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14. ABSTRACT This Test Operations Procedure (TOP) covers the span of requirements and technologies that are unique to Unmanned Aircraft Systems (UAS). The role of a UAS is significantly different than that of a manned aircraft. The nominal operating altitudes and methods of employment for armed UASs provide for unique test challenges not encountered with manned aircraft. Many armed UASs are flown at significantly higher altitudes than manned aircraft creating unique test conditions. The increase in slant range and angular perspective from sensor and weapons to target needs to be considered for these new systems. Additionally the threat set for UASs in the Global War on Terrorism is very different than the traditional large mechanized threat set typically used for manned aircraft. A TOP for weaponized UAS testing will provide standard procedures for all systems tested.					
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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 07-2-033
DTIC AD No. ADA568947

14 January 2013

WEAPONIZED MANNED/UNMANNED AIRCRAFT

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1. SCOPE.

This Test Operations Procedure (TOP) provides guidance for testing of weaponized Unmanned Aircraft Systems (UAS) (which may be manned for testing purposes) to confirm the predicted weapon system performance characteristics.

1.1 General Concept of Testing.

a. The purpose of testing is to confirm the predictions of engineering analysis, simulation, and subsystem tests. It is not to be employed as a substitute for any part of a complete system engineering substantiation. Thus, the airframe, power plant, ground control station (GCS), data control link, weapon(s), weapon(s) interface, and weapon targeting system will have been verified and/or demonstrated by other means to be safe to operate together in the planned environment prior to commencing any flight tests.

b. This means that before testing a UAS, especially a weaponized UAS, an Airworthiness Release or equivalent shall be presented by the applicant that covers the GCS, platform, weapons interface, weapon, and weapon targeting system.

c. Airworthiness Releases are issued by the following Department of Defense (DOD) organizations are listed in appendix C.

1.2 Airworthiness Releases.

Airworthiness Releases may require some or all of the following:

a. All software on the aircraft/rotorcraft, weapons interface, and GCS shall meet the applicable requirements of DO-178B^{1**} or Institute of Electrical and Electronics Engineers (IEEE) 12207².

b. All complex electronic hardware (systems using field programmable gate arrays (FPGA), application specific integrated circuits (ASIC), etc.) on the aircraft/rotorcraft, weapons interface, targeting system, and GCS shall meet the applicable requirements of DO-254³ or the DOD equivalent.

c. All electrical and electronic systems on the aircraft/rotorcraft, weapons interface, and GCS shall meet the applicable electromagnetic compatibility (EMC) requirements of Military Standard (MIL-STD)-461F⁴, MIL-STD 464⁵, Aeronautical Design Standard (ADS)-37A⁶, MIL-STD-704F⁷, and MIL-E-6051D⁸.

d. Additionally, the GCS shall meet the applicable human engineering requirements of MIL-STD-1472F⁹.

**Superscript numbers correspond to Appendix B, References.

e. Aircraft/rotorcraft with maximum gross weights greater than 598.7 kilograms (1,320 lb) and less than 5,669.9 kilograms (12,500 lb) shall meet the applicable requirements of Federal Aviation Regulation (FAR) 23¹⁰ (Aircraft) or FAR 27¹¹ (Rotorcraft) or the DOD equivalent. This includes the crew safety and crew control system requirements for UAS operated in a manned configuration.

f. Aircraft/Rotorcraft with maximum gross weights greater than 5,669.9 kilograms (12,500 lb) shall meet the applicable requirements of FAR 25¹² (Aircraft) or FAR 29¹³ (Rotorcraft) or the DOD equivalent. This includes the crew safety and crew control system requirements for UAS operated in a manned configuration.

g. At the discretion of the issuing organization, the foregoing requirements may be replaced by the procedures found in Range Commanders Council (RCC) 323-99¹⁴ and its supplement¹⁵.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

It is assumed that the ground support requirements for the UAS are addressed in other documents (TOP 07-1-001¹⁶); consequently, the discussion of facilities should focus on the test range requirements. When testing weapons, the test coordinator should consider the amount of control over the ground space and air space, and any possible restrictions associated with the area proposed for weapons testing. Control of the ground space is critical, especially with a system that utilizes some form of hazardous payload such as a non-eye safe laser. Airspace must allow the UAS to maneuver within its designated operations envelope and insure that any weapon impact and effect is limited to that ground space. Restrictions with respect to radio frequencies, lasing, etc. must also be addressed.

2.2 Flight Safety System (FSS).

FSS (Flight Safety System). The philosophy, hardware, and methods whereby a UAS can be tested in a reasonable and prudent manner without undue risk to personnel and private or public property. A variety of approaches are possible to produce this result. An FSS is required when operating a UAS.

a. The sponsor or operator shall provide the FSS for the UAS. The Range Safety Officer (RSO) and the Safety Review Board (SRB) shall approve the FSS. The operator shall perform a ground demonstration of the FSS, to the highest practical level, prior to the first operation of the UAS. The RSO and/or Test Coordinator (TC) shall witness and approve this demonstration. If no ground demonstration is practical, this must be reported and approved by the SRB and the RSO. The operator shall also perform a ground test, to the highest practical level, whenever maintenance or a change to the system affects components of the FSS. Subsequent tests may be verified by the TO. The operator shall immediately report any failure, anomaly, or change in an FSS component to the TO. All flight missions shall be suspended until corrective action is complete. The FSS must be effective throughout the UAS mission.

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b. Flight Termination System (FTS).

FTS (Flight Termination System). The entire system necessary to send, receive, decode, and execute a signal to terminate the flight of a UA. The FTS includes all wiring, power systems, methods or devices used to terminate flight, and is considered a subsystem of the FSS.

All armed UAS flight vehicles must have a FTS capable of terminating flight if the operator should lose control of the Unmanned Aircraft (UA). The FTS shall be in compliance with RCC STD 319-10¹⁷, or as approved by the SRB and RSO, and be a completely redundant, independent FTS. When required by the SRB and RSO, these systems shall use separate radio frequencies, ground transmitters, receivers, and termination initiators.

The operator shall perform a ground demonstration of the FTS, to the highest practical level, prior to the first operation of the UAS. The TO shall witness and approve this demonstration. A means and method to monitor the FTS frequency for indications that other competing signals are not present shall be provided during the test.

The flight termination decision and action is the responsibility of the TO, designated RSO, and the UAS operator. The TO and the UAS operator shall jointly develop flight termination criteria and submit them to the SRB and RSO for approval. The following are examples of conditions that require flight termination:

(1) The aircraft poses a threat to sensitive areas or is likely to exceed the mission boundaries.

