UNITED STATES AIR FORCE
ABBREVIATED AIRCRAFT ACCIDENT INVESTIGATION
BOARD REPORT

B-2A, T/N 89-0129

393d BOMB SQUADRON
509th BOMB WING
WHITEMAN AFB, MISSOURI

LOCATION: WHITEMAN AIR FORCE BASE, MISSOURI

DATE OF ACCIDENT: 14 SEPTEMBER 2021

BOARD PRESIDENT: COLONEL ROBERT P. M. COCKE

Abbreviated Accident Investigation, conducted pursuant to Chapter 12 of Air Force Instruction 51-307.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE GLOBAL STRIKE COMMAND

MAR 1 1 2022

ACTION OF THE CONVENING AUTHORITY

The report of the abbreviated accident investigation board, conducted under the provisions of AFI 51-307, that investigated the 14 September 2021 mishap near Whiteman AFB, MO, involving a B-2, T/N 89-0129, assigned to the 393d Bomb Squadron, substantially complies with the applicable regulatory and statutory guidance and on that basis is approved.

ANTHONY J. COTTON
General, USAF
Commander

EXECUTIVE SUMMARY
UNITED STATES AIR FORCE
ABBREVIATED AIRCRAFT ACCIDENT INVESTIGATION

B-2A, T/N 89-0129
WHITEMAN AIR FORCE BASE, MISSOURI
14 SEPTEMBER 2021

On 14 September 2021, at 0019 local time (L), the mishap aircraft (MA), a United States Air Force (USAF) B-2A Spirit strategic bomber crewed by two active duty pilots, experienced a left main landing gear (LMLG) collapse while landing on the runway at Whiteman Air Force Base (AFB), Missouri. The MA, Tail Number (T/N) 89-0129 (also known as the *Spirit of Georgia*), is assigned to the 393d Bomb Squadron (393 BS) of the 509th Bomb Wing (509 BW), located at Whiteman AFB.

At 0014L, while on approach to land, the Mishap Crew (MC) extended the MA's landing gear as normal, but almost immediately received system notifications of failures in two of the MA's four hydraulic systems. The MC assessed that the MA's landing gear were not fully deployed and, at 0015L, initiated a successful emergency extension to deploy the gear for landing. Cockpit indications then reflected all three landing gear in the down and locked position. At 0016L, the MC declared an inflight emergency (IFE) and received clearance to land. At 0019L, the MA touched down normally on the Whiteman AFB runway. Within seconds of touching down, however, the LMLG collapsed as the MA was still rolling down the runway at over 100 nautical miles (kts) per hour.

The gear collapse led to the MA's left wing contacting and dragging along the runway until the MA came to rest in the grassy area east of the runway, roughly one mile from its touchdown point. Both pilots were uninjured and exited the MA safely. The MA suffered significant damage due to the initial gear collapse and the resulting dragging of the wing along the runway. Preliminary estimates put the cost of repairing the MA at a minimum of $10.1 million, though further assessment of the MA will be required to determine a final cost.

The Abbreviated Accident Investigation Board (AAIB) President found, by a preponderance of the evidence, the cause of the mishap was that the MA's LMLG lock link springs failed to provide sufficient pressure to maintain the lock links in the locked position, which resulted in a LMLG collapse during the MA's landing. Further, the AAIB President found, by a preponderance of the evidence, that one factor substantially contributed to the mishap: the failure of a hydraulic CryoFit coupling that drove a rapid a loss of hydraulic fluid in the #1 and #4 hydraulic systems, which isolated the LMLG lock link actuator and prevented its use in assisting the LMLG lock link to remain down and locked.

SUMMARY OF FACTS AND STATEMENT OF OPINION
B-2A, T/N 89-0129
WHITEMAN AIR FORCE BASE, MISSOURI
14 SEPTEMBER 2021

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ACRONYMS AND ABBREVIATIONS

131 AMXS	131st Aircraft Maintenance Squadron
131 BW	131st Bomb Wing
393 BS	393d Bomb Squadron
509 BW	509th Bomb Wing
AAIB	Abbreviated Accident Investigation Board
AFB	Air Force Base
AFE	Aircrew Flight Equipment
AFI	Air Force Instruction
AFGSC	Air Force Global Strike Command
AFLCMC	Air Force Life Cycle Management Center
AFMAN	Air Force Manual
AMXS	Aircraft Maintenance Squadron
ANG	Air National Guard
AFRL	Air Force Research Lab
AFTO	Air Force Technical Order
A/R	aerial refueling
BWC	Bird Watch Control
Capt	Captain
Col	Colonel
CSMU	Crash Survivable Memory Unit
DoD	Department of Defense
DSG	Drill Status Guardsman
EGW	Ethanol Glycol Water
EP	Evaluator Pilot
ER	Exceptional Release
ERCC	Engine Running Crew Change
ESR	Engineering Support Request
FCIF	Flight Crew Information File
FL	Flight Lead
FOD	Foreign Object Debris
ft	feet
hrs	hours
g	gravity
IFE	In-flight Emergency
ILS	Instrument Landing System
IP	Instructor Pilot
k	one thousand
KCAS	Knots Calibrated Airspeed
KTAS	Knots True Airspeed
kts	Knots (nautical miles) per hour
L	Local Time
lbs	pounds
LD	Long Duration
LMLG	Left Main Landing Gear
LO	Low Observable
Lt Col	Lieutenant Colonel
MA	Mishap Aircraft
MAJCOM	Major Command
MC	Mishap Crew
MDU	Multi-Display Unit
MLG	Main Landing Gear
MP1	Mishap Pilot 1
MP2	Mishap Pilot 2
MS	Mishap Sortie
NLG	Nose Landing Gear
NM	Nautical Miles
NOTAM	Notice to Airmen
OG	Operations Group
OGP	On-Board Ground Processing
ORM	Operational Risk Management
PDM	Programmed Depot Maintenance
PNF	Pilot Not Flying
PPD	Personnel Protection Devices
psi	Pounds Per Square Inch
PSLU	Proximity Sensor Logic Unit
QA	Quality Assurance
RAPCON	Radar Approach Control
RMLG	Right Main Landing Gear
RSC	Runway Surface Condition
SBRA	Smart Bomb Rack Assembly
SOF	Supervisor of Flying
TAF	Terminal Aerodrome Forecast
TCTO	Time Compliance Technical Order
T/N	Tail Number
TO	Technical Order
USAF	United States Air Force
VFR	Visual Flight Rules

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 12 October 2021, General Anthony J. Cotton, Commander, Air Force Global Strike Command (AFGSC), appointed Colonel Robert P. M. Cocke to conduct an abbreviated aircraft accident investigation board (AAIB) for the 14 September 2021 mishap involving a B-2A Spirit aircraft, tail number (T/N) 89-0129, which occurred on runway 19 at Whiteman Air Force Base (AFB), Missouri (MO) (Tab Y-2). The investigation was conducted in accordance with Chapter 12 of Air Force Instruction (AFI) 51-307, *Aerospace and Ground Accident Investigations*, at Whiteman AFB, MO from 22 October 2021 to 10 November 2021. Additional board members were an Air National Guard member (Colonel), Legal Advisor (Major), Maintenance Member (Master Sergeant), and Recorder (Technical Sergeant) (Tab Y-2 to Y-8). A B-2A pilot (Major) was appointed as a Subject Matter Expert (Tab Y-6).

b. Purpose

In accordance with AFI 51-307, *Aerospace and Ground Accident Investigations*, this Accident Investigation Board 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. (Tab BB-28). This investigation was an abbreviated accident investigation conducted pursuant to Chapter 12 of AFI 51-307 (Tab BB-29 to BB-30).

2. ACCIDENT SUMMARY

On 13 September 2021, at approximately 2024L, the mishap aircraft (MA), a B-2A, T/N 89-0129, took off from Whiteman AFB, MO on its third sortie of the day (Tabs A-2, AA-2). The MA was assigned to the 509th Bomb Wing (509 BW) and operated by the 393d Bomb Squadron (393 BS), both located at Whiteman AFB (Tabs CC-5, CC-8). Near the completion of the flight, at approximately 0016L on 14 September 2021, the mishap crew (MC) declared an in-flight emergency (IFE) because of hydraulic system cautions identified by the MA's onboard systems (Tabs N-3, V-2.8, V-3.3). At approximately 0019L, the MA landed on Whiteman AFB's runway 19 and, during the landing, experienced a left main landing gear (LMLG) collapse (Tabs N-5, V-2.10, V-3.11). This failure caused the left wing of the MA to make contact with the runway, damaging parts of the left side of the MA (Tabs S-2 to S-15). Within seconds of the failure, the MA rolled onto the grassy area immediately east of the runway, where it came to a complete stop and the MC was able to safely exit the MA (Tabs N-5, V2.4, V-3.4). Whiteman AFB emergency personnel immediately responded and secured the MC and the MA at the scene (Tabs N5 to N11). Preliminary estimates put the cost of repairing the MA at a minimum of $10.1 million, though further assessment of the MA will be required to determine a final cost (Tab DD-41 to DD-43).

