, a locator line on the bottom right of screen indicated the direction of the target. In the auditory cueing condition, broadband noise pulses were presented from the target location. In the haptic cueing condition, force feedback on control stick guided the subject toward the target. In the control condition, no cueing was provided.

Results
Hit rates for warnings showed no effect of signal rate, but a significant benefit of sensory display format relative to the cognitive format. False alarms were lower for cognitive than for sensory displays. Target acquisition times were shorter for sensory displays than for cognitive. Visual, auditory, & haptic cue conditions produced similar benefits in target acquisition times, all of which were shorter than in control condition. Subjective workload was higher with cognitive than with sensory displays.

26) Hansman, R.J., & Weibel, R.E. (2004). Panel 1: UAV classification thoughts. *Paper presented at NRC Workshop on UAVs*.
Proposes a classification scheme for UAVs in NAS.

<u>High altitude, long endurance</u>
- Above FL 500, above majority of commercial air traffic
- Potential applications include long-dwell missions such as communications relay, precision mapping/imaging, and atmospheric research

<u>Medium altitude endurance</u>
- FL 180 - FL 500, Class A airspace
- Potential applications include meteorology, disaster monitoring, border patrol, and regional mapping

<u>Tactical</u>
- 1000 to FL 180/10,000 ft., mixed airspace
- Potential applications include law enforcement surveillance, pipeline/rail monitoring, search and rescue, agriculture

<u>Mini</u>
- Below 1200/700 ft. AGL
- --Potential applications include law enforcement, local imagery, and cinematography

<u>Micro</u>
- Below 1200/700 ft. AGL

- Potential applications include recreation, and local imagery

Rotorcraft

- Up to 2000 ft. AGL
- Potential applications include search & rescue, law enforcement, traffic monitoring, cinematography, and agriculture

27) Hansman, R.J., & Weibel, R.E. (2004). Panel 2: Operating and flight rules. *Paper presented at NRC Workshop on UAVs*.

Presents safety analyses of UAV, deriving acceptable failure rates (mean numbers of hours until failures) for varying classes of UAVs. Note a number of safety issues for UAVs operating under instrument and visual flight rules.

IFR

- Control latency
- Communication paths
- Controller workload and representation
- Separation standards
- Traffic load
- Flight plan filing
- Cost recovery

VFR

- See and be seen equivalence
- Rules of the road
- Operation at controlled and uncontrolled airfields

28) Kiekel, P.A., Gorman, J.C., & Cooke, N.J. (2004). Measuring speech flow of co-located and distributed command and control teams during a communication channel glitch. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 683-687.

An experiment used communication flow measures developed by the authors in earlier papers to examine effects of co-location and communication channel disruptions on team communications in a simulated UAV recon task. Teams of three members flew a simulated UAV, taking pictures of target items. Each team comprised three members: the data exploitation, mission planning and control (DEMPC) member planned the route, air vehicle operator (AVO) flew the aircraft, and the payload operator (PLO) controlled the camera and took pictures. Manipulations were A) teams colocated vs. teams distributed, B) workload high vs. low (workload effect not further discussed in this paper), and C) communications normal or disrupted by glitch in channel from DEMPC to AVO.

Three types of analysis were conducted. The first used Pathfinder algorithm to identify common sequences of communications events: XLoop (person X begins and ends a communication, then begins another), XYcycle (person X produces a complete communication, then person Y does), and XiY (person X interrupts person Y). CHUMS analysis measured the stability of communications, as reflected in the relative proportion of speech produced by each member in a one-minute window. Analysis of dominance measured the influence that each team member's communications had over other member's.

Expectation was that occurrence of glitch would modify communication pattern, that DEMPC should have high dominance score, and that dominance of DEMPC should drop in distributed teams and when glitch occurs.

Results
Pathfind analysis found that colocated teams produced more utterances in general than distributed teams. Glitch causes decrease in DAcycles (communications between DEMPC and AVO), increase in DPcycles, increase in PAcycles, and decrease in PDcycles. This is generally what would be expected if communications that normally would have gone from DEMPC to AVO were re-routed through the PLO following the glitch.

CHUMS analysis produced more models for distributed teams, suggesting less stable communications patterns. The communications glitch also reduced stability.

Analysis of dominance found that in co-located teams under normal conditions, the DEMPC is moderately dominant and the AVO is reactive. In distributed teams under normal conditions, AVO is distributed and DEMPC is reactive. During the communications glitch, co-located teams become AVO dominant and PLO reactive.

29) LaFleur, T., Draper, M.H., & Ruff, H.A. (2001). Evaluation of eye-dominance effects on target-acquisition tasks using a head-coupled monocular HMD. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 1433-1437.
Subjects performed a target acquisition task in a UAV simulation. A large FOV display was presented with a monocular HMD. Image was provided by the UAV's gimbaled camera, with camera control by operator's head movements. After spotting a potential target in the HMD, the operator was required to ID and designate it on a high-resolution, small FOV CRT display with camera view controlled by joysticks. Several dependent variables recorded. Of primary interest were effects of dominance of HMD viewing eye on performance.

Results
Eye-dominance had no effect.

30) Miller, C.A., Funk, H.B., Goldman, R.P., & Wu, P. (2004). A "playbook" for variable autonomy control of multiple heterogeneous unmanned air vehicles.

***Proceedings of the Second Human Performance, Situation Awareness, and Automation Conference (HPSAA II)*, Daytona Beach, FL, March 22-25.**
Discusses "delegation" as a technique for control of multiple UAVs. Characteristics of delegation are that supervisor sets agenda for subordinates, but subordinates are given authority to decide exactly how to carry out commands. The authors note five manners/components of delegation that can be employed in varying combinations:
1. Stipulation of goal
2. Stipulation of a plan to perform
3. Stipulation of constraints (via specification of actions or states that should be avoided)
4. Stipulation of actions or states to be achieved (i.e., subgoals)
5. Stipulation of an objective function that will allow the subordinate to assess the desirability of various states and actions

The authors describe their work on developing a "playbook" architecture for delegating to UAVs. Playbook would involve assigning a name to complex behavior patterns, then allowing UAVs to autonomously implement a play when it is called. The Playbook system would assess the feasibility of a commanded behavior before attempting to perform it. When given a high-level command, Playbook would assess various methods of achieving goal, then would issues specific commands to vehicles under its control. When given more highly-specified lower-level commands, Playbook would report to the human operator if the commands were infeasible, or would issues the commands to the vehicles if they were feasible, filling in additional details as necessary.

