UNITED STATES AIR FORCE AIRCRAFT ACCIDENT INVESTIGATION BOARD REPORT

F-16CM, T/N 91-0413

United States Air Force Air Demonstration Squadron
57th Wing
Nellis Air Force Base, Nevada

LOCATION: Nevada Test and Training Range

DATE OF ACCIDENT: 4 April 2018

BOARD PRESIDENT: Brigadier General Case A. Cunningham

Conducted IAW Air Force Instruction 51-503

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

OFFICE OF THE COMMANDER
205 DODD BOULEVARD SUITE 200
JOINT BASE LANGLEY-EUSTIS VA 23665-2788

AUG 2 1 2018

ACTION OF THE CONVENING AUTHORITY

The report of the Accident Investigation Board, conducted under the provisions of AFI 51-503, that investigated the 4 April 2018 mishap involving an F-16CM, T/N 91-0413, United States Air Force Air Demonstration Squadron, 57th Wing, Nellis Air Force Base, Nevada, complies with applicable regulatory and statutory guidance and on that basis is approved.

JAMES M. HOLMES
General, USAF
Commander

Dominant Combat Airpower for America

EXECUTIVE SUMMARY
UNITED STATES AIR FORCE
AIRCRAFT ACCIDENT INVESTIGATION

F-16CM, T/N 91-0413
Nevada Test and Training Range
4 April 2018

On 4 April 2018, the mishap pilot (MP), flying a F-16CM, tail number (T/N) 91-0413, assigned to the United States Air Force Air Demonstration Squadron, the "Thunderbirds," 57th Wing, Nellis Air Force Base (AFB), Nevada (NV), engaged in a routine aerial demonstration training flight at the Nevada Test and Training Range (NTTR) near Creech AFB, NV. During the training flight, at approximately 1029 local time, the mishap aircraft (MA) impacted the ground and fatally injured the MP, without an ejection attempt.

The mishap mission was planned and authorized as a practice of a Thunderbirds aerial demonstration in the south part of the NTTR. The mishap flight was a formation of six F-16CMs (Thunderbirds #1-6), the standard Thunderbirds aerial demonstration flight. Thunderbird #4 was the MA/MP. During the High Bomb Burst Rejoin, an aerial maneuver near the scheduled end of the aerial demonstration training flight, the MP flew the MA for approximately 22 seconds in inverted flight between 5,500 and 5,700 feet above ground level. During this time, the MP experienced a change in force due to acceleration measured in multiples of the acceleration of gravity felt at the earth's surface (G), between -0.5 to -2.06 G's. While experiencing -2.06 G's in inverted flight, the MP initiated a descending half-loop maneuver (Split-S). After five seconds in the Split-S, the MP attained a maximum +8.56 G's. The MP experienced G-induced loss of consciousness (G-LOC) and absolute incapacitation at the end of that five-second period.

For approximately the next five seconds, the MP remained in a state of absolute incapacitation and made no deliberate flight control inputs as the MA accelerated toward the ground. Approximately one second prior to ground impact, the MP began deliberate flight control inputs as he transitioned from absolute to relative incapacitation. The MA impacted the ground at 57 degrees nose low with 89 degrees of left bank and the MP was fatally injured on impact, without an ejection attempt.

The Accident Investigation Board (AIB) President found by a preponderance of evidence the cause of the mishap was the MP's G-LOC during the Split-S portion of the High Bomb Burst Rejoin maneuver. Additionally, the AIB President found by a preponderance of evidence two factors substantially contributed to the mishap: (a) the MP's diminished tolerance to +G's induced by the physiology of the MP's exposure to –G's ("Push-Pull Effect") and (b) an associated decrease in the effectiveness of the MP's Anti-G straining maneuver under those conditions.