3. BACKGROUND

a. Air Force Global Strike Command (AFGSC)

AFGSC provides strategic deterrence, global strike capability, and combat support to United States Strategic Command and other geographic combatant commands. The command is comprised of more than 33,700 professionals operating at two numbered air forces; 11 active duty, Air National Guard, and Air Force Reserve wings; and the Joint Global Strike Operations Center. Weapons systems assigned to AFGSC include all U.S. Air Force Intercontinental Ballistic Missiles; bomber aircraft including the B-1B Lancer, B-2A Spirit, and B-52H Stratofortress; UH-1N helicopters; E-4B National Airborne Operations Center aircraft; and the U.S. Air Force Nuclear Command, Control and Communications (NC3) weapons system (Tabs CC-2 to CC-4).

b. 509th Bomb Wing (509 BW)

The 509th Bomb Wing, located at Whiteman Air Force Base, Missouri, is one of only two Air Force units to operate the B-2A Spirit strategic bomber. Its mission is to execute strategic nuclear operations, global strike, and combat support anytime and anywhere directed. The unit can launch combat sorties directly from Missouri to any spot on the globe, engaging adversaries with large payloads of traditional or precision-guided munitions. (Tabs CC-5 to CC-6).

c. 131st Bomb Wing (131 BW)

The 131st Bomb Wing is a unit of the Missouri Air National Guard (ANG), also located at Whiteman Air Force Base. Its primary operational mission is to provide full spectrum, expeditionary, B-2A global strike and combat support capabilities. 131 BW personnel are also dedicated to providing for the unit's overall combat readiness, operating support functions for tenant and attached units, and for performing combat and emergency duty in support of both federal and state missions. The 131st Aircraft Maintenance Squadron (131 AMXS) is a subordinate unit of the 131 BW. (Tabs CC-3, CC-15 to CC-17).

d. 393d Bomb Squadron (393 BS)

The 393d Bomb Squadron, a subordinate unit of the 509 BW, provides worldwide combat capability with B-2A aircraft, aircrew and operations personnel in support of nuclear and conventional taskings. The 393 BS is the only squadron to carry out a nuclear attack on an enemy in combat. During World War II, 393 BS aircraft attacked Hiroshima, Japan, on August 6, 1945; and Nagasaki, Japan three days later, with atomic payloads. Reactivated in 1993, the unit became the first operational B-2A strategic bomber squadron. (Tab CC-8).

e. B-2A Spirit Strategic Bomber

The B-2A Spirit is a multi-role strategic bomber capable of delivering both conventional and nuclear munitions. It provides the penetrating flexibility and effectiveness inherent in manned bombers. Its low-observable, or "stealth", characteristics give it the unique ability to penetrate an enemy's most sophisticated defenses and threaten its most valued, and heavily defended, targets with capacity to deliver 40,000 pounds of munitions. Its low-observability provides greater freedom of action at high altitudes, thus increasing its range, and providing a better field of view for the aircraft's sensors. Its unrefueled range is approximately 6,000 nautical miles. It has a crew of two compared to the B-1B's crew of four and the B-52's crew of five. Whiteman AFB, MO, is the only operational base for the B-2A. (Tabs CC-11 to CC-14).

f. B-2A Spirit Main Landing Gear Theory of Operation

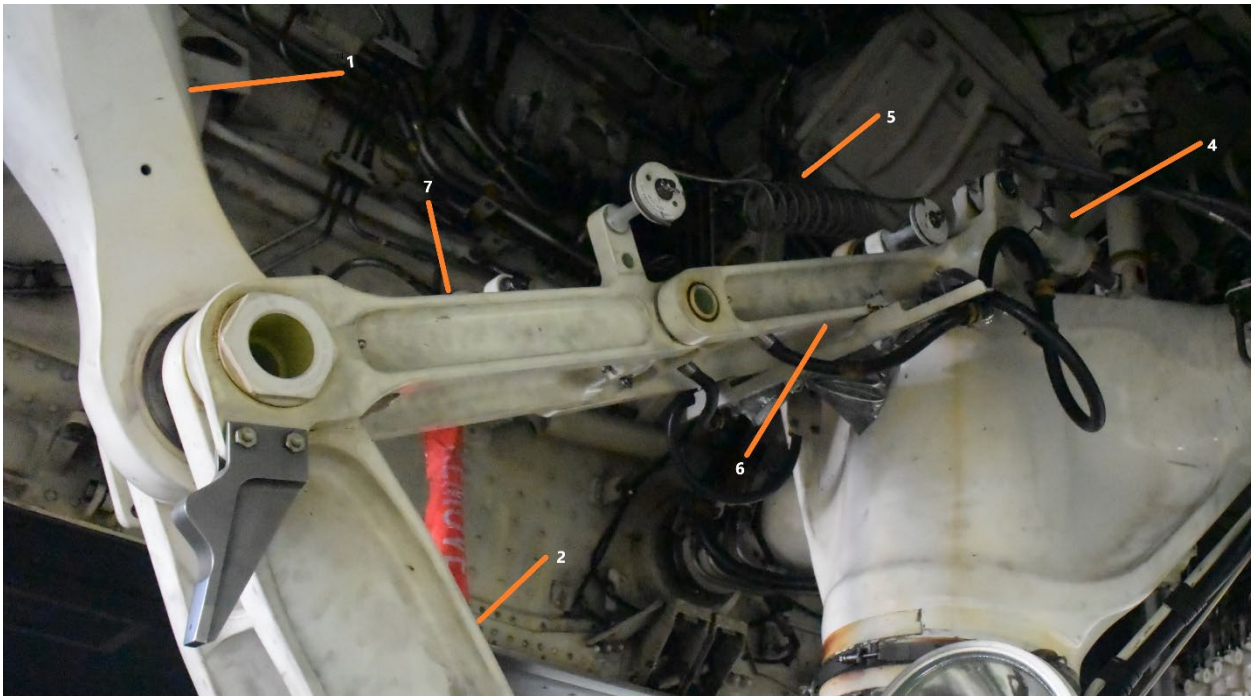
The landing gear on the B-2A consists of a nose landing gear (NLG) and a left and right main landing gear (LMLG and RMLG). The LMLG and RMLG are collectively referred to as the Main Landing Gear (MLG). Normal extension and retraction are controlled using the landing gear handle in the cockpit. A separate emergency extension switch is used to extend the nose and main landing gear in the event of a normal extension failure (Tabs V-17.1 to V-17.4).

The landing gear use the #1 hydraulic system (primary) or the #4 hydraulic system (alternate) to extend or retract the gear. The MLG use stored accumulator pressure to actuate the landing gear in the event that primary and alternate hydraulic sources fail (Tabs V-17.1 to V-17.4).

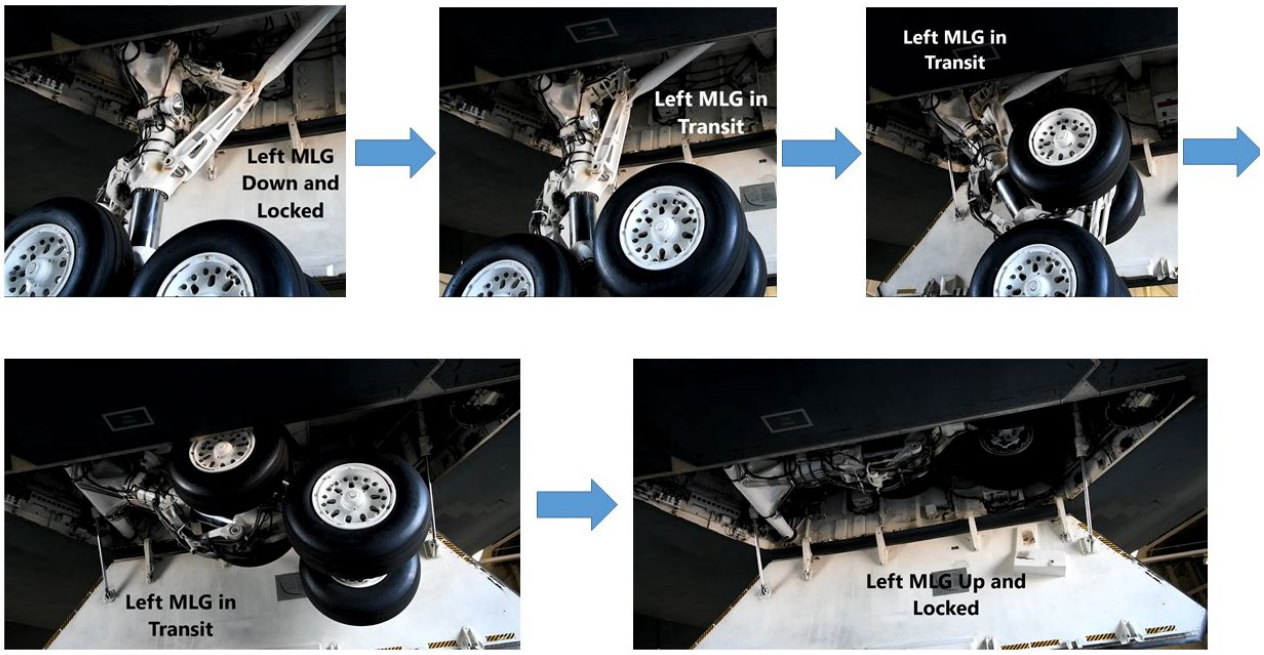
The landing gear has a position and warning subsystem, which consists of proximity sensors and two proximity switch logic units (PSLUs). These components provide status outputs and verify the position of various landing gear components during landing gear transition to ensure proper sequencing. The status and positions are displayed to the pilots via Multi-Display Units (MDUs) in the cockpit (Tabs V-2.9, V-17.1 to V-17.4).

Left Main Landing Gear Components

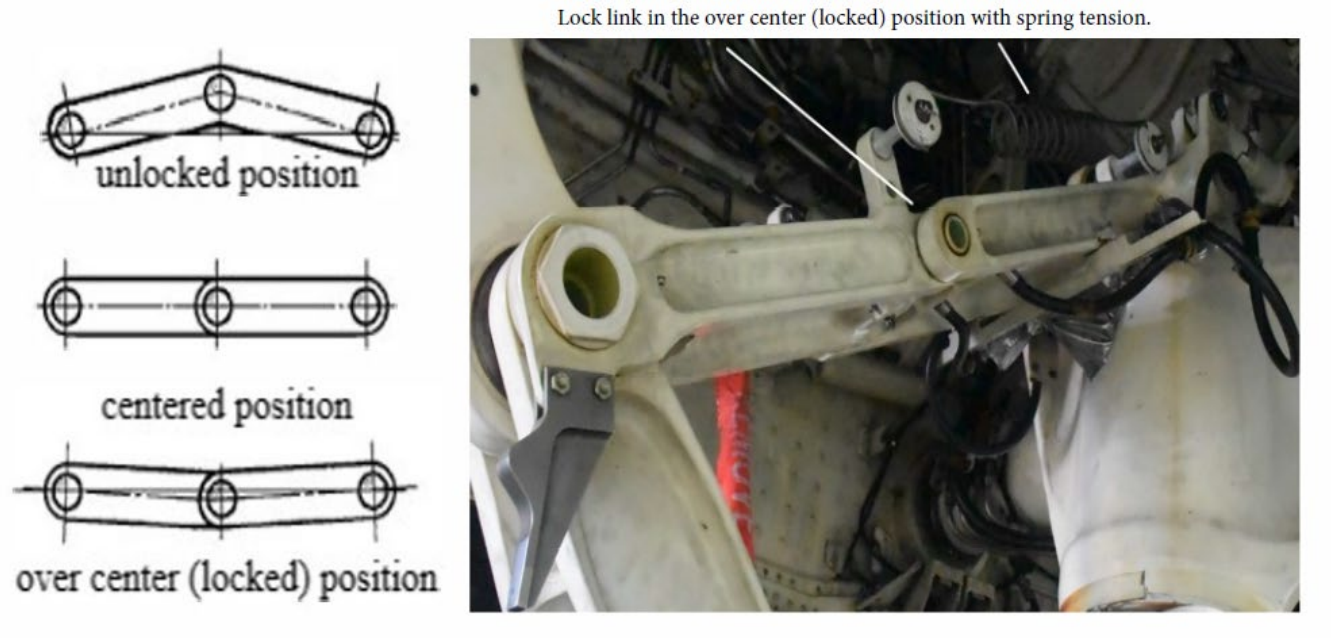
1. Upper Drag Brace
2. Lower Drag Brace
3. Retract Actuator
4. Lock Link Actuator
5. Lock Link Springs
6. Aft Lock Link
7. Forward Lock Link



landing gear strut, which in turn is attached to the aircraft. This combination of wheel, MLG truck, and strut is what supports the weight of the aircraft when on the ground. The MLG strut is held in position by a drag brace, which folds in the center during MLG retraction to allow the landing gear to retract into the wheel wells. When the landing gear is down and locked, the drag brace is prevented from folding by a lock link assembly. In this configuration, since the drag brace is unable to fold, the landing gear cannot retract (Tabs V-17.1 to V-17.4).