(2) Aircraft performance is unknown or erratic, and therefore, an indeterminate hazard exists.

When activated, the FTS must terminate flight so that the aircraft is contained within the prescribed hazard zone. Once activated, flight termination must be irrevocable. Flight termination can be accomplished by a variety of methods—any that achieves the desired result is acceptable. The most common methods include engine cutoff and parachute deployment.

2.3 Instrumentation.

a. The ideal data to be gathered for the UAS weapons tests is provided below. Reference TOP 07-1-001 for further details of data required.

<u>Devices for Measuring</u>	<u>Permissible Measurement Uncertainty</u>
Range timing (inter-range instrumentation group ((IRIG))-B or equivalent)	± 2 milliseconds
UAS position (full TSPI solution including attitude, attitude rates, velocity)	± 1 meter
Target position (stationary targets heading; moving targets full TSPI solution including full translational and rotational states)	± 1 meter
Sensor video (time tagged)	± 2 milliseconds
Operators comments (time tagged)	± 1 second
Observation calls (time tagged)	± 0.5 second
Meteorological Conditions:	
wind speed	± 2 knots
wind direction	± 2 degrees
temperature	± 1.1 °Celsius (C) (± 2 ° Fahrenheit (F))
humidity	± 5 percent
atmospheric transmittance	± 5 percent
scintillation	± 10 percent
solar illumination	± 10 percent
lunar illumination	± 10 percent
Laser hit point	± 0.2 meter
Sensor resolution target	± 5 percent
Weapon impact sequence	High-speed camera with 15 cm resolution at target

b. There is a variety of instrumentation that may be used to gather data on UAS weapons testing. The data required should be dependent upon the Test and Evaluation Master Plan (TEMP) requirements, customer test objectives and requirements, and test range requirements for safety and other purposes. Data requirements must be considered early in the test planning process to ensure that the required instrumentation is available and used appropriately. Those responsible for the data collection should be involved so instrument locations and requirements are considered and accommodated.

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c. The design of any airborne instrumentation system must center on the measurement requirements, including their type, quantities, frequency response, and accuracies. Without this knowledge, tradeoffs between instrumentation system performance, cost and power/weight/volume cannot be made. Measurement requirements vary significantly depending upon the type of flight test.

d. For purposes of flight test instrumentation, many UASs are small aircraft without a pilot on-board. There is a wealth of available information about flight test measurements for weapons separation from manned aircraft. Thus the task becomes an exercise in identifying instrumentation of appropriate size, weight, and power draw to make classical weapon system flight test measurements on a small aircraft. The weight and space limitations of the proposed instrumentation might affect an Air Worthiness Release (AWR) or local release for flight approval.

e. There is guidance from military handbooks about measurements that should be made. Military Handbook (MIL-HDBK)-516B¹⁸, “establishes the airworthiness certification criteria to be used in the determination of airworthiness of all manned and unmanned, fixed and rotary wing air vehicle systems” for all departments and agencies of the Department of Defense. It recommends a comprehensive set of verification and validation criteria, from which can be inferred measurements that need to be made. For example, in section 6.1.2.3 discussing flight control stability characteristics and transients, the instruction is “for autonomous vehicle control, verify that the net stability, with the guidance and control system operating, is safe for the intended mission under normal operating conditions.” From the guidance, we can infer the need to measure at the least airspeed, altitude, aircraft rates and accelerations, control surface positions, and control inputs. ADS-20-HDBK¹⁹, Section 5.3 references instrumentation and data analysis, with the additional, guidance: “test instrumentation should be provided to record armament, fire control, and aircraft data.” In that same section the handbook adds that “general guidance on instrumentation on helicopters is provided in ADS-51-HDBK²⁰. Guidance for test procedures and instrumentation for armament stores is contained in MIL-HDBK-1763²¹.” ADS-51-HDBK is the Aeronautical Design Standard Handbook, Rotorcraft and Aircraft Qualification Handbook published by the Army. MIL-HDBK-1763 is the Department of Defense Handbook for Aircraft/Stores Compatibility: Systems Engineering Data Requirements and Test Procedures. Both handbooks summarize the types of tests that should be conducted, the data requirements for those tests, and measurements required to collect the data. These are encompassing documents that include much information, not all of which is applicable to UAS flight test.

f. Both ADS-51-HDBK and MIL-HDBK-1763 reference the work of the Advisory Group for Aerospace Research and Development (AGARD), now part of the NATO Research and Technology Organization, for flight test guidance. One of these, Advisory Group for Aerospace Research and Development (AGARD) AGARDograph 300, Volume 10²², repeatedly references the same set of measurements regarding carrying weapons on fixed-wing aircraft. In any flight test, the following parameters are always important, if not critical:

<u>Parameter</u>	<u>Measurement Device</u>
Pressure altitude	Static pressure (Ps)
Airspeed	Dynamic pressure (Q)
Load factor (g)	Accelerometer (such as in inertial measurement unit (IMU))
Geographic location (latitude, longitude)	Global Positioning System (GPS)
Heading	GPS
Aircraft orientation (pitch, roll, yaw)	IMU

g. These parameters are frequently available from a data bus, and if the aircraft has one, it should be instrumented. The data may also be available on the Ground Control Station downlink. This set of data encompasses traditional airborne time-space-position instrumentation (TSPI) measurements. In most flight tests, the responsible test organization (RTO) wants to have an independent source of these parameters if at all possible. Further, the fidelity of these independent measurements should be better than the aircraft data source, the rule of thumb being an order of magnitude better if state-of-the-art is that advanced. For instance, production flight control sensors are typically just good enough to maintain control of the aircraft to minimize cost, and are not of the quality required for independent measurement.

h. If there are any anomalies that arise in the flight test, frequently the flight tester needs to evaluate the weapons release discrete data, weapons release constraint data, the arm and fire discrete data. It may also be necessary to understand the flight dynamics imparted to the weapon by the aircraft and vice-versa to understand the anomaly. Therefore, the flight tester may require knowledge of the structural inputs to the aircraft from the weapons release, and the aircraft aerodynamics. Pilot inputs are frequently important, which in a piloted UAS may translate into echoing the commands uplinked to the aircraft and in an autonomous vehicle the commands from the flight control system. The following parameters meet these contingencies:

<u>Parameter</u>	<u>Measurement Device</u>
Aircraft rates (pitch, roll, yaw rates)	IMU
Aircraft accelerations (x-, y-, z-axes)	IMU
Flutter	Accelerometer
Loads	Strain gages

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<u>Parameter</u>	<u>Measurement Device</u>
Control surface positions	Calibrated position transducers
Control surface hinge moments	Strain gages
Aircraft aerodynamics (angle of attack (AOA) and angle of slideslip (AOS))	Airdata boom
Total air temperature (TAT)	TAT probe
Pilot inputs	Uplink discrete data, signal strength

i. Other parameters that are sometimes valuable to know include certain propulsion system parameters and aircraft health parameters. This could be especially true of UASs operating with new heavy fuel engines that are an emerging technology:

<u>Parameter</u>	<u>Measurement Device</u>
Engine pressures	Pressure transducer
Engine temperatures	Thermocouples and resistance temperature detector (RTD)
Engine revolutions per minute (rpm)	Encoder, hall effect, etc.
Throttle position	Calibrated position transducers
Fuel flow	Flow meter
Aircraft bus voltage	Voltage
Aircraft bus current	Shunt or transducer
Aircraft bay temperature	Thermocouples, RTDs

j. In piloted aircraft, Heads-Up Display (HUD) video is almost always important. Not only does it show the aircraft flight condition, frequently it gives the pilot's-eye view of the target. UASs have sensor payload video downlinked to the GCS which provides the equivalent of the information in the pilot's HUD. Weapons separation cameras are frequently critical on fighter aircraft. That capability may not be as important on UASs, which typically have more restricted flight envelopes and having volume available for a system may not be realistic. However, it is worth investigating equipment that could gather that data if it were required. As

an example for weapons (missile) tracking, several (at least three) Kineto Tracking Mounts (KTM) could be used to track a shot from release to impact.

k. The following excerpt from AGARDograph 300, also sheds light on what should be instrumented with respect to weapons systems on a UAS:

“An F-16 instrumented for loads, flutter, and stability and control is maintained at Eglin Air Force Base to support store certification programs...Figure 12 (AGARDograph 300) shows the general position and types of instrumentation added to the aircraft.” Figure 12 from AGARDograph 300 is provided as Figure 1 of this document.

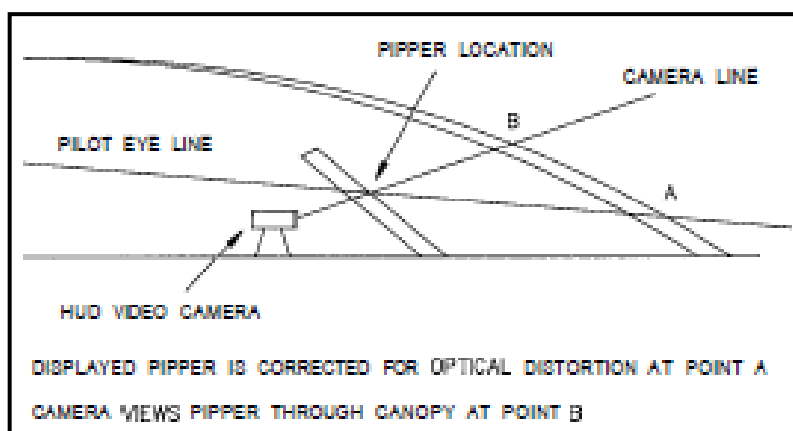


Figure 1. HUD video camera and parallax errors.

l. The list of instrumentation includes: Nose boom (Ps, total pressure (Pt), AOA, AOS), camera pod(s), roll/pitch/shear (load measurements in both wings, fuselage shear/bending/torsion (loads measurements), flaperon positions, horizontal stabilator accelerometers, horizontal stabilator positions, rudder position, and a vertical tail accelerometer.

m. ADS-51-HDBK, section 9-2.4 contains information available with respect to measurements for in-flight loads. The section includes:

“The test air vehicle should have instrumentation that provides the capability to measure and record all parameters necessary to substantiate the structural integrity of the vehicle. Telemetry of critical parameters is essential because it provides instantaneous load information and thereby increases flight safety and expedites test progress. As a minimum, instrumentation should record control positions, control rate and sequence, performance parameters, and specific critical loads, stresses, and pressures.”

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3. REQUIRED TEST CONDITIONS.

Test Documentation.

a. Strategy. The test coordinator shall review the TEMP, the System Specification, System Evaluation Plan (SEP), and any other applicable documents to determine a plan for providing the required data for analysis.

b. Test Plan. The test coordinator shall develop a test plan based on the established test objectives that provides enough detail to efficiently execute the data collection. Distinct data collection efforts should be presented in individual sub-tests. The test plan shall have sufficient detail that a particular sub-test can be recreated after it is initially performed.

c. Test Card. The test coordinator shall develop test cards that outline the specific events for a UAS sortie or a day's activities. TOP 07-1-001 references UAS required test conditions.

4. TEST PROCEDURES.

This section covers generic test procedures for several UAS mounted weapon systems. The procedural steps for the sub-tests represent a summary of the primary tasks required to evaluate the effectiveness of a given UAS and associated weapon. TOP 07-1-001 contains procedures for general UAS sub-tests including hardware component testing, software testing, data link/communications testing, range safety testing, and flight tests. TOP 07-1-002²³ contains procedures for testing of the sensors and targeting system. Much of the material presented in this section is from the Test Report for the Predator Hellfire Demonstration, Phase I Integration²⁴.

4.1 General Procedures for Testing of Weapons Fired/Launched/Released from UAS.

The testing of a weapon on a UAS shall be accomplished in two phases. Phase I will verify that all systems perform as expected and the UAS/weapon system combination is safe to demonstrate full functionality and performance during in-flight live weapons firing at a test range target. The live weapons in-flight firing is Phase II.

4.1.1 Phase I Pre-Firing General Integration Test Procedures.

A complete summary of integration tests conducted to prepare for the live fire test shall be provided to the Test Coordinator before scheduling live weapons flight tests. To meet this requirement, the following verifications may be accomplished with a combination of analysis and tests. Initial flight tests shall be conducted with inert weapons (inert warhead and inert propulsion system) configured to prevent the possibility of launch/release. Compliance with the following should be shown before live weapons flight tests will be conducted at US Army Test Facilities.

