UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION
BOARD REPORT

F-22A, T/N 06-4109

422ND TEST AND EVALUATION SQUADRON

53RD WING
EGLIN AIR FORCE BASE, FLORIDA

LOCATION: NELLIS AIR FORCE BASE, NEVADA

DATE OF ACCIDENT: 30 OCTOBER 2020

BOARD PRESIDENT: Colonel Richard B. Foster

Conducted IAW Air Force Instruction 51-307

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR COMBAT COMMAND
JOINT BASE LANGLEY-EUSTIS VA

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30 JUN 2021

ACTION OF THE CONVENING AUTHORITY

The report of the accident investigation board conducted under the provisions of Air Force Instruction 51-307, *Aerospace and Ground Accident Investigations*, that investigated the 30 October 2020 mishap involving an F-22A, T/N 06-4109, assigned to the 422nd Test and Evaluation Squadron, complies with applicable regulatory and statutory guidance, and on that basis it is approved.

CHRISTOPHER P. WEGGEMAN
Lieutenant General, USAF
Deputy Commander

EXECUTIVE SUMMARY

F-22A, T/N 06-4109
NELLIS AIR FORCE BASE, NEVADA
30 OCTOBER 2020

On 30 October 2020, at approximately 0930 local time, the Mishap Aircraft (MA), an F-22A, tail number (T/N) 06-4109, experienced an overheat condition in the Auxiliary Power Unit (APU) exhaust bay. The MA was assigned to the 422d Test and Evaluation Squadron, Nellis Air Force Base (AFB), Nevada (NV), 53d Wing, headquartered at Eglin AFB, Florida. The MA was maintained by the 757th Aircraft Maintenance Squadron, 57th Wing, Nellis AFB, NV. The estimated cost to replace damaged parts and repair the MA is $2,690,000.

On 26 June 2020, the MA began an extensive modification to prepare for operational test missions. On 28 October 2020, to facilitate troubleshooting of the MA modification, the APU Mixing Exhaust Duct (AMED) was removed, during which time applicable Circuit Breakers (CB) were not pulled and collared, and warnings were not applied to the MA's structure or the MA digital forms in accordance with Technical Order guidance by Maintenance Member (MXM) 1. Further, these errors were not corrected by MXM2, the on-scene 7-Level supervisor who verified the work of MXM1. On 30 October 2020, the MA required defueling and reconfiguration of the aircraft doors via Aerospace Ground Equipment (AGE), but a decision was made to use the APU instead. On the day of the mishap, the APU Emergency-Off Switch (AES) was incorrectly set to "Normal" by an unknown person. During pre-procedural checks, MXM3 failed to recognize during his review of the MA forms and via visual inspection that AMED installation was required before APU operations. After start of the APU, smoke began emanating from the APU exhaust bay and into the left main landing gear wheel well. MXM3 delayed emergency APU shutdown in order to review the digital forms for fault reporting codes (errors). A maintenance member in the vicinity approached the MA and set the AES to "Emergency Off," shutting down the APU manually.

The Accident Investigation Board President (BP) found by a preponderance of the evidence that the cause of the mishap was improper maintenance procedures resulting in the start of the APU while the AMED was removed. The BP also found by the preponderance of the evidence four additional factors that substantially contributed to the mishap: (1) the culture of the mishap unit, including limited use of CB collars and inconsistent use of warnings; (2) the design of test instrumentation on the MA which obscured access to applicable CBs; (3) the extensive nature of the MA's modification; and (4) the distractions caused by several non-standard events scheduled on the day of the mishap.

"Under 10 U.S.C. § 2254(d) the opinion of the accident investigator as to the cause of, or the factors contributing to, the accident set forth in the accident investigation report, if any, may not be considered as evidence in any civil or criminal proceeding arising from the accident, nor may such information be considered an admission of liability by the United States or by any person referred to in those conclusions or statements."

SUMMARY OF FACTS AND STATEMENT OF OPINION
F-22A, T/N 06-4109
NELLIS AIR FORCE BASE, NEVADA
30 OCTOBER 2020

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ACRONYMS AND ABBREVIATIONS

3-Level	3-Skill Level
422 TES	422nd Test and Evaluation Squadron
5-Level	5-Skill Level
53 WG	53rd Wing
57 WG	57th Wing
7-Level	7-Skill Level
757 AMXS	757th Aircraft Maintenance Squadron
A&P	Airframe and Powerplant
A1C	Airman First Class
AAR	Air to Air Fuel
ACC	Air Combat Command
AES	APU Emergency-Off Switch
AFB	Air Force Base
AFI	Air Force Instruction
AFGM	Air Force Guidance Memorandum
AFSC	Air Force Specialty Code
AFTO	Air Force Technical Order
AGE	Aerospace Ground Equipment
AIB	Accident Investigation Board
AMED	APU Mixing Exhaust Duct
AMU	Aircraft Maintenance Unit
APG	All Purpose General
APGS	Auxiliary Power Generating System
APU	Auxiliary Power Unit
BP	Board President
BRU	Bomber Release Unit
CAF	Combat Air Forces
Capt	Captain
CB	Circuit Breaker
Col	Colonel
COSO	Combat Oriented Supply Operations
CRL	Configurable Rail Launcher
CTG	Coating
DC	Direct Current
DCC	Dedicated Crew Chief
DoD	Department of Defense
DV	Distinguished Visitor
ECS	Environmental Control System
EMER OFF	Emergency Off
FI	Fault Isolation
FL	Florida
FLCS	Flight Control System
FRC	Fault Reporting Code
FSR	Field Service Representative
FTD	Field Training Detachment
HFACS	Human Factors Analysis and Classification System
HOT	Hands-On-Training
HQ	Headquarters
IAW	In Accordance With
IMDS	Integrated Maintenance Database System
IMIS	Integrated Maintenance Information System
ITP	Individual Training Plan
JCN	Job Control Number
L	Local Time
LAU	Launcher Unit
LEF	Leading Edge Flap
LO	Low Observable
MA	Mishap Aircraft
MICAP	Mission Impaired Capability Awaiting Parts
Mids	Midnight/Mid-Shift
MIPS	Modular Instrumentation Power Supply
MLG	Main Landing Gear
MOD	Modification
MSgt	Master Sergeant
MX	Maintenance
MXM	Maintenance Member
MWR	Morale, Welfare, and Recreation
NORM	Normal
NV	Nevada
PAO	Polyalphaolefin
PDC #4	Power Distribution Center 4
PMP	Planned Maintenance Package
Pro-Super/Pro-Sup	Production Supervisor
PSI	Pounds per Square Inch
PMA	Portable Maintenance Aid
SECDEF	Secretary of Defense
SES	Stored Energy System
SIB	Safety Investigation Board
SrA	Senior Airman

SSgt	Staff Sergeant	TSgt	Technical Sergeant
Super	Supervisor	QA	Quality Assurance
TBA	Training Business Area	USAF	United States Air Force
TCTO	Time Compliance Technical Order	USAFWC	United States Air Force Warfare Center
Thrm Barr	Thermal Barrier		
T/N	Tail Number	WCE	Work Center Event
TO	Technical Order		

The above list was compiled from the Summary of Facts, the Statement of Opinion, the Index of Tabs, and Witness Testimony (Tab V).

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 2 March 2021, Lieutenant General Christopher P. Weggeman, Deputy Commander, Air Combat Command (ACC), appointed Colonel Richard B. Foster to conduct an Accident Investigation of a mishap that occurred on 30 October 2020, involving an F-22A, Tail Number (T/N) 06-4109, at Nellis Air Force Base (AFB), Nevada (NV) (Tabs Y-5 to Y-6 and CC-13). On 9 March 2021, the Accident Investigation Board (AIB) convened at Nellis AFB, and concluded on 12 April 2021. A legal advisor (Captain), pilot member (Captain), maintenance member (Master Sergeant) and recorder (Master Sergeant) were also appointed to the Board (Tab Y-5).

b. Purpose

In accordance with (IAW) Air Force Instruction (AFI) 51-307_AFGM2020-01, *Aerospace and Ground Accident Investigations*, dated 26 February 2020, this AIB conducted a legal investigation to inquire into all the facts and circumstances surrounding this United States Air Force (USAF) aerospace accident, prepare a publicly releasable report, and obtain and preserve all available evidence for use in litigation, claims, disciplinary action, and adverse administrative action.

2. ACCIDENT SUMMARY

On 30 October 2020, at approximately 0930 local time (L), the Mishap Aircraft (MA), an F-22A, T/N 06-4109, experienced an overheat condition in the Auxiliary Power Unit (APU) exhaust bay (Tabs A-8, J-4 and R-27). The MA was assigned to the 422d Test and Evaluation Squadron (422 TES), Nellis AFB, NV, 53d Wing (53 WG), headquartered at Eglin AFB, Florida (FL), and maintained by the 757th Aircraft Maintenance Squadron (757 AMXS), 57th Wing (57 WG), Nellis AFB, NV (Tabs A-8, D-3, CC-7 to CC-8, and EE-4). The estimated cost to replace damaged parts and repair the MA is $2,690,000 (Tab J-3).

3. BACKGROUND

a. Air Combat Command

ACC, headquartered at Joint Base Langley-Eustis, Virginia, is one of ten major commands in the USAF (Tab CC-3). ACC is the primary provider of air combat forces to America's warfighting commanders and is the direct successor to Tactical Air Command (Tab CC-3). As the Combat Air Forces (CAF) lead agent, ACC develops strategy, doctrine, concepts, tactics, and procedures for air-, space-, and cyber-power employment (Tab CC-3). The command provides conventional and information warfare forces to all combatant commands to ensure air, space, cyber, and information superiority for warfighters and national decision-makers (Tab CC-3).

b. United States Air Force Warfare Center

The USAF Warfare Center (USAFWC) is the world's premier proving ground for air, space and cyberspace lethality (Tab CC-4). Its mission is to develop Airmen and advance warfighter capabilities through testing, training and tactics development to dominate the multi-domain fight (Tab CC-4). The USAFWC vision, mission, and priorities are central to supporting ACC's mission to provide dominant combat airpower for America with warrior Airmen committed to excellence, trained to fly, fight, and win anytime, anyplace (Tab CC-4).

c. 53rd Wing

The 53 WG, headquartered at Eglin AFB, FL, serves as the focal point for the CAF in electronic warfare, armament and avionics, chemical defense, reconnaissance and aircrew training devices (Tab CC-5). The wing is responsible for operational testing and evaluation of new equipment and systems proposed for use by these forces (Tab CC-5). Current wing initiatives include advanced self-protection systems for combat aircraft, aircrew life support systems, aerial reconnaissance improvements, new armament and weapons delivery systems, and improved maintenance equipment and logistics support (Tab CC-5).

d. 422nd Test and Evaluation Squadron

The 422 TES at Nellis AFB, NV, is a composite squadron executing headquarters ACC-directed operational test and evaluation for A-10, F-15C, F-15E, F-16C, and F-22A hardware, software, and weapons upgrades to maximize combat capabilities prior to CAF release (Tab CC-6). The squadron also conducts tactics development, foreign materiel exploitation and special access programs. (Tab CC-6).

e. 57th Wing

The 57 WG, as the most diverse wing in the USAF, provides advanced, realistic, and multi-domain training focused on ensuring dominance through air, space, and cyberspace (Tab CC-7). The 57 WG builds innovative leaders in tactics, training and high-end warfighting to ensure world-wide combat air forces are prepared for tomorrow's victories, while overseeing dynamic and challenging flight operations at Nellis AFB, NV (Tab CC-7). The 57 WG includes the USAF Weapons School, 57th Maintenance Group, 57th Operations Group, USAF Thunderbirds Aerial Demonstration Squadron, and the USAF Advanced Maintenance and Munitions Officer School (Tab CC-7).