The Left Main Landing Gear's Retract Sequence



The function of a lock link illustrating the over center (locked) position.

Each MLG also has a hydraulic lock link actuator which assists the lock link into the over center position. This hydraulic actuator is connected to the upper portion of the lock link and uses hydraulic pressure to help push the lock link past the centered position. However, the landing gear is designed to operate in the absence of hydraulic pressure, using both gravity and airflow to force the lock link over center into the locked position. In that situation, without hydraulic pressure, the MLG is designed so that the lock link will remain in the over center position, relying solely on the mechanical force of the lock springs (Tabs V-17.1 to V-17.4).

Under normal flight conditions, the main landing gear is retracted by the hydraulic retract actuator which pulls the main landing gear forward and upward into the wheel wells. Once the landing gear has completed the retraction sequence, hydraulic pressure is applied to the lock link actuator which forces it into the over center position. This locks the lock link and keeps the MLG retracted in the main landing gear wheel wells. The lock link is held in that locked position by the two lock link springs and is assisted by hydraulic pressure provided by the lock link actuator (Tabs V-17.1 to V-17.4, DD-44).

When the landing gear is lowered, the #1 hydraulic system triggers the lock link actuator to pull the lock link out of the over center position. This disengages the lock, which is holding the MLG

in the retracted position. Once the lock is disengaged, each MLG free falls into the down and locked position. While MLG extension is initiated with hydraulic pressure, once the lock link is disengaged, the remainder of the extension is accomplished using the force of gravity and airflow only. When the MLG has completed its extension, the lock link actuator again provides hydraulic pressure to assist the lock link into the over center (locked) position. The lock link is then held in the over center position by two lock link springs. While the hydraulic lock link actuator assists the lock link into the over center position, it is not required to keep the landing gear down and locked. The landing gear can be lowered using gravity and airflow alone, and then locked in the down position using the two lock link springs. However, under normal operating conditions, the hydraulic lock link actuator does maintain pressure on the lock link which assists the springs in maintaining the lock link in the over center (locked) positon. This hydraulic pressure on the lock link is maintained until hydraulic pressure is lost, which normally occurs when the aircraft is shut down. When shutdown occurs, the MLG will remain locked due to the tension supplied by the lock link springs (Tabs V-17.1 to V-17.4).

In the event that the landing gear fails to lower under normal conditions, the B-2A has a separate emergency extension system to lower and lock the landing gear. When activated, the emergency extension operation cuts off the flow of hydraulic pressure to the lock link actuator. Once this hydraulic system is isolated, the MLG is being held in the retracted position by the force of the lock link springs alone. The emergency extension system then releases accumulator pressure to the MLG emergency unlock release actuator, which pushes the MLG strut out of position, and exerts enough force on the lock link to force it out of the locked position. At this point, gravity then pulls the MLG struts out of the retracted position, allowing them to free fall into the extended positon. As with the normal gear extension, at the end of the emergency extension, the lock link springs hold the lock links over center to ensure the MLG remains down and locked. However, since the emergency extension isolates the MLG from the #1 and #4 hydraulic systems, no hydraulic pressure exists in the lock link actuator to assist and maintain the lock link in the over center position. In this situation the MLG are kept in the extended positon by the mechanical force of the lock link springs alone. (Tabs V-17.1 to V-17.4, DD-44).

In 2018, the B-2A System Program Office (SPO) directed changes to Northrop Grumman's Programmed Depot Maintenance (PDM) contract affecting MLG maintenance procedures. PDM is a standard Air Force maintenance process where each aircraft undergoes a scheduled major overhaul by a contracted provider on a recurring basis. The frequency of PDM for the B-2A is approximately every nine years. PDM takes place at a Northop Grumman facility in California (Tabs U-41 to U-46). A standard part of the B-2A's PDM includes the removal, inspection and reassembly of the landing gear. The 2018 maintenance procedure changes directed the replacement of the existing landing gear springs with new springs during each scheduled PDM. Prior to this change, when the landing gear was reassembled during PDM, the original springs were reinstalled on the MLG assemblies. Since the replacement springs are inexpensive and readily available, the SPO directed the change to take advantage of the opportunity presented by the landing gear disassembly. There is no requirement for routine replacement of the lock link springs except when undergoing a scheduled PDM. The MA's last PDM was accomplished in 2014, prior to this change in procedures (Tab U-2). A review of the MA maintenance logs revealed that the springs had not been replaced for at least 10 years. Additionally, no evidence was found that the springs had ever been replaced (Tab U-46).

Historically, there has been one previous landing gear collapse of a B-2A, which occurred in 2002 in a Whiteman AFB hangar, where the aircraft was undergoing maintenance on a landing gear proximity sensor. In this case, there was no power on the aircraft and consequently no hydraulic assistance holding the lock link over center (locked). In order to adjust the proximity sensor on the lock link, one aircraft maintenance Airman, who disregarded Technical Order procedures, removed the landing gear lock link safety pin and pushed up on the lock link. This action caused the lock link to disengage from the over center position causing the landing gear to collapse (Tab DD-19 to DD-40).

g. B-2A Spirit Hydraulic Theory of Operation

B-2A hydraulic power is provided by four independent, 4000-psi hydraulic systems. These hydraulic systems power a variety of aircraft components to include flight controls, nose wheel steering, the crew entry hatch and the landing gear. Each of these hydraulic systems is isolated. No hydraulic fluid is exchanged between the systems under normal operating conditions. However, the B-2A was designed to allow some fluid transfer between systems when required to support specific hydraulic actions. In the case of the MLG, the opening of the MLG doors and the disengagement of the lock link actuator is accomplished using hydraulic pressure from the #1 hydraulic system. This primary mode of operation is backed up by the #4 hydraulic system should the #1 system fail to extend the landing gear. The cycling between the primary hydraulic system and the secondary hydraulic system is accomplished through the use of a switching valve. When the hydraulic system is switched between the primary and secondary systems, hydraulic fluid is transferred between them (Tabs V-17.1 to V-17.4).

The B-2A fleet has encountered eight dual #1 and #4 hydraulic system failures in flight since 2002. Four of the eight failures resulted in the activation of the emergency landing gear system to extend the gear, however, all aircraft returned to base and landed safely (Tab U-47).

4. SEQUENCE OF EVENTS

a. Mission

The Mishap Sortie (MS) was scheduled as a night, two-ship, local aircraft commander upgrade training mission from Whiteman AFB (Tabs K-3, K-4, V-2.1 to V-2.2, V-2.5 to V-2.6, V-3.2, V-3.4 to V-3.5, AA-2). The Mishap Instructor Pilot (MP1) was in the left seat and the Mishap Pilot (MP2) was in the right seat (Tabs V-2.2, V-3.2). The planned mission profile included a formation departure, formation break up, simulated weapons activity along the route of flight, followed by each pilot flying an approach and landing at Whiteman AFB to update night landing currencies (Tabs K-3, V-2.5, V-3.2). No range airspace was scheduled for this sortie; all training was to be accomplished en-route, and there was no air refueling planned (Tabs K-3, K-4, V-2.7, V-3.6).

b. Planning

The Mishap Crew (MC) was scheduled to execute a Show-and-Go training mission using an off-the-shelf route and tactical scenario. For Show-and-Go sorties, the crew will make use of a

preplanned static set of mission materials, which they modify and update for their specific mission's objectives and timing. The MC completed a standard Show-and-Go mission planning profile for the MS in accordance with applicable regulations and standard operational practices (Tabs V-2.1, V-2.5, V-3.2). As a part of this process, the MC accomplished an Operational Risk Management (ORM) assessment, a standardized procedure used to identify and mitigate common risk factors (Tab K-4, V2.6, V-3.5). The calculated ORM level for the MS was assessed as "Low Risk" (Tabs K-4, V-3.5).

Prior to the crew brief, the Mishap Flight Lead conducted a standard formation briefing (Tabs V-2.5 to V-2.6, V-3.4). At the conclusion of the formation brief, MP2 conducted the crew brief. Both the formation brief and crew brief occurred without issue and had no impact on the mishap (Tabs V-2.5 to V-2.6, V-3.4).

On the day of the mishap, there were no Notices to Airmen (NOTAMs) in effect that played any part in the mishap sequence of events. The weather briefing for the MS indicated no significant weather for either the departure or recovery times; however, the Terminal Aerodrome Forecast (TAF) did include a remark about wind shear 1,500 feet above the field from 220° at 30 kts shifting down to 180° at 11 kts for touchdown (Tabs AA-3, F-2, F-3).

c. Preflight

On the day of the MS, following mission planning, the MC picked up their flight equipment from the Aircrew Flight Equipment (AFE) section and received a final briefing from the Operations Supervisor before proceeding to the flight line. For 393 BS B-2A sorties, the roles of the Supervisor of Flying (SOF) and Squadron Operations Support Supervisor (often referred to as "Ops Sup" or "Top 3") are performed by a single individual, referred to by the positional call sign "Maddog" (Tabs V-2.6 to V-2.7, V-3.5, V-3.7, V-4.3 to V-4.4).