SUMMARY OF FACTS AND STATEMENT OF OPINION
F-16CM, T/N 91-0413
4 April 2018

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ACRONYMS AND ABBREVIATIONS

57 WG	57th Wing
ACC	Air Combat Command
ADCC	Assistant Dedicated Crew Chief
AF	Air Force
AFB	Air Force Base
AFE	Aircrew Flight Equipment
AFI	Air Force Instruction
AFPAM	Air Force Pamphlet
AFTO	Air Force Technical Order
AGL	Above Ground Level
AGSM	Anti-G Straining Maneuver
AIB	Accident Investigation Board
ARMS	Aviation Resource Management System
ATAGS	Advanced Tactical Anti-G Suit
BPO	Basic Post Flight
CC	Commander
COMACC	Commander Air Combat Command
CSAF	Chief of Staff of the Air Force
DAS	Data Acquisition System
DCC	Dedicated Crew Chief
DoD	Department of Defense
ECSMU	Enhanced Crash Survivable Memory Unit
EP	Emergency Procedure
FOD	Foreign Object and Debris
ft	Feet
G	Force Due to Acceleration Measured in Multiples of the Acceleration of Gravity Felt at the Earth's Surface
G-LOC	G-induced loss of consciousness
G-Ex	G-Exercise
HARM	Host Aviation Resource Management
HFACS	Human Factors Analysis and Classification System
Hg	Mercury
HI BB	High Bomb Burst
HUD	Heads-Up Display
IAW	In-Accordance With
IFF	Introduction to Fighter Fundamentals
IMDS	Integrated Maintenance Data System
IP	Instructor Pilot
k	Thousand
KCAS	Knots Calibrated Airspeed
L	Local Time
LM-Aero	Lockheed Martin Aeronautics Company
MA	Mishap Aircraft
MF	Mishap Flight
MP	Mishap Pilot
MS	Mishap Sortie
MSL	Mean Sea Level
NOTAMS	Notices to Airmen
NTTR	Nevada Test and Training Range
NV	Nevada
OPMAN	Operations Manual
ORM	Operational Risk Management
PA	Public Affairs
PR	Pre Flight
PSI	Pounds Per Square Inch
RSO	Range Safety Officer
SAF	Secretary of the Air Force
SAR	Search and Rescue
SC	Show Center
SII	Special Interest Item
SQ	Squadron
SOF	Supervisor of Flying
TB	Thunderbird
TCTO	Time Compliance Technical Order
TDY	Temporary Duty
TO	Technical Order
T/N	Tail Number
TX	Transition Course
UPT	Undergraduate Pilot Training
USAFADS	U.S. Air Force Air Demonstration Squadron
USAF	U.S. Air Force
USAFWC	U.S. Air Force Warfare Center
Vol	Volume
WAI	Walk Around Inspection

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

SUMMARY OF FACTS

1. AUTHORITY AND PURPOSE

a. Authority

On 5 April 2018, General James M. Holmes, the Commander of Air Combat Command, appointed Brigadier General Case Cunningham to conduct an aircraft accident investigation of the 4 April 2018 mishap of an F-16 Thunderbirds aircraft at the Nevada Test and Training Range (NTTR) (Tab Y-3 to Y-4). On 27 April 2018, the Accident Investigation Board (AIB) convened at Nellis Air Force Base (AFB), Nevada (NV). A legal advisor (Lieutenant Colonel), medical member (Major), pilot member (Captain), maintenance member (Senior Master Sergeant), and a recorder (Technical Sergeant) were also appointed to the board (Tab Y-3 to Y-4). A subject matter expert in Aerospace Medicine (Major) was subsequently appointed on 30 April 2018 (Tab Y-5). The AIB was conducted in accordance with (IAW) Air Force Instruction (AFI) 51-503, *Aerospace and Ground Accident Investigations*, dated 14 April 2015, and AFI 51-503, *ACC Supplement*, *Aerospace and Ground Accident Investigations*, dated 28 January 2016.

b. Purpose

IAW AFI 51-503, this accident investigation board conducted a legal investigation to inquire into all the facts and circumstances surrounding this Air Force accident, prepare a publicly releasable report, and obtain and preserve all available evidence for use in litigation, claims, disciplinary action, and adverse administrative action.

