UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION
BOARD REPORT

KC-46A, T/N 15-046069

2D AIR REFUELING SQUADRON
305TH AIR MOBILITY WING
JOINT BASE MCGUIRE-DIX-LAKEHURST

LOCATION: NORTH ATLANTIC OCEAN (N 51º 15.90 W 052º 58.80)

DATE OF ACCIDENT: 15 OCTOBER 2022

BOARD PRESIDENT: COLONEL CHAD K. CISEWSKI

CONDUCTED IAW AIR FORCE INSTRUCTION 51-307

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR MOBILITY COMMAND

ACTION OF THE CONVENING AUTHORITY

The report of the Accident Investigation Board, conducted under the provisions of AFI 51-307, *Aerospace and Ground Accident Investigations*, that investigated the 15 October 2022 mishap that occurred while flying over the North Atlantic Ocean, involving a KC-46A, T/N 15-046069, assigned to the 305th Air Mobility Wing, Joint Base McGuire-Dix-Lakehurst (JBMDL), New Jersey, substantially complies with the applicable regulatory and statutory guidance and on that basis is approved.

REBECCA J. SONKISS
Lieutenant General, USAF
Deputy Commander (Convening Authority)

EXECUTIVE SUMMARY
UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION

KC-46A, T/N 15-04069
LOCATION: North Atlantic Ocean (N 51º 15.90 W 052º 58.80)
15 October 2022

On 15 October 2022 at 1313:46 Zulu (Z), a KC-46A Pegasus and an F-15E Strike Eagle conducting routine air refueling operations experienced a nozzle binding event during a breakaway which resulted in the Aerial Refueling Boom (ARB) striking the tail section of the KC-46A. Mishap Aircraft 1 (MA1), a KC-46A, T/N 15-046069, is assigned to the 305th Air Mobility Wing (AMW), Joint Base McGuire-Dix-Lakehurst (JBMDL), New Jersey, and operated by Mishap Crew 1 (MC1), assigned to the 2d Air Refueling Squadron (ARS), JBMDL. Mishap Aircraft 2 (MA2), an F-15E, T/N 87-0192, is assigned to the 4th Fighter Wing (FW), Seymour Johnson AFB, North Carolina, and operated by Mishap Crew 2 (MC2), assigned to the 335th Fighter Squadron (FS), Seymour Johnson AFB. The total monetary value of government loss was approximately $8,307,257.93.

I find, by a preponderance of the evidence, one cause for this mishap. Due to a limitation of the Air Refueling Boom (ARB) control system, Mishap Boom Operator 1 (MBO1) inadvertently placed a radial force on the ARB that caused the nozzle to become bound in the receiver's receptacle. As a result, the bound forces exceeded the structural limitations of the ARB and caused a rapid upward movement of the ARB when released, striking the tail cone of MA1.

Additionally, I find, by a preponderance of the evidence, two factors which substantially contributed to the mishap. The first factor is the failure of Mishap Pilot 1 (MP1) to alert Mishap Pilot 3 (MP3) and MBO1 to an engine power reduction on MA1. This action, combined with the known ARB stiffness limitation and the resulting high engine power setting on MA2, resulted in a rapid forward movement of MA2 relative to MA1.

The second factor is that due to a limitation of the automated boom control system, the ARB entered an uncontrollable state during its upward motion toward the aircraft tail, disabling the boom control laws which could have slowed the rate at which the ARB struck the tail cone, substantially contributing to 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
KC-46A, T/N 15-046069
LOCATION: North Atlantic Ocean (N 51º 15.90 W 052º 58.80)

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ACRONYMS AND ABBREVIATIONS

AB	Air Base
ACM1	Additional Crew Member 1
ACM2	Additional Crew Member 2
ACM3	Additional Crew Member 3
AFB	Air Force Base
AFE	Air Flight Equipment
AFI	Air Force Instruction
AFMAN	Air Force Manual
AFMC	Air Force Material Command
AFTO	Air Force Technical Order
AIB	Accident Investigation Board
ALAS	Automatic Load Alleviation System
AMC	Air Mobility Command
AMW	Air Mobility Wing
AMXS	Aircraft Maintenance Squadron
ANGB	Air National Guard Base
AOC	Air Operations Center
AOR	Area of Responsibility
ARB	Aerial Refueling Boom
ARCC	Air Refueling Control Computer
ARO	Aerial Refueling Operator
AROI	Aerial Refueling Operator Instructor
AROS	Aerial Refueling Operator Station
ARS	Aerial Refueling Squadron
APU	Auxiliary Power Unit
BOT	Boom Operator Trainer
BPO	Basic Post Flight
CAT	Category
DAFMAN	Department of the Air Force Manual
DoD	Department of Defense
DCO	Delivery Control Officer
DR	Deficiency Reports
DRI&R	Deficiency Reporting, Investigation, and Resolution
ETOPS	Extended-range Twin-engine Operations Performance Standards
FBO	Fixed Base Operator
FCS	Flight Control Stick
FS	Fighter Squadron
FW	Fighter Wing
ft	Feet
GVI	General Visual Inspections
HBRLI	High Boom Radial Load Indication
HFACS 7.0	Human Factors Analysis and Classification System 7.0
IAW	In Accordance With
IDS	Independent Disconnect System
IFR	In-Flight Refueling
IMDS	Integrated Maintenance Data System
JBMDL	Joint Base McGuire-Dix-Lakehurst
kts	Knots
L	Local Time
lbs	Pounds
MA1	Mishap Aircraft 1
MA2	Mishap Aircraft 2
MBO1	Mishap Boom Operator 1
MBO2	Mishap Boom Operator 2
MC	Mishap Crew
MC1	Mishap Crew 1
MC2	Mishap Crew 2
MCT	Mission Certification Training
MDS	Mission Design Series
MIS	Maintenance Information System
MP1	Mishap Pilot 1
MP2	Mishap Pilot 2
MP3	Mishap Pilot 3
MP4	Mishap Pilot 4
MX1	Flying Crew Chief 1
MX2	Flying Crew Chief 2
NC	North Carolina
NJ	New Jersey
PLI	Pre-Launch Inspection
PR	Pre Flight
RAIS	Refueling Alert Indication System
SAR	Search and Rescue
sec	Seconds
TTF	Tanker Task Force
TCTO	Time Compliance Technical Order
TCS	Telescope Control Stick
T/N	Tail Number
TO	Technical Order
USAF	United States Air Force
US SRD	United States Standards Related Document
WARPs	Wing Aerial Refueling Pods
WSO	Weapons Systems Operator
Z	Zulu

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 15 December 2022, Lieutenant General Randall Reed, Deputy Commander, Air Mobility Command (AMC), appointed Colonel Chad K. Cisewski, to conduct an aircraft accident investigation of a mishap that occurred on 15 October 2022 involving a KC-46A Pegasus aircraft and a F-15E Strike Eagle aircraft near Newfoundland, Canada (Tab Y-3). The aircraft accident investigation was conducted in accordance with (IAW) Air Force Instruction (AFI) 51-307, *Aerospace and Ground Accident Investigations*, at Joint Base McGuire-Dix-Lakehurst, New Jersey, from 10 January 2023 through 26 January 2023. Accident Investigation Board (AIB) members were a Legal Advisor Major, a KC-46 Pilot Member Major, a KC-46 Maintenance Member Technical Sergeant, and a Recorder Senior Airman (Tabs Y-3). The Subject Matter Expert (SME) was a KC-46 Boom Operator Technical Sergeant (Tab Y-5).

b. Purpose

In accordance with AFI 51-307, this AIB conducted a legal investigation to inquire into all the facts and circumstances surrounding this Air Force 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 15 October 2022 at 1313:46 Zulu (Z), a KC-46A Pegasus and an F-15E Strike Eagle conducting routine air refueling operations experienced a nozzle binding event during a breakaway which resulted in the Aerial Refueling Boom (ARB) striking the tail section of the KC-46A (Tab Y-3). Mishap Aircraft 1 (MA1), a KC-46A, T/N 15-046069, is assigned to the 305th Air Mobility Wing (AMW), Joint Base McGuire-Dix-Lakehurst (JBMDL), New Jersey, and operated by Mishap Crew 1 (MC1), assigned to the 2d Air Refueling Squadron (ARS), JBMDL. Mishap Aircraft 2 (MA2), an F-15E, T/N 87-0192, is assigned to the 4th Fighter Wing (FW), Seymour Johnson AFB, North Carolina, and operated by Mishap Crew 2 (MC2), assigned to the 335th Fighter Squadron (FS), Seymour Johnson AFB (Tab D-16). The total monetary value of government loss was approximately $8,307,257.93 (Tab CC-3).

3. BACKGROUND

a. Air Mobility Command (AMC)

Air Mobility Command (AMC), activated in June 1992, is Headquartered at Scott Air Force Base, Illinois. AMC is comprised of approximately 110,000 Total Force personnel and is responsible for Airlift, Air Refueling, Air Mobility Support, and Aeromedical Evacuation (Tab DD-4).

b. 305th Air Mobility Wing (305 AMW)

The 305 AMW is a United States Air Force strategic airlift and air refueling wing which generates, mobilizes, and deploys KC-46 Pegasus, KC-10 Extenders, and C-17 Globemaster IIIs to conduct strategic airlift and air refueling missions worldwide. In November 2021, the Wing began transitioning to the new KC-46 Pegasus air refueling aircraft. Additionally, the Wing operates two of America's largest stategic aerial ports supporting the delivery of cargo and personnel to combatant commanders abroad (Tab DD-11).

c. 2d Air Refueling Squadron (2 ARS)

The 2 ARS is the second-oldest squadron in the United States Air Force, having over 100 years of service to the nation. Today, it operates the KC-46 Pegasus aircraft, conducting aerial refueling missions (Tab DD-7).

d. KC-46A Pegasus

The KC-46A Pegasus is the first phase in recapitalizing the United States Air Force's aging tanker fleet. The aircraft has been in development since 24 February 2011, with its initial flight occurring in December 2014. The first KC-46A was delivered to McConnell AFB, Kansas on 25 January 2019.

The KC-46A is equipped with a refueling boom driven by a fly-by-wire control system, and is capable of fuel offload rates required for large aircraft. The aircraft's fuel can be pumped through the boom, drogue, and Wing Aerial Refueling Pods (WARPs). The boom operator controls the boom, centerline drogue, and WARPs during refueling operations. The Aerial Refueling Operator (ARO) station includes panoramic displays giving the ARO wing-tip to wing-tip situational awareness (Tab DD-7).

e. F-15E Strike Eagle

The F-15E Strike Eagle is a dual-role fighter designed to perform air-to-air and air-to-ground missions. An array of electronics systems gives the F-15E the capability to fight at low altitude, day or night, and in all weather. The "E"-model is a dual-role fighter, which has the capacity to fight its way to a target over long ranges, destroy enemy ground positions, and fight its way out. This aircraft uses two crew members, a pilot and a weapon systems officer. (Tab DD-9).