31) Morphew, M.E., Shively, J.R., & Casey, D. (2004). Helmet mounted displays for unmanned aerial vehicle control. *Paper presented at the International Society for Optical Engineering (SPIE) conference*, April 12-16, Orlando, FL.
Compared performance on a target search & ID task when subjects used a conventional CRT display & joystick control versus when they used a head-slaved HMD. UAV flight was automated. Subjects' task was to search for items in the virtual world display and ID them as target, non-target, or distractor. After spotting a target or non-target, subject was to center crosshairs on the item and press a button on control box to classify it. Independent variables were method of display/control (CRT/joystick vs. HMD/head-slaved), virtual world search width (2500 vs. 5000 ft.), and mission duration (3 vs. 9 minutes). Dependent variables were target detection accuracy (HR, CRR), cursor distance (distance of crosshairs from center of object when object was classified), slant range (distance from aircraft at which subjects were able to classify target),

Results
Accuracy was high (>98%) for both forms of display/control. However, cursor distance was smaller and slant range was larger (i.e., performance was better in both cases) for the CRT/joystick configuration. HMD configuration also produced higher levels of nausea, eyestrain, disorientation, and over simulator sickness rating than the CRT configuration.

Wide search width produced smaller cursor distance than did narrow width, but effect did not interact with any others.

32) Mouloua, M., Gilson, R., Daskarolis-Kring, E., Kring, J., & Hancock, P. (2001). Ergonomics of UAV/UCAV mission success: Considerations for data link, control, and display issues. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 144-148.

Lists a number of considerations and recommendations for optimal design of UAV/UCAV system interface and data transfer.

Data-link timing

If satellite-UAV or UAV-UAV relays are used, variable time delays of 1 second or longer are possible. This eliminates real-time feedback to controls inputs. One way of circumventing this problem is to task operator with supervisory monitoring of on-board automation using pre-programming flight parameters such as speed, altitude, direction. Predictive graphics displays may also be useful.

Controls

Neither full automated control nor full manual control is practical. Full automation prevents the operator from intervening in flight control when necessary, while full manual control can produce excessive workload and make control susceptible to communications delays. The authors recommend hybrid control in which human operator supervises automation by calling subroutines of pre-programmed software.

Display/control interfaces should be based on a standardized group of core functions described with common terminology. Keyboards, touchscreens, pointing devices, and joysticks/pedals are appropriate controls, but must be designed to resist dirt, damage, etc., especially for field operations. Keyboard inputs should be replaced with menu- or speech- inputs for on-line vehicle control.

Assuming semi-automatic flight, flight-management systems and terminology should emulate that of ARINC and DOD. Since commands are anticipatory, this approach allows for preview and escape actions. If manual flight control is used, a GCS with full-time joystick/pedal/power controls will be necessary, and real-time communication with UAV/UCAV will be required.

If menus are used for in-flight supervisory control, it will be necessary to determine optimal number of menus and menu items. Five seems like reasonable starting point, based on Miller's magic number.

Displays

Displays need to reduce and format data for easy interpretation. Other principles to follow include minimizing scene movement & unnecessary changes in viewpoint; using high-quality displays to help ID areas of interest; employing alerts/alarms for system faults; providing mechanisms of selection, comparisons, parsing, scaling of displayed info.

In addition to high-quality sensor-image displays, content should include:

- system conditions and communications status
- flight data
- threat advisories
- weapons status

33) Mouloua, M., Gilson, R., Kring, J., & Hancock, P. (2001). Workload, situation awareness, and teaming issues for UAV/UCAV operations. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 162-165.
The authors discuss UAV design considerations relevant to workload, SA, and teaming. Some of these issues pertain specifically to combat UAVs.

Physical & cognitive workload
Assuming that the UAV control will be highly automated, then the operator's task will consist primarily of supervisory monitoring and making small course adjustments. This is likely to be tedious, producing vigilance failures. UAV systems must therefore be designed not just to avoid overload, but underload as well. This might be done by combining manual and automated control. Operator would be responsible for higher-order tasks (target recognition, munitions deployment) and automation would be responsible for lower-order tasks (flight control, obstacle avoidance). On-board automation should require operator action only as needed.

Situation awareness
Poor SA is likely to contribute to UAV mishaps. One way to help maintain SA is to provide displays that keep the operator aware of the processes being controlled by the automation, with the goal "to make the deep relational structure of the system environment visible to operators and help to identify options for action and indicate the boundaries for successful performance." UAVs may also be able have and advantage relative to manned systems in providing good SA since large numbers of on-board and off-board sensor data streams are available.

Teaming
Research is needed to determine the appropriate crew size and structure for UAV control, and to ensure effective communications. One particular source of miscommunication is the large amount data provided to the various UAV operators. This demands that important information be shared appropriately among operators. Ways to do this include "creating a mechanism for communicating understanding the real-time situation at a higher level across several connected teams or individuals", creating teams of specialists for target detection/authentication and for emergency operations.

34) Nelson, W. T., Anderson, T.R., McMillan, G.R. (2003). *Alternative control technology for uninhabited aerial vehicles: Human factors considerations*. Book chapter.

Discusses potential alternative control technologies for UAVs. These include position and orientation tracking, eye-position tracking, speech recognition, gesture recognition, and electrophysiological measures. The authors advocate increasingly immersive environments for UAV pilots, with eventual possibility that alternative control technologies will replace traditional controls. Possible impediments to these goals include time delays in display updating, simulator sickness.

35) Nelson, J.T., Lefebvre, A.T., & Andre, T.S. (2004). Managing multiple uninhabited aerial vehicles: Changes in number of vehicles and type of target symbology. *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*.

The authors describe an experiment conducted with two goals. The first was to examine changes in performance that result from increasing the number of UAVs under an operator's supervision. Contrary to expectations, past research (Draper, Calhoun, & Ruff, 2003) found limited performance consequences when the number of UAVs under a single operator's supervision increased from 2 to 4. The present experiment compared performance using 3 and 5 UAVs, in an effort to increase the workload demands of the higher-load condition. The second was to compare performance with a novel set of stylized icons to performance with a set of standardized icons (MIL-STD_2525B). The authors hypothesized that the stylized icons, designed to have a physical resemblance to the objects they represented, would produce better performance.

After training, subjects flew two missions in the Multi-modal Immersive Intelligent Interface for Remote Operation (MIIIRO). One mission involved control of 3 UAVs, the other involved control of 5 UAVs (order of missions counterbalanced). Flight control was automated. Subjects were responsible for several additional tasks: identifying unknown aircraft, approving replans of UAV routes, identifying and selecting targets in the imagery from UAV sensors, completing tasks on a mission mode indicator, and counting symbols on the Tactical Situation Display (top-down map of terrain with UAVs and routes depicted) for later recall. Subjective workload measures were also collected.

Results

Data showed no difference between the 3 UAV and 5 UAV conditions in the number of enemy targets identified and selected. Other dependent variables showed significant effects favoring the 3 UAV condition. Specifically, the time to respond to unidentified aircraft was shorter, the number of Mission Mode Indicator tasks completed was higher, the time to check and approve UAV replan routes was shorter, and all subjective performance measures (ratings of situation awareness, perceived task difficulty, perceived performance, and perceived workload level) were better.

Recall of symbols on the TSD was better with the standardized icons than with the stylized set. The authors speculate that this might have happened because the standardized icons were easier to perceptually segregate from the background.