2. ACCIDENT SUMMARY

On 4 April 2018, the mishap pilot (MP), flying a F-16CM, tail number (T/N) 91-0413, assigned to the United States Air Force Air Demonstration Squadron (USAFADS), “the Thunderbirds,” 57th Wing, Nellis AFB, NV, engaged in a routine aerial demonstration training flight at the NTTR near Creech AFB, NV (Tabs K-2 to K-3, K-7 and U-4). During the training flight, at approximately 1029 local time (L), the mishap aircraft (MA) impacted the ground and fatally injured the MP, without an ejection attempt (Tabs U-4, U-17 to U-18 and X-4).

3. BACKGROUND

a. Air Combat Command (ACC)

ACC is the primary force provider of combat airpower to America's warfighting commands (Tab CC-3). To support global implementation of national security strategy, ACC operates fighter, bomber, reconnaissance, battle-management and electronic-combat aircraft (Tab CC-3). It also provides command, control, communications and intelligence systems, and conducts global information operations (Tab CC-3). ACC's mission is to support global implementation of national security strategy (Tab CC-3). ACC operates over 1,300 aircraft across 34 wings and 19 bases, comprising over 94,000 active duty and civilian personnel (Tab CC-3).

b. United States Air Force Warfare Center (USAFWC)

The USAFWC's mission is to develop innovative leaders and full spectrum capabilities through responsive, realistic, and relevant testing; tactics development; and advanced training across all levels of war (Tab CC-6). The USAFWC ensures deployed forces are well trained and well equipped to conduct integrated combat operations (Tab CC-6). The USAFWC oversees the operations of four wings, two named units and one detachment, comprised of 11,000 personnel located in 23 states and 37 different locations (Tab CC-6).

c. 57th Wing (57 WG)

The 57 WG provides advanced aerospace training to world-wide combat air forces and showcases aerospace power to the world while overseeing the dynamic and challenging flying operations at Nellis AFB (Tab CC-8). The 57 WG is comprised of seven distinct organizations; manages all flying operations at Nellis AFB; and conducts advanced aircrew, space, logistics and command and control training through the United States Air Force (USAF) Weapons School, Red Flag, and Green Flag exercises (Tab CC-8). The Wing additionally supports the USAFWC's test/evaluation activities and showcases air power through the "Thunderbirds" airshows (Tab CC-8).

d. United States Air Force Air Demonstration Squadron (USAFADS)

The USAFADS, also known as the Thunderbirds, performs precision aerial maneuvers demonstrating the capabilities of Air Force high performance aircraft to people throughout the world (Tab CC-13). The squadron exhibits the professional qualities the Air Force develops in the people who fly, maintain and support these aircraft (Tab CC-13).

e. F-16 Fighting Falcon

The F-16 is a compact multi-role fighter aircraft (Tab CC-16). It is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack (Tab CC-16). It provides a relatively low-cost, high performance weapon system and air demonstration capabilities for the United States and allied nations (Tab CC-16).

f. G-Force(s) (Gravitational Force Equivalent)

Fighter aircrew routinely experience changes in force due to acceleration measured in multiples of the acceleration of gravity felt at the earth's surface, abbreviated as "G" or G-Forces, as a result of maneuvers during flight (Tab BB-62 to BB-63). When a high-speed fighter aircraft turns in any direction, the velocity of the aircraft changes along that path and the pilot seated in the aircraft experiences the same acceleration based on velocity and radius of the turn (Tab BB-64). That acceleration and the changes in G can be either positive (+G) or negative (–G) (Tab BB-64). Fighter aircraft instruments measure +G (felt as heaviness in the aircraft seat) and –G (felt as lightness in the aircraft seat) in numerical units of G's (Tab BB-16 and BB-64). This report will refer to G's when referencing the numerical units and the letter "G" only when referring generally to G-Force (Tab BB-16, BB-47 to BB-57 and BB-60 to BB-71). For example, +1.7 G's refers to a force due to acceleration that is equivalent to 1.7 times the acceleration of gravity felt at the earth's surface (Tab BB-62). Much of the research used in the writing of the report refers to measurements of G in the z axis, or up and down (head to foot) axis, but for the sake of simplicity and since the other axes are not relevant to the investigation, the report text omits reference to the specific axis throughout (Tab BB-63).

