UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION
BOARD REPORT

KC-46A, T/N 15-46070

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

LOCATION: Off the Coast of Florida

DATE OF ACCIDENT: 7 November 2022

BOARD PRESIDENT: COLONEL JUSTIN D. BALLINGER

Conducted IAW Air Force Instruction 51-307

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 7 November 2022 mishap off the coast of Florida, involving a KC-46A, T/N 15-046070, assigned to the 305th Air Mobility Wing, Joint Base McGuire-Dix-Lakehurst, 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 15-46070
Off the Coast of Florida
7 November 2022

On 7 November 2022 at 1852:57 Zulu (Z), a KC-46A Pegasus and a F-22A Raptor conducting routine air refueling operations experienced a nozzle binding event during a breakaway which resulted in damage to the Air Refueling Boom (ARB) Nozzle of the KC-46A. Mishap Aircraft 1 (MA1), a KC-46A, T/N 15-046070, 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-22A, T/N 09-004183, is assigned to the 1st Fighter Wing (FW), Joint Base Langley-Eustis (JBLE), Virginia, and operated by Mishap Pilot 3 (MP3), assigned to the 94th Fighter Squadron (FS), JBLE. Total monetary value of government loss was approximately $103,295.12.

I find, by a preponderance of the evidence, one cause for this mishap. Mishap Boom Operator 1 (MBO1) made manual control inputs to the ARB which caused a radial force to be applied to the ARB nozzle, causing it to become bound inside the receiver's air refueling receptacle. As a result, the bound forces exceeded the structural limitations of the ARB nozzle, damaging the nozzle beyond repair.

Additionally, I find, by a preponderance of evidence, two factors which substantially contributed to the mishap. The first factor is the failure of Mishap Pilot 3 (MP3) to account for the KC-46A Stiff Boom characteristics, causing a rapid forward movement of MA2 relative to MA1, substantially contributing to the mishap.

The second factor is that MBO1 was unable to verify that the ARB nozzle was clear of MA2's air refueling receptacle prior to making ARB control inputs, substantially contributing to the mishap.

SUMMARY OF FACTS AND STATEMENT OF OPINION
KC-46A, T/N 15-046070
Off the Coast of Florida
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ACRONYMS AND ABBREVIATIONS

ACC	Air Combat Command
ACM	Additional Crew Member
ACU	Actuator Control Unit
AFB	Air Force Base
AFI	Air Force Instruction
AFMAN	Air Force Manual
AFOTEC	Air Force Operational Test and Evaluation Center
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
APT	Automated Performance Tool
ARB	Air Refueling Boom
ARMS	Air Refueling Management System
ARO	Air Refueling Operator
AROCDU	Aerial Refueling Operator Control Display Unit
AROI	Air Refueling Operator Instructor
AROS	Air Refueling Operator Station
ARS	Air Refueling Squadron
ARCC	Air Refueling Control Computer
BDA	Battle Damage Assessment
BPO	Basic Post Flight
BOT	Boom Operator Trainer
CAT	Category
CDS	Center Drogue System
DAFMAN	Department of the Air Force Manual
DoD	Department of Defense
DR	Deficiency Reports
EICAS	Engine Indication and Crew Alerting System
FBO	Fixed Base Operator
FCOM	Flight Crew Operations Manual
FCS	Flight Control Stick
FCTM	Flight Crew Training Manual
FLTS	Flight Test Squadron
FS	Fighter Squadron
FTU	Formal Training Unit
FW	Fighter Wing
GVI	General Visual Inspection
HBRLI	High Boom Radial Load Indication
HFACS	Human Factors Analysis Classification System
IAW	In Accordance With
ILS	Instrument Landing System
IDS	Independent Disconnect System
IMDS	Integrated Maintenance Data System
JBMDL	Joint Base McGuire-Dix-Lakehurst
JBLE	Joint Base Langley-Eustis
L	Local Time
LNAV	Lateral Navigation
MA	Mishap Aircraft
MBO	Mission Boom Operator
MC	Mishap Crew
MCT	Mission Certification Training
MIS	Maintenance Information System
MP	Mishap Pilot
MPC	Mission Planning Cell
NOTAMs	Notices to Air Missions
PDI	Pilot Director Indicator
PLI	Pre-Launch Inspection
PR	Pre Flight
QRH	Quick Reference Handbook
RAIS	Refueling Alert Indication System
RVS	Remote Vision System
SRD	Standards Related Document
TDY	Temporary Duty
TCS	Telescoping Control Stick
TLSCP at DISC	Telescope at Disconnect
TSAS	Tactical Situational Awareness System
VNAV	Vertical Navigation
WARPS	Wing Aerial Refueling Pods
Z	Zulu

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 6 February 2023, Lieutenant General Randall Reed, Deputy Commander, Air Mobility Command (AMC), appointed Colonel W. Alan Berck to conduct an aircraft accident investigation of a mishap which occurred on 7 November 2022 involving a KC-46A Pegasus aircraft and an F-22A Raptor aircraft near Pensacola, Florida. Upon Col Berck's retirement, on 31 May 2024, Lieutenant General Reed appointed Colonel Justin D. Ballinger to complete the AIB (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 16 February 2023 through 30 June 2025. Accident Investigation Board (AIB) members were a KC-46 Pilot Member Major, a Legal Advisor Captain, a KC-46 Boom Operator Master Sergeant, a Recorder Master Sergeant, and a KC-46 Maintenance Member Technical Sergeant (Tab Y-3).

b. Purpose

In accordance with AFI 51-307, *Aerospace and Ground Accident Investigations*, this AIB conducted a legal investigation to inquire into all the facts and circumstances surrounding this Air Force aerospace accident, prepared a publicly- releasable report, and obtained and preserved all available evidence for use in litigation, claims, disciplinary action, and adverse administrative action.

2. ACCIDENT SUMMARY

On 7 November 2022 at 1852:57 Zulu (Z), a KC-46A Pegasus and an F-22A Raptor conducting routine air refueling operations experienced a nozzle binding event during a breakaway which resulted in damage to the Air Refueling Boom (ARB) Nozzle of the KC-46A (Tab K-3). Mishap Aircraft 1 (MA1), a KC-46A, T/N 15-04670, 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 (Tab CC-17). Mishap Aircraft 2 (MA2), an F-22A, T/N 09-004183, is assigned to the 1st Fighter Wing (FW), Joint Base Langley-Eustis (JBLE), Virginia, and operated by Mishap Pilot 3 (MP3), assigned to the 94th Fighter Squadron (FS), JBLE (Tabs K-3, R-5). Total monetary value of government loss was approximately $103,295.12.

