Director, Operational Test and Evaluation F-35A and A-10C Comparison Test



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(U) Executive Summary

(CUI) This report provides the assessment of the results of a comparison test examining the capabilities of the F-35A and the A-10C aircraft in three mission areas: Close Air Support (CAS), Forward Air Controller (Airborne) (FAC(A)), and Combat Search and Rescue (CSAR), which are required missions for the F-35A as the replacement for the A-10.1 This report is based on a comparison test executed between April 2018 and March 2019 by the JSF (Joint Strike Fighter) Operational Test Team (JOTT) as part of F-35 Initial Operational Test and Evaluation (IOT&E). The comparison test was adequate to compare the mission effectiveness of two very different aircraft in a limited set of operationally representative low-threat "permissive" and medium-threat "contested" environments. High-threat missions were not included in this comparison test because the F-35A, along with the F-35B and F-35C, is being thoroughly evaluated during F-35 IOT&E in high-threat scenarios versus modern, dense SAM and fighter aircraft, missions for which the A-10C was not designed. The comparison test fulfills the Fiscal Year 2017 National Defense Authorization Act (FY17 NDAA), Section 134 (as modified by FY22 NDAA to deliver the report within 53 days of FY22 NDAA approval) mandate while yielding important conclusions that should be useful in improving F-35A performance in these mission roles as well as determining future force structures:





⁽CUI) Joint Strike Fighter (JSF) Operational Requirements Document (ORD), Change 3, August 19, 2008, paragraphs 1.3.1.1 and 3.0.





(U) The F-35 Joint Program Office (JPO), in concert with the U.S. Air Force and Lockheed Martin, should fix the F-35A gun, improve digital communications, video data link capability and interoperability with 4th generation aircraft, and develop training programs to further improve F-35A effectiveness in these missions. Additional recommendations are detailed in Section Four of this report.

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(U) Section One (U) System Description

(U) F-35A

(CUI) The JSF Operational Requirements Document² identifies the F-35A as the multirole fighter designed to replace the F-16 and A-10 within the U.S. Air Force. F-35A aircraft in the Block 3 hardware configuration with software versions 30R00 and 30R02.04 were used in this comparison test. Table 1-1 lists specific system attributes for both aircraft pertinent to the comparison test.



(U) A-10C

(CUI) The A-10 is the only U.S. Air Force aircraft specifically designed for close air support of ground forces. It is capable of attacking armored vehicles, tanks, installations, and enemy troops. The A-10, in service since 1975, accomplishes CAS, FAC(A), and CSAR missions using a variety of forward firing, guided and unguided weapons, sensors, and communication systems. The U.S. Air Force upgraded A-10 aircraft to the precision engagement configuration, designated A-10C, which were used for the comparison test trials.

(SUI) The A-10 was designed and built around its 30-mm gun, its primary weapon to support CAS missions, with a large ammunition capacity. (b) (3) 10 U.S.C. § 130





| (U) Table 1-1. Aircraft Confi | guration and Capabilities | Available in Co | mparison Test |
|-------------------------------|---------------------------|-----------------|---------------|
|-------------------------------|---------------------------|-----------------|---------------|

| C | |
|--|---|
| F-36A | A-10C |
| Air-to-Groun | id Munitions |
| GAU-22/A 25-millimeter (mm) rotary cannon³ GBU-12 Paveway II taser-guided bomb GBU-31 Joint Direct Attack Munition (JDAM) Global Positioning System (GPS)-aided bomb GBU-49 Enhanced Paveway II laser-guided and GPS-aided bomb GBU-39 Small Diameter Bomb | GAU-8/A 30-mm rotary cannon GBU-10/12/51 Paveway II laser-guided bombs GBU-31/38 JDAM GPS-aided bombs GBU-54 Laser JDAM dual GPS-aided and laser-guided bomb Mark 82/84 general purpose bombs CBU-87/89/97 cluster bombs CBU-103/104/105 Wind-Corrected Munitions Dispenser inertially-guided cluster bombs AGM-65 Maverick air-to-ground missile 2.75-inch rockets, including unguided rockets and the laser-guided AGR-20A Advanced Precision Kill Weapons System (APKWS) LUU-2 overt and LUU-9 covert illumination flares |
| Air-to-Ground Weapo | ns Carriage Capacity |
| Four external and two internal stations with up to 4,000 pounds Two internal stations each with one 500-lb GBU-12 or GBU-49 or one 2000-lb Joint Direct Attack Munition Four external stations each with one 500-lb GBU-12 or GBU-49 bomb; permitted only with the same weapon in the internal stations (i.e., mixed loads prohibited) 182 rounds of 25-mm ammunition | Eleven external stations shared with pods with up to 16,000 pounds 1,174 rounds of 30-mm ammunition |
| Air-to-Air | Weapons |
| AIM-120 Advanced Medium Range Air-to- Air Missile (AMRAAM) AIM-9X air-to-air missile | AIM-9M air-to-air missile |