4. SEQUENCE OF EVENTS

a. Mission

The mishap flight (MF) was a formation of six F-16CMs, the standard Thunderbirds aerial demonstration flight (Tabs K-2, K-6, V-14.13 and DD-3). The Thunderbirds "Diamond Formation" consisted of Thunderbird #1 (TB1), Thunderbird #2 (TB2), Thunderbird #3 (TB3) and Thunderbird #4 (TB4) as depicted in *Figure 1* (Tabs K-2, V-14.5, V-14.7, and BB-24). TB4, also known as the "Slot" pilot or position, was the MP/MA (Tabs K-2 and V-14.5). The solos, the aircraft flying independently of the Diamond Formation in the aerial demonstration, consisted of Thunderbird #5 (TB5) and Thunderbird #6 (TB6) and comprised the rest of the MF (Tabs K-2, V-2.4 and V-14.5).

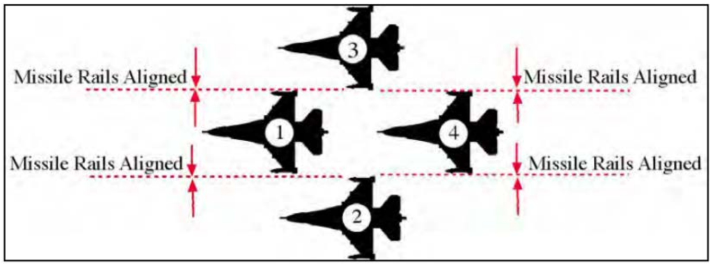


Figure 1: Diamond Formation (Tab BB-24).

The planned mission was to conduct a Thunderbirds practice aerial demonstration (Tabs K-7, V-2.5 to 2.6, V-13.4 and V-14.7). Planned mission tasks included practice aerial demonstration maneuvers on takeoff from Nellis AFB, a departure to a south area of the NTTR, and a practice of the "High Show" version of the Thunderbirds aerial demonstration (Tabs K-7, U-4, V-6.5 and V-14.13). In the High Show, the Thunderbirds perform a series of aerial demonstration maneuvers requiring cloud ceilings higher than 8,000 feet above the ground level (AGL) and visibility greater than five miles (Tab BB-43). The planned mission culmination was a return to Nellis AFB for landing (Tabs K-7 and V-14.7). The Thunderbirds operations officer authorized the mission on an Aviation Resource Management System (ARMS) Fighter Flight Authorization Form (Tab K-2).

b. Planning

TB1 conducted the preflight brief at approximately 0800L (Tab V-14.11). The brief was conducted IAW USAFADS standards and AFI 11-2F-16V3, *F-16 Operations Procedures* (13 Jul 2016) (Tabs V-14.11, BB-5 and BB-22). The brief covered mission objectives, operational risk management (ORM), current and forecasted weather, notices to airmen (NOTAMS), emergency procedures (EPs), special interest items (SIIs), and the lineup card mission materials (Tabs K-6 to K-18, V-2.3, V-2.11, V-4.7, V-5.8, V-13.8 and V-14.11 to 14.12). TB6 was in charge of collecting the ORM data for the mission and collecting any personal safety factors for the flight (Tab V-4.7, V-7.7 and V-14.11). The overall ORM for the mission was briefed as "Green" (Tab K-6). The MP gathered and briefed the weather, NOTAMS, and made the lineup card for the MF during the MF brief (Tab V-2.3, V-14.2 and V-14.11). This included writing the applicable timing data such as takeoff and landing and the airspace times (Tabs K-7 and V-2.3). The weather and NOTAMS supported the planned mission for that day (Tabs F-2, K-11 to K-18 and V-7.9). The brief was conducted in a timely manner, IAW squadron standards, with approximately 20 minutes until the MF pilots were to go out ("step") to the flight line and their aircraft (Tabs V-2.11, V-5.9, V-14.12, V-14.22 and BB-22).