f. 757th Aircraft Maintenance Squadron

The 757 AMXS accomplishes intermediate-level maintenance on aircraft and support equipment components, maintaining avionics, laser guided weapons systems, pneudraulics, fuel systems, engines, measurement/diagnostic equipment, electro-environmental and egress systems (Tab CC-8). Squadron Aircraft Maintenance Units (AMU) are Eagle (F-15C/D), Strike (F-15E), and Raptor (F-22) (Tab CC-8).

g. Raptor Aircraft Maintenance Unit

The Raptor AMU supports flying operations for the United States Air Force Weapon School and Test and Evaluation missions (Tabs CC-9 to CC-10, CC-12, and EE-4). The Raptor AMU is comprised of F-22 aircraft (Tabs CC-10, CC-12, and EE-7).

h. F-22 Raptor

The F-22 Raptor is a single seat, multi-role, air dominance fighter (Tab CC-12). Its combination of stealth, supercruise, maneuverability, and integrated avionics represents an exponential leap in warfighting capabilities (Tab CC-11). The Raptor performs both air-to-air and air-to-ground missions allowing it to project air dominance and defeat threats attempting to deny access to our nation's Air Force, Army, Navy, and Marine Corps (Tab CC-11). The sophisticated F-22 aerodesign, advanced flight controls, thrust vectoring, and high thrust-to-weight ratio provide the capability to outmaneuver all current and projected aircraft (Tab CC-12).

i. Maintenance Skill Levels

AFI 36-2101, *Classifying Military Personnel (Officer and Enlisted),* dated 25 June 2013, defines the skill levels (Tab BB-14 to BB-15). The 3-skill level (3-Level), or apprentice, identifies enlisted personnel who have obtained basic knowledge within an Air Force Specialty Code (AFSC) through completion of an initial skills course (Tab BB-15). Apprentices gain duty position experience and, upon completion, enter a structured apprenticeship program to gain qualification and experience required of a 5-skill level (5-Level), or journeyman (BB-15). The 5-skill level identifies enlisted personnel who, through experience and training, have demonstrated skilled proficiency in their AFSC BB-15). The 7-skill level (7-Level), or craftsman, identifies enlisted personnel who have gained a high degree of technical knowledge in their AFSC and who have additionally acquired supervisory capability through training and experience (Tab BB-15).

4. SEQUENCE OF EVENTS

a. Mission

Not applicable.

b. Planning

Not applicable.

c. Preflight

Not applicable.

d. Summary of Accident

The MA's last flight was on 26 June 2020, after which it began an extensive hardware and software modification in preparation for a new operational test mission (Tabs U-22 to U-46 and EE-3 to EE-5). After an extensive teardown and rebuild process, a disparate maintenance team consisting of Raptor AMU, Instrumentation, and Lockheed Martin subcontractors, began the final stages of the modification process (Tabs U-29 to U-30, V-14.22, V-16.17, and EE-3 to EE-5). On 26 October 2020, to enable troubleshooting, the MA's APU Mixing Exhaust Duct (AMED) was removed and replaced to allow for access and repair to wiring and components in its corresponding compartment (Tabs U-15, U-17, EE-3 and EE-5). On 28 October 2020 at 0620L, the AMED was again removed, but not replaced (Tabs U-18 to U-21, EE-3, and EE-5).

According to Technical Order (TO) guidance, to accomplish AMED removal Maintenance Members (MXMs) are required to set the APU Emergency Switch (AES) to "Emergency Off" (EMER OFF), as well as pull and collar APU circuit breakers (CB) (Tab BB-65). Setting the AES to EMER OFF prevents the APU from starting (Tab V-3.7). Pulling the APU CBs also prevents the APU from starting (Tabs V-3.10 and EE-5). CB collars, by their design, prevent inadvertent physically resetting of a CB and visually communicate the CB's status through an orange "REMOVE BEFORE FLIGHT" streamer, as seen in Figure 16 (Tab Z-16 and EE-5). MXM1 performed the AMED removal, set the AES to EMER OFF and pulled the applicable CBs prior to removal of the AMED; however, he did not install CB collars (Tab V-1.10). MXM1 documented the completion of these tasks in Integrated Maintenance Information System (IMIS) (Tabs U-18 to U-19, EE-3, and EE-5). MXM2, a 7-Level, inspected MXM1's work (Tabs U-18 to U-19, V-2.4, BB-15, EE-3 and EE-5). MXM2 confirmed CBs were out (pulled) however CB collars were confirmed as not installed (Tabs V-2.16, V-2.19, V-2.36, V-2.44, and EE-7 to EE-8). MXM2 did not recall if the AES was set to EMER OFF at the time of the task (Tab V-2.38). The next night, MXM2 returned to the MA and verified the AES was set to EMER OFF (Tab V-2.38 to V-2.39)

According to TO 00-20-1, *Aerospace Equipment Maintenance, Inspection, Documentation, Policies and Procedures*, whenever a discrepancy is of a nature that operation of an affected system could be hazardous or result in aircraft damage or injury to personnel, a warning should be included following the notation of the discrepancy (Tab BB-48). On 28 October 2020, when documenting the maintenance performed, MXM1 did not generate digital warning flags in the IMIS forms, and he did not remember applying physical warning tags (Tabs U-20, V-1.16, EE-3 and EE-7 to

EE-8). During task validation, MXM2 did not ensure that digital or physical warnings were applied to the Work Center Event (WCE) that MXM1 generated when documenting the maintenance in IMIS (Tabs U-20, V-2.37, EE-3, and EE-7 to EE-8).

Between 28 October 2020, 0620L, and the mishap on 30 October 2020, 0300L, the maintenance crew performed several maintenance actions unrelated to the mishap (Tabs U-22 to U-46, EE-3 and EE-5). These actions included test instrumentation reinstallation in the right side weapons bay, Stores Management System maintenance in the left side weapons bay, and removal of a panel above the right engine intake (Tabs U-22 to U-46, EE-3 and EE-5).

On 30 October 2020 at 0330L, the MA was towed from Hangar 285 to the low observable (LO) hangar (Tab V-11.20 and V-13.4). After the tow, the MXM11 executed his normal check around the MA, including his typical assessment of ensuring the AES was set to the EMER OFF position (Tab V-11.14 to V-11.15). Additionally, his check included ensuring the "Top 3" are open (Tab V-11.14 to V-11.15). The Top 3 are the gun door, air refueling doors, and APU doors (Tab V-9.16 and V-11.14). Testimony from MXM11 indicated nothing was abnormal during this check (Tab V-11.15). After the MA was towed into the LO hangar, the midnight shift (mid-shift) Production Supervisor (Pro Super) determined that the MA still needed to be defueled and that the MA doors required reconfiguration (Tabs V-14.34, V-14.38, EE-5 and EE-7). The mid-shift Pro Super directed MXM14, a Flightline Expeditor, to tow the MA and perform these tasks (Tabs V-14.2 to V-14.3, V-14.34, EE-5 and EE-7).

Later that day, Raptor AMU executed a planned "Training Day" that included a morale event, an aircraft demonstration, and a flight-line visit by a distinguished visitor (DV) (Tabs V-10.13 to V-10.14, V-10.69, V-11.5, V-14.11, and EE-7). This was described as a "fun day" by MXM10 and a "no-fly day" by MXM14 (Tab V-10.13 and V-14.10). MXM14 referred to the aircraft demonstration as "a distraction," but claimed they (the maintainers) "didn't have much else going on" (Tab V-14.11). MXM14 also claimed, "It was on everybody's mind that they want to come down and see the aircraft" (Tab V-14-11).

On this day during roll call, there were no assignments issued (Tab V-14.10). After roll call, MXM14 directed MXM10 to get a crew together to tow the MA out of the LO hangar to Row 16, supervise the defuel and reconfiguration of the "louvers" (engine bypass doors) (Tabs V-14.11 to V-14.12, V-14.36 and EE-6 to EE-7). He also coordinated for Aerospace Ground Equipment (AGE) to be brought down to the flightline, 0.7 miles away from the parking area near the aircraft demonstration (Tabs V-14.11 to V-14.12, V-14.36, Z-25, EE-6 to EE-7). According to MXM14, he specifically told them (the crew), "AGE will be on the spot" (Tab V-14.10 to V-14.11). MXM14 directed MXM10 to complete these tasks because MXM10 had been to the expeditor course and "could handle stuff down at Row 16 while [he] was at our ramp" (Tab V-14.11).

MXM10, however, testified that MXM14 did not say anything about defueling the MA, only to supervise the tow (MXM10 did admit his attention was divided by the events of the day and a DV visit, with whom he was scheduled for a meet and greet) (Tab V-10.56 to V-10.57, V-10.69, V-10.71, and V-10.79). Prior to the tow, MXM10 reviewed the MA forms and then supervised the MA tow (Tab V-10.14 and V-10.28 to V-10.29). During this time period, MXM10 and MXM12 had a disagreement as to the preferred way to defuel the MA, including MXM10's statement, "It

doesn't matter. Just as long as the fuel gets out of the jet safely" (Tab V-10.38 to V-10.40). MXM10 was not certain whether MXM3 was present for this discussion, but claimed he did not direct MXM3 to use the APU to defuel (Tab V-10.44 and V-10.109). MXM3, however, stated that he was directed by MXM10 to use the APU, which, according to MXM10, is a faster and easier method to defuel (Tab V-3.19 and V-10.45). MXM8, who was present at the time, testified that MXM10 told MXM3 to fire APU, open the bypass doors, and then defuel the aircraft (Tabs R-93, EE-5, and EE-7).

Thereafter, MXM10 left the area to see the aircraft demonstration, which drew a crowd of about 100 people (Tab V-10.103 and V-14.12). MXM12 also left and returned to the Raptor AMU area (Tabs V-12.34 and EE-7). With AGE available in the immediate area, MXM3 reviewed the MA forms, checked the MA CBs, and observed the AES was set to "Normal" (NORM) (Tabs V-3.30, V-3.39 to V-3.40, V-10.32 and EE-6). During MXM3's forms review, he did not recognize that the AMED required installation (Tabs V-3.35 to V-3.36 and EE-8). According to MXM3, this was because there were no warnings applied in the IMIS forms (Tab V-3.35 to V-3.36).

When asked whether he looked at the APU inlet/exhaust prior to starting the APU, MXM3 responded, "I believe it was MXM7… I had him look at it" (Tabs V-3.16, V-3.21, BB-63, and EE-7). TO guidance requires maintainers to visually inspect APU inlet and exhaust bay for foreign objects and remove debris if present, a task that requires a B-4 stand (Tab BB-63). On the day of the mishap, MXM7 provided written testimony stating that he inspected the APU exhaust and inlet and that it was clear (Tab R-151). MXM7, a 3-Level, was not qualified to perform this procedural task (Tabs BB-63, DD-158, EE-3, and EE-8). On 16 March 2021, MXM7 provided verbal testimony to the AIB, stating, "[He] was visually looking at the… vent where the fog gases come out… those were clear" (Tabs V-7.1, V-7.24 and EE-8). What MXM7 described in this statement was an area different than the APU exhaust areas (Tab EE-8). MXM7 did not recall if there was a B-4 stand available to inspect the bay as seen in Figure 13 (Tabs V-7.18 and Z-13). MXM3 then started the APU (Tab V-3.10). Upon starting the APU without the AMED installed, the hot exhaust gases from the APU entered the APU exhaust bay instead of being diverted out of the aircraft (Tab EE-3)

Figure 1: Flightline Map (Tabs Z-25 and EE-6)

After MXM3 started the APU, smoke began to fill the wheel well (Tab V-8.14). MXM3 then began reviewing Fault Reporting Codes (FRC) in IMIS to assess what was wrong (Tab V-8.14). MXM4, a 5-Level in the vicinity, approached the MA and set the AES to EMER OFF to manually shut down the APU (Tabs R-66, V-4.3 and V-8.6). The APU shut down, and the MA was subsequently impounded (Tab EE-5).

e. Impact

Not applicable.

f. Egress and Aircrew Flight Mishap Overview

Not applicable.

g. Search and Rescue

Not applicable.

h. Recovery of Remains

Not applicable.