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 CC-9).

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. (Tab CC-13).

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 conducts aerial refueling missions (Tab CC-17).

d. KC-46A Pegasus

The KC-46A Pegasus is the first phase in recapitalizing the United States Air Force's aging tanker fleet (Tab CC-3). 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 CC-3).

e. 1st Fighter Wing (1 FW)

The 1st Fighter Wing operates and maintains the F-22 Raptor. The Air Force announced in 2002 that the 1 FW would become the first F-22 operational wing, paving the way for the future of air dominance. (Tab CC-19).

f. 94th Fighter Squadron (94 FS)

The 94 FS is tasked to provide Air Superiority for the United States and allied forces by engaging and destroying enemy forces, equipment, defenses or installations. The squadron operates the world's most advanced Air Dominance fighter, the F-22A Raptor, and is ready for global deployment as part of the 1st Fighter Wing. (Tab CC-21).

g. F-22A Raptor

The F-22 Raptor is a combination of stealth, super cruise, maneuverability, and integrated avionics, coupled with improved supportability and represents an exponential leap in warfighting capabilities (Tab CC-5). The Raptor performs both air-to-air and air-to-ground missions, allowing full realization of operational concepts vital to the 21st century Air Force. The F-22, a critical component of the Global Strike Task Force, is designed to project air dominance, rapidly and at great distances and defeat threats attempting to deny access to our nation's Air Force, Army, Navy and Marine Corps (Tab CC-5).

4. SEQUENCE OF EVENTS

a. Mission

On 7 November 2022, MC1 was scheduled to fly MA1 on a local training mission from Cecil Field, Florida (Tab K-3). The mission was part of an ongoing temporary duty (TDY) in support of multiple flights of fighter aircraft participating in a joint force exercise at Tyndall Air Force Base (AFB), Florida (Tab AA-3 to AA-12). MC1 was supplementing a detachment of aircrew from the 78th ARS with the authorization of both the 2d ARS (Tab AA-19) and 78th ARS leadership (Tab AA-15). MA1, as part of the mission, originally departed JBMDL, NJ on 28 October 2022 and had been conducting training missions in support of the aforementioned joint force exercise out of Cecil Field, FL (Tab AA-15).

MP3 was scheduled to fly MA2 as the second aircraft in a four-aircraft formation of F-22As participating in a day-time joint force exercise from Tyndall AFB, FL (Tab R-5). The 94th FS leadership authorized the mission (Tab R-5).

b. Planning

Due to the nature of their exercise support mission, all initial mission, weather, and fuel planning was accomplished for MC1 by the joint exercise Tanker Mission Planning Cell (MPC) at Cecil Field (Tab V-1.3). Mission and flight information was physically delivered to the crew on the day prior to their mission (Tab V-1.3). Following their crew alert and show, MC1 reviewed all provided mission paperwork, familiarized themselves with applicable general and receiver specific information, and completed their review of weather and Notice to Air Missions (NOTAMs) information (Tab V-1.3, V-4.2). MC1 briefed the mission details in their hotel lobby and completed the briefing in the operations building provided by the Fixed Base Operator (FBO) at Cecil Field (Tab V-2.2).

All mission, weather and fuel planning were accomplished for MP3 by the joint exercise MPC at Tyndall AFB, Florida (Tab V-3.2). Following his arrival to operations, MP3 reviewed and was briefed on all provided mission paperwork, as well as the departure, enroute and airspace plan by their flight lead (Tab V-3.2). IAW applicable Air Combat Command (ACC) guidance, the formation did not discuss or brief any KC-46 specific air refueling procedures because it was understood that all members of the flight had previously refueled from a KC-46 (Tabs V-3.3, BB-436).

c. Preflight

MC1 was composed of one Instructor Pilot [Mishap Pilot 1 (MP1)], one Mission Pilot [Additional Crew Member 1 (ACM1)], one Mission Pilot undergoing Mission Certification Training (MCT) (ACM2), one Co-Pilot (MP2) and two Mission Boom Operators [Mishap Boom Operator (MBO1, MBO2)] (Tab K-4). The crew self-alerted at approximately 0915L Local Time (L)/1415Z on Monday, 7 November 2022 (Tabs V-1.2). MA1 was reported fully mission capable with a fuel load of 179,200 pounds (Tab L10). MC1 showed to the Cecil Field operations building at approximately 1030L/1530Z to complete their crew briefing and move to MA1 to perform preflight duties (Tab V-4.2).

MP3 was a recently certified Mission Pilot (Tabs G-230, V-3.2). He showed to his brief at Tyndall AFB at approximately 0930L/1430Z on Monday, 7 November 2022 and then moved to MA2 to perform preflight duties (Tab V-3.3).

Nothing of significance was noted during MC1's nor MP3's preflight, ground operations, or departure (Tab V-1.3).

d. Summary of Accident

On 7 November 2022, at 1759Z, MA1, callsign STEAM 46, took off from Cecil Field enroute to its assigned air refueling airspace (Tab AA-13). The takeoff and departure were uneventful (Tab V-3.3).

At approximately 1831Z, MA2, callsign RAPTOR 2, took off as the second aircraft in a four aircraft formation from Tyndall AFB (Tab V-3.3). The takeoff and departure were uneventful (Tab V-3.3).

At approximately 1843Z, STEAM 46 and RAPTOR flight rendezvoused in the vicinity of the W-155 airspace located off the coast of Pensacola, Florida, and began to conduct air refueling operations at 23,000 ft and 310 knots airspeed (Tabs DD-9, V-3.3). The leader of RAPTOR Flight, callsign RAPTOR 1, completed a successful refueling with MA1 and departed the formation as planned prior to MA2 maneuvering to begin air refueling with MA1 (Tabs K-3, V-6.5, DD-9).

At 1851:33Z, MBO1 extended the ARB telescope in a visual signal to MP3 that he was cleared into the proper air refueling position behind MA1 and MP3 began maneuvering MA2 into position (Tab DD-9). MC1 characterized MA2s initial maneuvers as “a little unstable” and transmitted on the shared air refueling frequency to return to a stable awaiting air refueling position approximately 50 feet behind MA1 (Tabs V-1.4, V-6.5).