The Mishap Aircraft (MA) had flown two sorties on the day of the mishap prior to the MS (Tabs AA-2, K-4). These sorties involved a total of 8.4 flying hours prior to the MS takeoff (Tab K-4). The first sortie of the day had been an inert weapons drop at the Smoky Hill Weapons Range in Kansas; the second had been a standard day continuation training sortie (Tabs AA-2, K-4). Between the first and second sortie of the day, the MA had conducted a Hot Pit refueling to set the fuel load required for the two following sorties (Tabs AA-2, V-6.2). There was no maintenance performed on the aircraft between the first and second sortie of the day apart from those required for refueling the aircraft. There was no refueling conducted between the second sortie and the MS (Tab AA-2).

The MS was scheduled to be an Engine Running Crew Change (ERCC) involving a handoff from the second sortie's flight crew to the MC while the aircraft's engines remained running (Tabs AA-2, V-2.7, V-3.2, V-3.7, V-4.4). Standard ERCC procedures dictate that, during the handoff between crews, the off-going crew will brief the oncoming crew of any maintenance issues affecting the aircraft (Tabs V-2.7, V-3.7). During the handoff between the second sortie and the MS, the only observed maintenance issue was an anti-skid malfunction, which maintenance personnel corrected, by resetting the Anti-Skid Controller, prior to the MS taxiing (Tabs V-2.2, V-2.7, V-3.7). Since the MS was an ERCC, the MC did not perform a pre-flight walk-around of the MA prior to boarding (Tabs V-2.7, V-3.7).

d. Summary of Accident

MS ground operations and taxi proceeded uneventfully (Tabs V-2.2, V2.6 to V-2.7, V-3.7). The takeoff, formation departure, split up and tactical portion of the sortie occurred without incident (Tabs V-2.2, V-2.6 to V-2.7, V-3.7). At no point in the sortie prior to the mishap were there any indications of hydraulic issues with the MA (Tabs V-2.7, V-3.7). The MS proceeded uneventfully until the transition to the airfield traffic pattern.

At 0013:12L on 14 September 2021, the MC was cleared for the Instrument Landing System (ILS) approach for runway 19 at Whiteman AFB by Kansas City Air Traffic Control Center (ZKC) (Tabs DD-3, V-3.2, V-2.2). At this time, MP2 was flying the MA and MP1 was performing Pilot Not Flying (PNF) duties. These duties included instruction for MP2, coordination with Maddog regarding aircraft status, configuring the aircraft for landing and monitoring the approach (Tabs V-2.2, V-3.2). The handoff from ZKC to Whiteman AFB Tower was initiated at approximately 10 miles, which was closer to the field than what usually occurs when Whiteman AFB approach control is active (Tabs AA-3, DD-3, V-2.2, V-3.2, V-13.2). However, the handoff was still initiated with sufficient time for the aircraft to configure for landing and accomplish all required pre-landing checklists (Tabs V-2.2, V-3.2, V-13.2). At this point, the MA was established on the approach, but still outside of the final approach fix. During the approach, Whiteman AFB runway 19 was in use, visual flight rules (VFR) were in effect, the runway surface condition (RSC) was dry, and the bird watch condition (BWC) was low (Tab N-2).

At 0014:42L, MP1 placed the landing gear handle in the down position (Tabs U-3 to U-4, DD-48, V-2.2, V-3.2). Simultaneously, the On-Board Ground Processing System (OGP) data indicates the nose landing gear (NLG) aft door opened and the NLG began transitioning to the down and locked position (Tab DD-48). One second later, at 0014:43L, the left main landing gear (LMLG) door opened, beginning the LMLG transition process (Tab DD-48).

Four seconds after the landing gear handle was lowered, at 0014:46L, the master caution panel illuminated with a HYD 1 (#1 hydraulic system) caution. Crash Survivable Memory Unit (CSMU) data indicates that the #1 hydraulic system pressure had dropped from 4,200 psi to 3,200 psi and the hydraulic reservoir had lost six of its 21 gallons (Tabs DD-48, V-2.2, V-2.8, V-3.2, V-3.9 to V-3.10). Over the next ten seconds, the landing gear extension process proceeded. By 0014:56L, the NLG had completed a normal extension, the NLG aft door had closed, the LMLG and RMLG doors were open, and the LMLG had begun its transition to the extended position (Tabs U-20, DD-48). At this time, the RMLG had not begun to extend. The hydraulic failure that occurred was to a high pressure CryoFit coupling in the RMLG well (Tab J-34).

At 0015:00L, OGP data indicates the master caution panel again illuminated with a HYD 4 (#4 hydraulic system) caution due to the hydraulic leak (Tabs U-21, DD-48). At that time, the #1 hydraulic system reservoir was indicating 2 gallons, while the #4 hydraulic system had lost 15 of its 17.6 gallons. The MC was able to observe these indications on the hydraulic display page of the Multi-Display Units (MDUs) (Tabs DD-48, V-2.9, V-3.9 to V-3.10). At 0015:01, the CSMU indicates that the MA began a right turn, changing heading from approximately 160° to a runway heading of 190° (Tab DD-48).

By 0015:03L, the LMLG was down and locked, but the RMLG had not begun to transition into the down position (Tabs DD-48, U-23 to U-24). At the time the LMLG indicated locked, the MA was in the process of a gradual turn to the right, to lineup with the runway. At the moment the LMLG lock link engaged, the MA was in a 5.5° roll to the right and the force of gravity (g) on the aircraft was registered at 0.98g. (Tab DD-48).

At 0015:21L, based on cockpit indications that the landing gear was not fully extended, MP1 initiated an emergency gear extension to ensure all landing gear were down and locked (Tabs U-26, DD-48, V-2.2, V-2.9, V-3.3, V-3.10). The actuation of the emergency extension system employs stored accumulator pressure to forcibly knock the landing gear out of its retracted position. The landing gear then falls into the down and locked positon through the combined force of gravity and airflow. When the emergency extension system is used, the MLG wells are isolated from the hydraulic system. Consequently, for the MA, the emergency extension stopped the fluid loss in the #4 hydraulic system. Had this isolation not occurred, based on the rate of loss, the #4 hydraulic reservoir would have also fully depleted prior to landing (Tab DD-48). The MA's emergency extension forced the RMLG to drop into the extended position (Tabs U-28, DD-48).

Because of how the emergency extension system operates, the aft NLG door remains open when the emergency extension is initiated. Under normal conditions, the aft NLG door opens only while the NLG is extending, and then closes behind the NLG. During an emergency extension, no hydraulic pressure is available to close the aft NLG door, and consequently it remains open. In the cockpit, the landing gear handle has a light in it, which illuminates when the landing gear is in transition and then goes out once the landing gear has completed an extension or retraction cycle. Because the aft NLG door remains open during an emergency extension, the light in the landing gear handle does not extinguish since the landing gear extension process, which includes the closing of the aft NLG door, has not completed. In the case of the MA, this was the situation experienced by the crew following the emergency landing gear extension (Tab V-3.3, V-3.10).

Three seconds after the emergency extension was accomplished, at 0015:25L, ZKC completed handoff of control and directed the MC to contact Whiteman AFB tower (Tab V-3.8). MP2 acknowledged ZKC's direction but, due to the ongoing analysis of the MA's systems, did not switch to tower frequency (Tabs DD-3, V-3.8).

Shortly after that radio call, at 0015:36L, the RMLG completed its transition and both the landing gear panel and the MDUs indicated all three landing gear were down and locked, with the NLG door remaining open due to the emergency extension (Tabs U-28, DD-48). Consequently, while the landing gear indications did show that all landing gear were down and locked, the light in the gear handle remained illuminated due to the non-standard configuration (Tabs V-3.3, V-3.9).

Twenty seconds after the RMLG indicated down and locked, MP2 attempted to contact Whiteman AFB tower to declare an emergency; however, because of the failure to switch to tower frequency, the emergency was initially communicated to ZKC (Tabs DD-3, V-3.8). ZKC clarified with MP2, who then switched to tower frequency and declared an emergency at 0016:24L (Tabs DD-4, N-3, V-3.3, V-3.8).

At this time, the MA was 6.5 miles from touchdown with a dual hydraulic failure and all three landing gear indicating down and locked (Tabs DD-4, N-3, V-3.3, V-3.8).

At 0016:34L, Whiteman AFB tower cleared the MA to land and began coordinating the emergency response consisting of the Fire Department, Crash Recovery, Airfield Management, Command Post, ambulance services and Security Forces (Tabs N-3, V-13.2, V-13.4, V-13.8). MP2 maintained an approach speed of 143 kts, which was slightly higher than the recommended approach speed, in order to overcome any issues with the forecasted wind shear that was briefed prior to takeoff (Tabs V-2.3, V-3.3). This approach speed was well within the MA's capabilities given the light gross weight at this point in the sortie (Tabs V-2.10, V-3.6).

e. Impact

At 0019:09L, the MA touched down at 129 kts indicated airspeed with wings level, 3.9° of pitch and just under 6° angle of attack. The crash survivable memory unit (CSMU) recorded a force of 1.12g on touchdown, indicating that it was not a hard landing. The B-2A's systems automatically record the g-force of all landings. It identifies landings in excess of 1.6g as hard landings and aircraft software notifies maintenance personnel. The RMLG touched down approximately one second before the LMLG, and for this initial contact, the NLG remained off the runway. The initial touchdown occurred on the runway approximately 1,200 feet from the runway threshold (Tabs U-34, DD-48-49, S-16).

Both the MA's OGP and the CSMU indicate that one second after the LMLG initially touched down, it lifted off the prepared surface followed by the RMLG two seconds later. At 0019:13L, the MA was again airborne at approximately 128 kts and maintaining runway heading. It remained airborne for 1 second before settling back to the runway (Tabs U-35 to U-36, DD-49).

Again, both the MA's OGP and the CSMU indicate that, at 0019:14L, both the LMLG and RMLG touched down for the second time (Tabs U-38, DD-49). At the moment of this second touchdown, the MA was still travelling at 128 kts with wings level, 5.7° of pitch and just over 2° angle of attack. This second touchdown had a recorded force of 1g on the CSMU indicating that it was also not a hard landing (Tabs DD-49, V-2.3, V-2.10, V-3.3).