4. SEQUENCE OF EVENTS

a. Mission

On 15 October 2022, MC1 was scheduled to fly MA1 on an international aerial refueling mission from Prestwick Airport, United Kingdom to Pease Air National Guard Base (ANGB), New Hampshire (Tabs V-2.2, V-8.2, V-8.6).

b. Planning

Following their crew alert and show, MC1 reviewed all provided mission paperwork, familiarized themselves with applicable Special Instructions, and completed their oceanic and formation planning (Tabs V-1.2, V-2.2, V-3.2, V-8.2, V-9.2, V-10.2, V-11.2). MC1 briefed the mission details at the Fixed Base Operator (FBO) and were at MA1 before takeoff, per standard operational practices (Tabs V-1.2, V-2.2, V-3.2, V-6.2, V-7.2, V-8.2, V-9.2, V-11.2). Additionally, a formation brief was conducted with three other aircraft in MA1's formation, prior to takeoff (Tabs V-1.2, V-2.2, V-3.2, V-8.2, V-9.2, V-11.2).

All mission, weather, and fuel planning were accomplished for MC2 (Tab V-10.2). Following their arrival, MC2 reviewed and was briefed on all provided mission paperwork, as well as the departure and enroute plan by the Delivery Control Officer (DCO) and their flight lead (Tab V-10.3).

c. Preflight

MC1 was composed of two Instructor Pilots (Mishap Pilot 1 (MP1), Mishap Pilot 4 (MP4), three Mission Pilots undergoing Mission Certification Training (MCT) (MP2, Additional Crew Member (ACM1, ACM2), one Co-Pilot undergoing MCT (ACM3), two Mission Boom Operators (Mishap Boom Operator (MBO1, MBO2), and two Flying Crew Chiefs (MX1, MX2) (Tabs V-1.1. V-2.1, V-3.1, V-4.1, V-5.1, V-6.1, V-7.1, V-8.1, V-9.1, V-11.1). The crew was alerted from Prestwick on Saturday, 15 October 2022 (Tabs AA-13, V-1.2, V-2.2, V-3.2, V-8.2, V-9.2, V-11.2). The Maintenance Personnel arrived approximately 90 minutes prior to the rest of the crew and reported MA1 fully mission capable (Tabs V-4.2, V-5.2). The pilots and boom operators showed to the

FBO at 0740Z to review planning documents and for the TTF Mission Director to brief the formation (Tabs V-1.2, V-2.2, V-3.2, V-8.2, V-9.2, V-11.2). The pilots and boom operators moved from the FBO to MA1 to perform preflight duties (Tabs V-1.2, V-2.2, V-3.2, V-8.2, V-9.2, V-11.2).

MC2 was composed of one Mission Pilot (MP3) and one Weapons Systems Officer (WSO) (Tab V-10.2). The crew showed to their brief at Mildenhall AB on Saturday, 15 October 2022 and then moved to MA2 to perform preflight duties (Tab V-10.2).

Nothing of significance was noted during MC1's nor MC2's preflight, ground operations, or departure (Tabs V-1.2, V-2.2, V-3.2, V-6.2, V-7.2, V-8.2, V-9.2, V-10.2, V-11.2).

d. Summary of Accident

On 15 October 2022, MA2's take off and departure were uneventful (Tabs V-10.2). MA2 began conducting refueling operations (Tab V-8.3).

At approximately 0915Z, MA1 took off as the fourth aircraft in a four aircraft air refueling tanker formation from Prestwick Airport (Tabs V-8.3, V-11.2). At approximately 1000Z, their formation rendezvoused with another tanker aircraft and the F-15E flight, prior to entering oceanic airspace (Tab V-8.3). The take off and departure were uneventful (Tabs V-1.2, V-2.2, V-3.2, V-6.2, V-7.2, V-8.2, V-9.2, V-11.2).

Following the rendezvous, one taker aircraft departed the formation and proceeded to its planned destination (Tab V-8.3). Two of the tanker aircraft conducted air refueling operations with the F-15E flight until departing the formation at approximately 1140Z (Tab V-8.3).

Prior to conducting air refueling operations, the F-15E flight leader coordinated with one of the tanker aircraft to increase the speed at which the flight would be continuing operations due to their heavier F-15Es efficiency at higher speeds (Tabs V-8.4, V-9.3, V-10.4). After an initial request of 330 knots, the tanker aircraft agreed to adjust to 320 knots, which would allow them to remain below the KC-46 ARB's flight manual limitation of 325 knots for air refueling (Tabs V-8.4, V-9.3, V-10.4, BB-79). At approximately 1216Z, MA1 began conducting air refueling operations with MA2 and two other F-15Es at 27,500 ft with each aircraft successfully refueling once prior to the breakaway event between MA1 and MA2 (Tabs V-6.4, V-7.3).

At 1334:36Z, MA1 achieved contact with MA2 and began transferring fuel between the aircraft (Tab FF-3). Both MBO1 and MP3 categorized MA2's initial position within the air refueling envelope as near the center and stable (Tabs V-6.4, V-10.5). MP3 verbally noted to his WSO that his engine power setting seemed slightly higher than normal but cited their slightly higher altitude as a probable cause (Tab S-9).

At approximately 1336Z, MP1 observed that MA1 was approaching the 325 knot ARB restriction (Tab V-8.4). In response, MP1 reduced the commanded engine power to within 1 degree of the aircraft engine's minimum setting in order to reduce MA1's speed (Tab V-8.4, Tab FF-2). MP1 did not coordinate this speed reduction via interphone or radio with MBO1 or MP3 (Tabs S-9, V-6.4, V-8.7). As a result of this engine power change, MA1 began to slow its airspeed at a rate of 1.1 knots per second (Tab FF-2).

At 1337:43Z, MA2 began a forward movement relative to MA1 which steadily increased to 1.73 ft/sec. At this time, MBO1 was maintaining a "hands off condition" on the ARB flight controls with negligible inputs (Tab FF-4). Due to this rapid forward movement, the radial and axial forces on the ARB nozzle began to build, with the vertical direction radial forces exceeding 500 lbs 2.5 seconds later (Tab FF-5).

At 1337:46.2Z, the ARB system automatically commanded a DISCONNECT between MA1 and MA2 in response to the rapid relative forward movement of MA2, causing it to approach the forward and lower boom limit at a rate greater than the ARB system allowed (Tab FF-5). Following the command, the disconnect systems engaged, releasing the mechanical connection between MA1 and MA2 (Tab FF-5). Immediately after the automatic disconnect, MA2 continued its relative forward movement, causing the telescope tube on the ARB to continue to retract into the telescope tube (FF-5).

At 1337:46.3Z, MBO1 simultaneously input a Flight Control Stick (FCS) pitch up command and Telescope Control Stick (TCS) retraction command while MA2 was still in physical contact with the ARB nozzle (Tab FF-5). These inputs amplified the vertical radial force on the nozzle (Tab FF-6). During this time, MA2's forward relative movement continued to push the telescope tube inward (Tab FF-6). This FCS movement corresponded with MBO1's use of the radio transmit switch on the FCS to transmit "*Back four*" on the shared air refueling radio frequency (Tabs V-6.4, V-8.4, V-9.5, S-9).

At 1337:46.7Z, MBO1 activated the BREAKWAY switch on the TCS, commanding the Breakaway procedure to both MC1 and MC2 over the shared air refueling radio frequency (Tabs FF-6, S-9, V-6.4, V-8.4, V-9.5). In conjunction with the BREAKAWAY switch and, in accordance with the proper procedure, MBO1 pulled the boom disconnect trigger switch located on the rear of the FCS (Tabs BB-66 through BB-69, V-6.4, V-6.5).

Following the breakaway command, MP3 reduced MA2's engine power to its minimum setting, in accordance with the proper procedure (Tabs L-25, V-10.5). MP1 increased engine power and MP2 turned on additional aircraft lights in accordance with the proper procedure (Tabs V-8.4, V-9.5).

At 1337:47.1Z, MBO1 continued to increase the FCS pitch up command and TCS retraction command with MA2 still in physical contact with the boom nozzle, increasing the radial force on the nozzle to an unknown value exceeding 2400 lbs in the vertical direction (Tab FF-6). The actual peak value is unknown as the system's sensor cannot identify force above 2400 lbs on the vertical axis (Tab FF-6). Due to this sensor limitation, the "HI-LOAD" alert triggered by the initial forces on the nozzle ceased to display on MBO1 and MBO2s screens (Tab FF-6)

At 1337:48.1Z, MA2 decreased its speed of forward movement to that of MA1 (Tab FF-6). At this time, the telescope tube length was 3.17 ft (Tab FF-6). As MA1 and MA2 began to laterally separate, the binding of the boom nozzle, caused by the radial force, kept the nozzle in physical contact with MA2s receptacle, pulling the telescoping tube from 3.17 ft to 10.75 ft, increasing the axial tension force beyond the end of range limitation of the nozzle axial sensor (Tab FF-6). Prior to the out-of-range condition, the peak recorded axial load was 9658 lbs (Tab FF-6).

At 1337:50.4Z, while the ARB was at a position of 32.16° pitch, -5.06° left roll, and 10.75 ft telescope, the nozzle physically cleared MA2's receptacle, beginning a rapid upward movement (Tab FF-6). The ARB moved upward at a peak rate of 73.69°/sec, which triggered a software detection limit (Tab FF-6). The software then disabled the boom control and caused a "BOOM INOP" message to be displayed on Air Refueling Operator Stations (AROS) message screens (Tab FF-6). As the ARB continued to move up vertically, the telescope retracted from 10.54 ft to 8.76 ft due to MBO1's continued TCS retraction command (Tab FF-6).

At 1337:51.1Z, the ARB struck the underside of the aircraft tail cone, along the body centerline (Tab FF-6). Multiple members of MC1 described this impact as a "*thud*", "*bang*", or "*jolt*" that was felt in the flight deck and crew compartment of the aircraft (Tabs V-1.4, V-2.4, V-3.3, V-4.3, V-5.3, V-11.5). MBO1 continued an FCS pitch up command until 0.2 sec after the impact (Tab FF-6).

As a result of the rapid boom movement, the boom hoist cable actuator encountered a software limitation, locking the hoist drum from rotating and freezing the hoist cable in the fully retracted position (Tab FF-6). Following the impact with the aircraft tail cone, the boom came to rest with the cable holding its weight (Tab FF-7).

At approximately 1338Z, due to the damage sustained by the ARB during the binding and impact events, MA1's center hydraulic system indicated a loss of quantity and pressure, triggering the aircrafts C HYD SYS PRESS and C HYD QTY messages in both the flight deck and AROS (Tab V-8.5, V-9.6). Following the loss of center hydraulic system pressure, MA1's center autopilot automatically disconnected and reverted to manual flight (Tabs V-8.5, V-9.6). MP1 established positive manual control and reengaged the autopilot (Tabs V-8.5, V-9.6).

Following the separation of MA1 and MA2, MP3 observed fluid leaking from the ARB, which he categorized as "*kind of not usual*" (Tabs S-10, V-10.5).