| Situational Awareness | and Targeting Sensors |
|--|--|
| AN/AAQ-40 Electro-Optical Targeting System (EOTS) AN/AAQ-37 Distributed Aperture System (DAS) AN/APG-81 radar Alr-to-ground capabilities include high resolution synthetic aperture radar (SAR) mapping and ground moving target indicator (GMTI)⁴ | AN/AAQ-28 LITENING Advanced Targeting Pod (ATP) AN/AAQ-33 SNIPER ATP |
| Communica | tions Suite |
| Ultra-high frequency (UHF) and very high frequency (VHF) radios Secure voice communications Single Channel Ground and Airborne Radio System (SINCGARS) Variable Message Format (VMF) messaging Link 16 Multifunction Advanced Data Link (MADL) A high-bandwidth, low-probability-of-intercept data link that allows sharing of detailed ownship status and sensor data with other MADL-equipped aircraft | UHF/VHF radios Secure voice communications UHF SATCOM SINCGARS VMF messaging Situational Awareness Data Link (SADL) A data link that allows sharing of J-series messages with other SADL-equipped aircraft Remotely Operated Video Enhanced Receiver (ROVER) compatible video data link provided by targeting pods AN/ARS-6 Lightweight Airborne Recovery System |
| Self-Protecti | on Systems |
| AN/ASQ-239 electronic warfare and countermeasures system | ALQ-213 electronic warfare controller ALR-69 radar warning receiver ALQ-131 electronic countermeasures (ECM) pod ALQ-184(V) ECM pod ALE-40 chaff and flare dispenser |

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(U) Mission Descriptions and Concepts of Employment

(U) Close Air Support (CAS)

(CUI) CAS is a mission where "air action by aircraft against hostile targets that are in close proximity to friendly (ground) forces and requires detailed integration of each air mission with the fire and movement of those forces."⁵ CAS can be conducted by many different types

| (b) | (1) (A) |
|-----|--|
| 5 | (U) Joint Publication 3-09.3, "Joint Close Air Support," June 7, 2021. |
| | 3 |

and numbers of aircraft, but coordination is standardized with specific communication protocols. For the comparison test, both the F-35A and A-10C aircraft conducted the CAS trials as 2-ship formations.

(U) A single CAS event, or "control," is initiated with a "game plan" tasking from either a FAC(A) or ground-based Joint Terminal Attack Controller (JTAC), who serves as the tasking authority to the CAS aircraft on behalf of the ground force commander. The tasking consists of a standardized, Joint Doctrine approved, "9-line" brief format describing nine specific details of the immediate task in short, clear terminology. This information can be transmitted verbally on the radio or digitally between like-configured participants. Details in the brief include aircraft heading and run-in distance for the attack, target details (e.g., elevation, description, location), terminal guidance (e.g., laser designation or mark point, often identified by latitude and longitude coordinates), location of friendly forces, and post-attack egress guidance. Following the brief, the CAS aircrew and platform must find the target and correlate the target with the FAC(A) or JTAC. Correlation is the process by which the controller confirms that the CAS aircraft has the correct target. Following correlation, the FAC(A) or JTAC clears the CAS aircraft to initiate the attack.

(U) Three different types of control can be used to minimize the risk of friendly fire while maximizing the opportunity for a successful attack. Type 1 control requires the JTAC or FAC(A) to maintain control of the attack by observing both the target and the attacking aircraft during the terminal phase (just prior to weapons release), minimizing the risk for collateral damage or friendly fire. Type 2 control allows the JTAC or FAC(A) to use means other than visual confirmation of the attack to ensure safe conduct. Type 3 control allows the controller to clear a CAS aircraft for multiple attacks within a single engagement provided specific constraints (e.g., location, attack azimuth) are met. The controller also specifies the CAS aircraft's method of attack, either bomb on target (BOT) using visual or sensor confirmation, or bomb on coordinate (BOC). CAS aircraft bring joint fire support to the Joint Force Commander (JFC) based on their objectives, guidance, and priorities. The JFC establishes target priority, desired weapons effects, and timing of CAS fire support within the boundaries the JFC's area of operations.

(U) Forward Air Controller (Airborne) (FAC(A))

(CUI) The FAC(A) is a "specifically trained and qualified aviation officer who exercises control from the air of aircraft engaged in close air support of ground troops."⁶ The FAC(A) role involves airspace management over the target area, assigning 9-line taskings to CAS aircraft and coordinating engagements in support of ground forces. The FAC(A) is the liaison between the supported JFC and the CAS aircraft. For the comparison test, both the F-35A and A-10C aircraft conducted the FAC(A) trials as 2-ship formations controlling F/A-18, F-16, or F-35A as the CAS aircraft.

⁽U) Joint Publication 3-09.3, "Joint Close Air Support," June 7, 2021.

(U) Combat Search and Rescue (CSAR)

-(CUI) CSAR is "a specific task performed by rescue forces to effect the recovery of distressed personnel during war or military operations other than war."7 CSAR operations are generally conducted to recover friendly personnel, normally downed aircrew, as opposed to providing or coordinating engagements as in CAS and FAC(A). The scope, scale, and complexity of a CSAR operation varies broadly based on threats, environmental conditions, and recovery assets available. CSAR aircraft use a "Sandy" call sign to identify them with the unique role of conducting CSAR operations, with "Sandy 1" designated as the overall CSAR lead aircraft, with support from other aircraft in formation. Initial tasks include escorting the recovery aircraft, locating and positively identifying the downed aircrew, and securing the rescue area of operations. Once these tasks are complete, Sandy 1 directs the recovery aircraft to "Execute" the rescue operation. The Sandy flight continues to coordinate the airspace and security of the rescue area of operations until the rescue is conducted, and subsequently escorts the recovery aircraft during egress to friendly territory. For the comparison test, both the F-35A and A-10C aircraft conducted the CSAR trials as 4-ship formations that operated primarily as two separate 2-ship elements to simultaneously locate the survivor and escort the recovery aircraft.

⁽U) Joint Publication 3-50.21, "Joint Tactics, Techniques, and Procedures for Combat Search and Rescue," March 23, 1998.