c. Preflight

The MP "stepped" to the MA with the other pilots of the MF, at approximately 0905L, where the MP donned his CSU-22/P Advanced Technology Anti-G Suit (ATAGS) (Tabs K-7 and V-11.6). The ATAGS is a pant-like garment consisting of bladders that fill with air from the aircraft to put pressure on the abdomen, thighs, and calves during an increase in +G's to increase a pilot's tolerance to +G's and help prevent G-induced loss of consciousness (G-LOC) (Tab BB-70). Once the MP was in the cockpit, the Dedicated Crew Chief (DCC) assisted the MP with connecting his ejection seat harness and ATAGS to the aircraft (Tab V-9.3). The MP appeared in good spirits, and correctly zipped his ATAGS (Tab V-5.8 and V-9.5 to V-9.6). TB1 then directed the MF to complete preflight checks prior to taking off (Tab V-2.17). During these checks, the pilots tested their ATAGS system via a button in the cockpit (Tab V-2.17, V-5.12, V-6.14, V-7.10 to V-7.11 and V-14.18).

d. Summary of Accident

The MF departed Nellis AFB at approximately 0950L (Tab U-4). The Diamond Formation coordinated with Nellis Tower for a Diamond Loop on takeoff while TB5 and TB6 took off as single ship aircraft (Tabs BB-26 and DD-7). The Diamond Loop is an aerial demonstration maneuver where the Diamond Formation performs a loop immediately after takeoff and was executed IAW the 57 WG Supplement to Air Combat Command Instruction (ACCI) 11-USAFADS Volume 3, *Operational Procedures-Thunderbirds*, 3 January 2018 (Tabs Z-6 and BB-26 to BB-27). The MF then proceeded toward the northwest and entered the NTTR (approximately 12 miles north of Creech AFB as depicted in *Figure 2*) at approximately 0956L (Tabs K-7, Q-5, Z-3, Z-6 and DD-7).

Figure 2: South NTTR (Tab Z-3)

The Range Safety Officer (RSO), equipped with a UHF/VHF radio, primarily served as a safety monitor and supervised the recording of the practice with video equipment for debriefing purposes (Tabs V-13.8 to V-13.9 and BB-22). Three enlisted personnel from the Thunderbirds accompanied the RSO to the NTTR to film the practice, record the timing, and provide communications expertise (Tabs V-13.8 to V-13.9 and BB-23). These personnel were located in a tower on the practice range to observe the practice demonstration (Tab V-13.7 to V-13.9). Upon reaching the area, the RSO radioed the MF the weather and the status of Creech AFB runways (Tab Z-6). The RSO reported the winds calm, with few clouds at 16,000 feet AGL and scattered clouds at 19,000 feet AGL, with an altimeter setting of 30.06 inches of mercury (Tab Z-6). The MF then setup to practice the High Show version of the Thunderbirds aerial demonstration (Tabs K-7 and V-14.13).

The practice area in the NTTR provides a similar appearance to an airfield typically used in aerial demonstrations, with a visible marker on the ground for show center (SC), as depicted in *Figure 3* (Tabs V-14.6 and BB-44). The first aerial demonstration maneuver the MF executed on the NTTR was the Diamond Cloverloop Opener to begin the High Show practice (Tabs V-14.13 and BB-43). During this maneuver, the Diamond Formation accomplished their G-Exercise (G-Ex) to assess ATAGS operation and personal tolerance for +G's (Tabs V-2.18, V-5.13 and BB-58 to BB-59). Because of the nature of the public demonstration, the Thunderbirds are not required to execute a stand-alone G-Ex, as authorized by an ACC waiver permitting deviation from AFI 11-2F-16V3 (Tab BB-58 to BB-59). This deviation permitted pilots to conserve fuel for the demonstration and maintain flight safety (Tab BB-58). The Data Acquisition System (DAS) also recorded three separate instances where the MP was previously greater than +4 G's on the date of the mishap, with one instance as high as +7.9 G's (Tab DD-8). Based on witness testimony and Heads Up Display (HUD) audio recordings, the MP did not announce problems with his ATAGS inflation or personal tolerance for +G's prior to the mishap (Tabs V-6.17, V-14.21, and DD-8).