At 1852:23Z, after MA2 had stabilized in its directed position, MBO1 signaled MP3 that he was cleared for a second attempt to close to the proper air refueling position (Tabs DD-9, V-6.5). MBO1 characterized MA2’s closure as a “good approach” and observed MA2 stabilize in the proper air refueling position behind MA1 (Tab V-6.5).

At 1852:50.2Z, MA1 achieved contact with MA2 and began transferring fuel between the aircraft (Tab DD-9). Immediately after, MBO1 observed MA2 “approaching in” and made two verbal corrections over the shared air refueling frequency (Tabs V-6.5, V-3.4). MP3 observed MA1’s Pilot Director Indicator (PDI) lights directing him to fly aft and attempted to correct and stabilize his position, reducing MA2s engine power setting (Tab V-3.4). As MP3 was making this correction, he observed an up light on MA1s PDI lights, which he simultaneously attempted to correct (Tab V-3.4).

At 1852:57.0Z, the ARB system registered a rapid relative forward movement of MA2, causing it to approach the forward boom limit at a rate exceeding the ARB system limits, at which point the system commanded a DISCONNECT between MA1 and MA2 (Tab DD-9). Following the command, the disconnect systems engaged, releasing the mechanical connection between MA1 and MA2 (Tab DD-9). Immediately after the disconnect command, MA1 maintained 310 KIAS as MA2 continued its relative forward movement at approximately 1.82 feet/sec, causing the ARB telescope tube to continue to retract (Tab DD-10). MBO1 testified that he attempted to initiate a manual disconnect using the disconnect switch located on the FCS (Tab V-6.6 and V-6.7).

Coincident with the automatic disconnect command, MBO1 manually input a Flight Control Stick (FCS) pitch up command initially holding up to 0.94° for 1.0 second while MA2 was still in physical contact with the ARB nozzle (Tab DD-10). This input, in conjunction with MA2s continued forward movement, generated a radial force on the nozzle which initially exceeded 500 pounds at 1852:57.6Z and steadily increased (Tab DD-10). In response to this radial force, a “HI-LOAD” annunciation displayed on MBO1 and MBO2s main display screens at 1852:57.9Z (Tabs DD-10, BB-364). Neither MBO1 nor MBO2 perceived this annunciation at the time (Tabs V-6.7, V-7.5).

At 1852:58.0Z, MBO1 further increased the pitch up command from 1.10° to 22.45° over a 1.3 second interval, with the peak occurring at 1852:59.3Z (Tab DD-10)

At 1852:58.2Z, MBO1 manually input a Telescope Control Stick (TCS) retraction command, causing the axial force on the ARB nozzle to transition from a compression to tension force, increasing steadily until a peak load of 4,574 lbs at 1853:00.1Z (Tab DD-10).

At 1852:58.8Z, the radial force on the ARB nozzle exceeded 2,400 lbs in the vertical direction, reaching the end of range limitation on the nozzle sensor (Tab DD-10). The actual peak value is unknown due to this end of range limitation (Tab DD-10). As a result of this exceedance, the "HI-LOAD" alert triggered by the initial forces on the nozzle ceased to display on MBO1 and MBO2s screens (Tab DD-10).

At 1852:59.4Z, MBO1 articulated the BREAKAWAY switch on the TCS and commanded the Breakaway procedure to both MC1 and MP3 over the shared air refueling radio frequency (Tabs DD-10, V-6.6, V-3.4). 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 (Tab V-6.6). Following the breakaway command, MP1 increased MA1s engine power setting and MP2 turned on additional aircraft lights in accordance with the proper procedure (Tabs 1.6, V-2.4). MP3 reduced MA2's engine power to its minimum setting, in accordance with the proper procedure (Tab R-5).

Coincident with the initiation of breakaway procedures, MBO1 gradually reduced his FCS and TCS inputs towards a relative neutral point of the controls, which was indicated at 1853:00.1Z, 0.7 seconds after the breakaway was initiated (Tabs DD-10).

At 1853:00.4Z, while the ARB was at a position of 32.73° pitch, 5.05° roll and 2.24 ft telescope, the ARB nozzle physically cleared MA2's receptacle (Tab DD-10). The ARB initiated an upward movement which peaked at a rate of 32.19°/sec, which triggered a software detection limit causing a momentary "BOOM INOP" message to be displayed on the Refueling Alert Indication System (RAIS) message screen (Tabs DD-10, V-6.7, V-7.5). This BOOM INOP state was momentary, and the ARB ceased its upward movement at 9.65° pitch before returning to a neutral centered position (Tab DD-10).

Following the separation of MA1 and MA2, MBO1, MBO2 and MP3 observed gas spraying from the ARB nozzle (Tab V-6.7, V-7.5, V-3.4, V-5.4).

At 1853:10.3Z, the ARB system registered a cancelation of the breakaway signal, coinciding with MP1 transmitting over the shared air refueling radio the command to terminate the breakaway procedures between MA1 and MA2 (Tabs DD-10, V-1.4).

Following the termination of the breakaway procedures, MP3 established MA2 in an observation position to the right of MA1 and conducted a visual inspection of his aircraft (Tabs R-6, V-3.4). He then joined with RAPTOR 3 and departed the air refueling formation (Tabs R-6, V-3.4). RAPTOR 3 conducted a Battle Damage Assessment (BDA) on MA2 and noted no damage, and MP3 was able to close MA2s air refueling receptacle doors, which indicated fully closed (Tabs R-6, V-3.4).

MA1 remained with RAPTOR 4, who conducted a BDA on the ARB and nozzle area at the request of MC1 (Tabs K-3, V-1.5, V-6.8). From their position, RAPTOR 4 was unable to identify any noticeable damage (Tabs K-3, V-1.5, V-6.8). After troubleshooting and following the procedures for the "BOOM INOP" message, MBO1 returned the ARB to a normal operating configuration and status (Tab V-6.8). Following discussion between MC1 and RAPTOR 4, MC1 decided to attempt an additional contact with RAPTOR 4 to verify the status of the ARB (Tabs K-3, V-1.5, V-6.8).