4.1.1.1 Verify Systems Integration.

- a. Weapons control electronics and packaging. Verify the function of all interconnected wiring cables.
- b. Command and communications data link protocol. Verify sample messages are sent and received correctly using the electronic equivalent of the weapon.
- c. Human machine interface (HMI). Particular attention should be given to the operator interface for the weapons release function.
- d. Hardware and software regression testing prior to implementing any changes. Verify changes do not have unintended consequences for previously validated system actions. If additional hardware or software changes occur during test, consider which executed subtests must be repeated to insure test results are not impacted. Also, verify occlusions of the designator line of sight to the target do not occur for shot geometry over the duration of the engagement in case the laser spot is lost.
- e. Electromagnetic interference (EMI)/radio frequency interference (RFI) compliance. The installed system shall meet the requirements of DO-160F²⁵ or later revision.
- f. After checking individual sub-systems, a complete functional test of the weapon system installed on the platform shall be accomplished using an electronic weapon emulator or equivalent. An example is the AWM-101 tester used for the Hellfire missile (Figure 2). This functional test shall include inhibit, arming and release functions, as well as any weapon status functions.



Figure 2. AWM-101 Hellfire emulator.

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4.1.1.2 Verify Structural Integrity/Safety.

- a. Static loads. Verify that the hard points for mounting have adequate margins throughout the approved operating envelope (V-n diagram).
- b. Weapon retention force compliance. The weapon shall not release under any flight or ground condition unless commanded to do so.
- c. Flutter speed margin. The mass of the weapon will change the aeroelastic characteristics of the wing and/or fuselage. These characteristics shall be investigated for adequate margins.
- d. Dynamic loads during taxi. Verify by instrumented taxi test that adequate margins exist in all structures affected by the weapon installation.
- e. Captive carry flight loads. Verify by analysis or test that adequate margins exist in all structures affected by the weapon installation.
- f. Dynamic loads during landing. Verify by analysis or test that adequate margins exist in all structures affected by the weapon installation.
- g. Launch loads. These should be verified by an instrumented ground launch of a weapon with an inert warhead. See Figure 3 for an example. This may be accomplished with a combination of analysis, ground tests, and flight tests. Tests shall not be performed with a live warhead.



Figure 3. Ground launch test.

4.1.1.3 Verify Systems Communications.

- a. Antenna masking effects. Verify through ground test that the weapon causes no significant masking of any antenna.
- b. Data link capabilities. Verify through ground test that the weapon causes no significant degradation of data link capabilities. Can also be verified in flight with a mass mockup or captive flight weapon system.

4.1.1.4 Verify Aerodynamics.

- a. Symmetric load flight stability and performance (laterally balanced weapons stores).
- b. Asymmetric load flight stability and performance (laterally unbalanced weapons stores).
- c. This shall be accomplished with an appropriate combination of analysis, ground tests, wind tunnel tests, and flight tests.

4.1.1.5 Verify Electrical Power Budget.

- a. Weapon status power.
- b. Weapon launch power.
- c. Complete system power.

4.1.1.6 Verify No Adverse Missile Plume Effects on Platform.

- a. From heat.
- b. From pressure.
- c. From debris.
- d. Plume/propulsive gas effects on platform and targeting system.
- e. These can be verified with an instrumented ground launch of a weapon with an inert warhead.

4.1.2 Instrumentation.

The instrumentation required in Phase I will vary according to the procedure. The applicant is responsible for selecting the instruments and apparatus that will produce accurate and repeatable results.

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4.2 Phase II General Live Firing Flight Test Procedures.

a. In Phase II, live weapon testing will be performed to confirm all systems perform properly and within expected accuracy. Unless circumstances dictate otherwise, the weapons used for these tests shall have an inert warhead.

b. The purpose of testing is to confirm the predictions of engineering analysis, simulation, and subsystem tests. It is not to be employed as a substitute for any part of a complete system engineering substantiation. Thus, the airframe, power plant, GCS, data control link, weapon(s), weapon(s) interface, and weapon targeting system shall have been verified and/or demonstrated by other means to be safe to operate together in the planned environment prior to commencing any flight tests with live weapons.

c. This means that before testing a UAS, especially a weaponized UAS, assurance must be presented by the applicant that the GCS, platform, weapons interface, weapon, and weapon targeting system meet appropriate established hardware and software engineering standards.

4.2.1 Procedures.

a. The RSO will verify the atmospheric conditions and planned launch range and altitude, are within the approved envelope of the targeting sensor system and the weapon system. The Government Flight Representative, if applicable, has final authority to approve/disapprove the flight and weapons tests.

b. All procedures shall be performed using prepared checklists and/or test cards. These checklists/test cards shall be approved by the RSO before the commencement of Phase II tests.

c. Preparation of the platform, loading of the weapon, and preflight systems check shall be performed by ordnance certified personnel and may be the manufacturer (weapon or platform, as appropriate) or its contractors. Unless otherwise approved by the RSO, operation of the platform and weapons firing shall be performed by certified civilian or current military pilots that are trained and rated for this duty.

4.2.2 Required Instrumentation.

Data collection shall be performed with the use of video recorders to record the weapon release and target impact, and a data recorder to provide airborne platform TSPI. Range instrumentation shall include a meteorological system for atmospheric documentation; temperature-calibrated infrared radiometers for documenting and validating infrared (IR) target conditions, a spectrometer for validating electro-optical (EO) targets, laser spot tracker for laser-guided munitions and a range time system for data correlation. See Section 2.2 for further instrumentation data and parameters.

4.3 Gravity Dropped Weapons.

4.3.1 Objective.

The objective of this subtest is to determine the effectiveness of a gravity dropped weapon released from a UAS. An example would be the CBU-97A/B Sensor Fuzed Weapon. See Figure 4.