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(U) Section Two (U) Comparison Test Adequacy

(CUI) In May 2015, DOT&E requested that the F-35 IOT&E incorporate comparison testing when the JOTT⁸ began developing detailed test plans. In December 2016, Congress passed the FY17 NDAA, requiring DOT&E to report on the comparison testing between the F-35A and the A-10C.

(CUI) Comparative testing included two categories of opposing threat environments: low-threat "permissive" and medium-threat "contested" environments. In order to reliably permit consistent execution of the subject mission types that could be scored, the opposing threat force composition planned for the contested environment scenarios included a limited set (innumbers and capabilities) of surface-to-air missile (SAM) threats, and no airborne threat. The F-35A and A-10C comparison test plan did not include higher-threat scenarios with modern SAMs and air threats. CAS, FAC(A), and CSAR missions in a high-threat environment would require additional aircraft conducting Suppression of Enemy Air Defenses (SEAD) and counter-air missions to reduce the threat level, which is beyond the scope of this comparison test. The F-35A, with its stealth, integrated avionics, and stand-off weapons, was designed to operate in high-threat scenarios, while the A-10C was not. The F-35A, along with the F-35B and F-35C, is being thoroughly evaluated during F-35 IOT&E in high-threat scenarios versus modern, dense SAMs and fighter aircraft, missions for which the A-10C was not designed, so high-threat missions were not included in this comparison test.

(CUI) The comparison test was adequate to compare the mission effectiveness of each aircraft in a limited set of operationally-representative conditions, even though the test team did not conduct the test completely in accordance with the DOT&E-approved test plan. The completion of all trials as matched pairs, total number of trials, number of runs in each trial, and conditions under which each run was completed all deviated from the test plan.⁹ Still, the data collected are sufficient to inform the conclusions in this report and fulfill the requirements of the NDAA.

(U) Test Design Overview

(CUI) Similar to the overall F-35 IOT&E test plan, the test team designed the comparison test to be able to detect differences, with statistical confidence, between the aircraft in critical measures of performance across a collection of operational conditions, broken out by factors and levels. The critical measures that the test team selected were times to complete mission tasks. The measures listed in Table 2-1 serve as the statistical basis of the test design, although they are



⁸ (U) The overall conduct of F-35 IOT&E is the responsibility of the JOTT, which includes five operational test units (one each from U.S. Air Force, U.S. Navy, U.S.M.C, United Kingdom, and the Netherlands) and observers and test personnel from Australia. Since the comparison test involved only a subset of the JOTT, "test team" is used throughout this report to refer to the personnel and units responsible to the conduct of the comparison testing.

⁽U) For purposes of test design discussions, a "run" is defined as a set of conditions enabling the collection of data against the critical measures.

not the only operationally relevant measures of performance included in the test plan. Factors identified by the test team as affecting outcomes in each mission area appear in Table 2-2. The statistical test design specifies the necessary number of measurements of the critical measures in each mission area and the particular combination of factor levels under which each of those measurements needed to occur. In the case of the CAS and FAC(A) missions, where each 9-line tasking provides a run, multiple runs can be accomplished in a single trial. The test design also specifies which runs should be conducted in each planned trial. The term "attack," which is used in the description of the CAS trials, differs from "run," as it refers to an aircraft executing the maneuver and systems alignment necessary to complete the delivery of ordnance on a specific target; sometimes an attack may consist of multiple runs.

| (U) Table 2-1. | Test Design | Critical | Measures |
|----------------|--------------------|----------|----------|
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| CAR | Targeting Time | From the initiation of the 9-line brief until the first target is correlated |
|--------|-----------------------|---|
| | Engagement Time | From the correlation of the first target until the first weapon release or gun employment on that target |
| EAC(A) | Brief Generation Time | From the receipt or discovery of target by FAC(A) until the initiation of the 9-line brief |
| FAG(A) | Correlation Time | From the initiation of 9-line brief until the CAS pilot has correlated the target |
| CSAR | Coordination Time | From when Sandy 1 first crosses the Forward Edge of the Battle Area (line differentiating friendly from hostile territory) until Sandy 1 commands "Execute" |
| | Recovery Time | From when Sandy 1 commands "Execute" until the downed aircrew is extracted and the recovery force is safe from threats |

(U) Acronyms: CAS – Close Air Support; CSAR – Combat Search and Rescue; FAC(A) – Forward Air Controller (Airborne)

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(U) Table 2-2. Test Design Factors

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| Factor | Louista | Applicable Mission Areas | | | |
|------------------------|------------------------------|--------------------------|--------|------|--|
| | Levela | CAS ¹ | FAC(A) | CSAR | |
| Time of Day | Day, Night | X | X | X | |
| Ground Threat Spectrum | Permissive, Contested | х | X | х | |
| Target Environment | Urban, Rural | x | | | |
| Target Category | Building, Vehicle, Personnel | X | | | |
| Control Interaction | Digital & Voice, Voice Only | X | X | | |
| CAS Type Control | Type 1, Type 2, Type 3 | X | | | |
| Formation | Single Ship, 2-Ship | X | | | |
| Target Movement | Moving, Stationary | x | | | |

| CAS Aircraft Type | Fixed Wing, Rotary Wing | 00 | X | |
|-------------------------------|-------------------------|----|---|--|
| Altitude Ceiling ¹ | Unlimited, Limited | X | | |

(U) Acronyms: CAS - Close Air Support, CSAR - Combat Search and Rescue, FAC(A) - Forward Air Controller (Airborne)

(CUI) The altitude calling factor was not varied over the test design. For most CAS trials, there was no ceiling constraint. However, a 10,000 foot Mean Sea Level ceiling (between 4,400 and 8,000 feet Above Ground Level in the tactical areas) was enforced in a limited number of excursions to simulate lower-altitude CAS engagements beneath cloud ceilings to compare differences in aircraft performance in that environment.