36) Purtee, M.D., Gluck, K.A., Krusmark, M.A., Koffe, S.A., & Lefebvre, A.T. (2003). Verbal protocol analysis for validation of UAV operator model. *Proceedings of the 25th Interservice/Industry Training, Simulation, and Education Conference*, 1741-1750.

Used concurrent and retrospective verbal reports from subject matter experts piloting a Predator UAV simulation to determine how accurately the lab's ACT-R model of Predator pilot performance represents the cognition/information processing of actual pilots.

Results

Overall, attention to performance instruments was verbalized more often than attention to control instruments during concurrent reports. However, retrospective reports suggested that SMEs were using the Control and Performance concept implemented by the model. Results also demonstrate that distribution of operator attention, as reflected in concurrent verbal reports, is influenced by goals/demands of maneuver being implemented. Ideas for improving the cognitive model include incorporating use of trim and a metacognitive awareness of passage-of-time to improve use of timing checkpoints for monitoring progress toward goal.

37) Quigley, M., Goodrich, M.A., & Beard, R.W. (2004). Semi-autonomous human-UAV interfaces for fixed-wing mini-UAVs. *Proceedings of IROS 2004,* Sep 28 – Oct 2, Sendai, Japan.

The paper describes work prototyping and testing several forms of interface for control of small (32" wingspan, in this case) semi-autonomous UAVs.

Control techniques

Numeric parameter-based interfaces provide text boxes in which operator types desired flight parameters.

PDA direct manipulation interface presents fixed-horizon wing-view representation from the viewpoint of an observer behind the UAV. Display also includes a compass and speedometer alongside the wing-view display. The user controls the UAV through drag-and-drop manipulation of the UAV icon or the compass/speedometer. Color differences (blue vs. red) are used to distinguish current state of UAV from desired state specified by user manipulation. This makes the future state of the UAV easy to predict. This interface was also tested with a laptop using trackpad and mouse.

Voice controller is allows UAV control using a grammar of twenty words (e.g., "climb", "go north"). Voice synthesizer provides immediate feedback in present progressive tense (e.g., "climbing", "going north").

Attitude joystick controller mimics a fly-by-wire controller by mapping deflection in joystick to deflection in aircraft attitude. This form of interaction is especially good for novices, non-experience pilots.

Trackpoint controller uses a trackpoint pointing device from ThinkPad laptop, with horizontal inputs mapped to UAV roll and vertical inputs mapped to UAV pitch.

The physical icon interface is a hand-held model of UAV. Orientation of model in 3-D space is tracked, and converted into pitch / roll commands for UAV. Should provide good SA since the operator is holding a representation of UAV in its actual orientation. An accompanying (optional) display helps the user distinguish actual and desired UAV states by presenting the current state in one color and the desired state (i.e., state of physical icon control) in another.

Assessments

The attitude joystick, physical icon, and trackpoint controller produce the fastest operator response times for UAV manipulations. However, these re problematic when UAV is traveling toward the operator, since they require reversal of control inputs.

Direct manipulation interfaces are useful because they don't required sustained attention. After the user has specified the desired UAV state, no further interaction is necessary until another change of state is desired. This can make these interfaces especially appropriate for control of multiple UAVs. The only difficulty is that subject must shift gaze between interface and UAV. This creates demand for frequent accommodation changes.

Voice control allows operator to maintain gaze on UAV, and, assuming commands can be issued in world-centered coordinates (e.g., "go north"), does not require mental transformation of commands depending on heading of UAV.

Parameter based interfaces are difficult because they require operator to type, and also demand mental math.

38) Ruff, H.A., Calhoun, C.L., Draper, M.H., Fontejon, J.V., Guilfoos, B.J. (2004). Exploring automation issues in supervisory control of multiple UAVs. *Proceedings of the Second Human Performance, Situation Awareness, and Automation Conference (HPSAA II)*, Daytona Beach, FL, March 22-25.

Experiment 1

Examined the effects of automation on task completion time and subjective workload levels in control of 2 or 4 UAVs. Two levels of automation (LOA) were compared, management by consent (MBC) and management by exception (MBE). Automation was provided for two tasks, image prosecution and route re-plans. Time limits for overriding automation in the MBE condition were 40 s for image prosecution and 15 s for route re-plan. Automation reliability was either 75% or 98% for image prosecution, 75% or 100% for route re-plan.

Overall task involved four sub-tasks
1. Responding to unidentified aircraft
2. Route re-planning
3. Image prosecution
4. Monitoring Mission Mode Indicator (MMI)

Results
An increase in number of UAVs increased completion times for image prosecution, route re-planning, and MMI monitoring, and also increased the amount of time was spent in threat zones. Subjects were more likely to respond before MBE automation acted (i.e., subjects were more likely to carry out the automation's recommendation than to simply let the automation carry out the action itself) when there were 2 UAVs than when there were 4. Subjective workload ratings were higher for 4 UAVs than for 2.

Fewer images were prosecuted and more errors committed when automation was less reliable. Subjective trust ratings were also lower.

No consistent differences obtained between MBC and MBE . This might be because the time limit for overriding MBE automation was too long. As noted above, subjects often pre-empted the automation under MBE by carrying out the recommended action themselves. Expt 2 therefore reduced time limits for MBE.

Experiment 2
Automation reliability and LOAs were same as in Expt 1, but the time limit for overriding MBE was now included added as a dependent variable. Time limits for image prosecution were 15 and 40 seconds. Time limits for route re-plan were 10 and 15 seconds. Execution of route re-plan task was also made more difficult. Only the 4 UAV condition was used.

Results
Only one measure, the percentage of images correctly prosecuted, showed an effect of automation reliability.

With MBC, subjective ratings were similar across time limits. With MBE, shorter time limits produced higher workload ratings and poorer performance on both tasks. Subjects were faster to complete tasks in MBE/short time limit condition than in any other combination of automation/time limit, suggesting that they felt time pressure. This may have contributed to higher subjective workload. MBE automation was more likely to execute action in short time limit condition.

39) Ruff, H.A., Draper, M.H., Lu, L.G., Poole, M.R., & Repperger, D.W. (2000). Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence. *Proceedings of the IEA 2000/ HFES 2000 Congress*, 3.41 - 3.44.

UAV operators are denied many of the sensory cues available to the pilot of a manned aircraft. One instance in which this might be consequential is in detecting turbulence. During flight of a manned aircraft, the onset of turbulence typically produces kinesthetic/haptic feedback. During UAV flight, turbulence is signaled to the operator only by perturbations of camera image.

Current experiment measured value of haptic alert (via control stick) for detection of turbulence onset. Participants flew simulated UAV landings. When turbulence occurred, subjects rated their level of SA. After each trial, participants rated the difficult of difficulty, assessed their performance, and judged the strength (mild or severe) and axis of perturbation (horizontal or vertical) of the turbulence. Note that the multimodal display did not mimic the haptic signals experienced in real flight, but was simply meant as an alerting signal.

Results

Haptic feedback improved SA ratings, but if when turbulence occurred when UAV was far from the runway. When UAV was near runway, no benefit of feedback. Authors suggest that heightened alertness near runway might facilitate turbulence detection, mitigating the effects of haptic feedback. RTs for turbulence detection would have provided useful data to test this hypothesis.