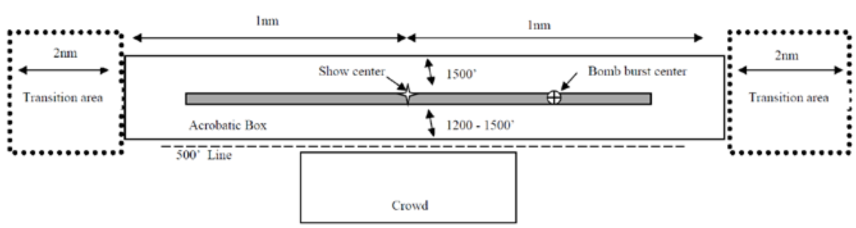


Figure 3: Typical Airfield Layout (Tab BB-44).

The practice aerial demonstration was uneventful, with only minor deviations up until and including the High Bomb Burst Cross near the planned end of the sortie (Tabs V-2.12, V-14.15 and DD-4). After the High Bomb Burst Cross (*Figure 4*) at 1028:18L, the Diamond Formation maneuvered to join back together in the High Bomb Burst Rejoin, as depicted in *Figure 5* (Tabs V-14.7 to V-14.8, Z-4, Z-5, BB-34 and BB-37). The objective of the High Bomb Burst Rejoin, an aerial demonstration maneuver performed by the Thunderbirds in the F-16 for the past 35 years, was to have the entire Diamond Formation together by SC (Tab V-8.9 and V-13.6). Just after the High Bomb Burst Cross, the MP was traveling on a heading of 175 degress, 414 knots calibrated airspeed (KCAS, the airspeed measurement available to the pilot in the cockpit) and 3,284 feet mean sea level (MSL, the altitude measured above sea level available to the pilot in the cockpit) (Tab DD-7). This MSL equates to approximately 300 feet AGL, based on the varying terrain elevation (Tab DD-7).

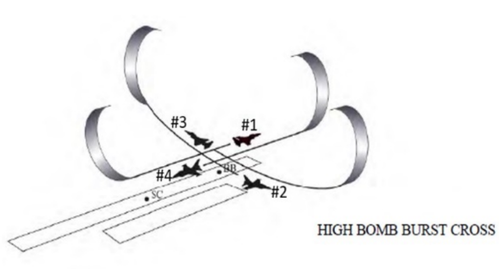


Figure 4: High Bomb Burst Cross (Tabs Z-4 and BB-34).

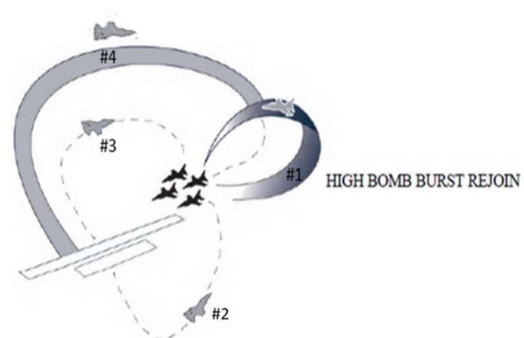


Figure 5: High Bomb Burst Rejoin (Tabs Z-5 and BB-37).

After the diamond formation passed each other IAW *Figure* 4, TB1 made the prescribed radio call to initiate the High Bomb Burst Rejoin at 1028:24L, shown in *Figure 5* (Tabs N-3, BB-36 and DD-8). The MP then executed an ascending half-loop, also known as an Immelmann (*Figure 6*), by selecting engine power at maximum afterburner and pulling back on the control stick, achieving +7.9 G's in the pull (Tabs Z-7 and DD-7). The MP arrived at the top of the Immelmann at 1028:38L, inverted, heading north, 312 KCAS, and 8,616 feet MSL, as depicted in *Figure 6* (Tab Z-8).