Following the second touchdown, at 0019:16L, two significant events occurred. First, the NLG contacted the runway resulting in all three landing gear indicating weight on wheels. Second, the LMLG began to collapse. These events began occurring approximately 2,300 feet from the runway threshold (Tabs DD-49, S-16). For the remainder of the landing run, the NLG and RMLG remained down and locked with weight on wheels and that status is reflected in both OGP and CSMU data (Tab DD-49).

In accordance with the design of the landing gear system, three seconds after the LMLG began to collapse, the gear horn sounded in the cockpit accompanied by a flashing light in the landing gear handle, which indicated that the MA was no longer properly configured for landing (Tabs DD-49, V-3.3, V-3.11). At this point, the MA was travelling at approximately 119 kts ground speed with the wings level and maintaining runway heading (Tab DD-49).

Eleven seconds after the LMLG began to collapse, at 0019:27L, it stopped collapsing and hung suspended under the aircraft as the MA continued down the runway resting on the NLG, RMLG and a combination of the lower left rudder, left wingtip and the LMLG door (Tab DD-49). At this time, the LMLG had partially collapsed into the left wheel well and only the two aft wheels on the LMLG truck remained in contact with the runway. During the landing gear failure, LMLG hydraulic retract actuator suffered a mechanical failure as the weight of the aircraft settled on to the collapsing LMLG (Tab S-14).

At the same time (0019:27L - 13 seconds after the final touchdown), the LMLG door came in contact with the prepared surface approximately 4,300 feet from the runway threshold (Tab S-16). At this time, the MA was travelling at approximately 109 kts ground speed with wings level (Tab DD-49). The LMLG door dragged along the runway surface for approximately 750 feet before it separated from the MA, damaging the undersurface of the wing (Tab S-16). During separation, the forward hydraulic actuator for the LMLG door ripped the forward hydraulic arm attachment point off the door. Simultaneously, the rear hydraulic actuator for the LMLG door suffered a catastrophic failure at the door attachment point. The failure of these actuators allowed the LMLG door to rotate outboard until the four door hinges failed and the door completely separated from the MA. Of the four hinges, three were torn from the left wall of the LMLG well and remained attached to the door as it proceeded to slide down the runway. The second hinge from the front of the door was similarly ripped off the left wall of the LMLG well, but also completely separated from the gear door, coming to rest approximately 770 feet from where the LMLG door initially contacted the runway (Tab S-16). From this point, the LMLG door continued to slide along the runway, coming to rest approximately 900 feet from where it first contacted the prepared surface (Tab S-16).

Following the LMLG door's contact with the runway, the MA experienced a large slip to the left as MP2 applied increasing amounts of right rudder in an effort to keep the MA on centerline (Tabs

DD-49, V-3.3, V-3.4). The loss of the LMLG door resulted in a rapid onset 5° dip of the left side of the MA that would peak at 7° just prior to runway departure (Tabs DD-49, V-3.3).

Following the LMLG door separation, the MA continued to travel down the runway leaving scrape marks from the left lower rudder and wingtip along the east edge of the runway surface (Tab S-16). Approximately 10 seconds after the LMLG door came in contact with the runway surface, the lower half of the left lower rudder separated and slid down the runway, coming to rest 5,800 feet from the runway threshold and 1,500 feet from where the LMLG door first contacted the runway (Tab S-16).

At approximately 0019:43L, 34 seconds after initial touchdown, the MA decelerated through approximately 75 kts ground speed and MP2 indicated that the aircraft was becoming increasingly difficult to keep on centerline (Tabs DD-49, V-2.4, V-3.4). Four seconds later, at approximately 0019:47L, MP1 took control of the aircraft and input a full control deflection to the right in an effort to keep the MA on the runway (Tabs DD-49, V-2.4, V-2.10). This consisted of a full right deflection of both stick and rudder accompanied by heavy braking on both rudder pedals (Tabs DD-49, V-2.10, V-3.4). At this point, the aircraft was still on runway centerline and travelling at approximately 62 kts ground speed (Tab DD-49). The brakes on both the RMLG and the rear wheels of the LMLG locked up and began a rapid deceleration of the MA as it slewed to the east side of the runway (Tab DD-49). The wheels on the RMLG left a 900-foot curving skid mark on the prepared surface while the dragging rear wheels of the LMLG left a 450-foot curving skid mark both of which ended at the east edge of the runway (Tab S-16).

At approximately 0019:55L, the MA was travelling at 10 kts ground speed when it departed the prepared surface on the east side of the runway 8,300 feet from the threshold (Tabs DD-49, S-16). One second later, the MA came to a stop on the infield 140 feet from the edge of the runway (Tabs DD-49, S-16). The MA had slewed 110° to the left in its final moments of travel and ended up with its nose pointed off the east side of the runway at 080° (Tab DD-49).

Immediately after the MA came to a stop, MP2 notified tower that they had departed the runway and were now on the grass infield (Tabs N-5, V-3.4, V-13.3). MP2 then opened the main crew entry hatch and, after verifying that there were no obstructions or fire, notified MP1 who then shut down all 4 engines (Tabs V-2.4, V-2.10). At this point, the MC accomplished an emergency ground egress of the aircraft in accordance with procedures (Tabs V-2.4, V-3.4).

f. Egress and Aircrew Flight Equipment (AFE)

The MC's AFE was properly configured, performed as expected, and there is no evidence to suggest it was a factor in the mishap (Tabs V-2.6, V-3.7).

MP1 and MP2 were able to accomplish an emergency ground egress from the MA without injury after the MA came to a stop (Tabs V-2.4, V-3.4). The emergency egress system was not utilized, so the ejection seats were not removed for analysis (Tab V-3.4).

g. Search and Rescue (SAR)

At 0020:03L, MP2 made a radio call to Whiteman AFB tower stating the MA was "off the runway, in the grass" (Tabs N-5, V-3.4, V-13.3). Whiteman AFB Fire and Rescue arrived at the MA and secured the MC (Tabs N-9, V-13.2).

h. Recovery of Remains

This section is not applicable.

5. MAINTENANCE

a. Forms Documentation

The AAIB's Maintenance Member conducted a review of the MA's maintenance documentation, including its Jacket File and Air Force Technical Order (AFTO) Form 781s; this review revealed no discrepancies. The MA last completed a PDM inspection on 8 August 2014 (Tab U-2). A 2,000 Hour Phase Inspection was completed by Whiteman AFB personnel on 7 February 2020. An Hourly Post-flight Inspection was completed by Whiteman AFB personnel on 26 August 2021 (Tab D-3).

A Pre-flight Inspection was documented at 2130L on 12 September 2021 (Tab D-3). Maintenance personnel completed Exceptional Release (ER) documentation, clearing the MA to fly. This occurred both prior to the first sortie of the day and following the Hot Pit (engines running) refuel between the MA's first and second sorties (Tabs D-3 to D-4). Other maintenance records, including Time Compliance Technical Orders (TCTOs), Engineering Support Requests (ESRs), Extension Letters and historical records were reviewed and determined not to be relevant.

b. Inspections

All MA inspections were current, with previous inspections annotated, complete and no discrepancies noted (Tab D-2 to D-31).

c. Maintenance Procedures

The Pre-flight inspection performed prior to the mishap was completed in accordance with the proper technical order. All servicing, required inspections, and visual inspections were accomplished in their entirety and signed-off on the Form 781H with no discrepancies (Tab D-3 to D-4).

d. Maintenance Personnel and Supervision

Maintenance activities were conducted on the MA by military personnel from the 509 BW and 131 BW, as well as civilian employees of the Air Force (Tabs V-5.1 to V-12.14, V-14.1 to V-15.3). Depot inspection and maintenance were last conducted in 2014 by Northrop Grumman personnel (Tab U-2). Review of records noted no discrepancies in training or certification for any

Whiteman AFB personnel performing maintenance on the MA. Maintenance personnel did not identify any supervisory shortfalls or noteworthy hindrances affecting the quality of maintenance on the MA (Tabs V-5.1 to V-12.14, V-14.1 to V-15.3).

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

Hydraulic fluid samples from the MA's four hydraulic systems and lubricating oil samples from the MA's four engines were sent to the Air Force Petroleum Office for analysis. The Board reviewed the results of the analysis, finding none causal or contributory to the mishap (Tab J-2 to J-10).

f. Unscheduled Maintenance

Following the pre-flight inspection, two BDU-50 inert (practice) bombs were loaded on to the MA's Smart Bomb Rack Assembly (SBRA) (Tabs V-11.1 to V-11.7). After installing the ordnance, the weapons team performed their post-load inspection with no discrepancies (Tab V-10.2).

After the inert ordnance was loaded, Electrics and Environmental personnel performed a de-aeration of the right-side Ethanol Glycol Water (EGW) coolant system to include an air entrapment check (Tabs V-10.7, V-15.4).

Following the EGW servicing, the MA was placed into flight configuration. This involved removal of safety pins and personnel protective devices (PPD), accomplishment of required inspections, and circuit breaker configuration for flight (Tabs D-5 to D-29).

On landing after the first sortie, a Hot Pit refueling task was initiated. The MA was placed into safe status for the Hot Pit refueling, meaning safety devices and landing gear pins were installed. At the completion of the refuel, the safety devices and pins were removed, and a tool and FOD check were completed (Tabs V-6.2, D-5 to D-29).

On landing after the second sortie, an Engine Running Crew Change (ERCC) was conducted during which the MC assumed control of the MA. Upon doing so, the MC notified maintenance personnel there was an Anti-Skid Caution displayed by the MA's systems. Maintenance personnel entered the MA to assist in clearing the caution by releasing the parking brake and resetting the Anti-Skid controller, which cleared the caution. This was the last known unscheduled maintenance performed on the MA prior to the mishap. (Tabs V-6.2, V-6.4, V-16.1 to V-16.2).

6. AIRFRAME

a. Structures and Systems

The MA sustained damage in the following areas: the Left Main Landing Gear (LMLG) door, the skin under the left wing, the left lower wingtip light, the left lower rudder, LMLG door actuators, the LMLG's retract actuator, the LMLG door mounts, and left elevator composite damage. There is also the potential for internal left wing structural damage, which will require further engineering assessment (Tab DD-41).

The Mishap Aircraft, depicted where it came to rest east of the Whiteman AFB runway.