Subjective ratings of landing performance were unaffected by haptic alert, but ratings of landing difficulty increased when haptic alert was provided. Perceived turbulence strength and judgments of turbulence direction were unaffected by haptic feedback.

40) Ruff, H.A., Narayanan, S., & Draper, M.H. (2002). Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. *Presence, 11*, 335-351

Subjects flew simulated UAV missions, with task of acquire four targets at unknown locations (3 enemy and 1 friendly) while avoiding enemy fire. Number of UAVs was 1, 2, or 4. Flight path was preprogrammed. Subjects were required to respond to/manage events as they occurred through course of scenario. Automation was provided to some subjects to help manage events. Two forms of automation were used, in addition to the no-automation baseline: management by consent, and management by exception. Two levels of automation reliability were used: 100% and 95%.

Results

Management by consent produced the highest level of mission efficiency (number of enemy targets destroyed divided by number of missiles fired). Management-by-exception and manual monitoring produced similar efficiency scores. Decision aid false alarms in the 95% reliability automation condition were more likely to be detected under management-by-consent than management-by-exception.

In manual condition, event management became poorer as the number of UAVs increased. Subjective workload estimated by NASA_TLX also increased with number of UAVs in the manual and management by consent conditions. SWORD ratings of workload were higher for manual control than for either form of automation, and were higher for management-by-consent than for management-by-exception when reliability was less than perfect. Sword ratings also increased as the number of UAVs increased.

Management-by-consent produced higher levels of self-rated situation awareness than did manual control or management-by-exception. Management-by-exception produced especially low ratings of SA when automation reliability was only 95%. SA ratings also decreased as the number of UAVs increased.

Trust in automation decreased as the number of UAVs increased.

41) Ryder, J.M, Scolaro, J.A., Stokes, J.M. (2001). An instructional agent for UAV controller training. *UAVs-Sixteenth International Conference,* 3.1-3.11. Bristol, UK: University of Bristol.

Describes development of an automated agent, EAGLE, to train pilots on a simulated Predator UAV landing task. The authors note that because there are minimal differences between operating a console during real missions and simulations, simulations may be ideal for UAV operator training. The current instructional agent was developed using CHI Systems' COGNET framework.

42) Schreiber, B.T., Lyon, D.R., Martin, E. L., & Confer, H.A. (2002). *Impact of prior flight experience on learning Predator UAV operator skills (AFRL-HE-AZ-TR-2002-0026)*. Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Examined subjects ability to learn & perform maneuvers on a Predator UAV. Compared several groups of subjects including experienced Predator pilots; experienced USAF pilots selected to fly the Predator; students who had recently completed USAF T-38 training; students who had recently completed USAF T-1 training; students who recently completed single-engine instrument training at Embry-Riddle; students who recently completed requirements for private pilot's license; Embry-Riddle ROTC students who planned to join USAF but had no flight training or experience.

Subjects flew basic maneuvers and landings until reaching a criterion level of performance, then flew 30 reconnaissance missions. Of interest was the number of trials necessary to reach criterion performance on the training task, and the transfer of training performance to the reconnaissance task.

Results

Training

As expected, predator pilots required the fewest trials to reach criterion performance, and nonpilot ROTC students required the most. This comparison demonstrates the validity of the simulation and task. Predator selectees and civilian instrument pilots required fewer trials than T-1 grads, required fewer trials. T-38 grads and private pilots were not significantly worse than Predator selectees/civilian instrument pilots, nor were they significantly better than T-1 grads. Results demonstrate that prior flight experience can reduce the number of trials to become proficient at maneuvering & landing the Predator simulation.

Transfer

Dependent variable was mean amount of time that sensor was focused on target during each trial. Predator pilots, Predator selectees, and T-38 grads had more time on target than other groups. ROTC nonpilots had less time on target than Predator pilots, selectees, T-38 grads, and T-1 grads. Results show that even after subjects achieved matched levels of performance on the training task, prior flight experience improved performance in the recon task. Authors suggest that good performance of T-38 grads as compared to T-1 grads may reflect the degree to which performance characteristics of the T-38 and T-1 are similar to those of the Predator.

43) Tvaryanas, A.P. (2004). Visual scan patterns during simulated control of an uninhabited aerial vehicle (UAV). ***Aviation, Space, and Environmental Medicine, 75,*** **531-538.**

An experiment examined pilots' eye movements during a simulated Predator UAV flight task. Goals were to determine A) how efficiently operators process the moving textbox instrument displays used in the Predator HUD, B) whether workload (as determined by windiness during flight and by the difficulty of flight maneuvers) affected scan patterns, and C) whether the absence of auditory and haptic cues caused UAV pilots to increase their dwell frequency on the engine instrument (RPM) relative to pilots in a manned aircraft. Of particular interest was whether or not the moving textbox instruments would be processed as digital/quantitative displays or as analog/qualitative displays. Past data has suggested that quantitative displays are processed less efficiently (i.e., require longer dwell times) than qualitative displays.

Subjects were 5 instrument rated pilots. Subjects flew an eight-leg flight plan twice, once in no-wind conditions and once in windy conditions (order randomized). Different segments of the flight profile included changes in heading, altitude, and airspeed, sometimes singly and sometimes in combination. Changes involving multiple parameters were presumed to impose higher workload, as were windy flight conditions.

Results

Dependent variables were dwell times and dwell frequencies. Independent variables were flight conditions (no wind vs. windy), flight segment (one, two, or three parameters changed), and instrument. Both dwell times and dwell frequencies showed a significant main effect of instrument, and neither showed any other main effects or interactions.

Dwell frequency was highest for the ADI, followed by the VSI, AS, HI, ALT, RPM, and AOA.

To determine whether moving textboxes were processed as qualitative or quantitative displays, dwell times for these instruments were compared to dwell time for the heading indicator, an instrument that is clearly quantitative. If moving textboxes are processed as qualitative displays, they should have dwell times shorter than those for the HI. Only the AOA and RPM had significantly shorter dwell times, suggesting that other moving textboxes were processed as quantitative displays.

The author also compares the current data to the results of earlier studies of instrument scanning in manned aircraft. In the present study, ADI was the most frequently fixated instrument, but still accounted for only 30% of all dwells. In contrast, previous research has found that the ADI can account for over 50% of all dwells in manned flight. Conversely, VSI was fixated more often in the present study (16% of all dwells) than in studies of manned flight (22%). The author suggests two possible reasons for these differences. First, ADI in the Predator HUD was very simple, showing only a horizontal line without any pitch or bank scale. VSI scanning might therefore be necessary to acquire or verify climb and descent rates. Second, pilots might rely on the VSI more heavily in UAV given the inherent system delays. In other words, delays in the system responses to control inputs might require operators to rely more heavily on the predictive VSI instrument than in manned flight.