5. MAINTENANCE

a. Forms Documentation

The F-22A features a digital form documentation process located in IMIS (Tabs BB-74 and EE-3). Data in IMIS is input directly onto a Portable Maintenance Aids (PMA), a laptop used by personnel who utilize an aircraft forms drive as they perform each task (Tabs BB-74 and EE-6). The Integrated Maintenance Database System (IMDS) is an additional management information system used by the USAF, which contains F-22A data transferred from IMIS (Tab BB-46). A comprehensive review on the MA's IMIS and IMDS records showed that the MA's AMED was not installed on the day of the mishap (Tabs U-20 and EE-3).

The AIB also reviewed the status of all Time Compliance Technical Orders (TCTO) and noted no discrepancies (Tabs D-12 to D-14 and EE-4). The AIB learned that the MA was in the process of an extensive modification (Tabs U-29 to U-30, V-14.22, and EE-5). The AIB ascertained that the IMIS and IMDS records contained 231 additional WCE including 51 Red X events (Tabs U-22 to U-46 and EE-3). When a maintainer writes up a WCE on a "Red X" for the removal of a part, it remains open until the part is removed (Tab EE-5). At that point, they sign off the removal Red X and IMIS automatically prompts the maintainer to generate a second Red X documenting the required installation of the same part (Tab EE-7). A Red X entry on an aircraft form indicates the most serious possible condition: that the aerospace vehicle is unsafe, unserviceable, or non-airworthy (Tab BB-47).

On the day of the mishap, there were two warnings open to prevent maintenance crews from towing or applying electrical power (Tabs V-3.14 and EE-3). These warnings were verified as forms errors by MXM3 after coordination with an expeditor (Tabs V-3.14 and EE-3). These warnings would be the first thing to populate on the screen when MXM3 opened the PMA (Tabs V-3.19 and EE-3).

The MA's AMED removal was documented as a Red X, but it did not have warnings appended that would populate on the opening screen (Tabs U-20 and EE-3). TO guidance states, "[w]henever an original discrepancy is of a nature that operation of the affected system could be hazardous or result in further damage or injury to personnel, include a warning note written or underlined in red following the original discrepancy statement" (Tab BB-48). The AMED install was also documented on a Red X with the narrative "APU MIXING DUCT REQS INSTALL" (Tabs U-20, EE-3, and EE-8). Additionally, the IMIS forms did not have APU CB positions documented on independent WCEs as per standard practice (Tabs U-42 to U-43, EE-3 and EE-7).

The AIB reviewed all F-22A IMIS records at Nellis AFB covering a period of 12 months prior to the mishap and analyzed trends on AMED documentation (Tabs U-3 and EE-3). This review indicated that during that period, the AMU performed 22 AMED removals (Tabs U-3 and EE-3). Of those removals, only 36.4% had the required warnings attached to the installation WCEs (Tabs U-3 and EE-3). Of the same 22 removals, only 54.5% were documented with CBs on individual WCEs (Tabs U-3 and EE-3). Further, a review of the MA IMIS forms revealed that of five occasions when the AMED was removed, warnings were documented zero times, and CBs were only documented once (Tabs U-3 and EE-3 to EE-4). In the MA's IMIS forms, the AMED

removal on 26 October 2020, prior to the 28 October 2020 removal, also lacked warnings (Tabs U-3 and EE-4).

b. Inspections

The MA last flew on 26 June 2020 (Tabs U-22 and EE-4). On 25 June 2020, a preflight inspection occurred one day prior to that flight (Tabs U-4 and EE-4). On 26 June 2020, a basic post operation inspection occurred after that flight (Tabs U-11 and EE-4). Several scheduled inspections occurred between then and the mishap date (Tabs U-5 to U-10, EE-3 and EE-5). These included configurable rail launcher, egress final, main gun, ammunition container, gun port, and bomb release unit inspections (Tabs U-5 to U-10, EE-3 and EE-5). There is no indication that any of these inspections were related to the mishap (Tabs U-5 to U-10, EE-3 and EE-5).

c. Maintenance Procedures

The AIB reviewed all maintenance procedures conducted on the MA (Tabs D-4115 to D-4138, U-4 to U-46 and EE-3). The AIB determined the MA's preflight servicing was unrelated to the mishap (Tab EE-4).

TO Procedural Task A498113A100300, *Remove APU Mixing Exhaust Duct*, directs maintainers to set the AES to EMER OFF before an AMED is removed (Tab BB-65). The AES was set to NORM at the time of APU start (Tab V-3.39 to V-3.40).

TO Procedural Task A498113A100300, *Remove APU Mixing Exhaust Duct,* directs maintainers to pull and collar three circuit breakers on power distribution center #4 (Tab BB-65). MXM1 did not install CB collars on the associated CBs prior to AMED removal (Tab V-1.10). These CBs were not pulled at the time of the APU start (Tab EE-5).

TO 00-20-1 states that whenever an original discrepancy is of a nature that operation of the affected system could be hazardous or result in further damage or injury to personnel, include a warning note written or underlined in red following the original discrepancy statement (Tab BB-48). MXM1 also did not document any warnings in IMIS or recall appending any physical warning tags to the MA (Tabs U-20, V-1.16, EE-3, and EE-7 to EE-8).

It is the responsibility of a 7-Level to verify the forms documentation of the job as well as inspect the job to ensure compliance with all applicable TOs (Tab EE-5). MXM2 confirmed the associated CBs were pulled and AES was set to EMER OFF (Tab V-2.19 and V-2.38 to V-2.39). MXM2 did not ensure compliance with use of CB collars or physical and digital warnings before signing off the Red X for AMED removal (Tabs U-20, V-2.8, V-2.16, V-2.19, V-2.36, and EE-7 to EE-8).

Although louvers can be reconfigured by using AGE or APU, TO guidance dictates maintainers use AGE. (Tabs V-11.35 to V-11.36 and EE-5). There exists, however, a known workaround procedure (a way to "trick the system") that involves the use of the APU to reconfigure the louvers (Tabs V-11.35 to V-11.36 and EE-5). This workaround is not approved in any TO (Tabs V-11.35 to V-11.36 and EE-6). Using the APU to both defuel and reconfigure the louvers was described as much easier (Tab V-10.100 to V-10.101) On 30 October 2020, MXM3 used the APU to attempt

defuel of the MA instead of AGE (Tab V-3.10 and V-3.22). A defuel procedure can be accomplished with either AGE or APU (Tab V-10.15).

TO Procedural Task A002000006001, *Verify Aircraft Safe for Maintenance,* requires maintainers to review updated electronic forms using the PMA, noting aircraft configuration and status (Tab BB-68). MXM3 did not accomplish a complete forms review and stated he only reviewed parent Job Control Numbers (JCN) and warnings (Tabs BB-68, V-3.14 to V-3.16, EE-6 and EE-8). Maintainers are required to investigate each Red X in the forms related to any maintenance or operations they plan to perform (Tab EE-6). Maintainers must assess each open JCN and WCE listed in the forms to accomplish a complete forms review prior to any proposed maintenance action (Tab EE-6).

TO Procedural Task A490001013012, *FI APU Inlet/Exhaust Door (Visual Inspection),* directs maintainers to visually inspect APU inlet and exhaust bay for foreign objects and remove debris if present and requires a B-4 stand (Tab BB-63). On the day of the mishap, MXM3 did not use a B-4 stand to visually inspect the APU inlet and exhaust bay for foreign objects (Tabs EE-6 to EE-7 and V-3.17).

The AES serves as a manual method of shutting down the APU, and maintainers should use this switch in the event of an APU emergency (Tab EE-5). When the smoke began pouring into the wheel well, MXM3 did not immediately shut down the APU, but instead reviewed the FRCs (V-8.14).

d. Maintenance Personnel and Supervision

A thorough review of maintenance personnel, supervision, and training records relevant to the mishap validated that all but one AMU maintainer who performed any servicing or inspections on the MA were fully trained and qualified (Tabs G-3 to G-103, DD-143 to DD-165, and EE-4).

Information below is current as of the day of the mishap:

(1) MXM1: 5-Level F-22A Crew Chief (Tab V-1.2 to V-1.3)

Time in service: approximately four years (Tab V-1.2)
Time at Nellis AFB: approximately three years (Tab V-1.2)
Part in mishap: Removed AMED on 28 October 2020 (Tabs U-19 and EE-5)
Training status: Fully qualified on all tasks performed (Tabs DD-34 to DD-57 and EE-4)

(2) MXM2: 7-Level F-22A Crew Chief (Tab V-2.2 to V-2.3)

Time in service: nine years and three months (Tab V-2.2)
Time at Nellis AFB: approximately two years (Tab V-2.2)
Part in mishap: Signed off MXM1's AMED removal Red X, responsible for verifying forms documentation and ensuring compliance IAW TO guidance (Tabs U-19 and EE-5)
Training status: Fully qualified on all tasks performed (Tabs DD-60 to DD-86 and EE-4)

(3) MXM3: 5-Level F-22A Crew Chief (Tab V-3.2 and V-3.5)

Time in service: approximately three years (Tab V-3.2)
Time at Nellis AFB: approximately 2 and one half years (Tab V-3.2)
Part in mishap: Started APU on 30 October 2020, and delegated the task of APU inlet/exhaust inspection to MXM7 (Tabs V-3.10 and EE-4)
Training status: Fully qualified on all tasks performed (Tabs DD-87 to DD-111 and EE-4)

(4) MXM7: 3-Level F-22A Crew Chief (Tab V-7.2 to V-7.3)

Time in service: 14 months (Tab V-7.2)
Time at Nellis AFB: 7 months (Tab V-7.2)
Part in mishap: Inspected APU inlet and exhaust (Tab EE-4)
Training status: Not qualified on Individual Training Plan item "*Operate APU from PMA*" (Tabs DD-143 to DD-165 and EE-4)

(5) MXM10: 7-Level F-22A Crew Chief (V-10.2 and V-10.8)

Time in service: 12 years (Tab V-10.2)
Time at Nellis AFB: 7.5 years (Tab V-10.2)
Part in mishap: Directed MXM3 to use APU for defuel (Tabs R-93 and V-3.10 to V-3.11)
Training status: Not applicable

(6) MXM14: Flightline Expeditor (Tab V-14.2)

Time in service: 14 years (Tab V-14.2)
Time at Nellis AFB: approximately 4 years (Tab V-14.2)
Part in mishap: Directed MXM10 to use AGE to defuel MA (Tab V-14.11)
Training status: Not applicable

The AIB determined that at the time of the mishap, there was no one formally assigned to provide oversight of the MA and its forms beyond standard production personnel (Tabs V-19.10 and EE-4).

e. Fuel, Hydraulic, Oil, and Oxygen Inspection Analyses

The six liquid samples taken from the MA or associated servicing carts were not submitted to the Air Force Research Laboratory for analysis, as there was no evidence to suggest that there was contamination necessitating the need for testing (Tab EE-5).

f. Unscheduled Maintenance

A thorough review of maintenance records, including unscheduled maintenance performed on the MA, was performed by the AIB (Tabs D-3843 to D-4075 and EE-3). The MA was undergoing extensive maintenance for a modification in the weeks leading up to the mishap (Tabs D-3843 to D-4075, U-22 to U-46 and EE-3 to EE-4). On 26 October 2020, the MA was towed into the hangar for troubleshooting of a wiring issue (Tab V-11.17). On this same day, the AMED removal was

completed to allow access to the APU firewall shutoff valve and wiring associated with troubleshooting (Tabs U-12, U-18, U-19, U-23, U-24, EE-3 and EE-5).