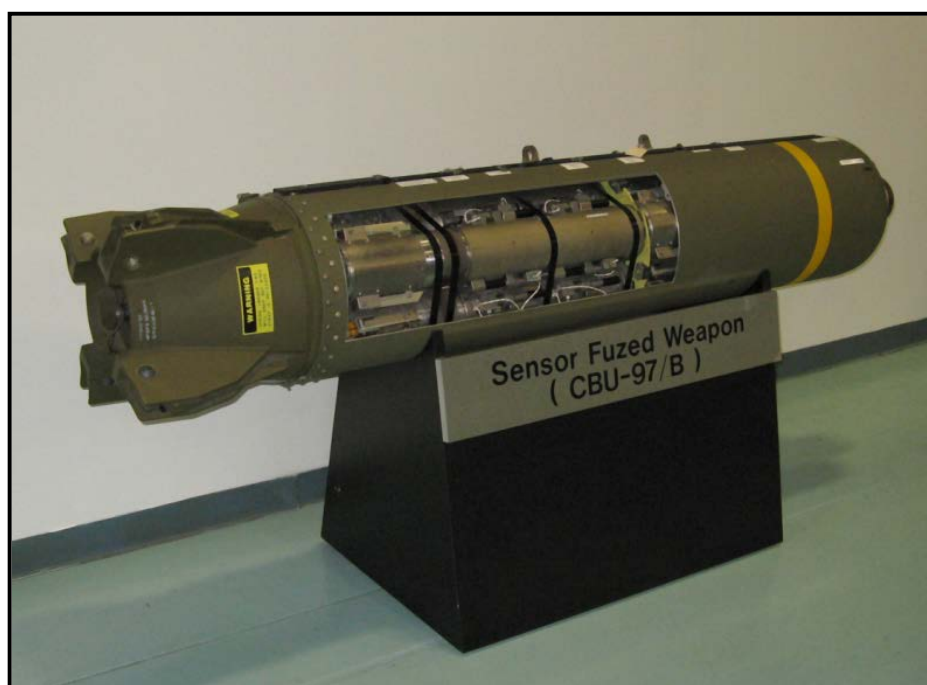


Figure 4. CBU-97A/B.

4.3.2 Instrumentation and Targets.

In addition to the general test procedures in section 4.1, the following shall be employed during live fire flight test:

a. Instrumentation. Range instrumentation shall include a meteorological system for atmospheric documentation; for IR targeting systems, temperature-calibrated infrared radiometers for documenting and validating target conditions; for EO targeting systems, a spectrometer for validating target conditions, as applicable. A common range time system is required to correlate the data collected from the various sources.

b. Targets. Targets should be selected that are appropriate to the weapon and provide an objective measure of accuracy. It is assumed that the weapon system effectiveness against typical targets has been previously validated by other means. Therefore, target boards with a camera array can be used to capture the weapon impact. If the targeting of the system is dependent on the shape of the target typical battlefield targets such as tanks, trucks, buildings,

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etc., can be utilized. A wooden target on a rail system is suitable as a moving target as well as remote controlled vehicles.

4.3.3 Specialized Test Procedures.

In addition to the general test procedures in section 4.1, the following shall be accomplished during live fire flight test:

a. For weapons guided independently of the UAS (e.g., inertial or GPS guidance), verify that releasing the weapon within the range and altitude specified for the weapon results in impact on the target within the specified Surface Danger Zone (SDZ) of the weapon.

b. For weapons dependent on the UAS for guidance (e.g., laser spot guidance), verify that releasing the weapon within the range and altitude limits specified for the weapon, and the laser guidance, results in impact on the target within the specified SDZ of the weapon. Before releasing the weapon, verify the weapon is locked onto the correct target.

c. Weapon firings shall be performed at representative extremes of the operating envelope of the weapon. For example, a low altitude, low airspeed drop at maximum specified range will verify performance at the lowest launch energy. A firing at high speed will verify the weapon releases cleanly over the operating airspeed range of the platform.

d. To accurately assess impact location, and for additional safety, the weapon shall be inert, unless special circumstances dictate otherwise.

4.3.4 Data Required.

Data collection during trials shall be performed with the use of video recorders to record the sensor and target video. If TSPI and flight data of the airborne platform can't be recorded on-board the UAS, then it should be recorded from the GCS. If feasible, video cameras shall be mounted on the UAS to verify clean release of the weapon. High-speed video cameras shall record the target impact. For laser guided munitions data from the laser spot tracker/camera will also be collected.

4.3.5 Analysis.

- a. The in-flight video should verify the weapon releases cleanly.
- b. The target video should verify the accuracy of the UAS/weapon combination.
- c. The telemetry from the UAS and the in-flight video should verify the platform encounters no instabilities as a result of the release.
- d. Scoring shall be accomplished using the same method employed during the original acceptance testing of the weapon.

4.4 Guided Self-Propelled Weapons.

4.4.1 Objective.

The objective of this subtest is to determine the effectiveness of a guided self-propelled weapon launched from a UAS. An example would be the AGM-114 Hellfire Missile, Figure 5.

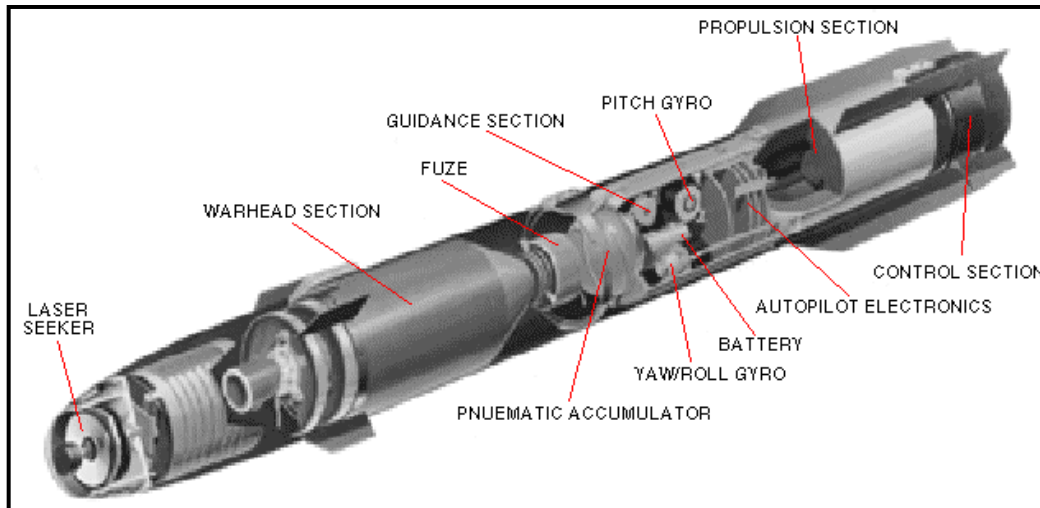


Figure 5. AGM-114 Hellfire.