Data also suggest that the engine instrument was not scanned more heavily in the current task than in previous studies of scanning in manned flight. This suggests that operators did not use the RPM to compensate for the absence of auditory and haptic information, and may indicate a sub-optimal performance strategy.

The author speculates that the high skill level of the participants in the current experiment might explain the null effect of workload on scanning behavior.

44) Van Erp, J.B.F. (2000). Controlling unmanned vehicles: The human factors solution. *RTO Meeting Proceedings 44 (RTO-MP-44)*, B8.1-B8.12.

The author notes that bandwidth constraints on the datalink between a ground control station and UAV will limit the quality of sensor information displayed to UAV operators. Two remedies to this problem are possible. The first is to reduce bandwidth needs by identifying task-critical sensor information and ensuring that only this is transmitted. The second is to design advanced interfaces that assist the operator in compensating degradations or limits in sensor imagery.

Several specific ways in which the information provided to a UAV operator is degraded are described. First, this information typically includes only imagery from an on-board camera. Input from other sensory modalities (audition, kinesthesia) is lost. Second, the sensor imagery provided to the operator is often of low resolution, achromatic, and limited to a small FOV. Third, sensor imagery is often of low temporal resolution. Fourth, the control devices used to manipulate sensor cameras do not provide proprioceptive/kinesthetic feedback similar to that obtained in using the scanning through head and eye movements.

The author next delineates a variety of sensor image characteristics that contribute to vehicle control: field size, magnification factor, chromaticity, temporal resolution, spatial resolution, monoscopic vs. stereoscopic presentation, fixed vs. variable viewing direction, and placement/aiming. To optimize performance, operator can be given the capability to manually adjust the temporal and spatial display resolution, reduce the image field size, and toggle between color/grayscale and between stereoscopic/monoscopic display modes.

The UAV operator is also confronted with difficulties in payload sensor control. First, controls do not provide feedback on camera responses to user inputs. Second, the operator does not receive vestibular feedback to specify vehicle attitude. Third, the operator has no proprioceptive feedback to indicate viewing direction. Fourth, control inputs do not produce immediate changes in sensor imagery. Fifth, spatial information within the sensor imagery is low in resolution. Sixth, the sensor FOV is often small, imposing the need for additional control inputs to scan a scene and degrading the operator's ability to integrate sensor images into a coherent and veridical mental representation. Seventh, camera imagery may be zoomed-in, disturbing the normal relationship between camera translation and image motion. Finally, image update rates may be low, degrading the temporal resolution necessary for dynamic tracking tasks. The author discusses a number of advanced display designs to address the difficulties in camera control produced by these degradations. Two of these involve computer-synthesized imagery superimposed upon or embedding the camera imagery. The value of such "augmented reality" displays is that they computer-generated components can be updated immediately in response to user inputs, even if the sensor imagery itself is not updated until after a delay. The computer-generated components thus can provide real-time feedback to assist in guiding the sensor footprint. The third novel display discussed is a radar image that includes actual and predictive sensory footprints. Thus, motion of the computer-generated predictive sensor footprint again provides operator with immediate feedback to aid camera targeting, despite delays in camera update rate. Head-coupled camera control, the author notes, does not improve camera control in a search task (effect of the head-coupled control is a speed-accuracy tradeoff), and may degrade performance because of mismatches in proprioceptive and visual information produced by sensor delays.

45) Van Erp, J.B.F., & Van Breda, L. (1999). ***Human factors issues and advanced interface design in maritime unmanned aerial vehicles: A project overview. TNO-report TM-99-A004*****. Soesterberg, The Netherlands: TNO Human Factors Research Institute.**

Report presents a summary of human factors issues in UAV control, and an overview of relevant research conducted at TNO.

Human factors concerns

The authors assume that vehicle control will generally be highly automated, and so focus their discussion of on manual control of payload camera. The studies reported assume that the most important source of information for camera control will be the imagery from the on-board camera.

The authors note that the perceptual information the operator receives from the remote environment is likely to be degraded in several ways:
--no proprioceptive feedback from controls
--no vestibular input based on attitude
--no proprioceptive feedback based on viewing direction
--limited spatial orientation
--no direct feedback (i.e., feedback delayed) in response to control inputs
--no auditory input
--limited resolution of camera images
--limited geometrical field of view
--zoomed-in camera image
--few points of reference at sea
--limited image update rate

Possible consequences for human performance include poor tracking; difficulty in judging camera, platform, and target motion; confusion about direction of platform flight; confusion about viewing direction of camera; disorientation; degraded situation awareness.

Experiments

Experiment 1

Examined the benefits of synthetic visual motion in guiding payload camera. A computer-generated grid of perpendicular lines was overlaid on camera image, and moved in response to camera inputs. In the first experiment, subjects had to track a moving ship with a simulated UAV sensor camera. Performance was improved by synthetic image augmentation, and benefits were largest when the update frequency of the camera was low. In a second experiment, subjects saw a target ship, then had to point camera at after a 15 s delay that included several translations and rotations of the MUAV. Again, performance was improved by the synthetic image overlay.

Experiment 2
Asked whether a computer-synthesized world embedding the camera image (called an ecological display, based on the notion that visual cues provided by embedding world are directly perceived) can aid in guiding camera. Subjects had to search for target ships with camera. Performance with ecological display was compared to performance with heading/pitch indicators adjacent to camera image. Such indicators require cognitive inference, in contrast to ecological display. Ecological display reduced search time and total number of camera motions. Indicators did not significantly improve performance relative to baseline.

Experiment 3
Asked whether an ecological display can allow an operator to control UAV airframe and camera simultaneously. The task required the subject to track a target ship while circling it. Four display types were used: two without augmentation (north up & track up), and two with augmentation (2D synthetic world and a 3D synthetic world). Data showed that augmented displays aided airframe control without degrading tracking. Augmented displays also allowed effective manual control with high airframe speeds.

Experiment 4
Experiment examined manual control of sensor under conditions of low update rates and delayed visual feedback, and measured the benefits of a predictive camera footprint. Data showed that update rates below 2 Hz and delays longer than 2 seconds degraded tracking performance. Predictor display eliminated costs of slow update rate and time delay except at the most extreme values.

Experiment 5
Examined the effects of head-slaved camera control, time delays, and advanced interface design on situational awareness. The authors speculate that proprioceptive feedback from head-slaved control may aid SA. However, helmet-mounted displays might be uncomfortable, and transmission delays could make the perception of spatial information difficult. In the experiment, HMD was compared to head-slaved dome projection. To overcome the problems of delayed image transmission, a method of compensation called delay handling was introduced. Delay handling preserves spatial relationships between input images by presenting them in the viewing direction of the camera at the moment image was recorded, rather than the moment at which image transmission is received. Data indicate that delay handling improves SA. No benefit was found for dome projection relative to helmet-mounted display.

Experiment 6

Compared head-coupled control/helmet-mounted displays to manual control of camera. Subjects had to locate five target ships as quickly as possible. In manual control condition, imagery was projected on a dome, so that proprioceptive info was available in both conditions. Head-slaved camera control increased search speed but enlarged the search path as compared to manual control.