At 1338:26Z, MP1 transmitted over the shared air refueling radio the command to terminate the breakaway procedures between MA1 and MA2 (Tabs S-9, V-8.5, V-9.6, V-10.5).

At 1339:37Z, MC1 requested the other aircraft in the formation conduct visual inspections of the boom area (Tabs S-10, V-6.7, V-7.4, V-8.7, V-9.7, V-10.5). From their position, MA2 was unable to identify any noticeable damage (Tab S-10, V-6.7, V-7.4, V-9.7).

MC1 proceeded to troubleshoot and follow their procedures for the following abnormal messages displayed: C HYD SYS PRESS, HOIST CABLE, C HYD QTY, ALAS ELEVATION, BOOM INOP, BOOM FORCE, and BOOM IDS (Tabs FF-6, V-6.6, V-7.4, V-8.5, V-9.6, V-11.6). During this time, MP3 reestablished MA2's position on the right side of MA1, slightly behind (Tabs S-10, V-10.5).

At 1346:49Z, MC1 requested an additional "*Battle Damage Assessment*" on the boom hoist cable to see "*where it is*" and if it "*extends past the rudder and elevators on the boom*" (Tabs S-12, V-6.7, V-7.4, V-8.7, V-9.7, V-10.5). The second F-15E was able to verify that the boom appeared in the "*full up, stowed position*" and that the hoist cable was intact (Tab S-10, V-6.7, V-7.4, V-9.7).

At 1353:14Z, MP1 made the following transmission over the shared air refueling frequency, formally ceasing any air refueling operations for MA1:

> *Alright guys from uh 26 here...alright we are done for the day, we have lost a center hydraulic system, uh, it looks like uh the boom as we had the emergency breakaway there that was caused by a combination of us approaching our limit for the boom at 325 knots, I pulled some power, he pushed in and during the emergency breakaway something happened with the boom getting caught, it shot up, took out one of our hydraulic systems and we are in a, uh, unknown position with our boom hoist here trying to evaluate that. So we will definitely not be giving fuel to anyone the rest of the day so for the fighters' planning, you need to start working with 16 for your fuel plan. We're running through our checklist trying to figure out, uh, what we need to do for our emergency landing.*

(Tab S-14).

Following the formal cessation of air refueling operations, MA1 remained in formation with one of the tanker aircraft until they had exited oceanic airspace and in radio range with air traffic control (Tabs V-9.7, V-11.6). Then MC1 departed the formation and made the decision to fly to JBMDL (Tabs V-8.6, V-9.7, V-11.6). MA2 continued to conduct air refueling operations with one of the tanker aircraft and landed uneventfully at Seymour Johnson AFB (Tab V-10.5).

Enroute to JBMDL, MP1, MBO1, and MBO2 made several phone calls over the aircraft's satellite telephone system, discussing their emergency and ensuring the applicable procedures were correctly followed (Tabs V-6.6, V-7.5, V-8.6, V-9.7, V-11.6). Calls were made to a Boeing test pilot, test boom and test engineer, AMC Standardization/Evaluation and Training offices, and 2 ARS subject matter experts (Tabs V-6.6, V-8.6, V-9.7, V-11.6).

MC1 made several crew position changes before flying the recovery (Tabs V-6.7, V-7.5, V-8.6, V-9.7, V-11.6). MP1 and MP4 occupied the pilot seat positions and MP2 moved to the Observer 2 position (Tabs V-6.7, V-7.5, V-8.6, V-9.7, V-11.6). MBO1 and MBO2 remained at their AROS positions, monitoring the boom during the landing (Tabs V-6.6, V-7.5, V-9.7).

At 1818Z, MC1 landed without incident at JBMDL (Tabs V-6.7, V-7.5. V-8.7, V-9.8, V-11.7).

e. Impact

At the conclusion of the event, MA1 was in level flight at approximately 320 knots indicated airspeed (Tabs V-8.4, V-9.3, V-10.4). The Boom Nozzle Poppet Valve and Boom Latch Hook fell into open ocean; no injuries or fatalities were reported (Tabs R-28, V-6.6). MA2 joined formation with one of the tanker aircraft and continued air refueling operations (Tab V-10.5).

f. Egress and Aircrew Flight Equipment (AFE)

MC1 landed at JBMDL and taxied off the runway without incident (Tabs V-6.7, V-7.5, V-8.7, V-9.8, V-11.7). The crew shut down the aircraft and remained on MA1 until it was towed by maintenance back to the parking ramp, where they egressed normally, without the use of emergency egress equipment (Tab V-8.7).

MC2 landed at Seymour Johnson AFB and taxied back to aircraft parking, where they egressed normally (Tab V-10.5).

g. Search and Rescue (SAR)

Not Applicable

h. Recovery of Remains

Not Applicable

5. MAINTENANCE

a. Forms Documentation

The Air Force Technical Order (AFTO) 781 series of forms collectively provides maintenance, inspection, service, configuration, status, and flight record of the aerospace vehicle for which they are maintained. The AFTO 781 forms, in conjunction with the Maintenance Information System (MIS) and/or Integrated Maintenance Data System (IMDS), provide a comprehensive database used to track and record maintenance actions and inspection histories on individual aircraft (Tabs U-29 to U-33).

A comprehensive review of the active AFTO 781 forms and MIS historical records for MA1 for the 75 days preceding the mishap revealed no recurring maintenance problems (Tabs U-4 to U-10). The AFTO 781 forms covering the prior three flights for MA2 also produced no correlated maintenance issues (Tabs D-16 to D-81). Other maintenance records, including Time Compliance Technical Orders (TCTOs) were reviewed and determined not to be related to the incident (Tab U-3).

For MA1, a Basic Post Flight Inspection (BPO) was documented at 0210Z on 5 October 2022 (Tab U-12). A Pre-flight Inspection (PR) was documented at 2200Z on 14 October 2022 (Tab U-12). A Pre-Launch inspection (PLI) was documented at 0710Z on 15 October 2022 (Tab U-12). The Exceptional Release was completed by MP1 (Tab U-13). All documentation items were completed before their respective flight (Tabs U-12, U-13).

For MA2, a PR/BPO was documented at 0110Z on 11 October 2022 and a successive PR completed at 1400Z on 12 October 2022 (Tab D-44).

b. Inspections

MA1 follows a scheduled inspection regiment established by the manufacturer called Aerospace Vehicle Manufacturer Inspection Concept consisting of A-Check and C-Check inspections. After a specified number of A-Check inspections are performed, a C-Check is performed. Each A-Check inspection and the C-Check consists of their respective maintenance procedures (Tab U-28).

The PR inspection is accomplished before the first flight of the next specified flying period. The PR inspection consists of checking the aircraft condition by performing a visual examination and operational checks of certain components, areas, or systems to ensure no defects exist that would be detrimental to flight. A new PR must be accomplished every three days if the aircraft is scheduled to fly. (Tabs U-30, U-31)

The PLI is accomplished before each flight and must be accomplished and signed off by a qualified maintenance individual within four hours of flight. The PLI includes general visual inspections (GVI). A GVI looks at specific items and the components in the general area for defects (Tab U-30).

All MA1 inspections were completed satisfactorily and documented according to Air Force guidance with no discrepancies noted (Tab U-12).

All MA2 inspections were completed satisfactorily and documented according to Air Force guidance with no discrepancies noted (Tab D-44).

c. Maintenance Procedures

The PR for MA1, MA2, and the PLI performed on MA1 prior to the mishap were all completed in accordance with the proper technical order (Tab U-12, D-44). All servicing, required inspections, system checks, and visual inspections were accomplished in their entirety and signed-off on the AFTO Form 781H with no discrepancies (Tabs D-44 to D-45, U-12 to U-13).

d. Maintenance Personnel and Supervision

Maintenance personnel from the 605th Aircraft Maintenance Squadron (AMXS) performed all required inspections, documentation, and servicing for MA1 prior to flight (Tabs U-11 to U-27). A detailed review of maintenance activities and documentation revealed no errors. No supervisory shortfalls or noteworthy hinderances affecting the maintenance quality on MA1 were identified. Personnel involved with the MA1's preparation for flight had proper and adequate training, experience, certification, and supervision to perform their assigned tasks (Tabs T-3 to T-42). There is no evidence to suggests that the training, qualifications, and maintenance personnel supervision were a factor in this mishap (Tabs T-3 to T-42).

Due to the nature of the accident this information is not applicable to MA2.

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

Hydraulic fluid samples from the MA1's three hydraulic systems, lubricating oil samples from the MA1's Auxiliary Power Unit (APU), two engines, and turbine fuel from the right-side wing tank were sent to the Air Force Petroleum Office for analysis. The board reviewed the results of the analysis and found no evidence contributing to the mishap (Tabs D-110 to D-125).

Due to the nature of the accident this information is not applicable to MA2.

f. Unscheduled Maintenance

Unscheduled maintenance is any maintenance action taken that is not the result of a scheduled inspection and normally is the result of a pilot-reported discrepancy during flight operations or a condition discovered by ground personnel during ground operations.

A review of MA1's active and historical maintenance records revealed nine unscheduled maintenance events during the nine days from the last scheduled inspection preceding the mishap. The nine unscheduled maintenance events are as follows:

Servicing potable water twice on 6 and 9 October 2022; upload/download of Data Transfer Devices three times on 5, 7, and 9 October 2022; replacement of a cargo door light on 7 October 2022; a Bird Air Strike Hazard inspection on 7 October 2022; replacement of a military high frequency radio coupler on 7 October 2022; and the inspection/cleaning of an aircraft entry door proximity sensor on 10 October 2022 (Tabs U-15 to U-21).

A review of MA2's active and historical maintenance records revealed three unscheduled maintenance actions completed preceding the mishap and the last scheduled inspection. The three unscheduled maintenance events are as follows:

Navigation pod service on 12 October 2022; left strut low side service on 12 October 2022; and left external tank probe replacement (Tabs D-61 to D-80).

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS

a. KC-46 Aerial Refueling Boom (ARB) Normal Systems and Procedures

(1) KC-46 Boom System

The KC-46 Boom System includes an ARB with an outer structural tube and an inner telescoping tube with a nozzle to connect to receiver aircraft (Tab BB-98). The ARB is aerodynamically maneuvered by elevators and rudders which are controlled by a fly-by-wire system with an FCS at the AROS (Tabs BB-96, BB-98). Through an array of sensors and actuators, the system monitors real time activity and provides auditory and/or visual alerts to the ARO (Tab BB-75).

A subset of these alerts also has the capability to disable specific functions of the system to maintain safe operation. One such auditory and visual warning alert (BOOM INOP) is to indicate that the boom system is inoperative (Tab BB-75). When this occurs, the ARB goes into a state known as "damped-trail" (Tab O-2642). In this state, the ARB movements by the ARO are disabled and the ARO receives a visual and auditory warning alerts that the boom is inoperative.