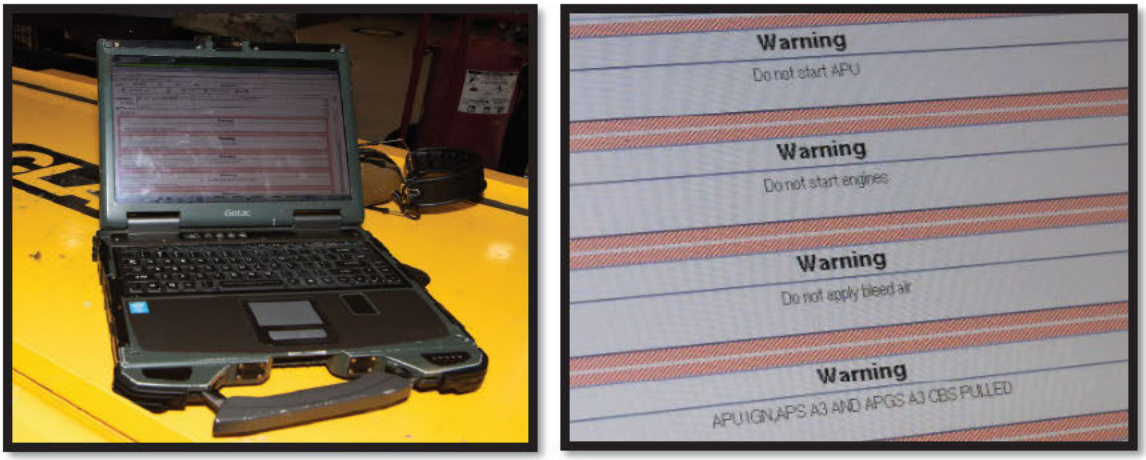
On 30 October 2020, in the midst of ongoing troubleshooting actions, the MA was towed to the LO hangar (Tabs V-11.20 and EE-5). After being towed to the LO hangar, the MA was towed back out to be defueled to avert thermal venting of fuel (Tab V-11.10 to V-11.11, and V-14.10). The MA also required reconfiguration of engine bypass louvers (Tabs V-14.10 to V-14.11 and EE-7).

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS

a. Structures and Systems

(1) Portable Maintenance Aid

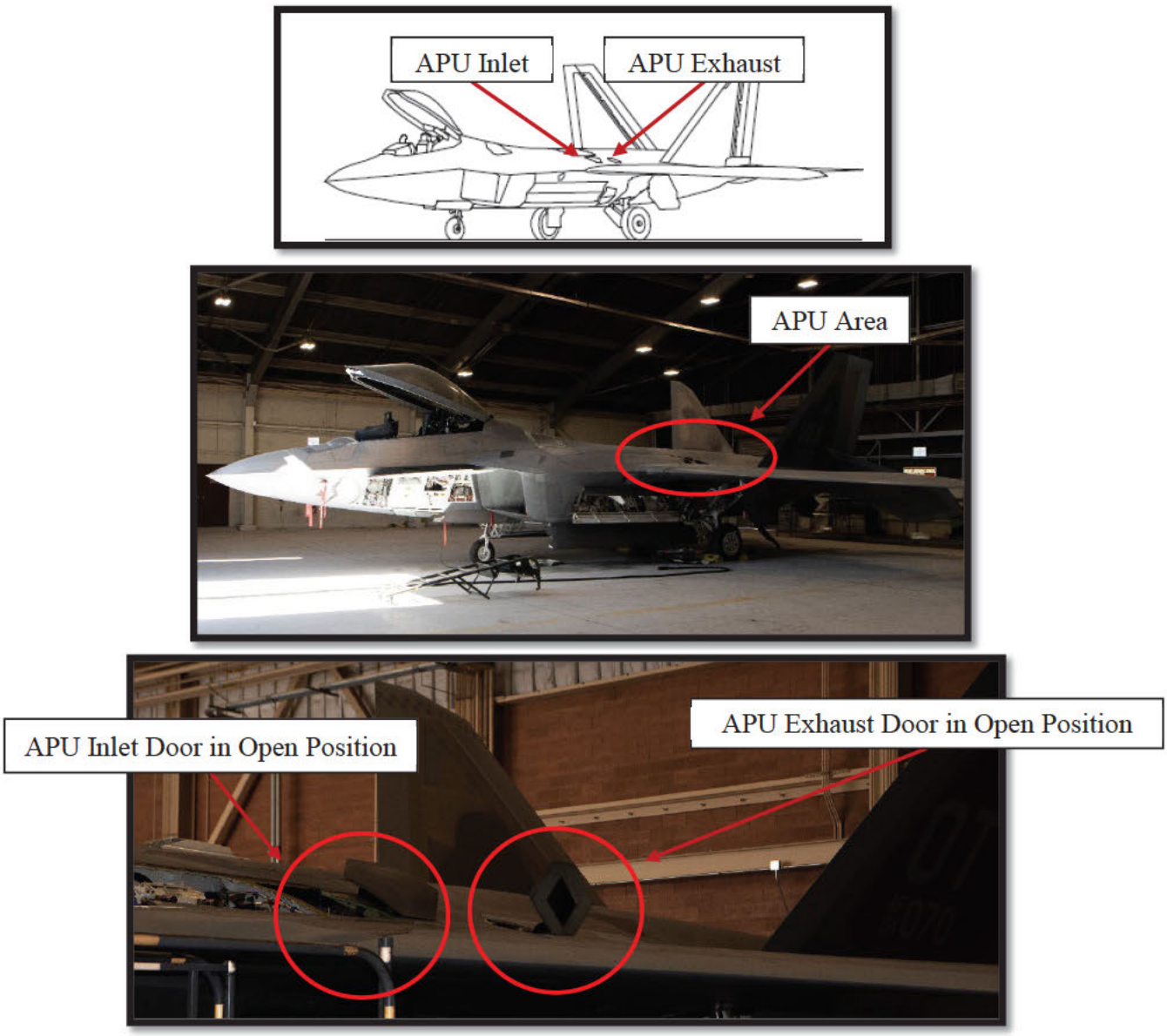
The PMA is a rugged laptop computer that replaces the traditional paper TOs and allows maintainers to navigate via links to other TOs referred to in the current procedure and parts information for the F-22A (Tab BB-74). A PMA has the ability to command certain systems on the aircraft (Tab EE-6). A PMA utilizes IMIS, where the user can view aircraft forms, warnings, JCNs, and WCEs (Tabs BB-46 and EE-6).



Figures 2-3: PMA and Digital Warnings that Populate on Screen When Opened (Tab Z-3 to Z-4)

(2) Auxiliary Power Unit

The APU itself is a jet engine capable of providing the entire aircraft with limited electrical and hydraulic power for maintenance operations on the ground (Tabs V-10.9 to V-10.10, V-10.12, and EE-6).



Figures 4-6: Aircraft Diagram, F-22A Left Side View, APU Doors (Tabs Z-5 to Z-6, BB-70, and EE-6)

(3) Auxiliary Power Unit Exhaust Bay

The APU Exhaust Bay houses the APU and associated components, as seen in Figure 7 (Tab EE-6). The MA sustained damages to airframe, systems, wiring, hydraulics and surrounding structure and components of the APU exhaust bay from an overheat event (Tab J-6). Temperatures within the exhaust bay reached 600-700 degrees Fahrenheit for less than 10 minutes (Tab J-6). This bay was in serviceable condition prior to the mishap with no documented damage in its last post-flight inspection (Tabs U-11, EE-3 and EE-6).

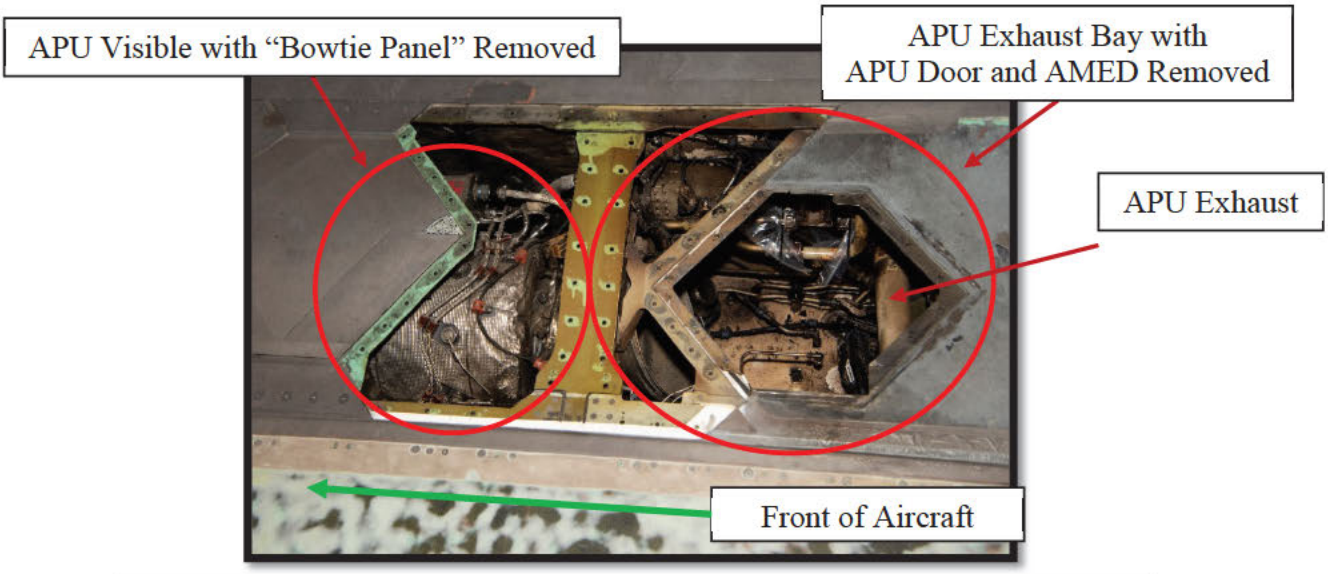


Figure 7: APU Exhaust Bay, Bowtie Panel, and AMED (Tabs Z-7 and EE-6)

(4) Auxiliary Power Unit Exhaust Mixing Duct

The AMED provides the final stage of exhausting the combusted by-product of the APU (Tab BB-57). The duct is made of Inconel, a material capable of withstanding temperatures of up to 1800 degrees Fahrenheit (Tab BB-57 and BB-75). One end of the duct is coupled to the APU secondary exhaust duct (Tab BB-57). The other end of the duct mounts to aircraft structure under the APU exhaust outlet door (Tab BB-57).