46) Veltman, J.A., & Oving, A.B. (2002). Augmenting camera images for operators of unmanned aerial vehicles. ***RTO Meeting Proceedings (RTO-MO-088)*****.**

UAVs flight path is often pre-programmed, but camera must still be steered manually. This can be difficult because of low camera update rates and communication time delays between GCS and vehicle. One method of addressing these difficulties is to provide current and predictive camera view footprints on a 2D map. This provides motion feedback when camera moves, along with information preview of where the camera will be shifting. The authors note that a 2D map provides primarily exocentric (authors use the term "local") spatial information, while a 3D map provides egocentric ("global") info. Authors speculate that providing a predictive camera footprint within a 3D map might therefore improve camera steering performance beyond that observed with a 2D map. The goal of the experiment was to test this speculation.

Subjects flew a simulated UAV recon mission which required them to search for military vehicles along roads and edges of woods. Two side-by-side displays were used. On the left was a 2D map which presented waypoints and route plan; flight direction; and actual and predicted camera footprints. On the right (in some conditions) was a 3D map which presented an immersed view from vantage point of UAV camera, along with actual and predicted footprints. In experimental conditions, subjects were provided the 3D display in addition to the 2D map. In control conditions, only the 2D map was provided. The camera image was presented in lower right display. Camera image quality had three levels: normal, 3 Hz update rate, 1 second delay. In some conditions, subjects also performed a secondary monitoring/memory task.

Results
When camera quality was normal, 3D camera produced a small increase in the percentage of roads and wood edges that were inspected (~35% vs. ~40%). When camera image quality was degraded, the benefits of the 3D map were larger (~20% vs. ~30%). Secondary task performance was better with 3D map, suggesting that map produced spare mental capacity, and subjective workload ratings were lower with 3D camera than without. EOGs indicated that subjects inspected 3D map frequently, especially when camera quality was low.

47) Walters, B.A., Huber, S., French, J., & Barnes, M.J. (2002). ***Using simulation models to analyze the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles (TUAVs) (ARL-CR-0483)*****. Aberdeen Proving Ground, MD: Army Research Laboratory.**

A study used simulation modeling to determine how fatigue, crew size, and rotation schedule affect operator workload and performance on a TUAV control task. Simulations were conducted using MicroSaint modeling architecture, from Micro Analysis and Design. 18 subject matter experts (SMEs) provided A) a list of tasks that are involved in controlling a TUAV during normal operations and during emergencies, B) the order in which the tasks are performed, C) the visual, auditory, cognitive, and psychomotor workload imposed by tasks, D) the types of emergencies that can occur during missions, and E) the probabilities of mishaps occurring during emergencies when soldiers are fatigued.

The fatigue algorithm used by simulation predicts human response capability for tasks over an extended period of sleep deprivation. The focus of algorithm is the interaction of sleep deprivation with circadian rhythms.

The model used simulates the tactical operations center (TOC) and launch/recover station (LRS) (including mission commander [MC], aerial vehicle operator [AVO], and mission payload operator [MPO] duties), and several functions: launch, transfer, recovery, mission support, emplacement, displacement, emergencies, mishaps, and maintenance during emplacement. The model was used to simulate 12- and 18-hr missions over a 24-hr period under 15 different conditions for three consecutive days. During the missions, there were times with 2 UAVs in-flight: one observing the targets, and one flying to assume control of search. Soldiers were modeled to work 2-, 3-, 4-, or 6-hr rotation schedules. The model does not simulate soldier activity in between shifts.

Models simulate one move (jump) per day for the TOC and one move every other day for the LRS. Each move comprises a 1/2 break-down, 1/2-hr move, and a 1-hr setup. The TUAV spends 5 hrs of simulation time in the air: 4 hrs of surveillance and 1 hr in transit to/from destination. The output of model includes performance times, target detection rates, and AV mishaps under each simulated condition. Several crew configurations (different numbers of MCs and AVOs/MPOs) were tested.

Some conditions that can affect a TUAV mission include
--type of search: area search, person search, airfield, tanks, building, road search, bridge, missile site, command post, air defense artillery, check points, battle damage assessment on SAM, artillery search
--emergencies: icing, generator failure, signal degradation or intermittent link loss, payload failure, AVO or MPO console failure, GPS failure
--weather: humidity, sun, gusting winds, crosswinds, flat clouds, ragged clouds
--terrain: high vegetation, desert (sand), high desert, city, town, village

Workload estimates were obtained from SMEs using a scale developed to be compatible with Wickens' (1984) multiple resources theory of attention. Four resource pools were assumed: visual, auditory, cognitive, and psychomotor.

The model simulates 5 TUAV launches per day for an 18-hr mission. Each launch, three types of target search were performed. Missions were repeated every day for 3 days for each crew rotation schedule.

Results
Decreasing crew size decreased target hit rates and increased target detection times.

Workload estimates suggested that when there was no MC in the LRS, the TOC MC was interrupted ~50% of the time to perform tasks that the LRS MC would otherwise have performed. When there was 1 MC in the LRS, the TOC MC was interrupted ~20% of the time with LRS MC tasks. Adding a third AVO to the LRS (compared to baseline condition of 2 AVOs) did not improve performance.

The model was adjusted to simulate 12-hr mission profiles with and without 1-hr gaps between flights. Three launches were simulated per day instead of 5. Results were similar to those from 18-hr mission conditions. No performance differences were produced by 1-hr gaps between missions.

48) Weeks, J.L. (2000). *Unmanned aerial vehicle operator qualifications (AFRL-HE-AZ-TR-2000-0002)*. Mesa, AZ: Air Force Research Laboratory, Warfighter Training Research Division.

Report compares selection criteria for UAV operators across branches of the U.S. military and British army.

Pioneer, USNL EP candidates go through a 24-week training course. Payload operator and AVO compete different 8-week courses. Mission commander has to be a flight officer. Health conditions related to hypoxia or pressure changes are not disqualifying. Health standards include corrected visual acuity of 20/20 in each eye, normal color vision, normal hearing, clear & distinct speech, and voice well modulated. EP requires normal depth perception.

Pioneer, USMC AVO and PO complete the same 8-week training course. Candidates for EP have to demonstrate satisfactory as AVO or PO, demonstrating good 3-D cognition/perception, then complete a 19-week training course. MC has to be an aviation officer. Physical standards are the same as for UAN UAV operators.

Hunter, USA AVO and PO have to complete a 23-week training course. Candidates for EP have to demonstrates satisfactory performance as AVO or PO, and are screened by interview and by performance using a radio-controlled model airplane. If selected, they must complete a 16-week training course. The AVO and PO are required to pass a class IV flight physical, which includes requirements for medium physical demands, a normal physical profile, and normal color vision. The EP is required to pass a class III physical, similar to that required for air traffic controllers.

Phoenix, British Army AVO is required to take a 3-week course. Flight crews are not required to take physicals.