4.4.2 Instrumentation and Targets.

In addition to the general test procedures in section 4.1, the following shall be employed during live fire flight test.

a. Instrumentation. Range instrumentation shall include a meteorological system for atmospheric documentation; for IR targeting systems, temperature-calibrated infrared radiometers for documenting and validating target conditions; for EO targeting systems, a spectrometer for validating target conditions, as applicable. A common range time system is required to correlate the data collected from the various sources.

b. A means shall be employed to monitor possible vibration effects of launch. Accelerometers, and/or fast response strain gauges mounted on or near the weapon pylon are candidates for this requirement.

c. Targets. Targets should be selected that are appropriate to the weapon and provide an objective measure of accuracy. It is assumed that the weapon system effectiveness against typical targets has been previously validated by other means. Therefore, target boards with a camera array can be used to capture the weapon impact. If the targeting of the system is dependent on the shape of the target typical battlefield targets such as tanks, trucks, buildings,

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etc., can be utilized. A wooden target on a rail system is suitable as a moving target as well as remote controlled vehicles.

4.4.3 Specialized Test Procedures.

In addition to the general test procedures in section 4.1, the following shall be accomplished during live fire flight test.

a. For weapons guided independently of the UAS (e.g., inertial or GPS guidance), verify that releasing the weapon within the range and altitude specified for the weapon results in impact on the target within the specified SDZ of the weapon. Verify proper boresight and laser range of the designation system prior to weapons launch. Also verify test personnel are wearing the proper laser goggles.

b. For weapons dependent on the UAS for guidance (e.g., laser spot guidance), verify that releasing the weapon within the range and altitude limits specified for the weapon and the laser guidance results in impact on the target within the specified SDZ of the weapon.

c. Before launching the weapon (hot run), perform dry runs to verify the weapon guidance system (i.e. laser spot) is locked onto the correct target.

d. Weapon drops shall be performed at representative extremes of the operating envelope of the weapon. For example, a low altitude, low airspeed drop at maximum specified range will verify performance at the lowest launch energy. A firing at high speed will verify the weapon releases cleanly over the operating airspeed range of the platform.

e. To accurately assess impact location, and for additional safety, the weapon shall be inert, unless special circumstances dictate otherwise.

4.4.4 Data Required.

Data collection during trials shall be performed with the use of video recorders to record the sensor and target video. If TSPI and flight data of the airborne platform can't be recorded on-board the UAS, then it should be recorded from the GCS. If feasible, video cameras shall be mounted on the UAS to verify clean release of the weapon. High-speed video cameras shall record the target impact. For laser guided munitions data from the laser spot tracker/camera will also be collected.

4.4.5 Analysis.

a. The in-flight video should verify the weapon releases cleanly. In some cases, a chase aircraft with high speed video may be required to document weapons release anomalies.

b. The target video should verify the accuracy of the UAS/weapon combination.

c. The telemetry from the UAS and the in-flight video should verify the platform encounters no instabilities as a result of the release.

d. Scoring shall be accomplished using the same method employed during the original acceptance testing of the weapon.

4.5 Unguided Self-Propelled Weapons.

4.5.1 Objective.

The objective of this subtest is to determine the effectiveness of rockets fired from a UAS. An example would be the standard 2.75-inch (70 mm) rocket, Figure 6.



Figure 6. 2.75-Inch (70 mm) Rocket.

4.5.2 Instrumentation and Targets.

In addition to the general test procedures in section 4.1, the following shall be employed during live fire flight test:

a. Instrumentation. Range instrumentation shall include a meteorological system for atmospheric documentation; for IR targeting systems, temperature-calibrated infrared radiometers for documenting and validating target conditions; for EO targeting systems, a spectrometer for validating target conditions, as applicable. A common range time system is required to correlate the data collected from the various sources.

b. A means shall be employed to monitor possible vibration effects of launch. Accelerometers, and/or fast response strain gauges mounted on or near the weapon pylon are candidates for this requirement.

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c. **Targets.** Targets should be selected that are appropriate to the weapon and provide an objective measure of accuracy. It is assumed that the weapon system effectiveness against typical targets has been previously validated by other means. Therefore, target boards with a camera array can be used to capture the weapon impact. If the targeting of the system is dependent on the shape of the target typical battlefield targets such as tanks, trucks, buildings, etc., can be utilized. A wooden target on a rail system is suitable as a moving target as well as remote controlled vehicles.

4.5.3 Specialized Test Procedures.

In addition to the general test procedures in section 4.1, the following shall be accomplished during live fire flight test.

a. Weapon firings shall be performed at representative extremes of the operating envelope of the weapon. For example, a low altitude, low airspeed drop at maximum specified range will verify performance at the lowest launch energy. A firing at high speed will verify the weapon releases cleanly over the operating airspeed range of the platform.

b. To accurately assess impact location, and for additional safety, the weapon shall be inert, unless special circumstances dictate otherwise.

4.5.4 Data Required.

Data collection during trials shall be performed with the use of video recorders to record the sensor and target video. If TSPI and flight data of the airborne platform can't be recorded on-board the UAS, then it should be recorded from the GCS. If feasible, video cameras shall be mounted on the UAS to verify clean release of the weapon. High-speed video cameras shall record the target impact. For laser guided munitions data from the laser spot tracker/camera will also be collected.

4.5.5 Analysis.

- a. The in-flight video should verify the weapon releases cleanly.
- b. The target video should verify the accuracy of the UAS/weapon combination.
- c. The telemetry from the UAS and the in-flight video should verify the platform encounters no instabilities as a result of the release.
- d. Scoring shall be accomplished using the same method employed during the original acceptance testing of the weapon.

4.6 Guns and Cannons.

4.6.1 Objective.

The objective of this subtest is to determine the effectiveness of a gun fired from a UAS. An example would be the M134 Minigun (Figure 7).

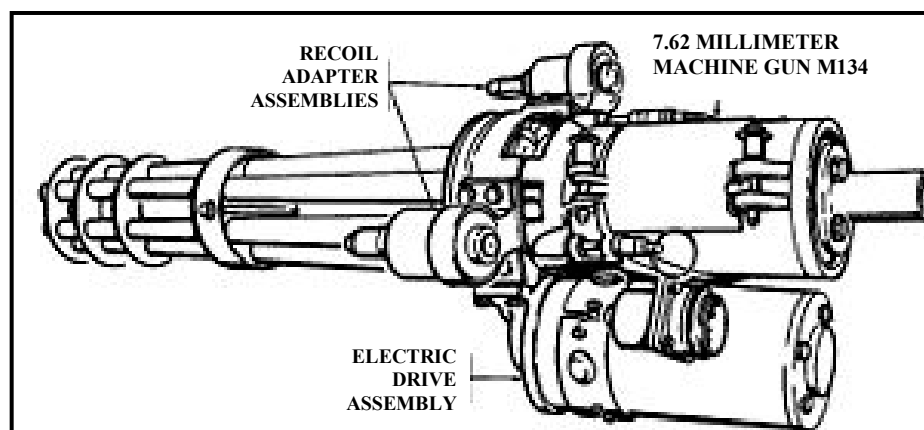


Figure 7. M134 Minigun.