(2) ARB Automatic Load Alleviation System

The KC-46 Boom System uses an Automatic Load Alleviation System (ALAS) to alleviate excessive force on the refueling nozzle during aerial refueling. When in contact with a receiver aircraft, this system uses sensors to gauge ARB Nozzle forces and automatically applies ARB flight control input to keep the forces on the ARB nozzle within prescribed limits (Tab BB-102). Under normal operations, while a receiver aircraft is in contact, this system provides receiver tracking and reduces the workload on the ARO (Tab BB-102). The system is intended to prevent the ARB Nozzle from binding in the receptacle of the receiver aircraft, so that upon disconnect, the ARB will not be under any force and the ARO can safely retract the ARB nozzle from the receiver aircraft receptacle (Tab BB-104). Before and after contact with a receiver aircraft, the ARO provides all ARB flight control input through the FCS (Tabs BB-101, BB-104).

If the force on the ARB Nozzle exceeds the prescribed limit, a visual HI-LOAD indicator displays on the AROS main display (Tab BB-107). In the event that the force on the nozzle is so great the Nozzle Load Sensors reach their maximum measurable value, the ARO visual indicator of HI-LOAD extinguishes and a separate visual and auditory warning indicator will alert to indicate that the ALAS system has exceeded its limits and is inoperative (Tab FF-6).

In this accident, the HI-LOAD indicator was displayed for 1.3 sec, starting 0.4 seconds before the automatic disconnect, when the force on the nozzle reached the prescribed limit (Tabs FF-5). Due to the force on the nozzle sensors reaching the maximum measurable value, the alert turned off 0.9 sec after the automatic disconnect (Tab FF-6). For the first 0.4 sec, the boom system was in a "contact state" (Tab FF-5). Therefore, ALAS was providing all ARB flight control inputs, and the MBO1 was not applying any input to the FCS (Tab FF-5). For the remaining 0.9 sec of the "HI-LOAD" annunciation, the boom system was in a "disconnect state" and the MBO1 was applying a pitch up command to the FCS (Tabs FF-6).

(3) ARB Telescope System

The KC-46 ARB Nozzle is connected to an inner telescoping tube that extends from and retracts into the main ARB outer structural tube. (Tab BB-98) The ARO controls extension and retraction of the telescoping tube before and after contact with the TCS (Tabs BB-96, BB-98). During contact with a receiver aircraft, the ARB control system uses sensors and actuators to move the telescoping tube automatically, following the receiver aircraft's relative movement to the tanker (Tab BB-102).

(4) KC-46A Nozzle Binding Procedures

KC-46 ARO's have one caution, which means it can lead to damage to an aircraft, located within the United States ATP 3.3.4.2 Standards Related Document that informs them that even after a disconnect signal, nozzle binding can occur (Tab BB-73). This caution informs the ARO that if nozzle binding occurs or is suspected, they should "*neutralize boom flight control inputs*" (Tab BB-73). This caution is not located in any KC-46 aircraft specific flight manuals or publications (Tab BB-73).

(5) KC-46 Air Refueling Breakaway Non-Normal Maneuver

During aerial refueling, if a condition occurs or exists that requires immediate separation of the tanker and receiver aircraft, each crewmember at a controlling position in both the tanker and receiver aircraft has a specific procedure to ensure a safe separation is achieved. This subset of emergency steps is commonly known as "Breakaway" procedures (Tab BB-106).

For the KC-46, in the event of the need for immediate separation of the tanker and receiver aircraft, the KC-46 ARO will simultaneously accomplish the following three steps (Tabs BB-106, BB-96):

1. Transmit "[Tanker Call Sign], BREAKAWAY, BREAKAWAY, BREAKAWAY" on the designated air refueling frequency.
2. Initiate an Independent Disconnect System (IDS) disconnect using the disconnect switch on the FCS.
3. Push the BREAKAWAY switch on the TCS.

The ARO will then immediately retract and clear the boom away from the receiver aircraft (Tab BB-106).

(6) KC-46A Deficiency Reports (DR)

During the Air Force acquisition process, a subprocess, known as Deficiency Reporting, Investigation, and Resolution (DRI&R) exists which provides the Air Force, "a means of identifying deficiencies, resolving those deficiencies within the bounds of the program recourses and the appropriate acceptance of risk for those deficiencies that cannot be resolved in a timely manner" (Tab BB-23). As part of DRI&R procedures, each deficiency is assigned a deficiency category (CAT) with an associated risk priority, "to capture the severity of the condition by relative importance and urgency of response" (Tab BB-24).

The governing document of the DRI&I process, T.O. 00-35D-54, *USAF Deficiency Reporting, Investigation, and Resolution*, defines the most important deficiencies as:

> CAT I deficiency - "*those which may cause death, severe injury, or sever occupational illness; may cause loss or major damage to a weapon system; critically restricts the combat readiness capabilities of the using organization; or result in a production line stoppage.*"
>
> CAT II deficiency - "*those that impede or constrain successful mission accomplishment (impacts operational safety, suitability and effectiveness but does not meet the safety or mission impact criteria of a CAT I deficiency)*"

(Tab BB-24). The KC-46 has two CAT I DRs and two CAT II DRs that are applicable to this investigation.

The first applicable CAT I DR is for the boom telescope being too stiff while in contact with a receiver aircraft (Tab O-2660). This report states the forces required by the receiver aircraft to push the telescoping tube inward are too stiff. This stiffness causes receiver aircraft to inadvertently carry excess thrust which following a disconnect can cause the receiver aircraft to rapidly accelerate towards the tanker aircraft (Tab O-2661). In the entire testing regime and for all receiver aircrafts tested, when the breakout forces were overcome to start a forward movement, an excessive telescope rate would then build (Tab O-2661). If a normal disconnect is made with the receiver aircraft pushing on the boom, the receiver aircraft may accelerate toward the tanker, greatly increasing the probability of a boom strike on the receiver aircraft (Tab O-2661).

The second applicable CAT I DR is for a lack of indication to the ARO of high forces on the ARB radial nozzle (Tab O-2636). The report states this can cause damage to the boom, could cause the ARB nozzle to depart the aircraft, and could cause high energy boom strikes on the receiver aircraft (Tab O-2639). Following the submission of this deficiency, the KC-46 air refueling system was updated with a High Boom Radial Load Indication (HBRLI), but the Air Force testing of this fix found that it had a marginal rating due to "lack of contrast" and a placement "outside the ARO's direct field of view" (Tabs O-868, O-2758). Boeing and the Air Force Life Cycle Management Office have recommended to downgrade this DR to a CAT II, but this is presently in dispute as the 418 FLTS, AFOTEC, and AMC have submitted formal challenges to this proposal (Tab O-2758).

The first applicable CAT II DR is for ARB FCS inadvertent movements. This report states the FCS stick is extremely sensitive and AROs can inadvertently make inputs into the FCS while in contact (Tab O-2667). The DR states:

> It has been observed during multiple flight test sorties that the ARO guarding the FCS or keying the intercom selector (ICS)/Radio switch or other FCS switches can cause command inputs while in contact. Pitch and roll command inputs from the ARO compete with the Automatic Load Alleviation System that uses the nozzle load sensor assembly as feedback to alleviate the radial boom loads.

(Tab O-2667). The DR also states, "Data analysis also showed that an FCS input of 2 degrees from the null position leads to an approximate load of 500 lbs and the input to load correlation is roughly linear" (Tab O-2667). This can cause high radial force on the ARB Nozzle which could result in boom damage, boom failure, nozzle binding upon disconnect, and/or rapid boom movement upon disconnect (Tab O-2669).

The second applicable CAT II DR is for ARB motion that is uncontrollable or unpredictable when the boom system becomes inoperable (Tab O-2640). This report states that when the ARB becomes inoperable, the ARB behavior may be dynamic and uncontrollable (Tab O-2640). While in this state, the ARO no longer has any ability to control the ARB (Tab O-2642). When this happens in a dynamic maneuver, it could cause structural damage to the boom and surrounding aircraft structure (Tab O-2642).

b. Structures and Systems

MA1 sustained damage in the following areas: the Aerial Refueling Boom, the left and right APU access doors, the APU exhaust, the APU exhaust deflector, and the aircraft tail section (Tab Z-12). There is potential for additional internal tail section structural damage, which will require further engineering assessment. MA2 sustained a damaged In-Flight Refueling (IFR) receptacle (Tab Z-12).

Figure 2: ARB After Landing (Tab Z-12)

(1) MA1 ARB

The ARB flexed beyond structural limits and cracked 13.5ft aft of its attachment point to the aircraft, where the ARB Stow/Unstow hook was located (Tab Z-5).

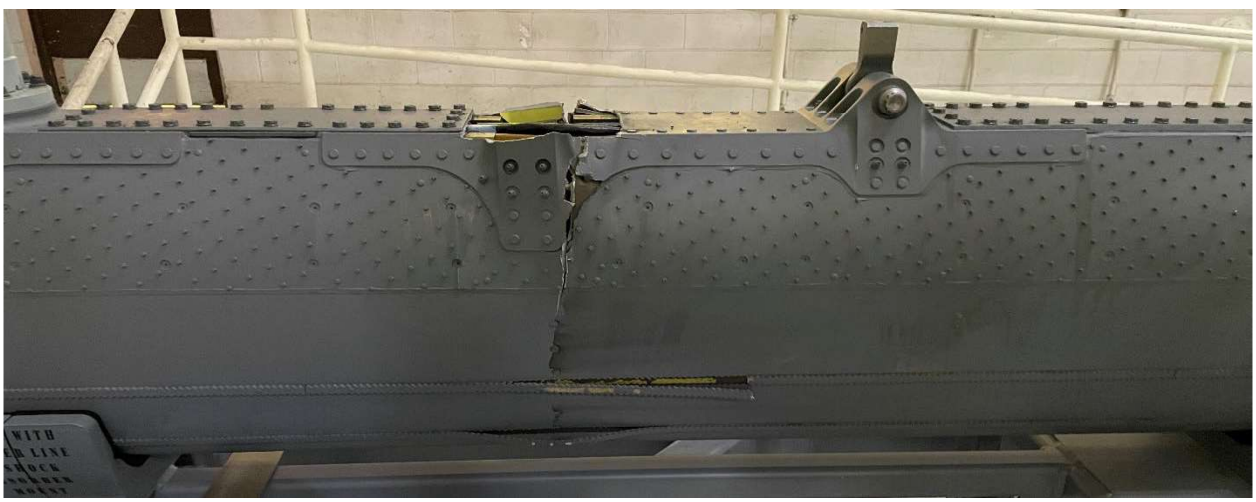

Figure 3: Close up of ARB Stow/Unstow Damage (Tab Z-5)

The second structural failure is 21.5ft down the ARB. This failure was caused by the ARB striking the tail section of the aircraft at a rate that exceeded expected capabilities. The fairing cracked along both sides and the bottom (Tab Z-6).

Figure 4: Close up of ARB Fairing Damage (Tab Z-6)

Due to the ARB striking the tail section of MA1, the ARB flight control fairing and the left ARB elevator were gauged beyond structural limits on the leading edge (Tab Z-7 AND Z-8).