(1) Left Lower Rudder/Lower Wingtip Light Assembly

Upon collapse of the LMLG on rollout, the fully deflected left lower rudder, left lower wingtip light assembly, and left lower wingtip skin contacted and scraped along the runway. This contact caused the bottom half of the left lower rudder to break off from the MA. Similarly, the left lower wingtip light assembly also separated from the MA. Substantial skid damage to the lower skin caused a large opening, exposing the internal structure of the wing.

(2) Left Main Landing Gear (LMLG) Door

Upon collapse of the LMLG on rollout, the LMLG door contacted the runway, damaging the lower blade seals, door lock points, LMLG tire bumpers, forward LMLG door actuator attachment point, aft LMLG door actuator, all door hinges, and upper blade seals.

The Mishap Aircraft's LMLG door depicted on the runway following the mishap.

(3) LMLG Retract Actuator

Upon collapse of the LMLG on rollout, the LMLG retract actuator, which was in its "locked out" state, suffered a structural failure due to its inability to support the weight of the MA as the collapse occurred.

The LMLG's broken retract actuator piston depicted following the mishap.

(4) Left Lower Skin

Upon collapse of the LMLG during the landing, the LMLG door separated from the MA. As it separated, it made contact with and damaged the skin on the underside of the MA's left wing.

Damage, covered with barrier paper, to the skin on the underside of the Mishap Aircraft's wing.

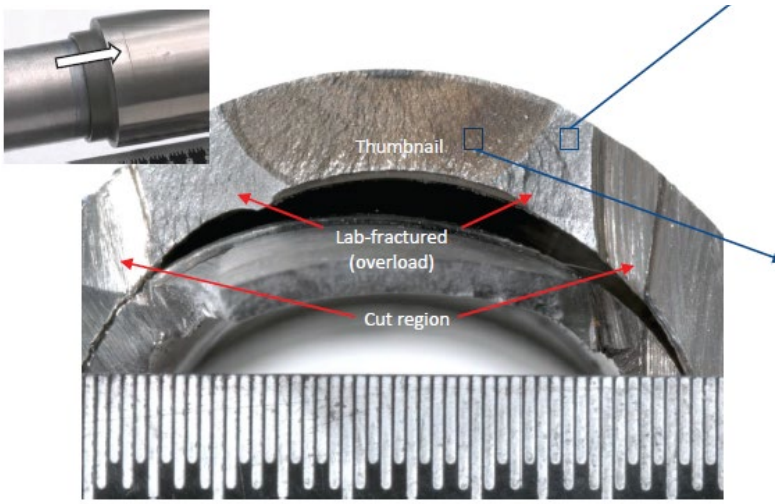
b. Evaluation and Analysis

The AAIB obtained analyses of several components, the results of which are described below.

(1) Analysis of CryoFit Coupling

Air Force Research Laboratory (AFRL) personnel at Wright-Patterson AFB, Ohio conducted an analysis of the CryoFit component that failed, which resulted in a loss of hydraulic pressure in the MA's #1 and #4 hydraulic systems. The analysis identified a metal fatigue-related "microcracking" in the CryoFit, which appears to have led to the CryoFit sliding off the tube to which it connected. The cause of separation is still under investigation (Tabs J-33 to J-58).

The CryoFit coupling is shown separated from the hydraulic line from which it was connected to prior to failure.

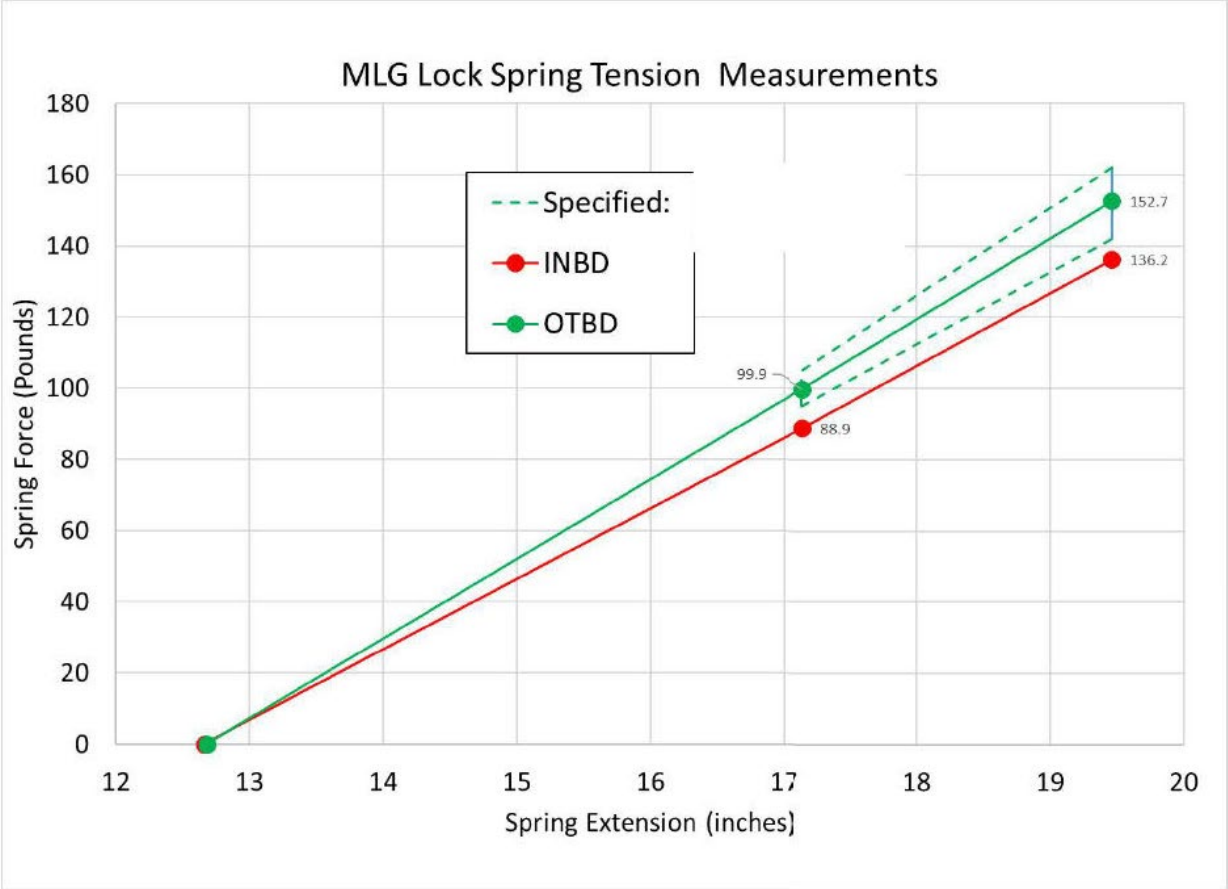


This laboratory image depicts the CryoFit with the blue lines indicating areas of metal fatigue.

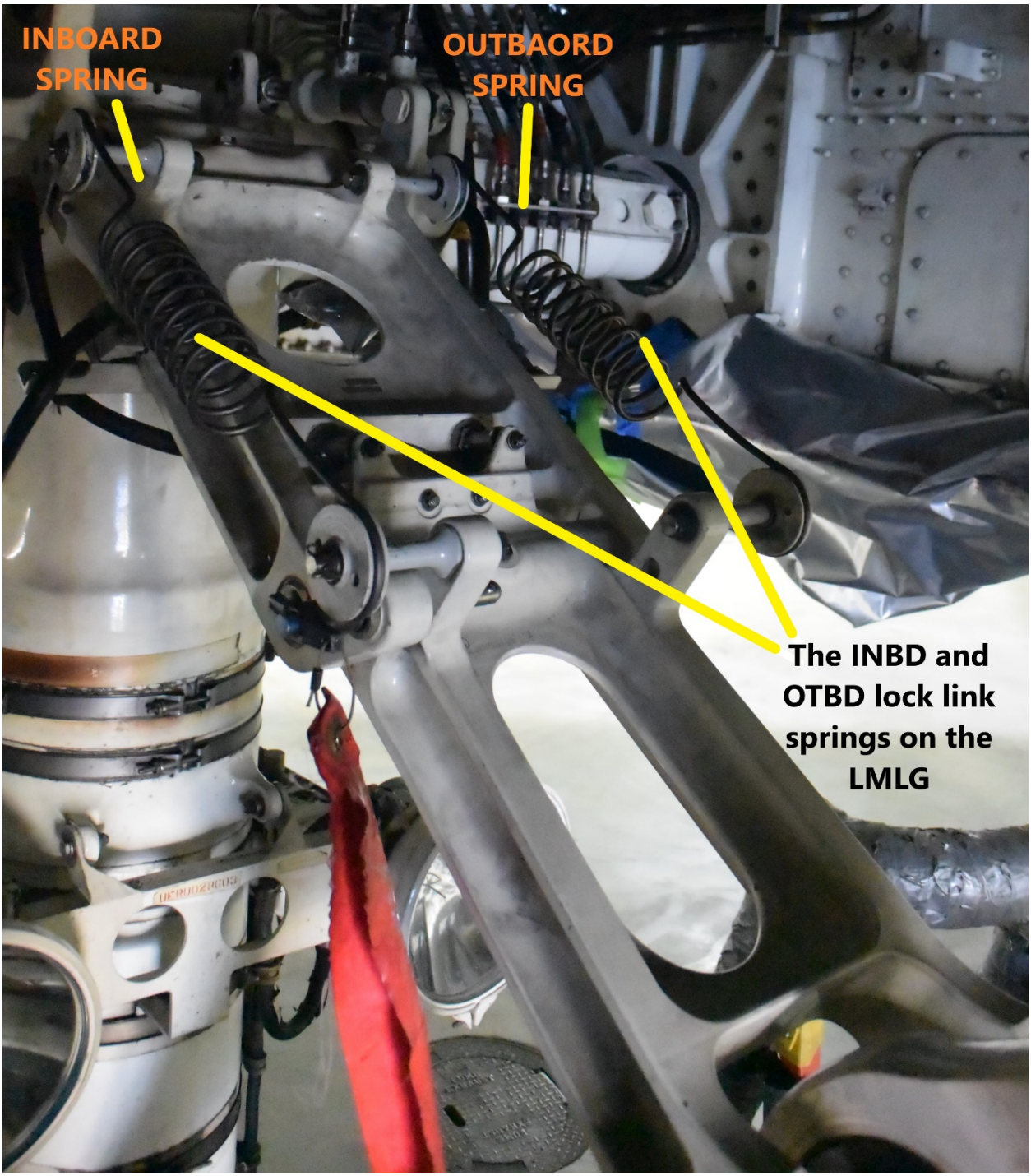
(2) Lock Link Springs

AFRL personnel at Wright-Patterson AFB also conducted an analysis of the LMLG's lock link springs. As depicted in the chart below, they assessed the amount of tension, in pounds (lbs), the springs produced at various extension lengths in comparison with the allowable tension tolerance the springs are designed to produce. The AFRL analysis found that, when fully down and locked, the inboard LMLG lock link spring produced 88.9 lbs of tension, which is below the spring's designed tension of 100 lbs and outside the +/-5 lb tolerance established for the spring at that extension. When at maximum extension, the inboard LMLG lock link produced 136.2 lbs of tension, which is below the designed tension of 152.7 lbs and outside the +/- 10 lb tolerance established for the spring at that extension. Thus, at the two positions tested, the inboard spring produced approximately 11.1% and 11.0% less tension, respectively, than the designed specification. Further, the spring produced 6.4% and 4.6% less tension than the minimum allowable tolerance for the component (Tabs J-17, J-26, J-28).