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(CUI) An important principle of the test design is that the comparison aircraft were to execute mission trials in matched pairs. The test design prescribes the same runs and trials for the F-35A and A-10C. The comparison aircraft were to execute the same mission trial under the same controlled factors, in the same airspace, with the same tasking, targets, and friendly forces, and scheduled as closely as practical – usually one immediately after the other – to ensure similar weather and environmental conditions. The matched pair execution notionally minimizes differences in controlled and uncontrolled factors that could affect the comparison of the performance of each aircraft. Table 2-3 summarizes the planned trial pairs for each mission. Table 2-4 includes only the "Time of Day" and "Ground Threat Spectrum" factors, which were to be held constant for each trial. A complete list of the planned runs for the CAS and FAC(A) missions that includes additional factors listed in Table 2-3 appears in Appendix A.

| | Trial Date | | Thread Colorean | R | ns | |
|--------|------------|-------------|-----------------|-------|-------|--|
| | That Fair | rune of Day | Inneat Category | F-35A | A-10C | |
| | 1 | Night | Permissive | 4 | 4 | |
| CAS | 2 | Day | Contested | 3 | 3 | |
| | 3 | Day | Permissive | 4 | 4 | |
| | 4 | Night | Contested | 3 | 3 | |
| | 5 | Night | Permissive | 4 | 4 | |
| | 6 | Day | Permissive | 4 | 4 | |
| | 1 | Day | Contested | 3 | 3 | |
| EAC(A) | 2 | Night | Contested | 3 | 3 | |
| FAC(A) | 3 | Day | Permissive | 3 | 3 | |
| | 4 | Night | Permissive | 3 | 3 | |
| | 1 | Day | Contested | 1 | 1 | |
| CRAD | 2 | Night | Contested | 1 | 1 | |
| COMR | 3 | Day | Permissive | 1 | 1 | |
| | 4 | Night | Permissive | 1 | 1 | |

(U) Table 2-3. Comparison Test Planned Trial Pairs

(U) Acronyms: CAS – Close Air Support; CSAR – Combat Search and Rescue; FAC(A) – Forward Air Controller (Airborne)

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(U) Test Conduct

(CUI) The test team generated 69 sorties¹⁰ totaling 117.5 flight hours in support of the comparison test. Table 2-4 shows a breakdown of sorties and flight hours by aircraft type and mission. The aircraft launched from Edwards Air Force Base (AFB), California and Nellis AFB, Nevada, and the trials were conducted at Naval Air Weapons Station China Lake, California and Yuma Proving Ground (YPG). Arizona. Because of range safety restrictions, aircraft employed simulated ordnance in all but one CAS trial. The test team collected cockpit video and radio transmissions recorded by the pilots on portable memory devices.¹¹ The test team also administered surveys and conducted post-mission interviews with participants, including pilots, the JTAC, and the CSAR survivor. Man-portable air defense system (MANPADS) threat missile operators provided detection and shot logs to the test team. The China Lake range provided data

¹⁰ (U) An aircraft sortic represents one flight from takeoff to landing of one aircraft. A test trial refers to the conduct of a test event required in the test plan.

^{11 (}U) Each pilot loads mission-unique files in the aircraft prior to each flight and retrieves data recorded by the aircraft after each flight via an encrypted, reusable portable memory device.

packages with recordings of threat activity. The timing of the test phases was primarily driven by the limited availability of operational A-10C units, which were heavily tasked at the time.

(CUI) The pilot force that flew the comparison test trials were representative of fielded units. Nineteen A-10C pilots from two different active duty operational units and eight F-35A operational test pilots participated. All pilots were qualified in the assigned missions. Demographic data collected from 14 of the A-10C pilots show total flight hours ranged from 540 to 3,700 hours; for the eight F-35A pilots they ranged from 1,900 to 2,800 hours. The A-10C pilot rank structure included nine captains, two majors, two lieutenant colonels, and one colonel; the F-35A pilots included one major and seven lieutenant colonels. A graphical representation of pilot demographics appears in Appendix B. Although overall flight hours and experience were similar between the A-10C and F-35A pilots, the A-10C pilots train for a limited set of missions, including the comparison test missions, while F-35A pilots are responsible for a more diverse set of missions. In addition, A-10C pilots receive specialized training and qualifications for FAC(A) and CSAR, but F-35A pilots did not as of the time of the comparison testing. To minimize the impact of this training shortfall on the comparison test, F-35A pilots previously qualified for FAC(A) and CSAR in the A-10 or other aircraft were used when possible, which was the majority of the trials. Much of the F-35A pilot flight hours were in aircraft other than the F-35A (primarily F-16 or A-10), while A-10C pilot flight hours were primarily in the A-10.

| Mission Area Dates | Operating Range / | Sorties | | | Flight Hours | | | |
|-----------------------|---|--|-------|-------|--------------|-------|-------|------|
| | Ranges | F-35A | A-10C | Total | F-35A | A-10C | Total | |
| CAS | July 6-12, 2018 | Edwards AFB / YPG, China Lake | 6 | 10 | 16 | 9.5 | 19.4 | 28.9 |
| FAC(A) | July 11-18, 2018, March 26-28, 2019 | Edwards AFB, Nellis AFB / China Lake | 9 | 12 | 21 | 12.8 | 24.3 | 37.1 |
| CSAR | April 3-5, 2018, July 10-11, 2018, March 25-27, 2019 | Edwards AFB, Nellis AFB / China Lake | 16 | 16 | 32 | 24.5 | 27.0 | 51,5 |

(U) Table 2-4. Comparison Test Events

(U) Acronyms: AFB – Air Force Base; CAS – Close Air Support; CSAR - Combat Search and Rescue; FAC(A) - Forward Air Controller (Airborne)

(U) See Footnote 10 for description of sortie.