Figure 5: Close up of ARB Fairing and Elevator Damage (Tabs Z-7, Z-8)

The force of the ARB striking the tail section of MA1 caused the ARB inner tube to contact the top of the ARB ice shield at 8.5ft extended and gouge the inner tube beyond structural limits (Tab Z-9, Z-11, and Z-14).

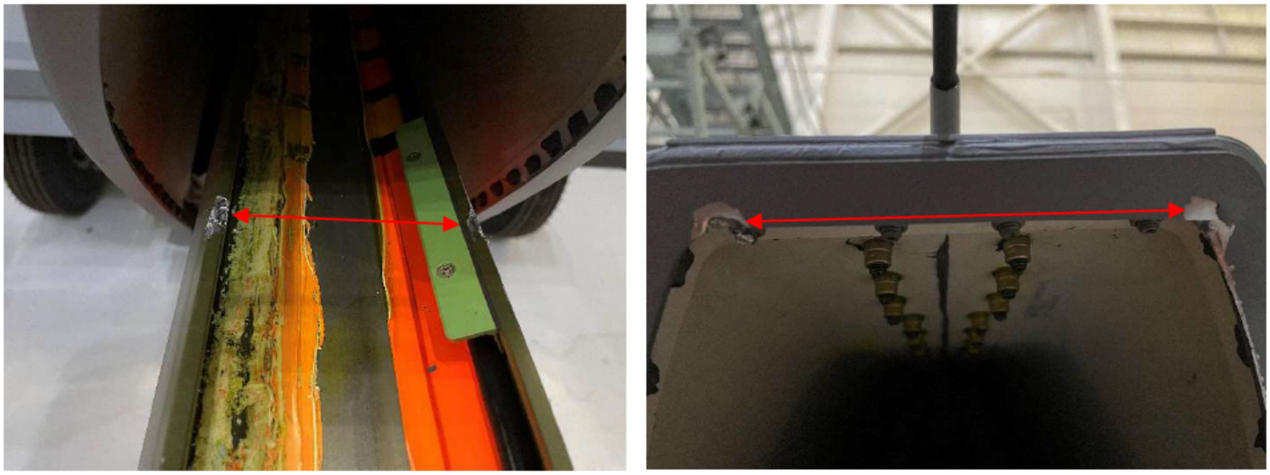

Figure 6: Close up of ARB Inner Tube and Ice Shield Damage (Tabs Z-9, Z-11)

Figure 7: ARB Inner Tube and Ice Shield (Tab Z-14)

Due to the binding incident, when attempting to disconnect from the receiver aircraft, the inner tube was pulled from the ARB, scraping the bottom edge of the ARB ice shield (Z-10). This caused abrasion damage to the ice shield composite material and to the bottom of the ARB inner tube (Tab Z-10).

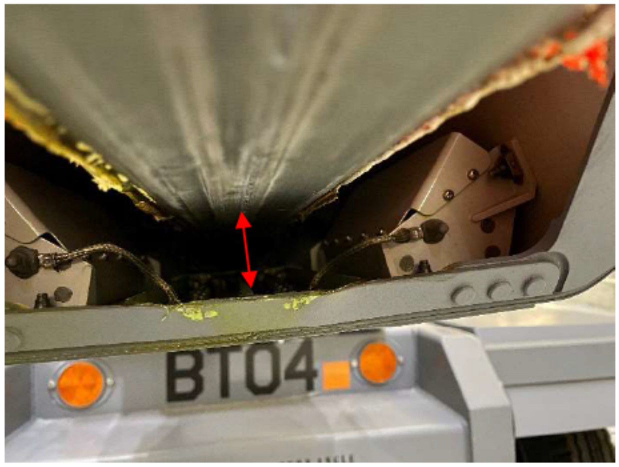

Figure 8: Close up of the Bottom Edge of the ARB Ice Shield Damage (Tab Z-10)

The binding of the ARB nozzle caused it to gouge the top of the nozzle and break off the ARB nozzle poppet valve (Tab Z-13).

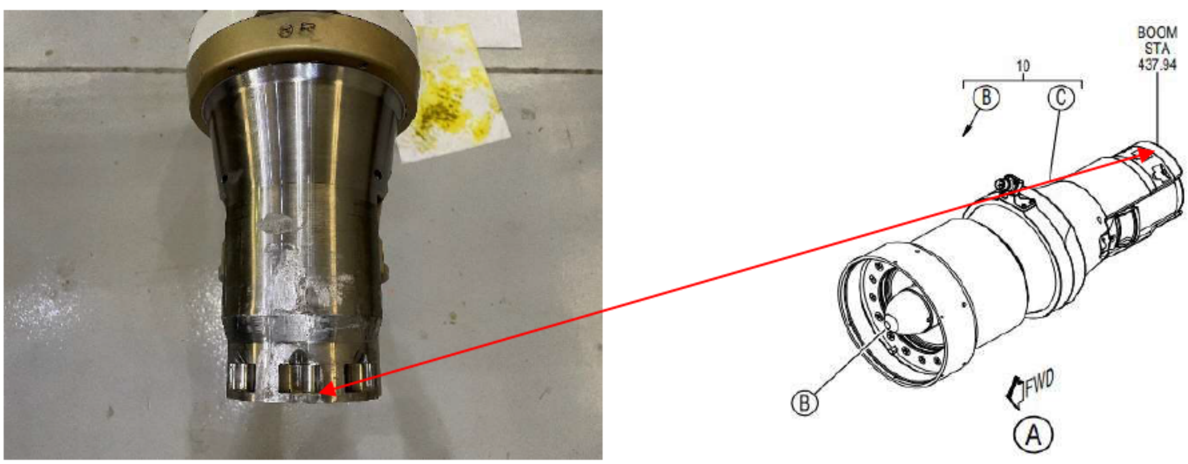

Figure 9: Close up of ARB Nozzle Damage (Tabs Z-13, D-4)

(2) MA1 Left APU access door

The Left APU access door received minor skin damage from the compression of the ARB impacting the aft section of MA1 and from compression derived from the right APU access door being damaged (Tab S-3).

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.

(3) MA1 Right APU access door

The Right APU access door received extensive damage from the ARB's impact with the aft section of MA1 (Tab Z-3 and Z-4). Multiple stiffeners were cracked and/or bent. The skin on the access door was bent and torn in multiple locations (Tab Z-3 and Z-4).

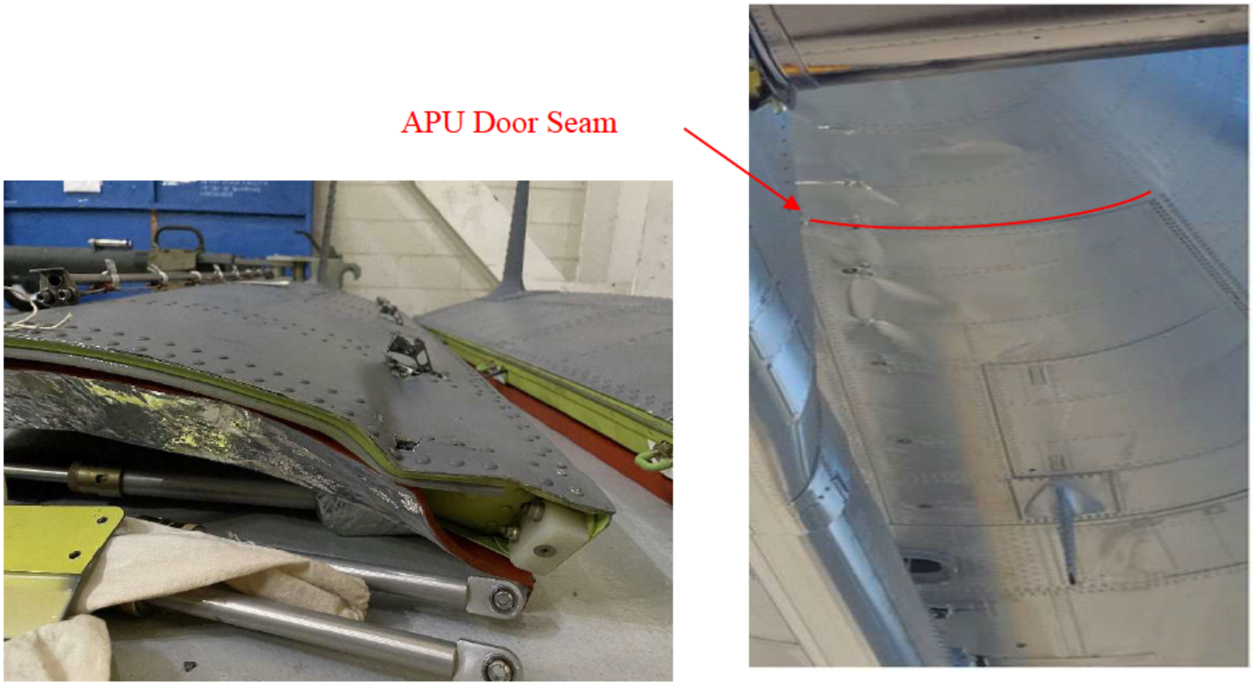

Figure 10: APU Access Door Damage (Tabs Z-3-4)

(4) MA1 APU Exhaust

The APU exhaust, located in the tail section of MA1, was crushed when the ARB struck MA1's tail section and the APU exhaust deflector (Tab Z-15).

(5) MA1 APU Exhaust Deflector

On the aft section of MA1, above the standard resting position of the ARB, is an APU exhaust deflector that diverts the APU exhaust away from the ARB flight controls. The APU exhaust deflector was pushed up into the APU exhaust by the force of the ARB striking the aft section of MA1 (Tab Z-15).

(6) MA1 Aircraft Tail Section

Multiple aircraft structural components in the tail section, aft of the APU enclosure doors, were cracked and/or pushed inwards from the impact of the boom on the lower surface of MA1's tail section (Tab Z-15).