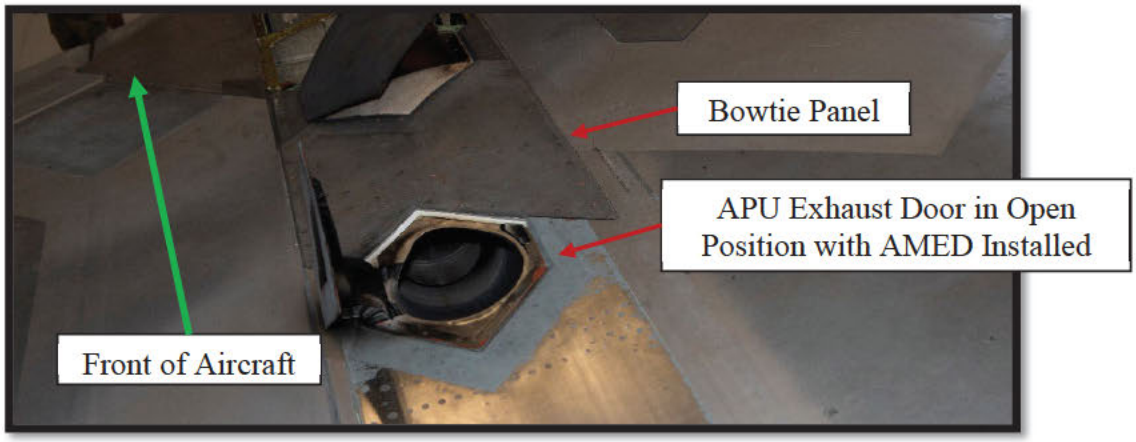
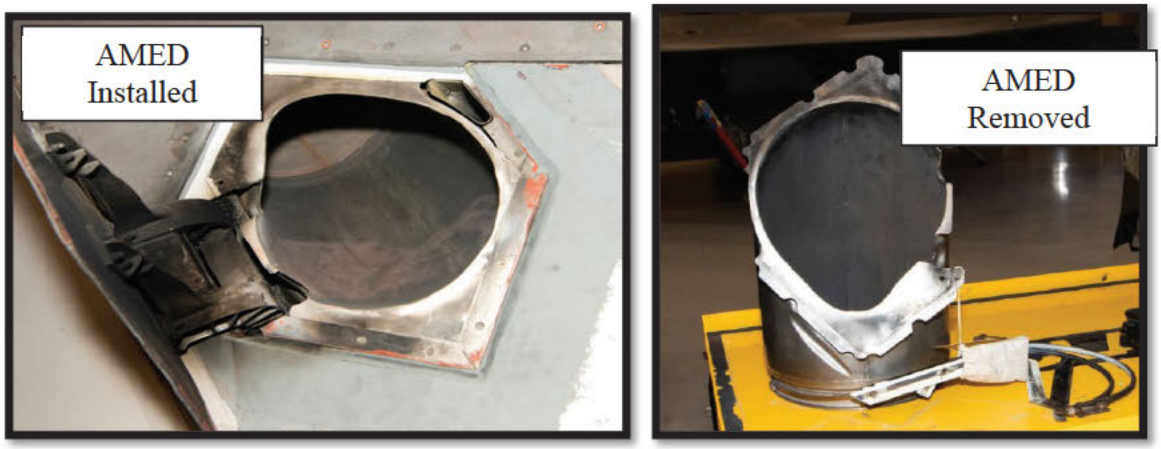


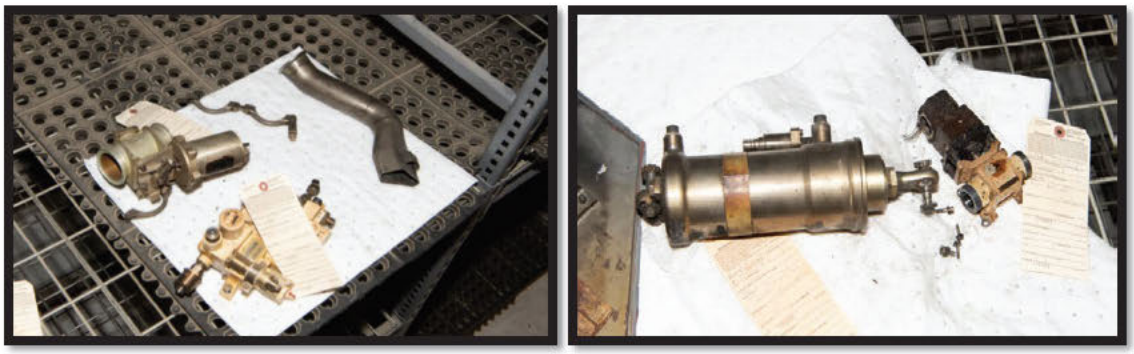
Figure 8: APU Exhaust Bay, Bowtie Panel, and AMED (Tabs Z-8 and EE-6)



Figures 9-10: AMED Installed and Removed (Tabs Z-9 to Z-10 and EE-6)

(5) Parts Damaged By Overheat Condition

The following parts required replacement due to overheat: firewall shutoff valve, Auxiliary Power Generating System (APGS) valve assembly, APU inlet/exhaust door actuator, and APU surge control valve (Tab J-7).



Figures 11-12: Damaged APU Exhaust Bay Components (Tab Z-11 to Z-12)

(6) B-4 Maintenance Stand

The B-4 maintenance stand is required by TO guidance to inspect the APU inlet and exhaust bays (Tab BB-63).

Figure 13: B-4 Maintenance Stand (Tab Z-13)

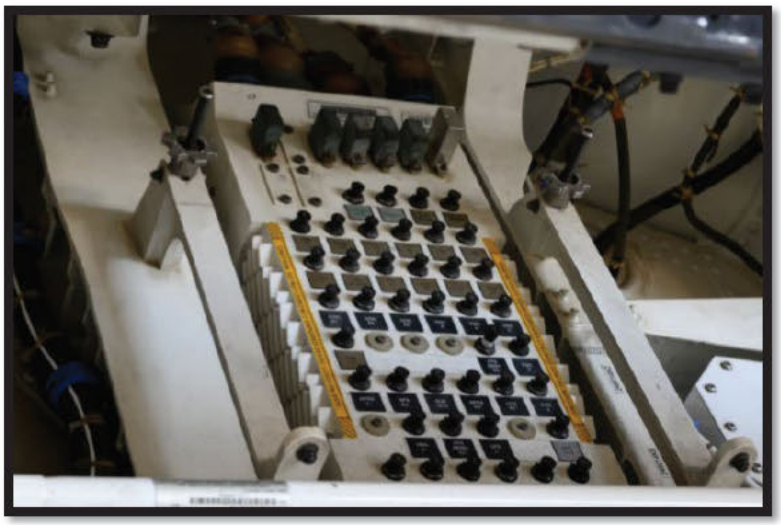
(7) Right Side Weapons Bay

The right side weapons bay houses Power Distribution Center #4 (PDC #4) (Tab EE-6).

Figure 14: Right Side Weapons Bay (Tab Z-14)

(8) Power Distribution Center #4 and Circuit Breaker Collars

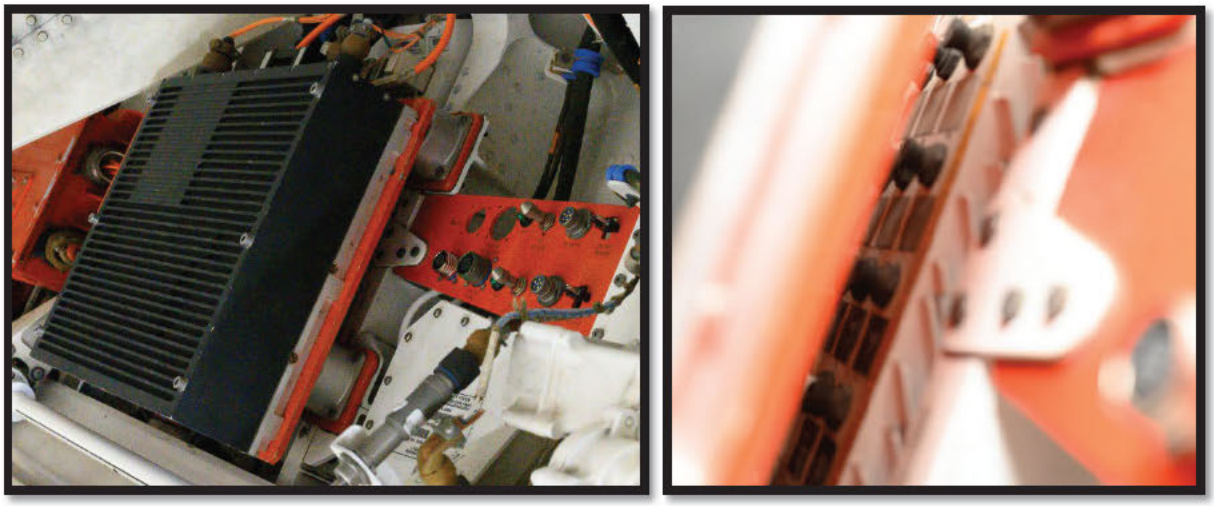
PDC #4 houses the CBs associated with the AMED (Tab BB-65). CB collars would be used in this area, and usually include a large orange "REMOVE BEFORE FLIGHT" streamer, as seen in Figure 16 (Tabs Z-16, BB-65, and EE-5). CB collars are small plastic "C-shaped" clips that snap around a CB when pulled out as seen in Figure 16 (Tabs Z-16 and EE-5). CB collars are required IAW TO guidance and prevent CBs from being inadvertently reset, or "pushed in" (Tabs EE-5, EE-7 and BB-65).



Figures 15-16: PDC #4, Circuit Breaker Collars (Tab Z-15 to Z-16)

(9) Instrumentation Test Equipment

The Instrumentation Test Equipment refers to specialized equipment utilized on the MA (Tabs Z-17 to Z-18, and EE-6). The Instrumentation Test Equipment power supply is located on top of PDC #4 and obstructs its access (Tabs V-15.13, V-16.3 and 16.4, Z-17 to Z-18, and EE-6). The clearance between the PDC #4 and the power supply is approximately one inch (Tabs Z-17 to Z-18, V-15.13, V-16.3, and EE-6). In order to confirm the position of CBs, to change their configuration (to "push in" or "pull out"), or to install CB collars, maintainers must contort around much of the airframe structure and use a combination of flashlights, mirrors, and other tools to complete these challenging tasks (Tabs V-15.13 to V-15.14, V-10.20 to V-10.21 and EE-6). Installing CB collars is particularly challenging (Tabs V-15.13 to V-15.14 and EE-6). According to MXM15, a Quality Assurance (QA) Inspector, it is very difficult to install CB collars on PDC #4, and characterized it as "not normal" to use CB collars there (Tabs V-15.13 to V-15.14, and EE-6). In reference to that location, he said, "The collars are brutal" (Tabs V-15.13 to V-15.14 and EE-6).



Figures 17-18: Test Instrumentation Installed Over PDC #4 (Tab Z-17 to Z-18)

(10) Auxiliary Power Unit Emergency-Off Switch

The left Main Landing Gear (MLG) wheel well houses the AES as seen in Figures 21 and 22 (Tabs Z-20 and EE-5). The AES provides maintainers the means of shutting off the APU in emergencies, as seen in Figures 21 and 22 (Tabs Z-20 and EE-5).