At 1857:51Z, MA1 established contact with RAPTOR 4's aircraft and attempted to initiate transfer of fuel (Tab DD-10). MBO1 observed "fuel spray" around RAPTOR 4's air refueling receptacle (Tabs K-3, V-6.8). During the 40 second connection, MA1's ARB system registered that 1,200 lbs had flowed out through the ARB. (Tab DD-10). MBO1 initiated a disconnect with RAPTOR 4 and observed additional fluid streaming from the ARB nozzle (Tabs DD-10, V-6.8). RAPTOR 4 departed the formation (Tab K-3).

MC1 then decided that MA1's ARB was inoperative, but they could continue air refueling operations utilizing MA1's Centerline Drogue System (CDS), allowing them to reduce their aircraft's gross weight below the allowed landing weight limitation of the KC-46A (Tabs V-1.5, V-6.9).

MA2 participated in the joint force exercise and returned to Tyndall AFB, where MP3 landed without incident. (Tabs R-6, V-3.4).

At 2144Z, MA1 landed without incident at Cecil Field (Tabs AA-13, V-1.5, V-2.5, V-4.5, V-5.4, V-6.9, V-7.6).

e. Impact

At the conclusion of the event, MA1 was in level flight at approximately 325 knots indicated airspeed, at approximately N 29° 19.80´ W 087° 33.60´ (Tab DD-10). The Boom Nozzle Poppet Valve separated from the aircraft, with the valve retaining ring remaining lodged in the receptacle of MA2 and the remainder of the assembly falling into the open ocean; no injuries were reported (Tabs R-6, K-3). MA2 joined formation with RAPTOR 3, and after performing a battle damage assessment, departed the air refueling formation to participate in the joint force exercise (Tab V-3.4).

f. Egress and Aircrew Flight Equipment (AFE)

MA1 landed at Cecil Field and taxied to the ramp without incident (Tabs V-1.5, V-2.5, V-4.5, V-5.4, V-6.9, V-7.6). The crew shut down the aircraft and egressed normally, without the use of emergency egress equipment (Tabs V-1.5, V-2.5, V-4.5, V-5.4, V-6.9, V-7.6).

MA2 landed at Tyndall AFB and taxied back to aircraft parking, where they egressed normally, without the use of emergency egress equipment (Tab V-3.4).

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.

All maintenance records were reviewed and determined not to be related to the incident (Tab U-2). MA2 was current with its maintenance, and no maintenance was performed on the in-flight refueling system (Tab U-3).

b. Inspections

Due to the nature of this incident, specifically no damage to MA2, this information is not applicable to MA2. An MFR was provided stating that all MA2's inspections and records were up to date at the time of the incident (Tab U-3)

c. Maintenance Procedures

Due to the nature of this incident, specifically no damage to MA2, this information is not applicable to MA2. An MFR was provided stating that all MA2's inspections and records were up to date at the time of the incident (Tab U-3)

d. Maintenance Personnel and Supervision

Due to the nature of this incident, specifically no damage to MA2, this information is not applicable to MA2. An MFR was provided stating that all MA2's inspections and records were up to date at the time of the incident (Tab U-3).

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

Due to the nature of the accident this information is not applicable to MA1.

f. Unscheduled Maintenance

Not applicable.

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS

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

(1) KC-46A Boom System

The KC-46A Boom System features an ARB, consisting of an outer structural tube and an inner telescoping tube with a nozzle for connecting to receiver aircraft (Tab O-5). The ARB is aerodynamically maneuvered using elevators and rudders controlled by a fly-by-wire system with FCS at the AROS (Tab O-5). Multiple sensors and actuators monitor activity in real time and deliver auditory/visual alerts to the ARO. A Remote Vision System (RVS) is used to facilitate boom refueling operations (Tab O-10).

(2) ARB Automatic Load Alleviation System

To maintain boom nozzle and receiver alignment during contact, the KC-46A incorporates an Automatic Load Alleviation System (ALAS). The ALAS provides receiver tracking which reduces the workload on the boom operator (Tab O-6). It also reduces the potential for nozzle binding in the receiver's refueling receptacle when attempting a disconnect and ensures the boom, elevators and rudders are in trim upon disconnect from the receiver (Tab O-6). This minimizes the transient motion of the telescoping boom upon disconnect (Tab O-6).

Sensors, located in the ALAS strain sleeve, measure the bending, radial and torsion loads applied to the boom nozzle joint by the receiver when in contact (Tab O-6). The ALAS strain sleeve is mounted on the end of the telescoping tube, forward of the nozzle and shock absorber recoil assembly (Tab O-6). The load measurements are transmitted back to the Actuator Control Unit (ACU), which computes a solution and controls the boom elevators and rudders to relieve the stresses induced by receiver movements which correspondingly reduces boom bending loads and nozzle binding (Tab O-6).

(3) KC-46A Remote Vision System

The RVS is an electro-optical, real time vision system to provide refueling situational awareness and detailed image information of the boom refueling scene to the boom operator prior to, and during refueling operations (Tab O-10). The RVS provides vision systems for boom and drogue system refueling of receiver aircraft and consists of a sensor subsystem, graphics processing subsystem, and a display subsystem (Tab O-10).

Optimal imagery for boom air refueling consists of stereoscopic image and visual cues (Tab O-10). Aircraft turns and transitions of backgrounds may result in a degraded image (Tab O-11. Under some conditions, receiver movement may create a shadow or washout condition (Tab O-10). Attempts to affect contact with less-than-optimal RVS imagery is at the discretion of the boom operator and may require adjustment of RVS settings during refueling operations to obtain optimal imagery (Tab O-10).

KC-46A ARO's have two cautions, located in the KC-46A Flight Crew Operations Manual (FCOM), expressing the importance of ensuring the best visual scene is obtained for current environmental conditions (Tab O-11). These cautions inform the ARO that disconnect and/or breakaway procedures should be initiated any time RVS imagery is not satisfactory, and that when refueling with less than optimum RVS imagery extreme care shall be exercised due to the reduced depth perception and lack of visual cues available (Tab O-11).

(4) KC-46A Telescope at Disconnect System

In Auto, the telescope tube will immediately fully retract anytime a disconnect command is received from the ARB system, the disconnect switch is actuated, or a receiver commanded disconnect is initiated (Tab BB-656).

(5) KC-46A Nozzle Binding Procedures

The KC-46A AROs have one caution, located within the United States ATP 3.3.4.2 Standards Related Document (SRD) stating that even after a disconnect signal, nozzle binding can occur (Tab BB-501). This caution informs the ARO that if nozzle binding occurs or is suspected, they should "*neutralize boom flight control inputs*" (Tab BB-501). This caution is not located in any KC-46A aircraft specific flight manuals or publications.