The chart below illustrates the analyzed spring tensions for the LMLG lock link springs. The inboard spring (INBD) is the spring closest to the centerline of the MA, while the outboard (OTBD) spring is closest to the wing tip of the MA. The dotted section depicted on the chart is the allowed spring tension tolerance for the lock link springs. The chart indicates that while the OTBD spring is within tolerances, the INBD spring was providing below tolerance (weaker) tension at both tested positions (Tab J-26).



A chart depicting the results of AFRL testing of post-mishap tension strength for the LMLG's two lock link springs. Note the inboard spring tested below the required tolerance range.



The Mishap Aircraft's LMLG lock link depicted following the mishap.

7. WEATHER

a. Forecast Weather

The MC received a flight weather briefing and mission execution forecast covering the forecasted weather for the departure and recovery base and the planned route of flight (Tab F-3). On the night of the mishap, the forecasted weather for takeoff and landing was a few clouds at 4,000 feet and 15,000 feet with winds out of the southwest at 10 kts and 7 miles or greater visibility (Tabs F-2, F-3). The Terminal Aerodrome Forecast (TAF) for Whiteman AFB at the expected recovery time included a remark of wind shear at 1,500 feet with winds at 220° at 30 kts (Tab F-2). The forecasted illumination was 52%, for the duration of the sortie (Tab F-3). This weather forecast was not expected to change significantly over the duration of the flight (Tabs F-1, F-2).

b. Observed Weather

The observed weather at Whiteman AFB at the time of the mishap was winds out of the south at 11 knots, few clouds at 25,000 feet with unlimited visibility (Tabs N-3, W-2). Both members of the MC testified that weather played no part in the mishap (Tabs V-2.3, V-2.8, V-3.6).

c. Space Environment

Not applicable.

d. Operations

No evidence suggests the MC was operating outside prescribed operational limits with respect to weather conditions or that the weather at the time of the mishap played any part in the mishap events (Tabs N-2, W-2, V-2.3, V-2.8, V-3.6).

8. CREW QUALIFICATIONS

a. Mishap Pilot 1 (MP1)

At the time of the mishap, MP1, who was acting as the MA instructor pilot, was current, qualified, and experienced in two aircraft, the B-2A and T-38A (Tabs G-24, G-27, G-29). MP1 was previously qualified as a B-52H pilot and had 2452.9 total flight hours, including 924.4 flight hours in the B-2A (Tabs G-51, G-3, G-5). In addition to B-2A qualification, MP1 was qualified to accomplish the following tasks in the B-2A: Evaluator Pilot (EP), Flight Lead (FL), Long Duration Sorties (LD), and Mission Commander (Tab G-98). MP1's most recent flight prior to the MS was on 1 September 2021 in a T-38A; his last B-2A sortie was on 18 August 2021 (Tabs G-11, G-13).

On the day of the mishap, MP1's recent flight time in the B-2A and T-38A was as follows:

B-2A	Hours	Sorties	T-38A	Hours	Sorties
Last 30 Days	3.0	1	Last 30 Days	1.1	1
Last 60 Days	25.9	6	Last 60 Days	6.3	6
Last 90 Days	48.2	8	Last 90 Days	6.3	6

(Tab G-3).

b. Mishap Pilot 2 (MP2)

At the time of the incident, MP2, who was undergoing aircraft commander upgrade, was current and qualified in two aircraft: the B-2A and T-38A (Tabs G-81 to G-82, G-88). He had previously qualified as a B-52H instructor pilot and had 1511.8 total flight hours, including 113.8 flight hours in the B-2A (Tabs G-81, G-92, G-60, G-64). In addition to the basic B-2A qualification, at the time of the mishap, MP2 was qualified to accomplish Long Duration (LD) sorties in the B-2A (Tab G-98). MP2's most recent flight prior to the MS was a 9 September 2021 sortie in a T-38A; his last B-2A sortie prior to the MS was on 2 September 2021 (Tabs G-68, G-70). At the time of the mishap, MP2's recent flight time in the B-2A and T-38A was as follows:

B-2A	Hours	Sorties	T-38A	Hours	Sorties
Last 30 Days	8.0	2	Last 30 Days	11.8	9
Last 60 Days	17.4	4	Last 60 Days	19.0	16
Last 90 Days	23.3	6	Last 90 Days	19.0	16

(Tab G-60).

9. MEDICAL

a. Qualifications

No evidence suggests the MC or maintenance personnel were physically or medically unqualified at the time of the MS.

b. Health

No evidence suggests the health of the MC or maintenance personnel was a factor in this mishap.

c. Pathology

Base medical personnel performed toxicology testing on the MC and relevant maintenance personnel following the mishap with negative findings (Tab G-100). Toxicology was not a factor in this mishap.

d. Lifestyle

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

e. Crew Rest and Crew Duty Time

Prior to performing flight duties, aircrew members must have proper rest, as defined in AFMAN 11-202, Volume (V) 3, *Flight Operations* (Tab BB-26). AFMAN 11-202 V3, paragraph 3.1 defines normal crew rest as a minimum of a 12-hour non-duty period before the designated flight duty period begins (Tab BB-26). Crew rest is defined as "free time" and includes time for meals, transportation, and the opportunity for at least 8 hours of uninterrupted sleep (Tab BB-26). The MC both testified they had adequate crew rest and denied fatigue played a role in the mishap (Tab V-2.11, V-3.13).

10. OPERATIONS AND SUPERVISION

a. Operations

AAIB interviews with pilots and maintenance personnel from both the 509 BW and 131 BW revealed that the operations tempo at the time of the mishap was normal with no surge operations, nuclear generations or bomber task force deployments being conducted (Tabs V-2.11, V-3.13, V-4.6, V-6.3, V-7.4, V-9.7, V-10.4, V-11.3, V-12.7, V-13.4, V-14.4, V-15.4). Airfield conditions at Whiteman AFB were in sufficient working order for the planned approaches and landings, and there were no identified airfield hazards or limitations (Tab AA-2). The AAIB found no evidence to suggest operations tempo or other operational conditions were factors in this mishap.

b. Supervision

The MC were both current and qualified for the mission (Tabs G-24, G-27, G-29, G-81 to G-82, G-88). During mission planning, B-2A crews accomplish an Operational Risk Management (ORM) assessment and annotate the result on the flight authorization (Tabs K-4, V-3.5). The overall risk assessment for the MS was correctly calculated and annotated as "Low Risk" (Tabs K-4, V-3.5). This ORM analysis is repeated prior to departing for the aircraft in order to incorporate any changes in the planned mission. "Step" is an Air Force term for the final preflight process that validates a mission crew and the aircraft are properly prepared for a sortie. Prior to step for the MS, the ORM level was reviewed and remained "Low Risk" (Tabs K-4, V-3.5).

For 393 BS B-2A sorties, the roles of the Supervisor of Flying (SOF) and Squadron Operations Support Supervisor (often referred to as "Ops Sup" or "Top 3") are performed by a single individual, referred to by the positional call sign "Maddog" (Tabs V-2.3, V-2.6, V-3.5, V-4.1, V-4.3). On the day of the mishap, the on duty Maddog was an experienced B-2A pilot qualified to perform Ops Sup/Top 3 duties (Tab G-98). The on-duty Maddog provided the step brief for the MC (Tabs V-2.6, V-3.5, V-3.7, V-4.1, V-4.3). As a part of the step brief, Maddog reviewed the sortie's flight plan, the aircrew's Go/No-Go checklists and training currencies. Maddog also ensured the MC reviewed the Flight Crew Information File (FCIF) and emergency procedures (Tabs V-2.7, V-3.5, V-3.7, V-4.3, V-4.4). All of the relevant, reviewed materials were found to be in order for the flight with the exception of MP2's night air refueling (A/R), which was

expired (Tab K-6). However, since A/R was not planned for this sortie and MP1 was current on night A/R, the expired currency was not an impediment to the planned flight. The AAIB found no evidence to suggest that supervision was a factor in the mishap.

11. HUMAN FACTORS ANALYSIS

The Department of Defense Human Factors Analysis and Classification System 7.0 (DoD HFACS 7.0) lists potential human factors that can play a role in aircraft mishaps and identifies potential areas of assessment during an accident investigation. The AAIB conducted an analysis of all listed, potential human factors relevant to the mishap and determined none to be causal or contributory.

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Publicly Available Directives and Publications Relevant to the Mishap

(1) AFI 51-307, Aerospace and Ground Accident Investigations, 18 March 2019

(2) AFMAN 11-202, Volume (V) 3, *Flight Operations*, 10 June 2020

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

b. Other Directives and Publications Relevant to the Mishap

(1) Not applicable.

c. Known or Suspected Deviations from Directives or Publications

(1) Not applicable.