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(U) CAS Test Conduct

(CUI) The test team completed eight CAS trials, six of which were matched pairs. Table 2-5 summarizes these trials. All trials were not conducted as matched pairs due to the limited time available with the A-10C operational aircraft. The test trials were flown over the Yuma and China Lake ranges. In each trial, the CAS aircraft conducted a check-in with a qualified JTAC

located either on the range or in the control center. The same JTAC participated in each of the CAS trials, using a script with the same scenarios and targets to ensure consistency. The JTAC transmitted a series of game plans and 9-line briefs to the CAS aircraft providing the location and description of the target and the manner in which to attack them. For each 9-line task, CAS aircraft correlated the targets, conducted attacks in accordance with the game plan, and provided a battle damage assessment if requested. Upon completion of each task, the JTAC transmitted a battle damage assessment and whether the 9-line task objectives were met. Targets included airfield infrastructure, moving and stationary vehicles, urban and rural combat town complexes, and surface threat systems. For moving targets, the JTAC frequently cued CAS aircraft to search for the target, and transmitted the 9-line brief after the target was found. In these cases, targeting time was initiated when the JTAC initially cued the CAS aircraft to find the moving target. While this sequence of events is not necessarily in accordance with doctrine, it is operationally representative and facilitated timely, consistent comparative trials.

| Data | Triai ¹ | | Time of Dou | These Colores | Runs | |
|-----------------|-----------------------------|------------------------|-------------|-------------------------|-------|-------|
| Date | F-36A | A-10C | Time or Day | Inteat Category | F-36A | A-10C |
| July 6, 2018 | | A10-12 | Day | Permissive | | 7 |
| July 6, 2018 | F35-P1 | A10-P1 | Day | Permissive | 3 | 5 |
| July 10, 2018 | F35-P2 | A10-P2 | Day | Contested | 5 | 5 |
| July 11, 2018 | | A10-2 | Day | Permissive | | 8 |
| huhu 44 - 204 R | 535 D2 | 440.00 | Alicha | Permissive ³ | | |
| | 2010 F35-F3 A10-P3 Night Co | Contested ³ | 1.4 | 6 | | |

(U) Table 2-5. Close Air Support Trials Completed

1 (CUI) Trials conducted as matched pairs include the letter P in their trial designation. Trial numbers denoted in this table are in order of execution, and as such, there is no relationship between the trial designation in this table and the trial pair number in Table 2-3.

2 (CUI) Incomplete video recordings from this trial prevent evaluation of quantitative measures.

3 (CUI) These trials began in with a permissive threat environment that was elevated to a contested environment CLII

(CUI) The CAS platforms completed a total of 43 runs compared to 44 planned. A 9line task may involve multiple targets and multiple attacks; the runs resulted in 121 attempted attacks against 88 targets. Although the test achieved a similar number of runs to the plan, the runs were not all in paired trials, distributed among the trials according to the plan, or necessarily executed under the planned conditions. Attempts by both A-10C and F-35A pilots to perform digital coordination with the JTAC using the VMF protocol were unsuccessful due to problems with the JTAC's radios. A complete list of the executed runs appears in Appendix A. In addition to the lack of runs with digital coordination, no runs were conducted with 1-ship formations, or personnel targets. Even so, the data are sufficient to support the conclusions in this report.

(U) FAC(A) Test Conduct

(CUI) The test plan required eight FAC(A) test trials in four matched pairs under the planned operational conditions. Eleven trials were flown, as shown in Table 2-6.

| Dete | Trial ¹ | | Time of Day | These Colores | Runs | | |
|----------------|------------------------------------|--------|-------------|-----------------|---------|--------|--|
| Date | F-35A | A-10C | | Inreat Category | F-35A | A-10C | |
| July 11, 2018 | F35-P1 | A10-P1 | Day | Permissive | 6 | 2 | |
| July 11, 2018 | 10.01 | A10-1 | Day | Permissive | 4 | 5 | |
| July 18, 2018 | F35-1 | | Night | Permissive | 8 | 10. 27 | |
| March 26, 2019 | F35-P2 | A10-P2 | Day | Contested | 4 | 4 | |
| March 26, 2019 | F35-P32 | A10-P3 | Day | Contested | 1 | 1 | |
| March 28, 2019 | Luc ante | A10-2 | Night | Permissive | 1322-14 | 5 | |
| March 28, 2019 | 2019 F35-P4 A10-P4 Night Contested | | 2 | 1 | | | |

| (U) Table 2-6. | Forward Air Controlle | r (Airborne) 🤉 | Frials Completed |
|----------------|-----------------------|----------------|-------------------------|
| | CHI | | 1.11 |

(CUI) Trials conducted as matched pairs include the letter P in their trial designation. Trial numbers denoted in this table are in order of execution, and as such, there is no relationship between the trial designation in this table and the trial pair number in Table 2-3.