(6) KC-46A 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 (Tab O-11). This subset of emergency steps is commonly known as "Breakaway" procedures (Tab O-12). For the KC-46A, in the event of the need for immediate separation of the tanker and receiver aircraft, the KC-46A ARO will simultaneously accomplish the following three steps without delay (Tabs O-12):

1. Transmit "[Tanker Call Sign], BREAKAWAY, BREAKAWAY, BREAKAWAY" on the designated air refueling frequency by using either the Comm Switch on the FCS or the Push to Talk Foot Switch at the AROS (Tab O-12).
2. Initiate an Independent Disconnect System (IDS) disconnect using the disconnect switch on the FCS (Tab O-15).
3. Push the BREAKAWAY switch on the Telescope Control Stick (TCS) (Tab O-15).

After the disconnect, the boom operator will immediately retract and clear the boom away from the receiver; if necessary, notify the pilot "clear to climb" to ensure vertical separation; advise the pilot of receiver position and movement trends, as needed; and call out "RECEIVER WELL CLEAR" on the primary interphone when the receiver is safely separated from the tanker (Tab O-15).

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

In the system of Air Force acquisition, Deficiency Reporting, Investigation, and Resolution (DRI&R) is the subprocess 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-

485). Deficiency categories (CAT) are assigned to each deficiency, with an associated risk priority, "to capture the severity of the condition by relative importance and urgency of response" (Tab BB-489).

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 severe occupational illness; may cause loss or damage to a weapon system; critically restricts the combat readiness capabilities of the using organization; or result in a production line stoppage" (Tab BB-489).
>
> 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-489).

The KC-46A has three CAT I Deficiency Reports (DR) and one CAT II DR that are applicable to this investigation.

The first applicable CAT I DR titled, "*No Indication of High Boom Radial Loads*" is for a lack of indication to the ARO of high radial forces on the ARB nozzle (Tab BB-562). The report states that this can cause, "damage to and failure of the boom, and damage to the receiver" (Tab BB-562). The report also elaborates, "failure of the boom due to high radial loads may result in departure of the nozzle from the boom and subsequent impact of the nozzle or boom telescoping tube with a receiver" (Tab BB-562). Following the submission of this deficiency, the KC-46A air refueling system was updated with a High Boom Radial Load Indication (HBRLI), but the Air Force testing of this modification gave it a marginal rating due to "lack of contrast" and its placement "outside the ARO's direct field of view" (Tab BB-356). Boeing and the Air Force Life Cycle Management Office have recommended to downgrade this DR to a CAT II, but this was in dispute as the 418th Flight Test Squadron, Air Force Operations, Testing, and Evaluation Center (AFOTEC), and AMC have submitted formal challenges to this proposal (Tab BB-277).

The second applicable CAT I DR is for the entire KC-46A RVS, titled, "*RVS does not support safe and effective aerial refueling operations*" (Tab BB-547). This lengthy report details a list of nineteen RVS deficiencies impacting five operational phases of the KC-46As mission (Tab BB-548). Of particular interest to this investigation are the following individual deficiencies:

> Lack of Image Detail Due to Image Size – Due to the smaller field of view on the ARO's display compared to the field of view of the cameras, there is a 40 percent reduction in the displayed image size. This reduces the amount of detail conveyed to the ARO (Tab BB-550).
>
> Lack of Image Detail Due to Grayscale – The image displayed by the RVS is in grayscale, which limits an AROs ability to differentiate between objects and identify visual cues (Tab BB-550).

> Lack of Image Detail Due to Polarization – The RVS 3D "passive polarization" halves the Hi-Def image resolution displayed to each of the AROs eyes, causing a reduction in visual cues detail (Tab BB-550).

This DR concludes that, "Controllability and image instability could cause major delays that prevent the ability to perform AR when fuel is required. Lack of depth and visual cues provided by the image could cause an increased risk in probability and severity of boom strikes and probe damage." (Tab BB-555).

The third applicable CAT I DR is titled, "*Boom Telescope Too Stiff While In Contact With Receiver*" (Tab BB-557). The primary issue contained within this report is that the forces required by the receiver aircraft to push the telescoping tube inward are excessively high (Tab BB-558). The stiffness that results from this excessive force causes receiver aircraft to inadvertently set an engine power setting higher than is normal for air refueling with other legacy tankers (Tab BB-558). In the entire testing regime, for all receiver aircraft tested, when the breakout forces were overcome to start a forward movement, an excessive telescope rate would then build (Tab BB-558). As a result of this excessive rate, the receiver aircraft may accelerate toward the tanker after disconnecting from the ARB, greatly increasing the probability of a boom strike on the receiver aircraft (Tab BB-559).

The applicable CAT II DR is for ARB FCS inadvertent movements and titled, "*Boom Flight Control Stick Inadvertent Movements*" (Tab BB-566). This report details how the FCS is extremely sensitive and AROs can inadvertently make inputs into the FCS while in contact (Tab BB-566). The DR states:

> It has been observed during multiple flight test sorties that the ARO guarding the FCS or keying the intercom selector/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 BB-566).

The DR also states, "Data analysis also showed that an FCS input of 2 degrees from null position leads to an approximate load of 500 lbs and the input to load correlation is roughly linear" (Tab BB-566). It concludes that these conditions can cause high radial force on the ARB nozzle which would result in boom damage, boom failure, nozzle binding upon disconnect, and/or rapid boom movement upon disconnect (Tab BB-566).

In response to the DRs highlighting inadvertent and undetected KC-46 boom movements by AROs, a warning exists in the US SRD warning AROs to, "Be prepared to immediately fly the boom away from the receiver upon disconnect" in order to avoid rapid movement of the boom towards the receiver upon disconnect (Tab BB-342, BB-501).

b. Structures and Systems

MA1 sustained damage to the Aerial Refueling Boom Nozzle.

Figure 1: ARB With Nozzle Covered (Tab S-4)

Figure 2: MA2 Air Refueling Receptacle (Tab S-22)

(1) Boom Nozzle

The Boom Nozzle was stressed beyond its limit, breaking the Nut Nozzle Assembly allowing the poppet valve to fall free of the aircraft.