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12 January 2022

ROBERT P. M. COCKE, Colonel, USAF
President, Abbreviated Accident Investigation Board

STATEMENT OF OPINION

B-2A, T/N 89-0129
WHITEMAN AIR FORCE BASE, MISSOURI
14 SEPTEMBER 2021

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 13 September 2021, the mishap aircraft (MA), a B-2A, with tail number (T/N) 89-0129, departed Whiteman Air Force Base, Missouri at 2024 hours local time (L) for a routine continuation training and aircraft commander upgrade sortie. This was the MA's third sortie of the day. The Mishap Crew (MC) was from the 393rd Bomb Squadron (393 BS) of the 509th Bomb Wing (509 BW) and consisted of the mishap instructor pilot (MP1) and the mishap pilot (MP2). The Mishap Aircraft (MA) was from the 509 BW.

The mishap sortie (MS) proceeded uneventfully until the MA began its transition to recovery. At 0013:12L on 14 September 2021, Kansas City Center (ZKC) cleared the MC for the instrument landing system (ILS) approach to runway 19 at Whiteman AFB. Just over a minute and a half later MP1 placed the landing gear handle in the down position beginning the landing gear extension process. Immediately following this, the MA suffered a failure in a hydraulic CryoFit connector in the right main landing gear (RMLG) well. This failure led to a rapid loss of hydraulic fluid in the #1 and #4 hydraulic systems. As result of this fluid loss, the MA had insufficient hydraulic fluid to accomplish a normal landing gear extension. At the completion of the normal landing gear cycle, the nose landing gear (NLG) and the left main landing gear (LMLG) were down and locked, but the RMLG had failed to begin extension. The hydraulic failure in the RMLG well prevented the accumulation of sufficient hydraulic pressure to begin the RMLG extension process. Approximately 39 seconds after the landing gear handle was placed in the down position, MP1 accomplished an emergency gear extension, which employed stored accumulator pressure to initiate the RMLG extension. Approximately 54 seconds after the landing gear handle was first lowered, all three landing gear were indicating down and locked. The remainder of the approach proceeded normally until aircraft touchdown.

The MA initially contacted the runway at 0019:09L. This initial touchdown was followed by a short bounce where the MA became airborne before settling back onto the prepared surface at 0019:14L. Both the initial and subsequent touchdowns had minimal force of gravity (g) indications on the Crash Survivable Memory Unit (CSMU) and on the On-Board Ground Processing system (OGP), indicating that they were not hard landings. As the NLG touched the runway, the LMLG began to collapse into the LMLG wheel well. During the course of this collapse, the MA continued to travel down the runway with the left side of the MA descending

towards the runway surface. During this descent, the LMLG door contacted the runway and separated from the MA. The MA remained on the runway centerline and decelerated resting on the NLG, RMLG and a combination of the left lower rudder and left wingtip. Approximately 34 seconds after initial touchdown, the decelerating aircraft became increasingly difficult to hold on the runway, with the MA eventually departing the prepared surface at 0019:55L approximately 7,100 feet from where it initially touched down. At this time, the aircraft was travelling at approximately 10 knots ground speed. After leaving the prepared surface, the aircraft travelled approximately 140 feet before coming to a stop on the grass infield. At this point, the MC accomplished an engine shutdown and performed an emergency ground egress. The MA suffered extensive damage to the left lower wing and control surfaces. Total costs to the Government were initially estimated to be at least $10.1 million.

2. CAUSE

I find, by a preponderance of the evidence, that the cause of the mishap was the failure of the MA's LMLG lock link springs to apply sufficient pressure on the lock link assembly to prevent it from folding, which resulted in a LMLG collapse during the MA's landing. The failure of the lock link springs resulted in the LMLG retracting into the LMLG well while the MA was travelling down the runway. The collapse caused a structural failure of the LMLG hydraulic retract actuator and caused the violent separation of the LMLG door as the MA settled onto its left side. The settling of the MA then caused the failure and separation of the lower half of the left rudder and caused extensive lower left wing damage as the MA continued its landing roll down the runway, resting on the NLG, RMLG and the left lower rudder/wing tip.

In the B-2A, the landing gear lock links are primarily held in place by the mechanical action of two lock link springs, which hold the lock link in the over center (locked) position. The lock link is assisted into the over center position by a hydraulic lock link actuator which maintains pressure on the lock link. However, the actuator is not required for normal landing gear operation. The landing gear is designed to operate mechanically, using the force of gravity and airflow to extend into a down and locked position without any hydraulic assistance. The evidence for this design is seen in the RMLG of the MA, which extended solely with gravity and airflow, and which remained down and locked without any hydraulic assistance. Over the history of the B-2A, there have been eight previous cases of a dual failure of the #1 and #4 hydraulic systems in flight, at least four of which included the use of the emergency landing gear extension system; however, none of those failures resulted in a landing gear collapse.

The only previous landing gear collapse of a B-2A occurred in 2002 in a hangar when the aircraft was undergoing maintenance on a landing gear proximity sensor. In that case, there was no power on the aircraft and consequently no hydraulic assistance holding the lock link over center. In order to adjust the proximity sensor on the lock link, aircraft maintenance personnel removed the landing gear lock link safety pin, in violation of technical orders, and pushed up on the lock link. This action caused the lock link to disengage from the over center position and the landing gear to rapidly collapse. The fact that an individual was able to break the lock link's over center by simply pushing up on it illustrates the relatively small amount of force required to break the over center (locked) position when it is not assisted by the hydraulic lock link actuator.

In most cases, when the B-2A does not have hydraulic power, the landing gear lock links are kept in an over center position by a landing gear safety pin which is inserted by maintenance personnel prior to engine shut down. That safety pin is removed prior to engine start, after which hydraulic pressure is present in the lock link actuator to assist in keeping the lock link over center. With the exception of engine start, the aircraft does not routinely rely on the lock link springs alone to hold the lock links over center. The only other time this is not the case is when the aircraft is in flight and the landing gear is extended, but hydraulically isolated due to either hydraulic fluid/pressure loss or emergency landing gear extension. On 14 September 2021, the MA found itself in that exact situation.

During the MS, the landing gear had extended and locked in the down position using gravity and airflow only. Cockpit indications on both the landing gear panel and on the landing gear displays on the Multi-Display Units (MDUs) provided this information to the pilots. In this case, without the assistance of the hydraulic lock link actuator, the lock link springs alone held the lock links over center and prevented the gear from retracting. Engineering analysis of the LMLG lock link springs indicate that one of the two springs on the MA's LMLG was not providing the required amount of tension on the lock link. The lock link springs are designed to provide 100 pounds of pressure at 17 inches of extension. The outboard spring met that requirement, but the inboard spring was only supplying 88.9 pounds at 17 inches of extension. This amounted to a decrease of approximately 11% in spring tension from one of the two lock link springs, which, when coupled with the dynamic environment on landing, was insufficient to hold the lock link over center (locked).

Since 2018, B-2As going through programmed depot maintenance (PDM) have had their lock link springs removed and replaced. The MA had not been through depot since this change in procedure, and a thorough search of the MA's maintenance records found that the springs had not been replaced in the last ten years. No evidence could be found that the springs had ever been replaced.

3. SUBSTANTIALLY CONTRIBUTING FACTORS

I find, by a preponderance of evidence that one additional factor substantially contributed to the mishap: the failure of a hydraulic CryoFit coupling that drove a rapid a loss of hydraulic fluid in the #1 and #4 hydraulic systems, preventing the use of the LMLG lock link actuator.

The failure of a CryoFit coupling resulting in the loss of hydraulic fluid in the #1 and #4 hydraulic systems

A hydraulic CryoFit coupling on a high-pressure hydraulic line in the RMLG wheel well failed during landing gear extension. This failure was likely caused by a metal fatigue induced "microcrack" identified by engineering analysis after the mishap.

The CryoFit coupling failure on the high-pressure line resulted in a rapid loss of hydraulic fluid from the #1 hydraulic system. Within 60 seconds, all 21 gallons in the #1 hydraulic system had been lost. By design, when landing gear extension is commanded and the #1 hydraulic system is inoperative, a switching valve shifts landing gear operation over to the #4 hydraulic system. When that shift occurred, the #4 hydraulic system also began to rapidly lose fluid from its hydraulic

reservoir. Within 20 seconds of the switching valve opening up, the #4 hydraulic system had lost 15 of its 17.6 gallons. Despite this fluid loss, the NLG and LMLG were both able to accomplish a normal landing gear extension, but due to the CryoFit failure in the RMLG well, the RMLG never received sufficient hydraulic pressure to begin lowering and consequently was still up and locked.

At this point, MP1 accomplished an emergency landing gear extension. This action employed stored accumulator pressure to forcibly release the RMLG causing it to drop free into the airflow. Critically, the activation of the emergency landing gear extension system isolated the landing gear from the #1 and #4 hydraulic systems. Following the activation of the emergency landing gear extension system, the RMLG successfully extended and locked into position.

Since the main landing gear is designed to free fall into a down and locked position with the use of gravity and airflow, the lack of hydraulic pressure should have had no impact on the LMLG remaining down and locked on landing. The landing gear lock link is a mechanical system designed to operate regardless of hydraulic pressure. When the landing gear is lowered, the force of gravity and airflow place the lock link in an over center (locked) configuration, which physically locks the landing gear into an extended position. The lock link is held in this over center position by two high-tension springs, and it is assisted into an over center position by a hydraulic lock link actuator. This actuator uses 4,000 psi hydraulic pressure to help ensure the lock link is over center and kept in the locked position. While the springs are the primary mechanical means of holding the lock link in place, the hydraulic lock link actuator maintains pressure on the lock link when the landing gear is in the extended position.

In the case of the MA, the lock link actuator was isolated from the hydraulic systems due to the use of the emergency landing gear extension system. Consequently, the lock link actuator was providing no assistance to the high tension springs in keeping the lock link over center.

As a result of the lack of hydraulic pressure in the main landing gear wells, both the LMLG and RMLG were completely reliant on the lock link springs to hold the lock links in position and keep the MLG down and locked.

4. CONCLUSION

After a comprehensive investigation into this mishap, I find, by a preponderance of the evidence, the cause of the mishap was the failure of the LMLG lock link springs to apply sufficient pressure on the lock link assembly to prevent it from folding, which resulted in a LMLG collapse during the MA's landing. Additionally, I find, by a preponderance of the evidence, that one factor substantially contributed to the mishap: the failure of a hydraulic CryoFit coupling that drove a rapid a loss of hydraulic fluid in the #1 and #4 hydraulic systems which ultimately isolated the LMLG lock link actuator preventing its use in assisting the LMLG lock link to remain down and locked.

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