Predator, USAF AVO candidate has to be a pilot of a fixed-wing aircraft or a navigator with FAA instrument rated commercial license. Beyond undergraduate flight training, follow-on training, then 9 weeks of Predator basic training. DEMPC and SO complete 24 weeks of initial-skills training as an Imagery Interpretation Apprentice, then 9 weeks of Predator basic training. AVO has to pass a Class I physical. DEMPC and SO have to pass a Class III flight physical, but with visual acuity and depth perception standards equivalent to Class I standards.

49) Wickens, C.D., & Dixon, S. (2002). *Workload demands of remotely piloted vehicle supervision and control: (1) Single vehicle performance (Technical report AHFD-02-10/MAD-02-1)*. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.

Examined the benefits of offloading tasks from visual channel in a single-UAV control task, and compared the results to the predictions of single-channel theory (SCT), single-resource theory (SRT), and multiple-resource theory (MRT) of attention. Subjects each flew a series of missions involving three tasks: mission completion (flight path tracking), inspecting command targets (CTs) / searching for targets of opportunity (TOOs), and monitoring system gauges for system failures (SFs) (i.e., out of bounds values). Flight instructions (fly-to coordinates of next target and a question about the target to be answered) were provided during the task. Instructions could be refreshed with a button press. In baseline condition, pilots flew with all manual flight controls and all visual displays. In auditory condition, SF alerts and flight instructions were provided aurally. In an automation condition, flight control was offloaded to an automated system. All alerts/instructions/automation were perfectly reliable.

Results
Flight path tracking was unaffected by auditory offloading.

Button-press refreshes of instructions were reduced in both the auditory offloading and the automation conditions. In auditory condition, this might have been because aural presentation reduced visual conflict during time that instructions were first presented. In automation condition, it may have been because the subject was not required to remember target coordinates.

TOO detection rates improved under autopilot flight control both for single and dual-UAV tasks. This was in part due to the fact that the autopilot flew directly over each target, while the human operator sometimes did not. However, an autopilot benefit was evident even restricting analysis to those trials on which the TOO appeared in the 3D display. This suggests a role for the autopilot in improving cognitive/attentional performance in TOO detection.

Auditory alerts significantly improved SF detection rates and SF response times compared to baseline, except in cases where the subject was loitering/inspecting a target at time of SF occurrence. This suggests that difficult image interpretation produced cognitive tunneling. Automation condition also improved SF detection rates (though not under all circumstances), but did not affect SF response times.

50) Wickens, C.D., Dixon, S., & Chang, D. (2003). ***Using interference models to predict performance in a multiple-task UAV environment-2 UAVs (Technical report AHFD-03-09/MAAD-03-1)*****. Savoy, IL: University of Illinois, Institute of Aviation, Aviation Human Factors Division.**

Examined the benefits of task offloading to pilots performing single- and multiple-UAV tasks and compared the results to predictions of single-channel attention theory (SCT), single-resource theory (SRT), and multiple-resource theory (MRT) of attention. Subjects each flew a series of missions involving three tasks: mission completion (flight path tracking), inspecting command targets (CTs) / searching for targets of opportunity (TOOs), and monitoring system gauges for system failures (SFs). Flight instructions (fly-to coordinates of next target & a question about the target to be answered) were provided during the task. Instructions could be refreshed with a button press. In the baseline condition, pilots flew with all manual flight controls and all visual displays. In the auditory condition, SF alerts and flight instructions were provided aurally. In the automation condition, flight control was offloaded to an automated system. All alerts/instructions/automation were perfectly reliable.

Results

Flight path tracking was unaffected by auditory offloading. Button-press refreshes of flight instructions were reduced in both the auditory offloading and the automation conditions, suggesting that these conditions freed up processing resources. The number of refreshes was higher in dual-UAV conditions, but the effect was primarily in the baseline & auditory offloading conditions, not in the automation condition. TOO detection rates improved under autopilot flight control both for single and dual-UAV tasks. This was in part due to the fact that the autopilot flew directly over each target, while the human operator sometimes did not. However, an autopilot benefit was evident even restricting analysis to those trials on which the TOO appeared in the 3D display. This suggests a role for autopilot in improving cognitive/attentional performance in TOO detection.

Auditory alerts improved SF detection rates and reduced detection times. Autopilot had no effect. Dual-UAV costs to SF detection time obtained in the baseline and autopilot conditions, but not in the auditory alert condition. SF detection times were longer for faults that occurred during target inspection than for faults that occurred under normal flight, lending some support to CST and SRT. However, this effect was mitigated somewhat by auditory alerts, consistent with MRT.

51) Williams, K.W. (2004). A summary of unmanned aircraft accident/incident data: Human factors implications.

Examines military UAV accident/incident data for various UAV systems.

Army

Hunter

Hunter takes off & lands using an external pilot (EP) in visual contact using controller similar to that used for remote controlled hobby planes. After takeoff and climb, internal pilot (IP) assumes controls from GCS. The IP controls the aircraft using knobs to select altitude, heading, & airspeed. 47% of accidents were HF related. The largest percentage (47%) of HF issues arose during landing. An additional 20% arise during takeoff. Control difficulties are caused in part by the need for the operator to reverse control inputs when aircraft is headed toward him/her. Other problems include:

--pilot-in-command issues
--failure of alerts/alarms to inform operator of non-normal conditions
--mode display errors
--crew failure to follow proper procedure

Shadow

The Shadow uses a launcher for takeoff and an automated system, the tactical automated landing system (TALS), for recovery. Landing generally does not require intervention from the operator in the GCS. In flight, the aircraft is controlled through a menu-based interface that allows operator to select altitude, heading, & airspeed. During landing, operator in GCS has no visual contact with aircraft, and receives no data from onboard sensors. An external observer is required to communicate to the operator when the craft has touched down, at which time the operator gives a command to stop the engine. HF errors were less frequent with Shadow than with Hunter.

Navy

Pioneer

The Pioneer requires an EP for takeoff & landing. After takeoff, IP controls the vehicle from the GCS in one of three modes: autonomously using preprogrammed waypoint coordinates; semi-autonomously using airspeed, altitude and heading values specified with rotary knobs; manually, with a joystick. There are plans to implement an automated system for ship-based landings. 28% of accidents were HF related. Of these, 68% occurred during landing and 10% during takeoff. An additional 13% were due to aircrew coordination lapses (procedural & communication errors) and 10% were weather related errors resulting from errors in pilot decision making.

Fire Scout
A vertical takeoff & landing vehicle, the Fire Scout was involved in one accident. Antenna was damaged during ground handling (human error), causing incorrect altimeter reading when vehicle was airborne.

Air Force
Predator
The Predator is flown from a GCS using a joystick and rudder pedals and a forward looking camera with a 30-deg FOV. The camera is also used for takeoffs and landings. Human factors lapses contributed to 67% of accidents. A majority of these (75%) were procedural errors, including a failure to follow checklist steps during handoff between crews and an accidental activation of a program that erased the aircraft computer's internal RAM.