Figure 3: ARB Nozzle After Landing (Tab Z-3)

Figure 4: ARB Nut Nozzle Assembly (Tab Z-5)

c. Evaluation and Analysis

Due to the nature of the accident, individual aircraft systems components were not sent for analysis.

d. Testing and Analysis—Analysis of Data retrieved from Air Refueling Control Computer (ARCC)

Analysis of the MA1's ARCC data was conducted by the AIB's Pilot and Boom Members with technical information from a Boeing employee (Tabs DD-9-11, DD-3). This analysis yielded a detailed sequence of events focused on the period where the ARB was powered on, including the air refueling contact and breakaway emergency procedure with MA2 (Tab DD-9). Additionally, the AIB was able to plot the position of the ARB (elevation and telescope), the radial force placed on the ARB nozzle, and the position of the AROI FCS and TCS controls to illustrate the multiple forces which interacted over the very brief period (3.4 seconds) in question (See figure 3) (Tab DD-11).

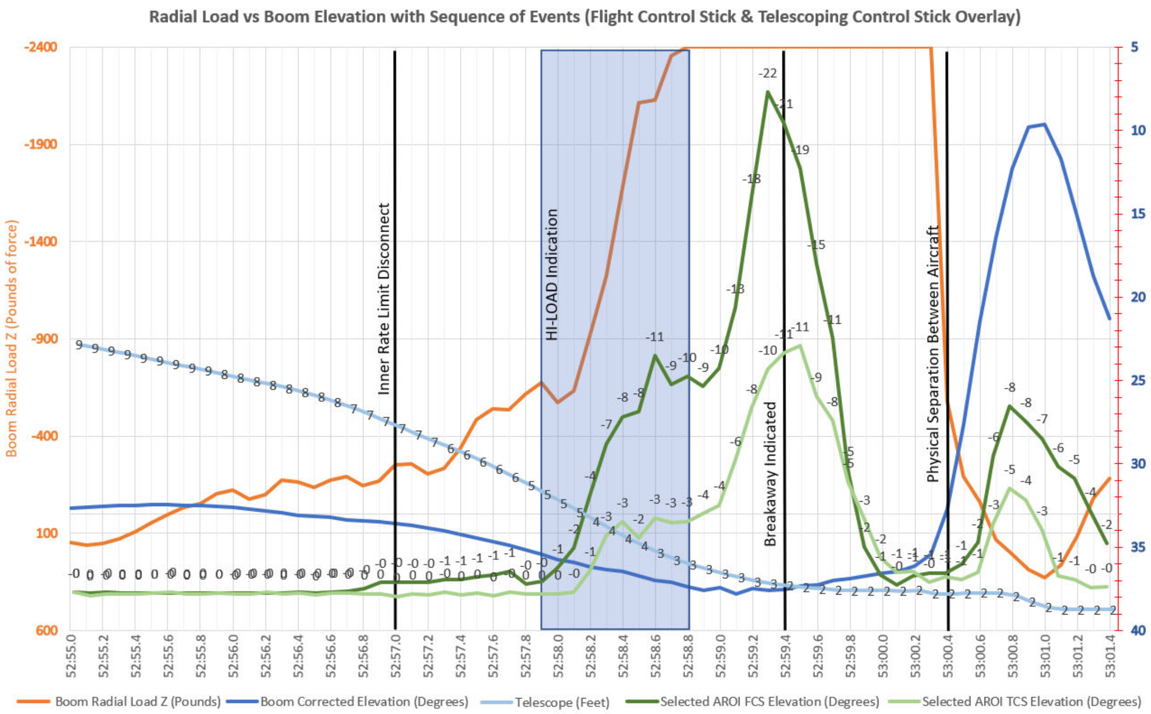

Figure 5: Radial Load vs Boom Elevation with Sequence of Events (FCS & TCS Overlay) (Tab DD-15)

7. WEATHER

a. Forecast Weather

Due to the nature of the mishap, forecast weather used by MC1 or MP3 was not captured and preserved. A historical search of weather in the vicinity of Cecil Field, Tyndall AFB, and Pensacola revealed no adverse weather or weather hazards (turbulence, icing, or thunderstorms) (Tab W-3-9).

b. Observed Weather

Neither MC1 or MP3 reported mission impacting weather or weather hazards (turbulence, icing, and thunderstorms) (Tab V-1.3).

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 (Tab BB-479). No evidence suggests weather was a factor in the mishap.

8. CREW QUALIFICATIONS

All crewmembers were qualified for their respective crew positions (Tabs G-3-874). At the time of the mishap, all necessary flight currencies and training requirements were accomplished and verified by the scheduling authority (Tabs AA-15). 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. Additionally, MP3 was a recent mission qualified wingman in the F-22A, certified in KC-46A refueling operations by his Squadron (Tabs G-231). However, there is no evidence to suggest crew qualifications were a factor in the mishap.

a. Flying History/Crew Qualification Table

Table 8.1 illustrates the flight history up to 90 days prior to the mishap, the highest qualifications 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 Instructor Pilot	535.2	Jul 23	23.5	6	8	2	9.4	2
MP2	KC-46A First Pilot	116.9	Sept 23	15.2	5	0	0	3.8	1
MP3	F-22A Mission Pilot	94.1	Jul 23	8.5	5	5.5	4	22.6	10
MBO1	KC-46A Mission Boom	54.3	Dec 23	17.2	4	0	0	13.8	3
MBO2	KC-46A Mission Boom	85.4	Sept 23	19.8	6	3	1	8.6	2

Table 8.1 (Tabs G-3-874)

9. MEDICAL

a. Qualifications

At the time of the mishap, both MC1 and MP3 were medically qualified for flying duties IAW Department of the Air Force Manual (DAFMAN) 48-123, *Medical Examinations and Standards*

(Tab T-15-17). There is no evidence to suggest that any members of MC1 or MP3 had a medical condition, illness or performance-limiting condition that would have caused or contributed to the mishap (Tab T-15-17).

b. Health

Due to the nature of the mishap, no toxicology reports were generated immediately after the incident (Tab T-15-17). There is no evidence to suggest that toxicology factors were a factor in the mishap.

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 MC1 and MP3 followed 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 BB-475, V-1.2, V-2.2, V-3.2, V-4.2, V-5.2, V-6.2, V-7.2). Due to the nature of the mishap, neither MC1 or MP3 completed 72-hour/14 day histories, but no witness testimony indicated a lack of opportunity for adequate crew rest.