4.6.2 Instrumentation and Targets.

In addition to the general test procedures in section 4.1, the following shall be employed during live fire flight test.

a. Instrumentation. Range instrumentation shall include a meteorological system for atmospheric documentation; for IR targeting systems, temperature-calibrated infrared radiometers for documenting and validating target conditions; for EO targeting systems, a spectrometer for validating target conditions, as applicable. A common range time system is required to correlate the data collected from the various sources.

b. A means shall be employed to monitor possible vibration effects of firing. Accelerometers, and /or fast response strain gauges mounted on or near the gun are candidates for this requirement.

c. A means shall be employed to assess the possible blast effects on the platform and/or gun.

d. Targets. Targets should be selected that are appropriate to the weapon and provide an objective measure of accuracy. It is assumed that the weapon system effectiveness against typical targets has been previously validated by other means. Therefore, target boards with a camera array can be used to capture the weapon impact. If the targeting of the system is dependent on the shape of the target typical battlefield targets such as tanks, trucks, buildings,

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etc., can be utilized. A wooden target on a rail system is suitable as a moving target as well as remote controlled vehicles.

4.6.3 Specialized Test Procedures.

In addition to the general test procedures in section 4.1, the following shall be accomplished during live fire flight test.

a. Weapon firings shall be performed at representative extremes of the operating envelope of the weapon. For example, a low altitude, low airspeed drop at maximum specified range will verify performance at the lowest launch energy. A firing at high speed will verify the weapon releases cleanly over the operating airspeed range of the platform.

b. To accurately access impact location, and for additional safety, the weapon shall be inert, unless special circumstances dictate otherwise.

4.6.4 Data Required.

Data collection during trials shall be performed with the use of video recorders to record the sensor and target video. If TSPI and flight data of the airborne platform can't be recorded on-board the UAS, then it should be recorded from the GCS. If feasible, video cameras shall be mounted on the UAS to verify clean release of the weapon. High-speed video cameras shall record the target impact. For laser guided munitions data from the laser spot tracker/camera will also be collected.

4.6.5 Analysis.

- a. The in-flight video should verify the weapon releases cleanly.
- b. The target video should verify the accuracy of the UAS/weapon combination.
- c. The telemetry from the UAS and the in-flight video should verify the platform encounters no instabilities as a result of the release.
- d. Scoring shall be accomplished using the same method employed during the original acceptance testing of the weapon.

5. DATA REQUIRED.

5.1 General.

a. The following data are similar per subtest section and should be collected during testing:

- (1) Flight test number.

- (2) Date and time of test.
- (3) Mission type (technical target baseline, test point identification).
- (4) UAS/sensor configuration (software (S/W), hardware (H/W) loads).
- (5) Test Observer(s)/Operator(s) and Aircrew identification.
- (6) Target type/identity.
- (7) Target position.
- (8) GPS UAS position information.
- (9) Time of observation call.
- (10) Observer video.
- (11) Observer(s) and Test Coordinator(s) comments/remarks.
- (12) Meteorological conditions:
 - (a) Wind speed.
 - (b) Wind direction.
 - (c) Temperature.
 - (d) Humidity.
 - (e) Atmospheric transmittance.
 - (f) Scintillation.
 - (g) Solar illumination.
 - (h) Lunar illumination.
- (13) Software revision.
- (14) GCS (type, name, serial number, etc.).
- (15) Weapons system.

b. Due to the significant number of procedures in this TOP, other specific guidance for data required is covered within each associated test procedure section/paragraph.

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5.2 Uncertainty Analysis.

The measurement uncertainty is the result of a number of systematic and random sources of error. These include, but are not limited to, the following: the environment, the measuring equipment, the test item itself, and relevant assumptions made during the test program.

6. PRESENTATION OF DATA.

Data should be presented in such a way as to support the conclusions. This may include, but is not limited to, tables, charts, scatter diagrams, graphs, etc. If the data presentation from the original acceptance test of the weapon is available, the applicant is encouraged to use the same format.

a. Example: Hellfire Missile Test.

(1) Each weapon system UAS combination will likely require a different format. But, as an example, live fire testing of a Hellfire missile may be condensed into the following chart. Of course, each sortie will likely have a discussion section, particularly if there were anomalies in the test.

(2) The basis of the presentation would most likely come from the test plan. Incorporated into this would be the reference to the criteria towards the beginning of the section. The analysis of the criteria would be addressed after the procedures.

(3) The description in the analysis should revolve around any observations or calculations that were made. Samples of ways to analyze data include: accuracy, consistency of performance per event, the arithmetic mean, the standard deviation, and the Root Mean Square value.

(4) A simple sample may include the following:

(a) Criterion: The system must be accurate at least 90% of the time.

(b) Analysis: The system has successfully completed function testing to verify currently fielded systems.

b. Once data have been reviewed and quality assured, run-by-run data should be compiled. Each trial conducted may be represented in a single row of a summary table containing all relevant information such as the event time, range-to-target, and meteorological conditions (Table 1). No trials will be omitted unless significant rationale exist. Run-by-run data would usually be placed in an appendix for reference.

TABLE 1. RUN-BY-RUN DATA

Sortie No.	Date	Target	Trajectory	Altitude MSL (ft)	Altitude AGL (ft)	Slant Range (m)	Offset Angle (deg)	X-Miss Distance (ft)	Y-Miss Distance (ft)
1									
2									
..									
N									

c. In some cases, scatter diagrams may be appropriate. But, if the points on the diagram do not represent identical conditions, a detailed note will need to be made for each point.

d. If available, photographs should be included to illustrate results. This is true for both ideal and anomalous results.

e. In each case, it is important to document everything. What went wrong is as important as what went right.

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APPENDIX A. ABBREVIATIONS.