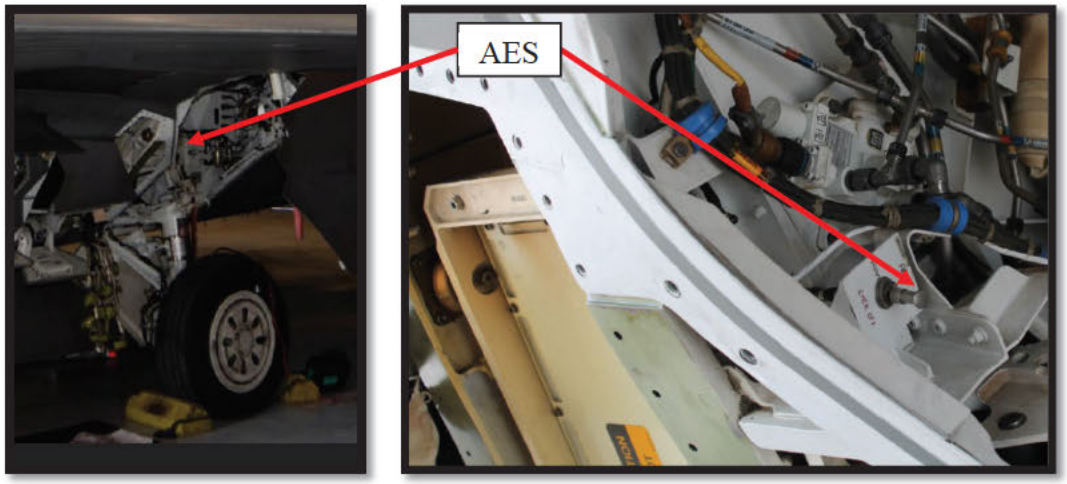
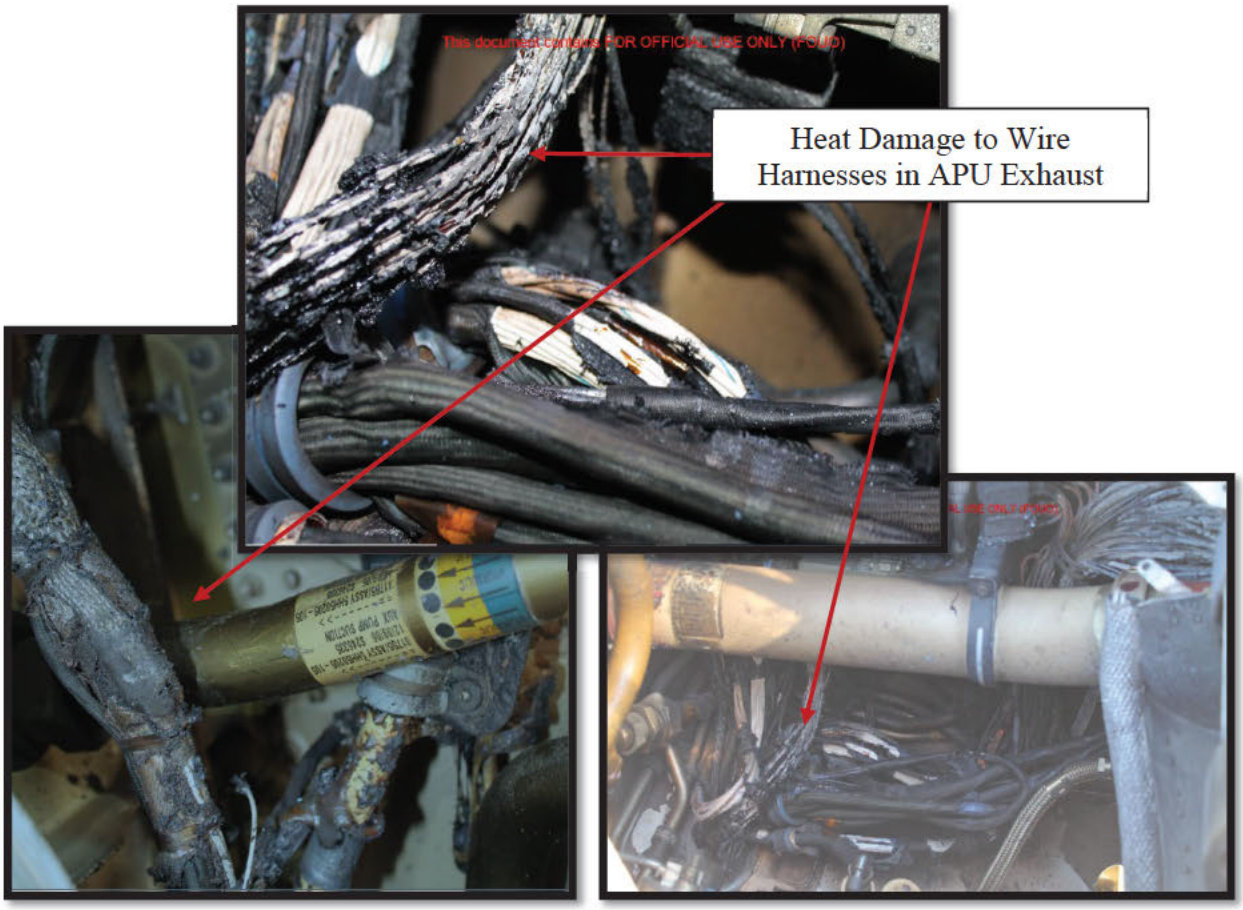


Figure 19-20: Left Main Gear Well and APU Emergency Switch (Tabs Z-19 to Z-20 and EE-5)

Figure 21: APU Emergency Switch (Tab Z-

b. Evaluation and Analysis

The firewall shutoff valve, APGS valve assembly, APU inlet/exhaust door actuator, and APU surge control valve were all contained in the APU exhaust bay (Tab J-7). These parts along with 47 wire harnesses and miscellaneous aluminum brackets in the bay needed replacement (Tab J-7 and J-8).



Figures 22-24: Components Damaged in APU Exhaust Bay (Tabs Z-22 to Z-24 and EE-6)

7. WEATHER

a. Forecast Weather

The forecast weather at Nellis AFB for the day of the mishap called for variable winds at six knots with skies clear and no visibility restrictions (Tab W-3 and W-6).

b. Observed Weather

The weather observation at Nellis AFB at the time of the mishap reported no wind, unrestricted visibility, a clear sky, and a temperature of 59 degrees Fahrenheit (Tab W-3 to W-4).

c. Space Weather

Not applicable.

d. Operations

There is no evidence to suggest that the MA was operated outside prescribed operational limits with respect to weather conditions (Tabs W-3 to W-6 and EE-8).

8. CREW QUALIFICATIONS

Not applicable.

9. MEDICAL

a. Qualifications

There is no evidence to suggest that any MXM directly involved with the MA had any reason to be medically disqualified for duty on the day of the mishap (Tabs R-83 to R-88, R-101-R-110, R-111 to R-116, and R-141 to R-146 and DD-3 to DD-33).

b. Health

There is no evidence to suggest that any MXM directly involved with the MA had any health issues relevant to the mishap (Tabs R-83 to R-88, R-101-R-110, R-111 to R-116, and R-141 to R-146 and DD-3 to DD-33).

c. Pathology

The Defense Health Agency performed a Forensic Toxicology Examination on the blood and urine of the MXMs directly involved with the MA on the day of the mishap for the indications of drug abuse, ethanol, and carbon monoxide; none were detected (Tabs R-83 to R-88, R-101-R-110, R-111 to R-116, and R-141 to R-146 and DD-3 to DD-9).

d. Lifestyle

There is no evidence to suggest that lifestyle factors were a factor in the mishap (Tabs R-83 to R-88, R-101-R-110, R-111 to R-116, and R-141 to R-146 DD-10 to DD-33).

e. Crew Rest and Crew Duty Time

There is no evidence to suggest that work-rest cycles were relevant to the mishap (Tabs R-50 to R-61, R-68 to R-73, R-83 to R-88, R-100 to R-116, R-129 to R-134, R-141 to R-146, and DD-12 to DD-21).

10. OPERATIONS AND SUPERVISION

a. Operations

Coronavirus disease 2019 operational precautions, such as segmented 50/50 “black” and “gold” split shifts, were in effect (Tab V-10.62). In the month leading up to the mishap, the operations tempo was described as normal (Tab V-3.6). The day of the mishap was a no-fly day (Tab V-14.10). There is no evidence to suggest that operations tempo and operations issues were a factor to the mishap (Tab V-3.6, V-10.62 and V-14.10).

b. Supervision

Not applicable.

11. HUMAN FACTORS ANALYSIS

a. Introduction

The AIB assessed Human Factors relevant to the mishap IAW Department of Defense (DoD) Human Factors Analysis and Classification System (HFACS), Version 7.0 (Tab BB-16). The HFACS model presents a systematic, multidimensional approach to error analysis and mishap prevention and provides a template that organizes the human factors identified in the investigation (BB-16 to BB-36). Ten human factors were relevant to the mishap:

b. Human Factor 1: AE102 (Checklist Error)

AE102 Checklist Not Followed Correctly is a factor when the individual, either through an act of commission or omission, makes a checklist error or fails to run an appropriate checklist (Tab BB-20).

c. Human Factor 2: PP108 (Communication Error)

PP108 Failed to Effectively Communicate is a factor when communication is not understood or is misinterpreted as the result of behavior of either sender or receiver (Tab BB-29). Communication failed to include backing up, supportive feedback or acknowledgement to ensure that personnel correctly understood announcements or directives (Tab BB-29).

TO guidance says to review updated electronic forms using PMA, noting aircraft configuration and status (BB-68). MXM3 completed a “quick” five to ten minute review of the forms prior to initiating the remainder of the APU start procedure (Tab V-3.30 to V-3.31). Further testimony from MXM8 indicated that MXM3 reviewed the forms for “about a minute, or a little over a minute” (Tab V-8.24). Forms review for an F-22A with the MA’s status (having been grounded for several months for various maintenance actions and the corresponding 231 WCEs and 51 Red X items) would take approximately 15-30 minutes (Tabs U-22 to U-46, V-2.62, V-14.45, V-15.36 and EE-3). IMIS shows that MXM1 annotated the AMED’s removal under the WCE “APU MIXING DUCT REQS INSTALL” (Tabs U-20 to U-21, EE-3 and EE-8). MXM3 failed to review this item, instead keying in on the top-level JCN (Tabs V-3.14, EE-6, and EE-8).

d. Human Factor 3: AE103 (Procedure Error)

AE103 Procedure Not Followed Correctly is a factor when a procedure is performed incorrectly or accomplished in the wrong sequence (Tab BB-20).

e. Human Factor 4: AE206 (Wrong Action)

AE206 Wrong Choice of Action During an Operation is a factor when the individual, through faulty logic or erroneous expectations, selects the wrong course of action (Tab BB-21).

f. Human Factor 5: AV002 (Widespread Violations)

AV002 Commits Widespread/Routine Violation is a factor when a procedure or policy violation is systemic in a unit/setting and not based on a risk assessment for a specific situation (Tab BB-22). It needlessly commits the individual, team, or crew to an unsafe course of action (Tab BB-22). These violations may have leadership sanction and may not routinely result in disciplinary/administrative action (Tab BB-22). Habitual violations of a single individual or small group of individuals within a unit can constitute a routine/widespread violation if the violation was not routinely disciplined or was condoned by supervisors (Tab BB-22).

g. Human Factor 6: SV001 (Failure to Enforce)

SV001 Failure to Enforce Existing Rules (supervisory act of omission) is a factor when unit (organizational) and operating rules have not been enforced by a supervisor (Tab BB-30).

h. Human Factor 7: OC001 (Organizational Culture)

OC001 Organizational Culture (attitudes/actions) Allows for Unsafe Task/Mission is a factor when explicit/implicit actions, statements, or attitudes of unit leadership set unit/organizational values (culture) that allow an environment where unsafe task/mission demands or pressures exist. (Tab BB-36).