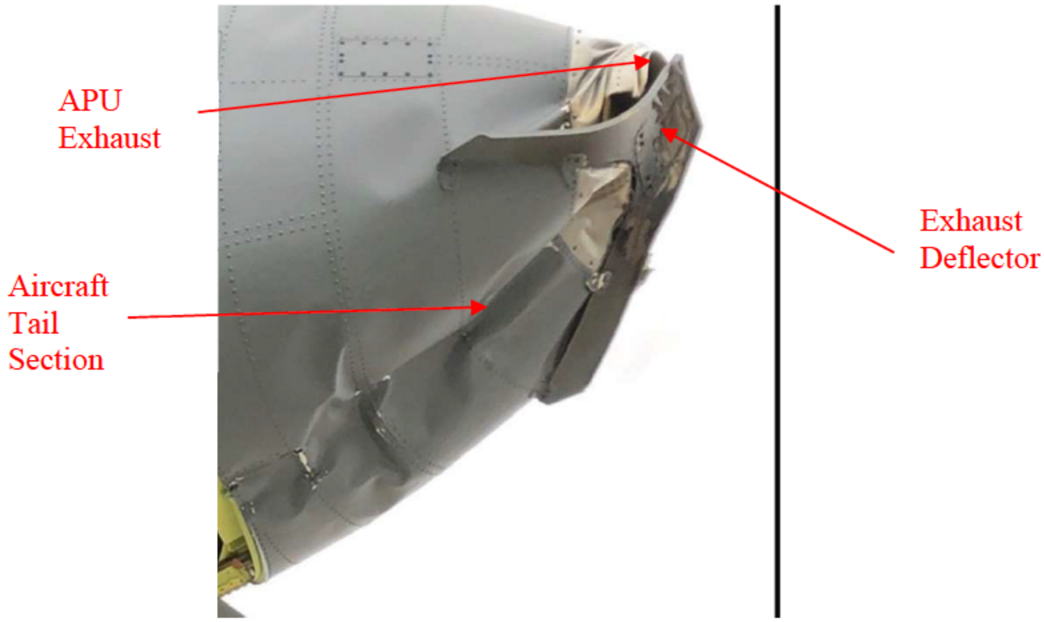

Figure 11: APU Exhaust, Exhaust Deflector and Tail Section Damage (Tab Z-16)

(7) MA2 IFR Bucket

The lower roller within the receptacle was broken off, the induction coil was cracked, and the seal for the IFR fuel line was gouged due to the binding force applied by MA1's ARB nozzle (Tab D-85).

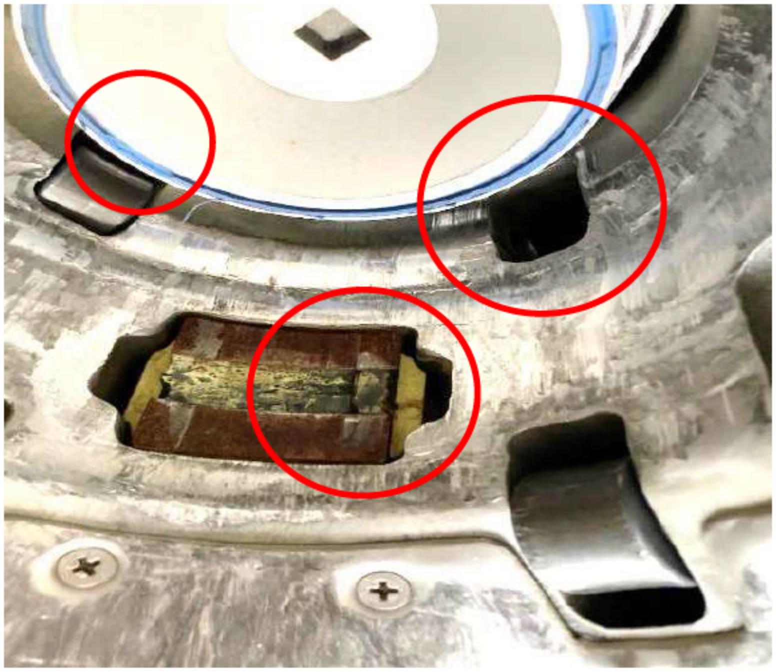

Figure 12: MA2 IFR Bucket Damage (Tab D-85)

c. Evaluation and Analysis

After review of MA1's and MA2's MIS, IMDS, and AFTO 781 series Forms, the board has concluded there was no indication of faulty operation or maintenance practices of the damaged systems prior to mishap occurrence (Tabs U-4-27. D-16-81).

Due to the nature of the incident, individual aircraft system components were not sent for analysis. Maintenance, Vendor, and Engineering evaluations of the damaged aircraft components provided a summarized damage cost. An itemized damage report estimates the total damage cost. (Tab CC-3)

d. Testing and Analysis

(1) KC-46A Boom Operator Trainer Simulator

1. Test Explanation

On 19 January 2023, the AIB Boom Operator SME performed simulated air refueling with an F-15E receiver in a KC-46A Boom Operator Trainer (BOT) at JBMDL (Tab EE-3). During the test, the Boom Operator SME performed multiple contacts and disconnects in different scenarios to help identify causal and contributing factors relevant to the mishap (Tab EE-3). These scenarios included: 1) disconnects with full up input on the FCS; 2) disconnects with both full up input on

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the FCS and full aft input on the TCS; and 3) disconnects with the receiver moving forward and down in the AR envelope to identify boom nozzle binding and HI-LOAD annunciation (Tab EE-3).

2. Disconnect Scenarios

The following scenarios were used during the disconnects from the receiver:

a. Scenario 1

While the receiver was stable in the center of the refueling envelope, a disconnect was triggered to release the mechanical connection between the ARB and the receiver aircraft receptacle (Tab EE-3). As there was no input on either FCS or TCS, the boom nozzle remained in physical contact with the receiver aircraft (Tab EE-3). Then a full FCS up input was applied (Tab EE-3). The boom nozzle remained in physical contact with the receiver aircraft receptacle with a full FCS up input and no TCS retract input (Tab EE-3). This indicates the boom nozzle could be bound in the receiver receptacle (Tab EE-3). A HI-LOAD indicator was not displayed on the ARO main display (Tab EE-3). The BOT data screen indicated 15 lbs of force on the nozzle in the vertical direction with full FCS up input (Tab EE-3).

b. Scenario 2

While the receiver was stable in the center of the refueling envelope, a disconnect was triggered to release the mechanical connection between the ARB and the receiver aircraft receptacle (Tab EE-3). Initially, no FCS or TCS inputs were made, to ensure the boom nozzle remained in physical contact with the receiver receptacle (Tab EE-3). Then a full FCS up input was applied (Tab EE-3). The nozzle remained in physical contact with the receiver with a full FCS up input and no TCS retract input (Tab EE-3). A HI-LOAD annunciation was not displayed on the ARO main display (Tab EE-3). The BOT data screen indicated there was only 15 lbs of force on the boom nozzle in the vertical direction with full FCS up input (Tab EE-3). At this time, a full aft TCS input was applied (Tab EE-3). The boom nozzle immediately retracted from the receiver receptacle and the boom did not visually respond as if there was force on the nozzle (Tab EE-3).

c. Scenario 3

While in contact with the receiver, the receiver was commanded to move forward and down at the fastest rate of motion the BOT simulation would allow (Tab EE-4). A disconnect was triggered to release the mechanical connection between the ARB and the receiver receptacle (Tab EE-4). Then a full FCS up input was applied (Tab EE-4). The nozzle remained in physical contact with the receiver aircraft with a full FCS up input and no TCS retract input (Tab EE-4). A HI-LOAD annunciation was not observed on the ARO main display (Tab EE-4). The boom data screen indicated that there was 15 lbs of force on the boom nozzle in the vertical direction with full FCS up input (Tab EE-4). Then a full aft TCS input was applied (Tab EE-4). The boom nozzle immediately retracted from the receiver receptacle and the boom did not visually respond as if there was force on the nozzle (Tab EE-4).

3. Results

The AIB found that the KC-46 BOT is unable to replicate a bound nozzle condition (Tab EE-4). The AIB Boom Operator SME attempted to re-create the incident in the BOT simulator (Tab EE-4). The BOT was unable to establish any condition that caused the boom nozzle to remain in physical contact with the receiver aircraft while the ARO activated the TCS retract command and FCS fly up command (Tab EE-4). When the TCS retract command was input, the nozzle immediately retracted from the receptacle, even with full FCS up input (Tab EE-4).

The AIB Boom Operator SME also found that the BOT is unable to provide a HI-LOAD indicator to the ARO when the nozzle is under high force (Tab EE-4). When the AIB Boom Operator SME provided a full fly up input into the FCS while the boom was mechanically disconnected but still in physical contact with the receiver aircraft, the BOOM DATA display in the BOT did not replicate accurate vertical boom nozzle force data (Tab EE-4). The vertical nozzle force displayed in the BOT with a full fly up input on the FCS was far less than the threshold that would trigger a HI-LOAD annunciation (Tab EE-4).

(2) Analysis of Data retrieved from Flight Data Recorder (FDR)

Analysis of the MA1's FDR Data was conducted by the AIB's Pilot Member (Tab FF-1-4). This analysis yielded a detailed sequence of events focused on the actions of MP1 between the initiation of air refueling contact with MA2 until after the termination of the emergency breakaway procedures (Tab FF-3). Additionally, the AIB was able to plot the position of the Engine Thrust Levers and MA1's airspeed to illustrate the magnitude of MP1's engine thrust change and effect this had on MA1's airspeed while in physical contact with MA2 (Tab FF-3).

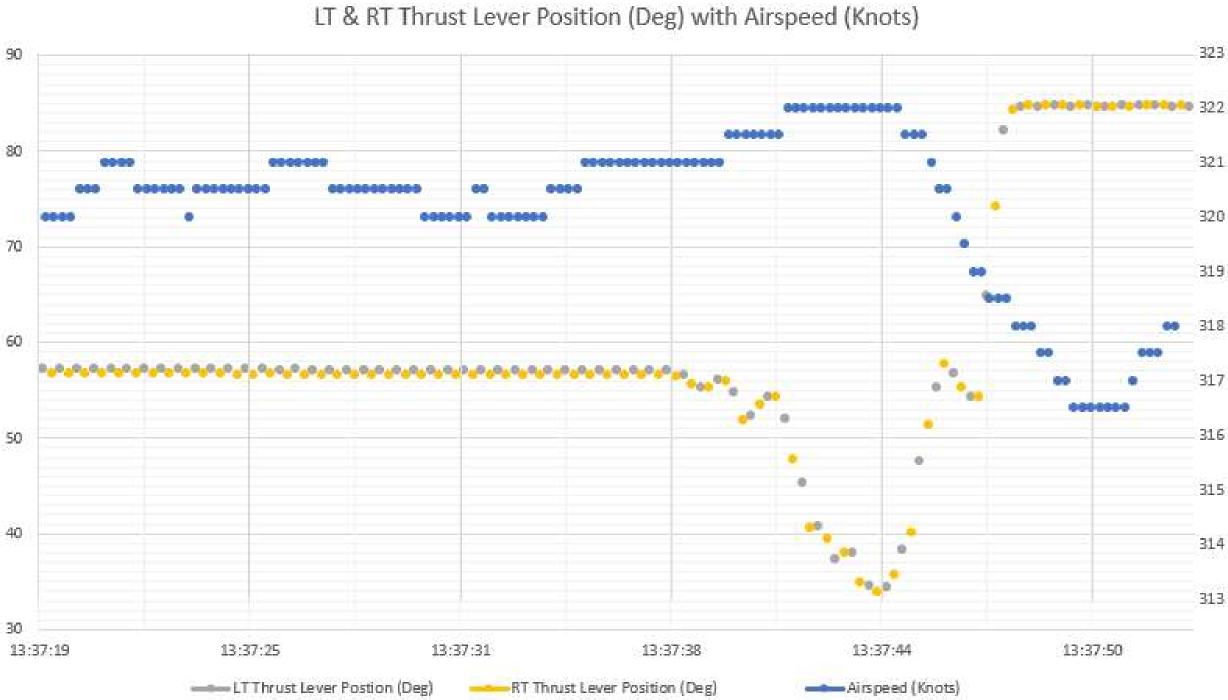

Figure 13: LT & RT Thrust Lever Position with Airspeed (Tab FF-5)

(3) Analysis of Data Retrieved from Air Refueling Control Computer (ARCC)

Analysis of the MA1's ARCC data was conducted by the AIB's Pilot Member (FF-5-7). This analysis yielded a detailed sequence of events focused on the period where the ARB was powered on and until the Tail Strike event, including the air refueling contact and breakaway emergency procedure with MA2 (Tab FF-5.7).