ADS	Aeronautical Design Standard
AGARD	Advisory Group for Aerospace Research and Development
AOA	angle of attack
AOS	angle of sideslip
AR	Army Regulation
ASC	Aeronautical Systems Center
ASIC	application specific integrated circuit
ATEC	US Army Test and Evaluation Command
DOD	Department of Defense
E3	electromagnetic environmental effects
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EO	Electro-optical
FAR	Federal Aviation Regulation
FPGA	field programmable gate array
GCS	ground control station
GPS	Global Positioning System
HMI	human machine interface
HQ	headquarters
HUD	heads-up display
IEEE	Institute of Electrical and Electronics Engineers
IMU	inertial measurement unit
IR	infrared
IRIG	Inter-Range Instrumentation Group
MIL-HDBK	military handbook
MIL-STD	military standard
Ps	static pressure
Pt	total pressure
RCC	Range Commanders Council
RFI	radio frequency interference
rpm	revolutions per minute
RSO	Range Safety Officer
RTD	resistance temperature detectors
RTO	Responsible Test Organization

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APPENDIX A. ABBREVIATIONS.

SDZ	Surface Danger Zone
SEP	System Evaluation Plan
SOAR	Special Operation Airworthiness Release
SRB	Safety Review Board
TEMP	Test and Evaluation Master Plan
TOP	Test Operations Procedure
TSPI	time, space, position information
UA	unmanned aircraft
UAS	unmanned aircraft system
USAF	US Air Force
USAMRDEC	US Army Aviation and Missile Research, Development and Engineering Center

APPENDIX B. REFERENCES.

1. DO-178B, Software Considerations in Airborne Systems and Equipment Certification, 1 December 1992.
2. IEEE 12207, Standard for Information Technology-Software Life Cycle Processes, 27 May 1998.
3. DO-254, Design Assurance Guidance for Airborne Electronic Hardware, 7 May 2005.
4. MIL-STD-461F, Department of Defense Interface Standard, Requirements for the Control of Electromagnetic Interface Characteristics of Subsystems and Equipment, 10 December 2007.
5. MIL-STD-464, Military Standard, Electromagnetic Effects, Requirements for Systems, 18 March 1997.
6. ADS-37A, Aeronautical Design Standard, Electromagnetic Environment Effects (E3) Performance and Verification, 28 May 1996.
7. MIL-STD-704F, Department of Defense Interface Standard, Aircraft Electric Power Characteristics, 12 March 2004.
8. MIL-E-6051D, Military Specification, Electromagnetic Compatibility Requirements, Systems, 7 September 1967.
9. MIL-STD-1472F, Department of Defense Design Criteria Standard, Human Engineering, 23 August 1999.
10. FAR 23, Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes.
11. FAR 27, Airworthiness Standards: Normal Category Rotorcraft.
12. FAR 25, Airworthiness Standards: Transport Category Airplanes.
13. FAR 29, Airworthiness Standards: Transport Category Rotorcraft.
14. RCC-323-99, Range Safety Criteria for Unmanned Air Vehicles, December 1999.
15. RCC-323-99 Supplement, Range Safety Criteria for Unmanned Air Vehicles, Rationale and Methodology Supplement, November 2010.
16. TOP 07-1-001, Unmanned Aircraft Systems (UAS) Testing Overview, 02 December 2008.

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APPENDIX B. REFERENCES.

17. RCC-319-10 Flight Termination Systems Commonality Standard, November 2010.
18. MIL-HDBK-516B, Department of Defense Handbook, Airworthiness Certification Criteria, 26 September 2005.
19. ADS-20-HDBK, Aeronautical Design Standard Handbook, Armament and Fire Control System Survey for Army Aircraft Handbook, 19 December 2005.
20. ADS-51-HDBK, Aeronautical Design Standard Handbook, Rotorcraft and Aircraft Handbook, 21 October 1996.
21. MIL-HDBK-1763, Department of Defense Handbook, Aircraft/Stores Compatibility: Systems Engineering Data Requirements and Test Procedures, 15 June 1998.
22. AGARDograph 300, AGARD Flight Test Techniques Series, Volume 10, Weapon Delivery Analysis and Ballistic Flight Testing, July 1992.
23. TOP, 07-1-002, Air Portability and Airdrop Service Testing, 14 September 1970.
24. Test Report, Predator Hellfire Demonstration Phase I, Integration Test Report, General Atomics Aeronautical Systems, Inc., July 2001.
25. DO-160F, Environmental Conditions and Test Procedures for Airborne Equipment, 6 December 2007.
26. AR 70-62, Airworthiness Qualification of Aircraft Systems, 21 May 2007.

APPENDIX C. AIR WORTHINESS RELEASE INFORMATION.

C.1 US Army.

a. Per Army Regulation (AR) 70-62²⁶, the top level authority for issuance of Airworthiness Releases is the US Army Aviation and Missile Research, Development and Engineering Center (USAMRDEC):

Commander
USAMRDEC, AMSRD-AMR-AE
Redstone Arsenal, AL 35898-5000

b. As a practical matter, the following two organizations issue Airworthiness Releases for Army platforms.

(1) For Programs of Record:

Aviation Engineering Directorate
AMSRD-AMR-AE
Building 5400
Redstone Arsenal, AL 35898-5000

Phone: DSN: 897-8400 Commercial: (256) 313-8400
Fax: DSN: 746-7174 Commercial: (256) 876-7174

(2) For Programs in Development:

Aviation Applied Technology Directorate
AMSRD-AMR-AA
Fort Eustis, VA 23604-5000

Phone: DSN: 826-2208 Commercial: (757) 878-2208
Fax: DSN: 826-1323 Commercial: (757) 878-1323

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APPENDIX C. AIR WORTHINESS RELEASE INFORMATION.

C.2 US Air Force (USAF).

Typically, airworthiness certification is issued by the platform Single Manager based on demonstration of compliance with certification criteria identified as part of the platform's certification basis. If this is not the approach utilized, an application for a permission to utilize the USAF Special Operation Airworthiness Release (SOAR) process may be made to:

Aeronautical Systems Center (ASC)
Director of Engineering (ASC/EN)
2530 Loop Road West
Wright-Patterson AFB, OH 45433-7101

Phone: DSN: 785-0126 Commercial: (937) 255-1026
Fax: DSN: 785-5597 Commercial: (937) 255-5597

C.3 US Navy and Marine Corps.

Commander
AIR-4.0P UAS, Bldg 460
Naval Air Systems Command
22244 Cedar Point Road
Patuxent River, MD 20670-1906

Phone: DSN: 342-3776 Commercial: (301) 342-3776
Fax: DSN: 342-3776 Commercial: (301) 342-3776

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, MD 21005-5001. Technical information may be obtained from the preparing activity: Aviation and Air Delivery Systems Division (TEDT YPY AV), 301 C Street, Bldg. 3021, Yuma, AZ 85365-9498. Additional copies can be requested through the following website: <http://itops.dtc.army.mil/RequestForDocuments.aspx>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.