Interface issues are discussed in 89% of Predator accidents, and are cited as a contributing factor in 44%. Four categories of interface issues: design of HUD; design of HDD; alerts and alarms; functioning of the autopilot.
--HUD problems: FOV (30 degs) is too narrow; attitude indicator is inadequate; RPM indicator needs improvement; symbology obscured during low-link conditions; symbology contrast too low; symbology inadequate.
--HDD problems: too many levels to maneuver through to reach needed info; info display unintuitive; critical commands unprotected or unemphasized; operational value ranges inconsistent within display.
--Alerts/alarms problems: do not capture attention; audio warnings insufficient or absent; info provided inadequate or poorly prioritized; info provided invalid; data that need to be compared not always collocated on same display page.
--Autopilot problems: no indication of autopilot status on HUD; flight controls are disabled while autopilot is engaged (i.e., no override capability) and four separate menus have to be traversed in order to deactivate autopilot (requires about M = 7 seconds); autopilot tends to command extreme measures and overstress aircraft; autopilot functionality does not conform to AF standards.

Global Hawk
Global Hawk is the most fully automated of UAV systems. All phases of flight are automated, including takeoff & landing. The crew's task is to monitor the aircraft and control payload. This makes flying the relatively easy, but makes mission planning exceedingly difficult. Mission planning process begins up to 270 days prior to mission. Once the target set is finalized, 3-5 weeks are required to write and validate mission plan. Of three accident reports available for Global Hawk, only one involved HF issues. Aircraft was forced to perform an emergency landing at a preprogrammed alternate airport. At point of airport, a taxi speed of 155 knots had been set due to software bug

during preprogramming. When aircraft was commanded to begin taxiing for takeoff, it reached a speed where it was unable to turn at appropriate point and ran off the runway. Fundamental HF problem with the Global Hawk is that the system does not encourage close monitoring by operators, resulting in reduced SA. An additional problem is that status reports are provided in hexadecimal and do not include trend data.

52) Wilson, G.F., & Russell, C.A. (2004). Psychophysiologically determined adaptive aiding in a simulated UCAV task. ***Proceedings of the Second Human Performance, Situation Awareness, and Automation Conference (HPSAA II)*****, Daytona Beach, FL, March 22-25.**

An experiment tested the benefits of adaptive aiding based on psychophysiological assessment of operator workload. The task required subjects to monitor 4 vehicles flying preplanned routes. When vehicles reached designated points, radar images of target area were presented to subject. Subject searched target area then selected targets for bombing. The search/target designation task was conducted under time stress. The subjects chose the order in which images from the vehicles were presented. Images were presented at two levels of difficulty. The more difficult level included more distractors and required more difficult decisions regarding target priority.

Subjects were also required to monitor vehicles for potential emergencies (e.g., loss of communication). Memory load was manipulated by having subject hold up to 4 aircraft/problem combinations simultaneously until a command was given specifying which problem to address.

EEG, ECG, and EOG data were recorded. An artificial neural network was trained to recognize periods of low and high task difficulty using these data. During criterion task performance, three levels of adaptive aiding were used: 1) no aiding, 2) aiding during times of high workload, and 3) random aiding. Aiding involved decreasing velocity of vehicle so that time stress was reduced. Subjective workload was measured with NASA-TLX.

Results

The neural net was 70% accurate at classifying high/low task difficulty levels during task performance. For all conditions, the number of correctly selected targets was lower when the task was difficult. The number of designated points of impact was lower for the difficult task level in the unaided and the randomly-aided conditions, but was unaffected by task difficulty in the adaptively-aided condition. Similarly, the number of missed weapons releases was higher in the difficult level for the unaided and randomly-aided conditions but was unaffected by difficulty in the adaptively aided condition. Differences in subjective workload were marginal and inconsistent.

Appendix B

Research Matrix

This appendix provides a cross-index of the research issues discussed in the main body of the text with the research literature described in Appendix A. Only those articles deemed directly relevant to each question are included. Bold-faced italics indicate research articles that present empirical data.

1. To what extent should en route flight control be automated?
Relevant articles: ***2,*** 7, 19, ***25***, 32, 33, ***38***, 40, ***49***, 50, 51, ***52***

2. What are the consequences of degraded reliability of automated UAV functions for performance of the automated task and of concurrent tasks?
Relevant articles: ***11***, ***12***, 40

3. How will see and avoid requirements be addressed in UAV flight? Can automated detect, see, and avoid (*DSA*) technology allow a UAV operator to maintain acceptable levels of separation? What are the consequences of imperfectly reliable DSA automation on conflict detection and on performance of concurrent tasks?
Relevant articles: 27

4. To what extent should takeoff and landing be automated?
Relevant articles: ***2***, 51

5. Through what form of control interface should internal and external pilots manipulate a UAV?
Relevant articles: ***37***, 51

6. What compromises should be adopted between spatial resolution, temporal resolution, time delay, and field-of-view (FOV) in the display of visual imagery for flight control and/or conflict detection?
Relevant articles: ***10***, 32, 44, ***45***, ***46***, 51

7. Can augmented reality displays or synthetic vision systems successfully compensate for the degrade visual imagery provided by onboard sensors?
Relevant articles: 3, ***13***, ***15***, 16, ***17***, ***18***, ***29***, 44, ***45***, ***46***

8. Can multimodal display technology be used to compensate for the dearth of sensory information available to a UAV operator?
Relevant articles: ***4***, ***5***, ***11***, ***12***, ***14***, 19, ***20***, ***25***, *32*, 34, ***39***, ***43***, 44, ***49***, ***50***, 51

9. To what extent can displays and controls be standardized across UAV systems? What level of standardization should be mandated? (Basic T instrument panel? HUD overlay?)
Relevant articles: 21

10. What are the consequences for system safety of pilot judgment when the pilot no longer has a "shared fate" with the vehicle? Will there be subtle shifts in risk taking that might affect overall airspace safety?
Relevant articles: none

11. How will hand-offs between crews be accomplished during long-endurance flights?
Relevant articles: none

12. What are the effects of variable total loop time delays on response to ATC instructions?
Relevant articles: 19, 27, 32, ***43***, 44, ***45***

13. What form of predictable autonomous behavior should a UAV adopt following a loss of ground-to-air communications?
Relevant articles: none

14. How many members will each crew comprise, and what will be each crewmember's responsibilities? Can an operator supervise multiple UAVs simultaneously while maintaining an acceptable level of performance?
Relevant articles: 7, ***8***, ***15***, 21, ***23***, ***28***, 30, 33, ***38***, ***47***, 51, ***52***

15. What are the core knowledge, skills, and abilities (KSAs) that should be required for UAV pilot certification? What KSAs should be required for certification to fly particular UAV systems or classes of systems?
Relevant articles: ***2***, 26, 48

16. Should experience piloting a manned aircraft be prerequisite for UAV pilot certification?
Relevant articles: ***2***, ***42***, 48

17. What medical qualifications should a UAV operator be required to meet?
Relevant articles: ***25***, ***47***, 48

Appendix C

Contact Information

This appendix provides available contact information for first and/or senior authors on the research articles summarized in Appendix A.

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