7. WEATHER

a. Forecast Weather

The weather forecast for the mishap area called for broken clouds beginning at 10,000 ft and layered clouds up to 45,000 ft (Tab AA-24). Visibility was forecast at one nautical mile in-cloud and unlimited out-of-cloud (Tab AA-24). Winds at 24,000 ft were forecast out of the northwest at approximately 45 knots (Tab AA-22). Turbulence, icing, and thunderstorms were not forecasted (Tab AA-24).

b. Observed Weather

Neither Mishap Crew (MC) reported mission impacting weather or weather hazards (Turbulence, icing, and thunderstorms) (Tabs V-1.3, V-2.3, V-3.3, V-6.2, V-7.3, V-8.3, V-9.3, V-10.3, V-11.3).

c. Space Environment

Not Applicable

d. Operations

Observed weather, cloud ceilings, and visibility were well above the minimums required by Air Force Manual (AFMAN) 11-202v3, *Flying Operations*, to conduct the mission, and both MCs conducted the mission within their prescribed operational weather limitations (Tabs BB-93, BB-25). No evidence suggests weather was a factor in the mishap.

8. CREW QUALIFICATIONS

All crewmembers were qualified for their respective crew positions (Tabs G-105-244, T-418-453). At the time of the mishap, all necessary flight currencies and training requirements were accomplished and verified by the scheduling authority (Tabs K-3). Due to the recent transition of the 2 ARS to the KC-46A, the total Mission Design Series (MDS) flight hours of the KC-46A crewmembers are low when compared to similar crew positions in legacy platforms. However, there is no evidence to suggest crew qualifications were a factor in this mishap.

a. Flying History/Crew Qualification Table

Table 8.1 illustrates the flight history up to 90 days prior to the mishap, the highest qualification held, and evaluation expiration date:

	Highest Qualification Held	Current MDS Hours	Expiration of Evaluation	1-30 days prior		31-60 days prior		51-90 days prior	
				Hours	Sorties	Hours	Sorties	Hours	Sorties
MP1	KC-46A Evaluator Pilot	138.4	Mar 2023	24.9	6	4.5	1	9	3
MP2	KC-46A First Pilot	100.5	Apr 2023	21.8	5	5.5	1	9.6	2
MP4	KC-46A Instructor Pilot	245.1	Jan 2023	35.9	9	50.4	8	15.9	4
MBO1	KC-46A Mission Boom	60.2	Aug 2023	21.8	5	4	2	0	0
MBO2	KC-46A Mission Boom	186.9	Sept 2023	27.4	6	47.3	7	14.4	3

MP3 Data Unavailable

Table 8.1 (Tabs G-3, G-255, T-49-52, T-149-155, T-289-295, T-454-457, T-471-475)

9. MEDICAL

a. Qualifications

At the time of the mishap, both MCs were medically qualified for flying duties IAW Department of the Air Force Manual (DAFMAN) 48-123, *Medical Examinations and Standards* (Tab T-592).

There is no evidence to suggest that any member of the MC had a medical condition, illness, or performance-limiting condition that would have caused or contributed to the mishap (Tab T-592).

b. Health

Toxicology reports of both MCs and involved maintenance members were reviewed and all were negative for ethanol, amphetamines, barbiturates, benzodiazepines, cannabinoids, cocaine, opiates, phencyclidine, and sympathomimetic amines (Tab G-245-254).

c. Pathology

Not Applicable

d. Lifestyle

There is no evidence to suggest lifestyle factors were a factor in the mishap.

e. Crew Rest and Crew Duty Time

There is no evidence to indicate that crew rest was a factor in the mishap. Both MCs appear to have been in compliance with AFMAN 11-202v3, *Flight Operations*, which requires a minimum of 12 non-duty hours prior to a flight, including an opportunity for at least eight hours of uninterrupted sleep (Tabs R-41-154). Both MCs completed 72-hour/14 day histories, none of which indicated a lack of opportunity for adequate crew rest (Tab R-41-154).

10. OPERATIONS AND SUPERVISION

a. Operations

MC1's flight complied with all applicable AMC guidance (Tab BB-3-21).

MC2 was scheduled to transit the North Atlantic. The flight complied with all applicable Air Combat Command guidance (Tab BB-3-21).

There is no evidence to suggest operations were a factor in the mishap.

b. Supervision

The 2 ARS leadership ensured all flight members were current and qualified for the mission (Tab K-3).

There is no evidence to suggest supervision was a factor in the mishap.

11. HUMAN FACTORS ANALYSIS

a. Introduction

Human Factors describe how our interaction with tools, tasks working environments, and other people influence human performance. This report includes an analysis of the human performance variables that contributed to this mishap. Interviews with personnel involved in the air refueling mission, including the MC, maintenance personnel and other involved individuals, as well as the Department of Defense (DoD) Human Factors Analysis and Classification System 7.0 (HFACS 7.0) model were used to present a systematic, multidimensional approach to mishap analysis (Tab BB-29).

The AIB found elements of each of the following human factors across operations throughout the investigation:

b. Unintended Operation of Equipment (DoD HFACS AE101)

When an individual's movements inadvertently activate or deactivate equipment, controls or switches when there is no intent to operate the control or device (Tab BB-33). This action may be noticed or unnoticed by the individual. MBO1 inadvertently made inputs to the ARB control system while accomplishing his proper procedures for an emergency breakaway (Tab V-6.8).

c. Controls and Switches are Inadequate (DoD HFACS PE204)

When the location, shape, size, design, reliability, lighting or other aspect of a control or switch are inadequate (Tab BB-37). Multiple design deficiencies exist for the KC-46 ARB control system which contributed to the mishap circumstances.

d. Automated System Creates an Unsafe Situation (DoD HFACS PE205)

When the design, function, reliability, lighting, or other aspect of automated systems creates an unsafe situation (Tab BB-37). The Stiff Boom and Uncontrollable Boom deficiencies are both related to automated functions which contributed to an unsafe situation.

e. Failure to Provide Adequate Operational Information Resources (DoD HFACS OR008)

When weather, intelligence, operational planning material or other information necessary for safe operations planning are not available (Tab BB-46). The KC-46 BOT was unable to simulate a high radial force scenario, making it impossible for ARS to perform hands on training in this situation.

f. Provided Inadequate Procedural Guidance or Publications (DoD HFACS OP003)

When written direction, checklists, graphic depictions, tables, charts or other published guidance is inadequate, misleading or inappropriate (Tab BB-46). The United States SRD contains a warning and a caution paragraph whose guidance requires the ARO to take action in less time than is reasonable for a human operator.

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Publicly Available Directives and Publications Relevant to the Mishap

- AFI 51-307, *Aerospace and Ground Accident Investigations*, 18 March 2019
- DAFMAN 48-123, *Medical Examinations and Standards,* 8 December 2020
- AFMAN 11-202v3, *Flight Operations*, 10 January 2022
- AFMAN 11-2KC-46v3, *KC-46 Operations Procedures*, 12 July 2021
- AFMAN 11-2F-15Ev3, *F-15E – Operations Procedures,* 24 September 2020
- AFI 11-221, *Air Refueling Management (KC-10, KC-46, KC-135),* 5 June 2020

NOTICE: All directives and publications listed above are available digitally on the Air Force Departmental Publishing Office website at: https://www.epublishing.af.mil.

b. Other Directives and Publications Relevant to the Mishap

- Technical Order (TO) 1C-46(K)A-1, *Flight Manual – Flight Crew Operations Manual,* Revision 17 – 17 October 2022
- TO 1C-46(K)A-1CL-1, *Flight Manual – Quick Reference Handbook, Pilot Handheld Checklist*, Revision 17, 17 October 2022
- ATP 3.3.4.2. (D) *United States Standards Related Document*, 27 June 2022
- TO 00-20-1-WA-1, *Aerospace Maintenance Inspection, Documentation, Policy, and Procedures,* 26 September 2022
- TO 00-20-2-WA-1, *Maintenance Data Documentation,* 22 July 2021
- TO 00-25-172-WA-1 *Ground Servicing of Aircraft and Static Grounding Bonding,* 23 May 2022

- AFI 21-101 AMC Supplement, *Aircraft and Equipment Maintenance Management,* 11 March 2022
- TO 1C-46(K)A-2-WA-1, *Maintenance Manuals – KC-46A Aircraft Interactive Electronic Technical Manual (IETM),* 13 January 2023
- TO 1C-46(K)A-1-724C, *Modification of the Aerial Fueling Management System (ARMS), ARMS 1.3, SB KC46-28-0014 Rev A, KC-46A Aircraft,* 6 April 2022
- TO 1C-46(K)A-1-784, *Modification of Aerial Refueling Boom Hoist Cable Detent Pin, SB KC46-28-0012 Rev A, KC-46A Aircraft,* 19 August 2022
- TO 1C-46(K)A-1-725C, *Modification of the Remote Vison System, ARMS 1.4 ERVS, SB KC46-28-0013 Rev B, KC-46A Aircraft,* 13 May 2022
- TO 1C-46(K)A-1-837, *Inspection of the Boom Telescope Tube Slider Assembly P/N 842-349881-1, KC-46A Aircraft,* 9 November 2022
- TO 1C-46(K)A-1-788, *Installation of Software for KC-46A Flight Management Computer, KC46(M)-34-0004 and SB-767-34-0981, KC-46A Aircraft,* 20 July 2022
- TO 1F-15E-6WC-1-WA-1, *Combined Pre-flight Post-Flight Inspection USAF Series F-15E Aircraft,* 18 August 2022
- TO 1F-15E-6WC-2-1-WA-1, *Aircraft Pre-Launch Inspection USAF Series F-15E Aircraft,* 1 July 2021
- TO 1F-15E-6WC-2-2-WA-1, *Aircraft Launch Inspection Procedures USAF Series F-15E Aircraft,* 15 August 2022
- TO 1F-15E-6WC-2-3-WA-1, *End-of-Runway Inspection USAF Series F-15E Aircraft,* 1 March 2022

c. Known or Suspected Deviations from Directives or Publications

Not Applicable

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Chad K. Cisewski, Colonel, USAF
President, Accident Investigation Board

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.