10. OPERATIONS AND SUPERVISION

a. Operations

MC1 was scheduled to fly a routine Air Refueling support mission in support of a joint force exercise at Tyndall AFB (Tab K-3). The flight complied with all applicable AMC guidance (BB-499).

MP3 was scheduled to fly as the second aircraft in a four aircraft formation of F-22As participating in a daytime joint force exercise from Tyndall AFB (Tab R-6). The flight complied with all applicable ACC guidance (Tab BB-386).

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-6).

The 94 FS leadership ensured all flight members were current and qualified for the mission (Tabs R-11).

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 the MC and the Department of Defense (DoD) Human Factors Analysis and Classification System 7.0 (HFACS 7.0) model were used to present a systematic, multi-dimensional approach to mishap analysis.

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. This action may be noticed or unnoticed by the individual. (Tab BB-461).

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. Multiple design deficiencies exist for the ARB control system which contributed to the mishap circumstances (Tab BB-461), specifically, those documented in three DRs:

- CAT I (in dispute) "*No Indication of High Boom Radial Loads*" and inadequate HBRLI modification (Tab BB-356, BB-561).
- CAT I "*RVS does not support safe and effective aerial refueling operations*" (Tab BB-547).
- CAT II "*Boom Flight Control Stick Inadvertent Movements*" (Tab BB-565).

d. 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.

e. 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.

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-22Av3, *F-22A – Operations Procedures*, 11 April 2022

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 Oct 2022
- TO 1KC-46-A-05-05-0200-09A0A-280-A
- TO 1KC-46-A-05-05-0400-09A0A-280A-A
- 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 00-35D-54, *USAF Deficiency, Reporting, Investigation, and Resolution,* 1 September 2015

d. Known or Suspected Deviations from Directives or Publications

No known or suspected deviations were found during the investigation.

JUSTIN D. BALLINGER, Colonel, USAF
President, Accident Investigation Board

STATEMENT OF OPINION

KC-46A, T/N 5-46070
Off the Coast of Florida
7 November 2022

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 7 November 2022 at 1852:57 Zulu (Z), a KC-46A Pegasus and a F-22A Raptor conducting routine air refueling operations experienced a nozzle binding event during a breakaway which resulted in damage to the Air Refueling Boom (ARB) Nozzle of the KC-46A. Mishap Aircraft 1 (MA1), a KC-46A, T/N 15-046070, 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), a F-22A, T/N 09-004183, is assigned to the 1st Fighter Wing (FW), Joint Base Langley-Eustis (JBLE), Virginia, and operated by Mishap Pilot 3 (MP3), assigned to the 94th Fighter Squadron (FS), JBLE. Total monetary value of government loss was approximately $103,295.12.

I find, by a preponderance of the evidence, one cause for this mishap. Mishap Boom Operator 1 (MBO1) made manual control inputs to the ARB which caused a radial force to be applied to the ARB nozzle, causing it to become bound inside the receiver's air refueling receptacle. As a result, the bound forces exceeded the structural limitations of the ARB nozzle, damaging the nozzle beyond repair.

Additionally, I find, by a preponderance of evidence, two factors which substantially contributed to the mishap. The first factor is the failure of Mishap Pilot 3 (MP3) to account for the KC-46A Stiff Boom characteristics, causing a rapid forward movement of MA2 relative to MA1, substantially contributing to the mishap.

The second factor is that MBO1 was unable to verify that the ARB nozzle was clear of MA2's air refueling receptacle prior to making ARB control inputs, substantially contributing to the mishap.

2. CAUSE

Following a thorough review and analysis of the ARB system data captured by the Air Refueling Control Computer (ARCC) on 7 November 2022, this AIB identified a high radial nozzle force as the primary factor of the boom nozzle becoming bound in MA2's air refueling receptacle. In the absence of this high radial nozzle force, the ARB telescope would have fully retracted under the

Telescope Control Stick (TCS) command which MBO1 input after the commanded disconnect and averted the aircraft damage.

Further review of the AIB's ARCC analysis and witness testimony reveals two factors which contributed to this high radial nozzle force. First, it was witnessed, and the data demonstrated that MA2 continuously moved forward relative to MA1 at a high rate, compressing the ARB telescope mechanism beyond its allowed inner limit. Second, MBO1 made inputs to the ARB Flight Control Stick (FCS), with the first registered movement coincident with the initial command to disconnect MA1 from MA2. The AIB found no documented demonstrations of nozzle binding between a KC-46A and F-22A solely due to receiver position at MA1's and MA2's refueling speed. Therefore, of the two factors, by a preponderance of the evidence, this AIB concludes that MBO1's FCS inputs had the greatest impact on the overall radial nozzle force and caused the ARB nozzle to become bound in MA2's receptacle.

While MBO1's inadvertent FCS inputs caused the nozzle to bind, his subsequent intentional FCS inputs intensified the radial force causing the nozzle damage. Details and information uncovered during this investigation leads me to the opinion that MBO1's inadvertent FCS inputs were due to known limitations in the ARB control system and MBO1's intentional FCS inputs were due to training and guidance limitations. Considering all the above and given the interval of time involved, it is unreasonable to assume MBO1 would have acted differently. Additionally, it is my opinion that MBO1's actions of neutralizing the controls following the breakaway reduced the binding and allowed for the physical separation of MA1 and MA2 and averted what could have been a much more serious and damaging accident.

a) KC-46A Deficiency Reports

The first DR titled "*Boom Flight Control Stick Inadvertent Movements*" was submitted on 2 October 2018. Officially categorized as a Category (CAT) II deficiency, it details the possibility for inadvertent ARO inputs to the FCS. In the normal response to a rapidly closing receiver like MBO1 observed, the procedure requires AROs to actuate the disconnect trigger 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 his testimony, MBO1 indicated that he actuated the disconnect trigger prior to commanding the breakaway, but the ARCC data indicates the disconnect was first commanded by the automatic system. MBO1 also stated that he used the radio switch on the FCS to make his verbal corrections to MP3 and to command the breakaway for MA1 and MA2. These switches were highlighted by the CAT II DR as potential causes for inadvertent inputs on the FCS, emphasizing that only 2 degrees of FCS input can lead to approximately 500 lbs of radial forces on the nozzle.