Standard maintenance guidance mandates that whenever an original discrepancy is of a nature that operation of the affected system could be hazardous or result in further damage or injury to personnel, include a warning note written or underlined in red following the original discrepancy statement (Tab BB-48). During the course of the investigation, 13 of 13 (100%) MXMs reported they should apply digital warnings, 3 of 13 MXMs (23.1%) indicated they would not use physical warning tags, and 2 of 11 (18.2%) reported they themselves would use CB collars. However, 7 of 8 reported a widespread lack of CB collar use in Raptor AMU (Tabs V-1.10, V-1.16, V-1.18, V-2.16, V-2.37, V-3.12, V-3.24, V-4.9, V-5.7, V-5.12 to V-5.13, V-6.6 to V-6.7, V-6.16, V-7.6, V-7.11, V-7.32, V-8.12, V-9.8, V-9.22, V-12.34 to V-12.35, V-13.13 to V-13.14, V-14.28 to V-14.30, V-14.42, V-15.11, V-15.6, and EE-3 to EE-4). MXM2 likewise affirmed there was a lack of CB collar use at Raptor AMU and stated, “we don’t use them here” (Tab V-2.16). MXM8 testified he did not know what CB collars were (Tab V-8.12).

i. Human Factor Set 8: PC106 (Distraction)

PC106 Distraction is a factor when the individual has an interruption of attention and/or inappropriate redirection of attention by an environmental cue or mental process goals (Tab BB-28).

j. Human Factor 9: PP101 (Failure of Team Leadership)

PP101 Failure of Crew/Team Leadership is a factor when the crew/team leadership techniques failed to facilitate a proper crew/team climate, to include establishing and maintaining an accurate and shared understanding of the evolving task and plan on the part of all crew/team members (Tab BB-29).

TO guidance requires maintainers to visually inspect APU inlet and exhaust bay for foreign objects and remove debris if present, a task that requires a B-4 stand (Tab BB-63). On the day of the mishap, MXM3 was obligated to perform this task prior to starting the APU (Tab BB-63). MXM3, as a 5-Level, was fully qualified to perform this task (Tabs V-3.2 and DD-103). Rather than complete this task himself, he "had [MXM7] look at it" (Tabs V-3.16, V-3.21, and EE-7). MXM7, a 3-Level, was not yet qualified to perform this task IAW TO guidance (Tab V-7.2 and DD 158). On the day of the mishap, MXM7 stated that he inspected the APU exhaust and inlet and that it was clear (Tab R-151). According to MXM7, he inspected the "vent where the fog gases come out" (Tabs V-7.1, V-7.24 and EE-7). The area he described as being clear was not the area specified in the applicable TO (Tab EE-6). Based on MXM7's statement, and believing the APU exhaust area to be clear, MXM3 started the APU (Tab V-3.10).

k. Human Factor 10: OP007 (Purchasing Poorly Designed Equipment)

OP007 Purchasing or Providing Poorly Designed or Unsuitable Equipment is a factor when the processes through which aircraft, vehicle, equipment or logistical support are acquired allows inadequacies or when design deficiencies allow inadequacies in the acquisition (Tab BB-35).

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Publically Available Directives and Publications Relevant to the Mishap

(1) AFI 21-101, *Aircraft and Equipment Maintenance Management*, dated 16 January 2020
(2) AFI 36-2101, *Classifying Military Personnel (Officer and Enlisted),* dated 25 June 2013

NOTICE: All directives and publications listed above are available digitally on the Air Force Departmental Publishing Office website at: https://www.e-publishing.af.mil or the Official Department of Defense Website: http://www.dtic.mil/whs/directives/index.html.

b. Other Directives and Publications Relevant to the Mishap

(1) DoD Human Factors Analysis and Classification System (HFACS) Version 7.0
(2) TO 00-20-1, *Aerospace Equipment Maintenance Inspection, Documentation, Policies, and Procedures,* dated 1 June 2018

(3) TO 00-20-1, *Aerospace Equipment Maintenance Inspection, Documentation, Policies, and Procedures, 57 MXG Supplement,* dated 24 January 2018
(4) F-22A IMIS TO Procedural Tasks (TOD Version 091.01.00 (current as of 30 October 2020):
    (a) A490000103001-008*, Auxiliary Power Generating System*
    (b) A121010610001*, Defuel Aircraft*
    (c) A490001013009*, FI APU 1st Stage Turbine Over-Temp/Thrm Barr CTG Loss*
    (d) A490001013012*, FI APU Inlet/Exhaust Door Visual Inspection*
    (e) A498113A1003001*, Remove APU Mixing Exhaust Duct*
    (f) A002000006001*, Verify Aircraft Safe for Maintenance*
(5) TO 1F-22A-1, *F-22A Raptor* (current as of 24 November 2020)
(6) TO 1F-22A-2-00GV-00-1, G*eneral Vehicle Description* (current as of 20 July 2020)
(7) Inconel Material Data Sheet

c. Known or Suspected Deviations from Directives or Publications

The AIB identified the following known or suspected deviations from directives or publications:

TO Procedural Task A498113A1003001, *Remove APU Mixing Exhaust Duct*, step one, says to position APU switch on APU emergency shutdown panel to EMER OFF (Tab BB-65). The AES was set to NORM at an unknown time by an unknown person without the AMED being reinstalled (Tab V-3.39 to V-3.40).

TO Procedural Task A498113A1003001, *Remove APU Mixing Exhaust Duct,* step two, says to pull and collar CBs on PDC #4 (Tab BB-65). On 28 October 2020, CB collars were not installed on the aforementioned CBs (Tabs V-1.10, V-2.36 and EE-7 to EE-8).

TO 00-20-1, *Aerospace Equipment Maintenance Inspection, Documentation, Policies, and Procedures*, says that whenever an original discrepancy is of a nature that operation of the affected system could be hazardous or result in further damage or injury to personnel, include a warning note written or underlined in red following the original discrepancy statement (Tab BB-48). Digital warnings were not documented in the IMIS forms (Tabs U-20 to U-21, EE-3, and EE-5).

TO 00-20-1, *Aerospace Equipment Maintenance Inspection, Documentation, Policies, and Procedures*, says the Air Force Technical Order (AFTO) Form 492, Maintenance (MX) Warning Tag, shall be used during maintenance actions, as required by Major Design Series specific technical data and/or local procedures (Tab BB-48). The warning tag is a communication device used to prevent the inadvertent activation, movement or configuration change of a system, flight control, stored energy, etc. that will cause injury to personnel and/or damage to equipment (Tab BB-48). Physical warning tags were not applied to the aircraft (Tabs V-1.16, V-2.37, and EE-7 to EE-8).

TO Procedural Task A002000006001*, Verify Aircraft Safe for Maintenance*, step two, says to review updated electronic forms using PMA, noting aircraft configuration and status (BB-68). The APU MIXING DUCT REQS INSTALL WCE was not noted prior to starting APU (Tabs U-20 to U-21, V-3.14, EE-3, and EE-8).

TO Procedural Task A490001013012, *FI APU Inlet/Exhaust Door (Visual Inspection)* says to visually inspect APU inlet and exhaust bay for foreign objects and debris if present (Tab BB-63). This procedural task also says a B-4 stand is required support equipment (Tab BB-63). APU inlet and exhaust bays were not visually inspected with a B-4 stand before APU start (Tabs V-3.16 to V-3.17 and EE-6).

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29 June 2021

RICHARD B. FOSTER, Colonel, USAF
President, Accident Investigation Board

STATEMENT OF OPINION

F-22A, T/N 06-4109
NELLIS AIR FORCE BASE, NEVADA
30 OCTOBER 2020

Under 10 U.S.C. § 2254(d) the opinion of the accident investigator as to the cause of, or the factors contributing to, the accident set forth in the accident investigation report, if any, may not be considered as evidence in any civil or criminal proceeding arising from the accident, nor may such information be considered an admission of liability of the United States or by any person referred to in those conclusions or statements.

1. OPINION SUMMARY

On 30 October 2020, at approximately 0930 local time (L), the Mishap Aircraft (MA), an F-22A, tail number (T/N) 06-4109, experienced an overheat condition in the Auxiliary Power Unit (APU) exhaust bay. The MA was assigned to the 422d Test and Evaluation Squadron, Nellis Air Force Base (AFB), Nevada (NV), 53d Wing, headquartered at Eglin AFB, Florida. The MA was maintained by the 757th Aircraft Maintenance Squadron, 57th Wing, Nellis AFB, NV. The estimated cost to replace damaged parts and repair the MA is $2,690,000.

I find by a preponderance of the evidence that the cause of the mishap was improper maintenance procedures resulting in the start of the APU while the APU Mixing Exhaust Duct (AMED) was removed. I also find by the preponderance of the evidence four additional factors that substantially contributed to the mishap: (1) the culture of the mishap unit, including limited use of circuit breakers (CB) collars and inconsistent use of warnings; (2) the design of test instrumentation on the MA which obscured access to applicable CBs; (3) the extensive nature of the MA's modification; and (4) the distractions caused by several non-standard events scheduled on the day of the mishap.

I developed my opinion by carefully considering the standard of proof for a preponderance of evidence. I analyzed the damage summary, available maintenance records, medical records, photographs, technical and engineering reports, training records, weather records, witness testimony, Air Force Technical Orders (TO), regulations, and guidance.

2. CAUSES

I find by a preponderance of the evidence, the cause of the mishap was improper maintenance procedures resulting in the start of the APU while the AMED was removed.

At the time of the mishap, the APU Emergency-Off Switch (AES) was incorrectly set to "Normal" (NORM); had it not been, the APU would not have started. On 28 October 2020, Maintenance Member (MXM) 1 removed the AMED from the MA to allow for other maintenance actions. In accordance with (IAW) TO guidance, maintainers must first set the AES to the "Emergency Off" (EMER OFF) position before removing the AMED to prevent the ability to start the APU. During his interview with the Accident Investigation Board (AIB), MXM1 testified to having set the AES

to EMER OFF as directed, and documented this by signing off the completion of the task in the Integrated Maintenance Information System (IMIS). MXM2, the 7-Level that inspected MXM1's work, testified that she could not recall specifically checking the AES on the night the maintenance was performed, but she remembered checking it the following night, 29 October 2020 and verified it was set to EMER OFF at that time. Additionally, on 30 October 2020 at approximately 0330L, MXM11 recalled executing his normal check around the MA after towing it. During this check, MXM11 typically confirms the AES is set to EMER OFF and he did not note anything out of the ordinary. However, MXM3 testified that on 30 October 2020 at 0930L, he personally observed the APU emergency switch in the NORM position, which was one of many indications to MXM3 that he was clear to start the APU. It is unknown when, how, or by whom the AES was set to NORM on the morning of 30 October 2020. However, had the AES been set to EMER OFF and remained in this position, the APU would not have started.

At the time of the mishap, all CBs associated with the mishap were not pulled; had they been, the APU would not have started. IAW TO guidance, following the setting of the AES, the next step is to pull and collar CBs on Power Distribution Center #4 (PDC #4). MXM1 testified that he did pull all three associated CBs, but acknowledged that he did not install CB collars, a plastic clip that prevents the CB from being inadvertently pushed in and includes an orange "REMOVE BEFORE FLIGHT" streamer. The AIB was unable to verify whether the CBs were ever actually pulled or were pushed in at a later time. Though I assess it as unlikely anyone would have intentionally pushed in a pulled CB, it is possible, especially given the number of hours between AMED removal and APU start (51 hours), and the extensive maintenance accomplished during that period near PDC #4. Given that CB collars restrict the resetting of CBs and have a large streamer warning MXMs of their condition, it is my assessment that had CB collars been installed as directed by the TO, the likelihood of these CBs being prematurely pushed in is essentially zero. Therefore, this violation of the TO directly increased the risk of CBs being mistakenly reset during the course of subsequent maintenance. Further, MXM2, as the 7-Level who inspected the task, had a responsibility to verify completion of MXM1's work and correct any errors. Although MXM2 testified that she remembered confirming the position of all three associated CBs, she also confirmed that CB collars were not used. Had MXM1 or MXM2 pulled and collared the CBs, MXM3 would have observed the orange "REMOVE BEFORE FLIGHT" streamers and not started the APU. Furthermore, if he had attempted start, APU ignition would not have occurred.