² (CUI) The test team conducted this trial with a single-ship formation due to aircraft availability.

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(CUI) The FAC(A) trials were flown over the China Lake range. The scenarios had the 2-ship FAC(A) aircraft coordinate with the JTAC to conduct area control of supporting CAS aircraft over permissive and contested threat environments. The FAC(A) aircraft had to accomplish several tasks: deconflict multiple CAS aircraft as they arrived and departed the target area, locate and suppress or destroy ground threats, provide target designations, and target "talk ons" to the CAS aircraft and provide Battle Damage Assessment (BDA) after the attacks. The FAC(A) targets were similar to those used in the CAS scenarios.

(CUI) The test trials completed 39 runs compared to 24 planned. As with the CAS missions, the runs were not all in paired trials, distributed among the trials according to the plan, or necessarily completed under the planned conditions. A complete list of the executed runs appears in Appendix A. F-35A and A-10C pilots attempted to use VMF to communicate with wingmen and strikers throughout the FAC(A) trials, but were successful only with aircraft of the same type. In most trials, the striker aircraft differed from the FAC(A) aircraft. Only unpaired trial F-35-1, which included F-35A FAC(A) aircraft and F-35A strikers, involved any runs with digital coordination. The test plan also included controlling rotary wing CAS aircraft, but due to high operational taskings, no attack helicopters were available during the limited A-10C testing windows, so only fixed-wing CAS platforms participated. Still, the data collected are sufficient for the conclusions in this report.

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(U) CSAR Test Conduct

(CUI) The eight CSAR test trials, planned as four matched pairs, were completed under the operational conditions shown in Table 2-7. Only four of the eight trials were completed as two matched pairs, as indicated.

| Date | Trial ¹ | | Time of Dou | Thread Calescon | Runs | | |
|----------------|--|--------|-------------|------------------|-----------|-------|--|
| | F-35A | A-10C | Time or Day | I nreat Category | F-35A | A-10C | |
| April 3, 2018 | F35-1 | S.G. C | Night | Contested | 1 | | |
| April 5, 2018 | F35-2 | A LEAK | Day | Contested | 1 | 19450 | |
| July 9, 2018 | | A10-1 | Day | Contested | 10 Steele | 1 | |
| July 10, 2018 | Ma area | A10-2 | Night | Contested | 112 | 1 | |
| March 25, 2019 | F35-P1 | A10-P1 | Day | Permissive | 1 | 1 | |
| March 27, 2019 | rch 27, 2019 F35-P2 A10-P2 Night Permise | | Permissive | 1 | 1 | | |

| (U) Table 2-7. | Combat Search and Rescue | Trials | Completed |
|----------------|--------------------------|--------|-----------|
| | CUII | | |

(CUI) Trials conducted as matched pairs include the letter P in their trial designation. Trial numbers denoted in this table are in order of execution, and as such, there is no relationship between the trial designation in this table and the trial pair number in Table 2-3.

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(CUI) The CSAR trials were flown over the China Lake range. The scenarios were designed to have a 4-ship (Sandy flight) coordinate the rescue of a downed aircrew from a preplanned response posture, i.e., notified prior to takeoff to conduct the CSAR mission vice reacting airborne from another mission to initiate the CSAR operation. Tasks included coordinating the Personnel Recovery Task Force (PRTF), escorting the personnel Recovery Vehicles (RV), locating and authenticating the downed aircrew, sanitizing the recovery area by suppressing or destroying factor ground threats, coordinating the pickup, and escorting the RVs back to a designated safe zone.

(U) Threat Representation







(U) Ordnance

(CUI) Due to range safety and airfield restrictions, no live ordnance was used on any of the trials. Inert ordnance was carried and expended on only one day of CAS comparison test trials by the F-35As and A-10Cs over the Yuma test range. All of the test trials flown on the China Lake test range were conducted with simulated weapons only. Whether inert or simulated, the weapons load for each aircraft varied with mission/target types, threat level, and aircraft tactics. Table 2-9 shows a typical loadout for each aircraft in a permissive and in a contested environment.



(U) Table 2-9. Typical Simulated Loadout

(U) Test Limitations

(CUI) The test team conducted fewer than the number of planned runs under the specified operational conditions for CAS and FAC(A) missions. However, the sample sizes available for analysis provide sufficient data to draw the conclusions in this report. The gaps do not detract from the value of the data for the measures used to compare the two aircraft.

(CUI) The test plan called for both fixed wing and rotary wing CAS aircraft to participate in the FAC(A) trials; however, rotary wing aircraft were not available due to heavy operational taskings. All FAC(A) test trials were flown controlling fixed wing CAS aircraft. This is not considered a significant shortfall in the evaluation.

(CUI) The overall environment chosen by the test team for the comparison test was a simplified representation of typical combat environments. There were no live ground forces

maneuvering or operating in conflict against each other on any mission, primarily due to range safety restrictions. The airspace management system and processes attendant to these missions, typically governed by command and control of the friendly forces supported by CAS and FAC(A) activity, were simulated. The absence of these influences does not invalidate the conclusions of this report. However, a more dynamic and representative environment for operational testing of these missions may be needed to judge improvements in performance in these or any other systems under test.