In the 1.0 sec following the triggered disconnect, ARCC data indicates MBO1 applied up to 0.94 degrees of FCS input which is consistent with MBO1's testimony of commanding a disconnect and making radio calls. In combination with the receiver's rapid forward movement, ARCC data showed that the radial nozzle load exceeded 500 lbs. 0.6 seconds later, MBO1 starts to retract the ARB which was unsuccessful, indicating the bound condition had already occurred.

The second DR titled "*No Indication of High Boom Radial Loads*" was submitted on 10 September 2018. Categorized as a CAT I (In Dispute) deficiency, it details the threat induced to KC-46A

ARB operations from a lack of radial load indication. Software changes have been made to the ARB indication system since the submission of the CAT I (In Dispute) DR to address the lack of indication for high radial loads, but Air Force test documentation and witness testimony demonstrate the limited effectiveness of this “HI-LOAD” display indication.

Neither MBO1 nor Mishap Boom Operator 2 (MBO2) testified they were positively aware of the indication, even though ARCC data indicates it was displayed for 1.2 seconds. This is consistent with findings published by the 412th Test Wing in April 2021, which declared 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.” If MBO1 had been aware of the indication, MBO1 likely would have recognized and reacted to the situation in a manner that would have avoided aircraft damage.

b) Contradictory Command Guidance

The AIB also found two paragraphs in the US SRD which led MBO1 to perform contradictory actions. The first is a warning, meaning it can lead to loss of life or loss of aircraft, which states:

> Due to inadvertent or 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, meaning 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.

Considering the compressed time interval and rapidly developing situation with two aircraft in close formation, in this situation, the two directives were contradictory. In only a 3.0 second interval, MBO1 complied with both paragraphs throughout the sequence of events. While his application of the warning to clear the boom away from MA2 contributed to the binding, his timely application of the caution by neutralizing the controls potentially averted significant additional damage. Had the guidance been clear, MBO1 likely would have reacted to the situation in a manner that would have avoided aircraft damage.

3. SUBSTANTIALLY CONTRIBUTING FACTORS

a. Failure of MP3 to Account for the KC-46A Stiff Boom Characteristics

In testimony given to the AIB, MP3 and MBO1 asserted that MA2 was stable in the proper air refueling position prior to beginning the forward movement which precipitated the emergency breakaway. Although the ARCC data analysis supports these observations, it also indicates that an additional factor was present that MP3 failed to account for.

The DR titled, "*Boom Telescope Too Stiff While In Contact With Receiver*" was submitted 10 September 2018. Officially categorized as a CAT I, it details the high telescope force that can cause "objectionable interactions of the boom with receivers." This condition, commonly referred to as the "Stiff Boom", exerts an excessive amount of force on the receiver after contact which can result in excessively high receiver engine power settings. A secondary complaint noted in the DR, asserts that, "once the breakout forces were overcome an excessive telescope rate would build if the receiver pilot did not apply an immediate power correction to arrest or slow the forward or aft motion."

MA2 moved from pre-contact to contact in 27 seconds (1852:23Z-1852:50Z). Per the SRD this closure should occur at 1 foot per second or approximately 50 seconds. Failing to account for the faster closure rate may indicate excessive power that continued through the contact phase.

Based on the Boom Axial Load trend in the 7.1 seconds from MA2s contact with the ARB and until the automatic disconnect command, MP3 initially slowed and appeared stabilized after contact, but then failed to adequately change his power to respond to MA2's overcoming of the Stiff Boom breakout forces, which was indicated by a momentary reduction in boom axial load. As a result, MA2 moved forward relative to MA1 while the aircraft were still physically connected.

Air Force test data shows that the 0.9° FCS input inadvertently made by MBO1 which triggered the binding action should have only generated half of the forces required to initiate a high force scenario. The forces generated by MA2's movement forward through the disconnect and until the breakaway, lowered the threshold required for FCS input to trigger a high force load. Therefore, MBO1's inadvertent 0.9° FCS input was then enough to generate an excess of 500 lbs radial force on the ARB nozzle, initiating the binding action.

Following MBO1's emergency breakaway command, MP3 followed his appropriate procedures and finally slowed and reversed this forward movement, but his failure to apply appropriate engine power changes during his normal refueling in response to the Stiff Boom forces caused his forward movement, leading to the disconnect and substantially contributing to the mishap.

b. MBO1 Was Unable to Verify ARB Nozzle Was Clear of Receiver Receptacle

In legacy air refueling aircraft, like the KC-135 and KC-10, the ARO observes and controls the ARB through a window located in the rear of the aircraft. In the development of the KC-46A, its creators broke from this conventional system and designed a system of 3D cameras through which KC-46A AROs could observe the ARB and control its actions from a station near the front of the aircraft. The CAT I DR titled, "Remote Vision System (RVS) does not support safe and effective aerial refueling operations" was submitted on 8 March 2018 and details nineteen sub-deficiencies which were found with this system.

It is my opinion that the individual deficiencies directly related to the "Lack of image detail" the AROs see on the 3D images substantially contributed to MBO1's ability to correctly respond to the situation which he was presented. The reduced quality of the ARB display, to include a reduction in depth perception due to the grayscale of the presented image, made it impossible for MBO1 to adequately verify that the ARB Nozzle was clear of the receiver receptacle. Had MBO1 been able to better observe that the ARB Nozzle was not clear of MA2 air refueling receptacle, the initial onset of the binding action could have been avoided.

4. CONCLUSION

I find, by a preponderance of the evidence, one cause for this mishap. Mishap Boom Operator 1 (MBO1) made manual control inputs to the ARB which caused a radial force to be applied to the ARB nozzle, causing it to become bound inside the receiver's air refueling receptacle. As a result, the bound forces exceeded the structural limitations of the ARB nozzle, damaging the nozzle beyond repair.

Additionally, I find, by a preponderance of evidence, three factors which substantially contributed to the mishap. The first factor is the failure of Mishap Pilot 3 (MP3) to account for the KC-46A Stiff Boom characteristics, causing a rapid forward movement of MA2 relative to MA1, substantially contributing to the mishap.

The second factor is that MBO1 was unable to verify that the ARB nozzle was clear of MA2's air refueling receptacle prior to making ARB control inputs, substantially contributing to the mishap.

JUSTIN D. BALLINGER, Colonel, USAF
President, Accident Investigation Board

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