STATEMENT OF OPINION

KC-46A, T/N 15-046069
LOCATION: North Atlantic Ocean (N 51º 15.90 W 052º 58.80)
15 October 2022

1. OPINION SUMMARY

On 15 October 2022 at 1313:46 Zulu (Z), a KC-46A Pegasus and an F-15E Strike Eagle conducting routine air refueling operations experienced a nozzle binding event during a breakaway which resulted in the Aerial Refueling Boom (ARB) striking the tail section of the KC-46A. Mishap Aircraft 1 (MA1), a KC-46A, T/N 15-046069, is assigned to the 305th Air Mobility Wing (AMW), Joint Base McGuire-Dix-Lakehurst (JBMDL), New Jersey, and operated by Mishap Crew 1 (MC1), assigned to the 2d Air Refueling Squadron (ARS), JBMDL. Mishap Aircraft 2 (MA2), an F-15E, T/N 87-0192, is assigned to the 4th Fighter Wing (FW), Seymour Johnson AFB, North Carolina, and operated by Mishap Crew 2 (MC2), assigned to the 335th Fighter Squadron (FS), Seymour Johnson AFB. The total monetary value of government loss was approximately $8,307,257.93.

I find, by a preponderance of the evidence, one cause for this mishap. Due to a limitation of the Air Refueling Boom (ARB) control system, Mishap Boom Operator 1 (MBO1) inadvertently placed a radial force on the ARB that caused the nozzle to become bound in the receiver's receptacle. As a result, the bound forces exceeded the structural limitations of the ARB and caused a rapid upward movement of the ARB when released, striking the tail cone of MA1.

Additionally, I find, by a preponderance of the evidence, two factors which substantially contributed to the mishap. The first factor is the failure of Mishap Pilot 1 (MP1) to alert Mishap Pilot 3 (MP3) and Mishap Boom Operator 1 (MBO1) to an engine power reduction on MA1. This action, combined with the known ARB stiffness limitation and the resulting high engine power setting on MA2, resulted in a rapid forward movement of MA2 relative to MA1.

The second factor is that due to a limitation of the automated boom control system, the ARB entered an uncontrollable state during its upward motion toward the aircraft tail, disabling the boom control laws which could have slowed the rate at which the ARB struck the tail cone, substantially contributing to the mishap.

2. CAUSE

a. Inadvertent Radial Force Placed on the Air Refueling Boom

Upon review of the ARB system data captured by the Air Refueling Control Computer (ARCC) on 15 October 2022 and analyzed by the Board's Pilot Member, the Accident Investigation Board (AIB) identified the high radial load, which exceeded the end-of-range limitation of the ARB sensors, as the primary cause of the boom nozzle becoming bound in MA2's air refueling receptacle. I believe that had this high radial load not been introduced, the boom nozzle would have fully retracted under the Telescope Control Stick (TCS) command which MBO1 input at the onset of the breakaway.

While further review of the ARCC data demonstrates that this high radial load was a result of inputs made to the FCS by MBO1, witness testimony shows that MBO1 did not make any conscious inputs to the Flight Control Stick (FCS) but was only conscious of his TCS inputs and procedurally required disconnect switch actuation and radio transmission. When this information is considered with two of the Deficiency Reports which exist for the KC-46, a pattern begins to emerge which leads me to conclude that this FCS input by MBO1 was inadvertent and due to a limitation of the KC-46 ARB control system.

The first deficiency report, submitted 2 October 2018 and officially categorized as a Category (CAT) II deficiency, is titled "*Boom Flight Control Stick Inadvertent Movements*" and details the possibility for inadvertent Aerial Refueling Operator (ARO) inputs to the FCS. The second deficiency report, submitted 10 September 2018 and categorized as a CAT I deficiency, is titled "*No Indication of High Boom Radial Loads*" and details the threat which a lack of radial load indication can pose to KC-46 ARB operation.

In the event of an emergency breakaway like MA1 and MA2 experienced, the procedure for the ARO is to actuate the disconnect trigger switch located on the rear of the FCS and transmit on the shared air refueling radio frequency using either the FCS mounted switch or a floor mounted foot switch. In testimony given to the AIB, MBO1 stated that he normally used the radio switch located on the FCS to make radio transmissions. The CAT II deficiency report highlighted these switches as potential causes for inadvertent command inputs on the FCS, emphasizing that only 2 degrees of FCS input can lead to approximately 500 lbs of radial nozzle forces.

While software changes have been made to the ARB indication system to help address the lack of warning, Air Force test documentation and witness testimony from MBO1 and MBO2 demonstrate the limited effectiveness of this "HI-LOAD" indication. In the 1.3 seconds that "HI-LOAD" was indicated on the ARO and Aerial Refueling Operator Instructor (AROI) screens, MBO1 and Mishap Boom Operator 2 (MBO2) were so task saturated with their emergency breakaway procedures that neither became aware of the condition. This is consistent with findings published by the 412th Test Wing in April 2021, which deemed the KC-46A High Boom Radial Load Indications visibility as "unsatisfactory due to a lack of contrast against the imagery provided by the Remote Vision System and its placement outside the ARO's direct field of view."

The AIB found that, due to the ongoing development of the KC-46 program, the command guidance and training for inadvertent FCS inputs, radial boom forces, and nozzle binding was incomplete and in one case, contradictory. The KC-46 Boom Operator Trainer (BOT), a contract simulator where AROs can practice normal and abnormal procedures, was found by the AIB to be unable to replicate nozzle binding due to intentional or unintentional forces on the FCS.

Additionally, the AIB found the BOT to be unable to display the "HI-LOAD" indicator, leaving AROs unable to experience this indicator except while operating the ARB in flight.

The United States Standards Related Document (US SRD), which standardizes air refueling procedures for all United States Forces, contains two paragraphs which when applied to the scenario MBO1 found himself in, can reasonably lead to contradictory actions. The first is a warning, which means it can lead to loss of life or loss of aircraft, which states:

> Due to inadvertent and undetected KC-46 boom loading, the boom may rapidly move towards the receiver upon disconnect. The boom operator should be prepared to immediately fly the boom away from the receiver upon disconnect.

The second paragraph is a caution, which means it can lead to damage to an aircraft, which states:

> Binding of the boom nozzle in the receiver's receptacle is possible, even with a disconnect signal. While nozzle binding can occur in most disconnect positions, it is most likely at high receiver roll and low boom elevation. If nozzle binding occurs or is suspected, neutralize boom flight control inputs. Avoid abrupt boom flight control input.

While each paragraph is easily applicable when taken separately, when held together and, considering the 4.9 sec timeframe from automatic disconnect to the ARB striking the tail cone, it is not a reasonable conclusion that MBO1 could have recognized his inadvertent input and corrected the situation with the current ARB control deficiencies.

3. SUBSTANTIALLY CONTRIBUTING FACTORS

a. Lack of Coordination from MP1 to MBO1 and MP3 in Conjunction with MA2's Higher Power Setting

The first part of this contributing factor is the higher power setting used by MA2, which can in part be explained by a documented ARB deficiency in the KC-46. This deficiency report, submitted 10 September 2018 and officially categorized as a CAT I deficiency, is titled, "*Boom Telescope Too Stiff While In Contact With Receiver*." It details the excessive force receiver aircraft are required to exert on the boom nozzle to trigger a retraction of the ARB to accommodate forward motion of the receiver. In some demonstrated cases, the forces exerted by the ARB hydraulic actuation system would even push receivers back and out of the air refueling envelope. In the case of the F-15, it was demonstrated during certification testing that pilots would require, "significantly more fore-aft thrust input in order to move the boom telescope in and out while in contact" due to the stiff boom. This was demonstrated by MA2 and observed by MP3 immediately prior to the emergency breakaway between MA1 and MA2.

MA2's higher power setting alone did not cause its rapid forward movement in the ARB envelope, but in combination with MP1's engine power reduction while approaching the KC-46 ARB speed limitation, the two states compounded. I believe it is important to note that the act of making an engine power reduction by MP1 was not wrong or outside proper operating procedures, but his failure to alert MP3 and MBO1 in combination with magnitude of the engine power reduction was in contradiction to safe operation.

The US SRD contains a common warning that states, "Tanker airspeed and altitude changes must be made smoothly and cautiously while the receiver is in or near the contact position." Additionally, KC-46A Flight Crew Operations Manual limitations section directs pilots and boom operators to, "*Discontinue air refueling*" if the aircraft exceeds the ARB speed limitation but also directs, "*Air refueling may be resumed when the aircraft returns within the...envelop*e." Considering the direction of the limitation and the common US air refueling guidance, the engine power reduction to its minimum setting made by MP1 with no coordination exceeded what can be deemed a reasonable definition of "*smoothly and cautiously*".

b. Air Refueling Boom Entered an Uncontrollable State

Under normal operation of the ARB, a complement of software known as "boom control laws" control the output of the ARB elevator and rudder to keep the ARB within its allowed movement envelope. In the analysis of the event's ARCC data, it was identified that an ARB flight control input was made by the boom control laws to attempt to arrest the upward movement in the moment immediately following the release of MA1's boom nozzle from MA2's air refueling receptacle. Due to a documented deficiency in the ARBs control system, this input was terminated 0.1 seconds after initial onset and the ARB flight controls reverted to neutral positions, causing the ARB to become uncontrollable.

The deficiency report, submitted 8 January 2018 and officially categorized as a CAT II deficiency, is titled, "*Aerial Refueling Boom Motion is Uncontrollable/Unpredictable When the Boom System Becomes Inoperable.*" It details hazards associated with the dynamic and uncontrollable behavior of the ARB, when its control system becomes inoperable. This inoperable state, triggered when the ARB movement exceeds 25°/sec, disables all ARO controls and any automated safeguards imposed by the boom control laws. In one specific test event, the ARB exceeded the structural limits of the system, causing damage to the boom and surrounding aircraft structure.

When MA1's ARB began its rapid upward movement, the rate of travel (73.69°/sec) exceeded the fault threshold documented in the deficiency, disabling the ARO controls and halting the automatic elevator movements triggered by the boom control laws. I believe that had these automatic safeguards continued their efforts, the rate of motion would have been lessened and some of the damage to the ARB and aircraft structure could have been avoided. Instead, due to the limitation of the ARB control system, the ARB reverted to a state that was documented as dynamic and uncontrollable, leading to considerable damage.

4. CONCLUSION

I find, by a preponderance of the evidence, one cause for this mishap. Due to a limitation of the ARB control system, MBO1 inadvertently placed a radial force on the ARB that caused the nozzle to become bound in the receiver's receptacle. As a result, the bound forces exceeded the structural limitations of the ARB and caused a rapid upward movement of the ARB when released, striking the tail cone of MA1.

Additionally, I find, by a preponderance of the evidence, two factors which substantially contributed to the mishap. The first factor is the failure of MP1 to alert MP3 and MBO1 to an engine power reduction on MA1. This action, combined with the known ARB stiffness limitation and the resulting high engine power setting on MA2, resulted in a rapid forward movement of MA2 relative to MA1.

The second factor is that due to a limitation of the automated boom control system, the ARB entered an uncontrollable state during its upward motion toward the aircraft tail, disabling the boom control laws which could have slowed the rate at which the ARB struck the tail cone, substantially contributing to the mishap.

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CHAD K. CISEWSKI, Colonel, USAF
President, Accident Investigation Board

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