(CUI) JTAC communications did not include much-preferred digital communications capability, which drove all transmissions to and from the JTAC to voice communications. This was either a result of the JTAC's digital communications capability failing or not being available due to the method chosen to simulate the JTAC role. This limitation likely slowed down A-10C performance timelines in CAS and FAC(A) roles in comparison to the F-35A. Since the F-35A did not have a fully functional VMF digital communications capability to link with the JTAC, their performance timelines likely would have remained the same.¹² During the comparison testing, F-35A aircraft could only use VMF digital communications with other F-35A flight members.



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(U) Section Three (U) Comparative Effectiveness



(U) CAS

(CUI) The CAS engagements show some differences in effectiveness between aircraft.

(CUI) Targeting time and engagement time (defined in Table 2-3) assess how quickly CAS pilots can find and attack targets, respectively. A single run can result in multiple attacks against multiple targets. To ensure a fair comparison, analysts measured those times only for the first independent target of each run, but did not include times from additional runs that occurred during an attack. (b) (3) (A)



(b) (3) (A) The estimated median targeting and engagement times, excluding incorrectly correlated targets, appear in Figure 3-1. Confidence intervals (CIs) in Figure 3-1 and elsewhere in this report are at the 80-percent level. (b) (3) (A)





(U) Figure 3-1. CAS Median Targeting and Engagement Times







¹³ (U) Joint Publication 3-09.3, "Joint Close Air Support," June 7, 2021, page V-39. The objective of a talk-on is to correlate a specific target or target area between the JTAC/FAC(A) and the CAS aircrew to a level of fidelity such that the terminal attack controller knows the CAS asset has acquired the target.



| 1.1 | 1977 | CUI | | | |
|---------|----------------|----------------|----------------------|--------------------|--|
| A1 | Targets C | orrelated | Weapons Employe | | |
| AITCHIL | Correct | Total | Valid | Total | |
| F-35A | (h) | (2) | (Λ) | | |
| A-10C | (\mathbf{u}) | (\mathbf{J}) | (n) | | |
| | | elli | Station and Addition | Shinese from Shine | |

(U) Table 3-1. Targets Correctly Correlated and Valid Weapons Employment

(CUI) The typical loadout of the A-10C enabled more attacks than the typical loadout of the F-35A, particularly in the contested threat environment. (b) (3) (A)



increase with increasing range to the target. The test team did not record the slant range to the target with the generated coordinates, so its effect cannot be directly assessed. Even so, tactics typically caused A-10C pilots to fly closer to the target than F-35A pilots, which could explain some of the difference in the measured location errors. Target location error only affects the use of GPS-aided weapons. In any case, the location error is sufficient to cue another CAS aircraft's targeting pod.



(U)(b)(1)



numbers of more capable, modern threat systems or the addition of an air threat would likely result in the need to dedicate additional aircraft to threat suppression and destruction and counter-air roles, either pre-emptively or concurrent with CAS. Trials in such an environment could yield important lessons, but the F-35A has a clear capability advantage over the A-10C in higher threat environments – an environment where the A-10 was not designed to operate.





(U) FAC(A)

(CUI) A-10C pilots reported a significantly lower workload than F-35A pilots in the taskintensive FAC(A) mission. (b) (3) (A)





(CUI) Virtually all runs were executed with valid clearance and weapons employment, as shown in Table 12, likely due to a high degree of pilot proficiency in both aircraft for these tasks.

(U) Table 3-2. Valid Controls and Weapons Employments







(CUI) A frequent comment by both F-35A and A-10C pilots during debriefings was the synergies that would occur if A-10C Sandy-qualified formations operated with F-35A escort during contested CSAR missions. This would combine the strengths of both platforms while mitigating their limitations to improve the likelihood of mission success.

(U) Human Factors Assessment

(CUI)(b) (3) (A)

b) (3) (A) Usability and workload survey results are shown in Figure 7. Pilots reported workload on the seven-point Air Force Flight Test Center Revised Workload Estimate Scale. The test team measured system usability on the System Usability Scale (SUS) using a modified version of the UMUX-Lite questionnaire and the UMUX-Liter regression equation to predict SUS scores. (b) (3) (A)





CUI (U) Figure 3-7. Pilot Workload and System Usability

(U) Time-On-Station - All Missions

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(CUI) Time-on-station can be a key contributor to the overall success of each of these mission areas. (b) (3) (A)





CUI (U) Figure 3-8. Estimated Maximum Sortie Duration¹⁴



(U) Section Four (U) Recommendations

(U) The F-35 JPO in concert with the U.S. Air Force should consider the following recommendations to improve the F-35A effectiveness in the CAS. FAC(A) and CSAR missions:

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(U) Appendix A (U) Planned and Executed Runs

(U) Table A-1. Planned CAS Trials and Runs

CUI Ground Threat Spectrum arget Category Altitude Ceiling Target Environment **Type Control** Time of Day Control Interaction **Trial Pair** Formation Target Movemen Night Permissive Vehicle Voice 2 Rural 2 Moving Unlimited Night Permissive Building Voice 1 Urban 1 Stationary Unlimited 1 Night Permissive Vehicle 3 Voice Rural 1 Stationary Unlimited Night Permissive 2 Building Voice Urban 2 Stationary Unlimited Day Contested Vehicle 1 Digital Rural 2 Moving Unlimited 2 Contested Day Vehicle 3 Digital Rural 2 Stationary Unlimited Day Contested 2 Personnel Digital Urban 2 Stationary Unlimited Day Permissive Vehicle 2 Voice Rural 2 Stationary Unlimited Day Permissive Building Voice 1 Urban 2 Stationary Unlimited 3 Day Permissive Personnel 3 Voice Urban 1 Stationary Unlimited Day Permissive Building Voice Rural 2 1 Stationary Unlimited Night Contested 2 Building Digital Urban 2 Stationary Unlimited 4 Night Contested 2 Vehicle Digital Urban 2 Stationary Unlimited Night Contested Vehicle Digital Rural 2 2 Stationary Unlimited Night Permissive Building Digital Urban 2 2 Stationary Unlimited Night Permissive Vehicle 2 2 Digital Urban Stationary Unlimited 5 Night 2 Permissive Building 2 Digital Rural Stationary Unlimited Night Permissive Vehicle Digital Rural 2 2 Stationary Unlimited Day 2 Permissive Vehicle Digital Rural 1 Moving Limited Day Permissive Vehicle Digital 3 2 Urban Moving Limited 6 Day Permissive Personnel Digital 1 2 Rural Stationary Limited Day Permissive Building Digital Urban 2 1 Stationary Limited