Additionally, on 28 October 2020 after completion of AMED removal, the applicable Work Center Event (WCE) was documented as complete by MXM1 and verified by MXM2, both of whom signed off the task. When the AMED removal WCE was closed, it opened an AMED install WCE, leaving the MA on a "Red X." This indicated that further investigation was required prior to any operations by maintenance personnel. Per TO guidance, warnings (physical and digital) are to be used on any discrepancy that renders a system hazardous to either the operator or aircraft. When MXM1 completed his task, he did not apply digital warnings in the IMIS forms and did not attach physical warnings to an APU system component. Likewise, MXM2, after inspecting MXM1's work, did not ensure accomplishment of these warnings. Had either MXM1 or MXM2 done these required steps, an obvious red "WARNING" advisory would have populated on the screen in IMIS and a physical tag on the MA would have been visible to MXM3. Correctly-documented warnings would have immediately alerted MXM3 to the absence of the AMED, which would have resulted in delaying start until he completed further investigation.

On the day of the mishap, MXM14 intended for routine maintenance on the MA to be performed using Aerospace Ground Equipment (AGE), not APU. If the maintenance crew executed the maintenance as intended, the mishap would not have occurred. MXM14, the AMU Expeditor, gave instructions to tow the MA out of the Low Observable (LO) hangar and accomplish a routine defueling operation followed by opening the engine bypass louvers. There was AGE on the specified spot upon their arrival and the AGE's presence corroborated the intention of the instruction.

A defuel procedure can be accomplished by either AGE or APU, however, using the APU is the faster method. TO guidance only permits reconfiguring the F-22A's engine bypass louvers with AGE. There is a known workaround in IMIS to accomplish reconfiguration of engine bypass louvers using the APU, but the TO does not permit this method. During the course of this investigation, multiple MXMs admitted it is possible to reconfigure the engine bypass louvers using the APU by "tricking the system," which would be easier and take less time.

MXM14 relayed his intention for the MXMs to use AGE to MXM10. MXM10 testified he did not remember any specific instructions, but he did admit that his attention was divided because of an upcoming Distinguished Visitor (DV) visit. Later on this same day, MXM10 and MXM12 had a disagreement as to the preferred way to defuel the MA, concluding with MXM10's statement, "It doesn't matter. Just as long as the fuel gets out of the jet safely." MXM3, a 5-Level, as well as another MXM, testified that MXM10, a 7-Level, directed MXM3 to use the APU. Ultimately, had AGE been used as directed by MXM14 and IAW TO guidance, the mishap would not have occurred.

On 30 October 2020, the AMED remained uninstalled in the MA, the AES switch was incorrectly set to NORM, the CBs were incorrectly pushed in, and there were no physical or digital warnings indicating anything would preclude operation of the APU. Proper TO adherence, including a complete review of the IMIS forms and visual inspection of the APU would have still alerted MXM3 to the unsafe condition of the MA and prevented the mishap. When MXM3 began to work on the MA, he was obligated to accomplish a complete aircraft forms review IAW TO guidance. Upon opening the IMIS forms on the Portable Maintenance Aid (PMA), the first tab that populated was the "WARNINGS" page. MXM3 testified that he failed to recognize that the AMED required installation because there were no warnings applied in the IMIS forms. Though these warnings should have been documented, MXM3 still had an obligation to accomplish a complete review of the IMIS forms in order to ensure the MA was safe for APU start. Keep in mind, the MA had not flown in approximately four months, had undergone an extensive hardware and software modification, and was in the stages of troubleshooting. Because of the modification, IMIS contained 231 open WCEs including 51 Red X's. A sampling of MXMs interviewed by the AIB testified that an appropriate IMIS review prior to APU start on the MA would take 15-30 minutes. By MXM3's own testimony, he spent about five minutes reviewing IMIS forms, and witnesses present testified it was likely less; one MXM estimated "about a minute." During this abbreviated review, MXM3 failed to see the WCE indicating "APU MIXING DUCT REQS INSTALL" in the sub-header WCEs, where the discrepancy was listed on a Red X. MXM3 admitted during his testimony that during his "quick" scan of IMIS, he only keyed in on the top-level Job Control

Numbers (JCN). Thus, had MXM3 accomplished a complete IMIS review, he would not have started the APU.

On 30 October 2020, MXM3 also failed to visually inspect the APU exhaust area prior to starting the APU. TO guidance requires maintainers to inspect the inlet and exhaust bays of the APU using a B-4 stand prior to start up. Instead of inspecting the bay himself, MXM3 asked MXM7 to do it; a 3-Level who was not qualified to do that inspection. MXM7 stated that he inspected the APU exhaust and inlet and that it was clear, but in his testimony he stated he was looking at the "vent where the fog gases come out" which is a different area than the APU exhaust areas. Additionally, MXM7 acknowledged he did not use the required B-4 (or any other) stand IAW TO guidance. Therefore had MXM3 properly inspected the APU or delegated the task to a qualified MXM, he would have discovered the AMED was missing, and not started the APU.

Finally, after starting the APU and recognizing something was wrong, MXM3 delayed APU shutdown, extending the duration of the overheat condition. When MXM3 started the APU to defuel the MA, hot exhaust gas flowed directly into the APU exhaust bay, rather than being diverted out of the MA via the AMED. After the APU was started, smoke was clearly visible from the APU exhaust bay and flowing through the MA and into the left main landing gear wheel well. Rather than initiate emergency shutdown by setting the AES to EMER OFF, MXM3 selected the wrong course of action by making an improper attempt to run diagnostics and review Fault Reporting Codes (FRC) in IMIS. MXM4, a passing 5-Level, approached the MA and shut down the APU by setting the AES to EMER OFF. MXM3's failure to promptly set the AES to EMER OFF unnecessarily prolonged the duration of the overheat condition.

For the reasons stated above, I find by a preponderance of the evidence that the cause of the mishap was a combination of improper maintenance procedures resulting in the start of the APU while the AMED was removed for other maintenance. If maintenance crews correctly executed proper maintenance procedures in accordance with TO guidance, this mishap would not have occurred.

3. SUBSTANTIALLY CONTRIBUTING FACTORS

Additionally, I find by a preponderance of evidence that each of the following factors substantially contributed to the mishap:

a. Culture Regarding Circuit Breaker Collars and Warnings

During the investigation, the AIB learned that the failure to use CB collars and inconsistent use of digital warnings was not isolated to this mishap. Of eleven MXMs surveyed, nine testified that they did not install CB collars at the Raptor Aircraft Maintenance Unit (AMU). Of eight MXMs surveyed on Raptor AMU's culture, seven reported a widespread lack of CB collar use. MXM1 did not to use CB collars on 28 October 2020, despite clear guidance directing the use of CB collars on PDC #4. MXM1 was fully qualified in the AMED removal and certified he completed the task IAW TO guidance. Likewise, MXM2 indicated she did not observe the use of CB collars for that particular task, and in terms of the Raptor AMU, she stated, "We don't use them here." Additionally, MXM8 stated he did not even know what CBs collars were. Therefore, I find by a

preponderance of the evidence that MXM1 and MXM2's failure to use CB collars was influenced by Raptor AMU's systemic culture of non-use.

Additionally, although it was also acknowledged that warnings are to be used on any discrepancy that renders a system hazardous to either the operator or aircraft IAW TO guidance, warning documentation was not regularly followed or enforced at the time of the mishap. Of 13 MXMs surveyed, all testified that digital warning should be applied. However, a review of Raptor AMU's IMIS server showed that of 22 AMED removals performed within one year prior of the mishap, only 36.4% of them had digital warnings documented in forms. In fact, on 26 October 2020, when the AMED in the MA was removed and replaced, the IMIS forms showed that digital warnings were not appended. Ultimately, Raptor AMU's culture of not using CBs collars and inconsistently applying digital warnings substantially contributed to the mishap.

b. Test Instrumentation Obstructing Access to Applicable Circuit Breakers

The location of test instrumentation mounted above PDC #4, obstructs access to applicable CBs. By design, the location of the test instrumentation allows for approximately one inch of clearance above the CBs. In order to confirm the position of CBs, to change their configuration (push in or pull out), or to install CB collars, maintainers are required to contort around much of the airframe structure and use a combination of flashlights, mirrors, and other tools. It is my opinion that this increases the complexity in executing maintenance actions regarding PDC #4, thereby increasing the likelihood of errors. According to MXM15, a Quality Assurance (QA) Inspector, it is very difficult to install CB collars on PDC #4, and characterized it as "not normal" to use CB collars there. In reference to that location, he said, "The collars are brutal." It is therefore my assessment that the location of the test instrumentation, which obstructs access to applicable CBs, directly influenced the culture of inconsistent CB collar usage, and substantially contributed to the mishap.

c. The Extensive Nature of the Mishap Aircraft's Modification

At the time of the mishap, the MA was undergoing an extensive modification that complicated the maintenance actions being performed leading up to the mishap. This modification required disparate maintenance teams to accomplish multiple unscheduled maintenance actions resulting in the creation of 231 WCEs and 51 Red Xs. Each one of these open JCNs and WCEs must be carefully assessed and evaluated prior to any proposed maintenance action by the tasked member. It is my assessment that MXM3's tasking to start the APU for defueling required him to search for a "needle-in-a-haystack" by processing more than two hundred WCEs to find the one WCE that stated that the AMED required installation, thereby indicating the APU should not be started. It is my opinion that the sheer amount of data to be processed by an individual increases the likelihood of error. Thus, I have determined that the extensive nature of the modification substantially contributed to the mishap.

d. Distractions on the Day of the Mishap

The distractions caused by several non-standard events on the day of the mishap substantially contributed to the mishap. On the morning of the mishap, Raptor AMU executed a planned no-fly "Training Day" that included a morale event, an aircraft demonstration, and a flight-line visit by a DV. That day, assignments were not given out at roll call, and the day was described as a

"fun day" by MXM10 and a "no fly day" by MXM14. However, unscheduled maintenance on the MA required maintainers to reposition 0.7 miles away to accomplish defueling and reconfiguration actions, resulting in several follow-on effects. MXM10's divided attention due to the events of the day resulted in his inability to recall the specific direction relayed by MXM14 to use AGE. MXM10 then had a disagreement with MXM12 on the preferred way to defuel the MA that ultimately resulted in MXM10 telling MXM3 to use the APU, which was known to be the "fastest and easiest" method to defuel and reconfigure the MA, even though this act directly contrasted with MXM14's direction and TO guidance. MXM10, a supervisory 7-level who was requested by MXM14 to remain in place to supervise the crew working the MA, elected to leave the area to see the aircraft demonstration and prepare for the DV's arrival. Thereafter, MXM3 admitted he performed a "quick" forms review, and did not appropriately assess a critical piece of data, which would have averted the mishap. I find that the non-standard events on the day of the mishap influenced the decisions of MXM10 and MXM3 and substantially contributed to the mishap.

4. CONCLUSION

I find by a preponderance of the evidence that the cause of the mishap was improper maintenance procedures resulting in the start of the APU while the AMED was removed. I also find by the preponderance of the evidence four additional factors that substantially contributed to the mishap: (1) the culture of the mishap unit, including limited use of CB collars and inconsistent use of warnings; (2) the design of test instrumentation on the MA which obscured access to applicable CBs; (3) the extensive nature of the MA's modification; and (4) the distractions caused by several non-standard events scheduled on the day of the mishap.

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29 June 2021

RICHARD B. FOSTER, Colonel, USAF
President, Accident Investigation Board

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