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A-1 SECRET

| (U) Table A-2. | Executed CAS | Trials | and | Runs |
|----------------|---------------------|--------|-----|------|
|----------------|---------------------|--------|-----|------|

| Trial | Time of Day | Ground Threat Spectrum | Tarryet Category | Control Interaction | Target Environment | Type Control | Formation | Target Novement | Atttude Ceiling |
|-------|-------------|------------------------------|---------------------|------------------------|-----------------------|--------------|-----------|--------------------|--------------------|
| | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| - | Day | Permissive | Vehicle | Voice | Urban | 1 | 2 | Stationary | Unlimited |
| 5 | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| < | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| - | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| 5 | Day | Permissive | Vehicle | Voice | Rural | 1 | 2 | Moving | Limited |
| ŭ | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Limited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| Ŧ | Day | Permissive | Vehicle | Voice | Urban | 1 | 2 | Moving | Limited |
| 0 | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Limited |
| × | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Limited |
| · | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Limited |
| | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 2 | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 10-P | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| × | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| N | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 35-P | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| Щ | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 2 | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| A10 | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |

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A-2 SECRET

| | · | | | | | | | | |
|--------|-------|------------|---------|-------|-------|---|---|------------|-----------|
| | Day | Permissive | Vehicle | Voice | Rurai | 2 | 2 | Moving | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rurai | 3 | 2 | Stationary | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 3 | 2 | Moving | Unlimited |
| З., | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| ا م | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| F35 | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 1.6 | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| 11 | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Permissive | Vehicle | Voice | Rurat | 2 | 2 | Stationary | Unlimited |
| 5 | Night | Contested | Vehicle | Voice | Rurai | 2 | 2 | Stationary | Unlimited |
| A10 | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Contested | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |

(CUI) Cockpit video recordings did not include the on-station period, preventing collection of quantitative mission performance data.

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(U) Table A-3. Planned FAC(A) Trials and Runs CUI

| Trial | Time of Day | Ground Threat Spectrum | Control Interaction | CAS Aircraft Type |
|-------|-------------|---------------------------|------------------------|----------------------|
| | Day | Contested | Voice | Fixed Wing |
| 1 | Day | Contested | Digital | Rotary Wing |
| | Day | Contested | Digital | Rotary Wing |
| | Night | light Contested | | Fixed Wing |
| = 2 | Night | Contested | Digital | Fixed Wing |
| | Night | Contested | Voice | Rotary Wing |
| | Day | Permissive | Voice | Rotary Wing |
| 3 | Day | Permissive | Digital | Fixed Wing |
| £ | Day | Permissive | Voice | Fixed Wing |
| | Night | Permissive | Voice | Rotary Wing |
| 4 | Night | Permissive | Digital | Rotary Wing |
| | Night | Permissive | Digital | Fixed Wing |

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A-3 SECRET

| | 1 | | | | | | | | |
|--------|-------------|---------------------------|--------------------|------------------------|-----------------------|--------------|-----------|--------------------|------------------|
| Trial | Time of Day | Ground Threat Spectrum | Target Category | Control Interaction | Tanget Environment | Type Control | Formation | Target Movement | Attitude Celling |
| | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| ÷. | Day | Permissive | Vehicle | Voice | Urban | 1 | 2 | Stationary | Unlimited |
| 5 | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| × | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| 5 | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| 35-Р | Day | Permissive | Vehicle | Voice | Rural | 1 | 2 | Moving | Unlimited |
| Ë | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| T | Day | Permissive | Vehicle | Voice | Urban | 1 | 2 | Moving | Unlimited |
| 10-P | Day | Permissive | Vehicle | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| × | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Permissive | Building | Voice | Urban | 2 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 2 | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 10-P | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| Ä | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 2 | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 35-P | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| Ш Ш | Day | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Day | Contested | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| 5 | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| A1(| Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |

(U) Table A-4. Executed FAC(A) Trials and Runs

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A-4 SECRET

| | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
|---------|-------|------------|---------|-------|-------|---|---|------------|-----------|
| | Day | Permissive | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 3 | 2 | Moving | Unlimited |
| | Day | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| ĥ | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| F35 | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Permissive | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| БЧ Г | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| A10 | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Moving | Unlimited |
| | Night | Contested | Vehicle | Voice | Rural | 2 | 2 | Stationary | Unlimited |
| | Night | Contested | Vehicle | Voice | Rural | 3 | 2 | Stationary | Unlimited |

(CUI) Cockpit video recordings did not include the on-station period, preventing collection of quantitative mission performance data.

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(U) Appendix B (U) Pilot Demographics

(U) Figure B-1. Comparison Test Pilot Experience and Qualifications

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