Figure 6: MP Immelmann Maneuver during HI BB Rejoin (Tab Z-8)
(Depicted 17:28:38 Coordinated Universal Time (UTC) was L+7 hours)

At 1028:44, TB1 made the prescribed radio call to signal that he was beginning his 5/8 of a loop before rolling to wings level (Half Cuban Eight) to point south towards SC, as depicted in *Figure 5* (Tabs N-4 and BB-37). At this point TB2 and TB3 made the prescribed radio calls indicating they were visual with TB1 before they initated their rejoins (Tabs N-4 and BB-37). IAW the 57 WG Supplement to ACCI 11-USAFADS Volume 3, the MP followed with his prescribed radio call to announce he was visual with TB1 and provide his altitude and airspeed parameters: "*4's Gotcha, 4's on top 85* [8,500 feet MSL], *400* [400 KCAS]" (Tabs N-4 and BB-37). This altitude and airspeed met the minimum requirements for the MP to safely perform the descending half loop (Split-S) to rejoin with TB1, as depicted in *Figure 5* (Tabs V-8.6 to V-8.7, Z-5, BB-37 and DD-7).

At 1028:56L, TB1 made the prescribed radio call as he reached his maximum altitude during his Half Cuban Eight (Tabs N-4 and BB-38). Two seconds later at 1028:58L, the MP selected idle engine power and pushed forward on the control stick to attain -2.06 G's, with a resulting 2,250 feet per minute climb at five degrees nose high (Tab DD-7). One second later, the MP began his Split-S maneuver as depicted in *Figure 7* by pulling the nose of the MA down towards TB1 (Tabs

V-13.11 and DD-5). The MP continued this manuever and achieved a maximum of +8.56 G's at 1029:03L (Tab DD-7).

Figure 7: Beginning of Split-S Manuever with TB1's Approximate Flight Path for Reference (Tab DD-5).

Based on the DAS data, the MP stopped providing deliberate flight control inputs at 1029:04L, as depicted in *Figure 8* (Tabs Z-9 and DD-8). This left the aircraft 68 degrees nose low, 30 degrees left bank, accelerating through 356 KCAS, and rapidly descending through 6,556 feet MSL, with a 38,500 feet per minute descent rate (Tab DD-8). This descent continued until 1029:08L, when the MP began to increase engine power and pulled back on the control stick at 1029:09L (Tab DD-8). At that point, the MA was at 415 KCAS, 3,452 feet MSL (406 feet AGL), 60 degrees nose low, and 65 degrees left bank (Tab DD-8). Based on F-16 dive recovery procedures, once the aircraft descended below 2,300 feet AGL at that dive angle, a safe recovery above the ground was not possible (Tab DD-6 to DD-7).

Figure 8: Deliberate Flight Control Inputs Stop (Tab Z-9).

e. Impact

At 1029:10L, the MA impacted the ground at 419 KCAS, 57 degrees nose low, 89 degrees left bank, and a descent rate of 39,750 feet per minute with maximum control stick input and high engine power setting, as depicted in *Figure 9* (Tabs U-4 and Z-10). The RSO made the radio call "*4, recover*" just as the MA impacted the ground (Tabs Z-11 and V-13.12). Both the RSO and TB6 called "*Knock it off*" on the radio to cease demonstration maneuvers (Tabs N-4, V-2.13, V-14.15 and DD-8). The MA impact resulted in the MP's fatal injuries (Tab X-4).

Figure 9: Last Recorded Data recorded approximately .343 seconds before impact (Tab Z-10).

The MA carried no weapons, external fuel tanks, or stores (Tabs U-4 to U-5 and DD-8). The terrain of the practice area is flat with low shrubs and some rising terrain surrounding the practice "runway" (Tab U-5). The MA debris field was south-southeast of the impact site, as depicted in *Figure 10* (Tab U-6).

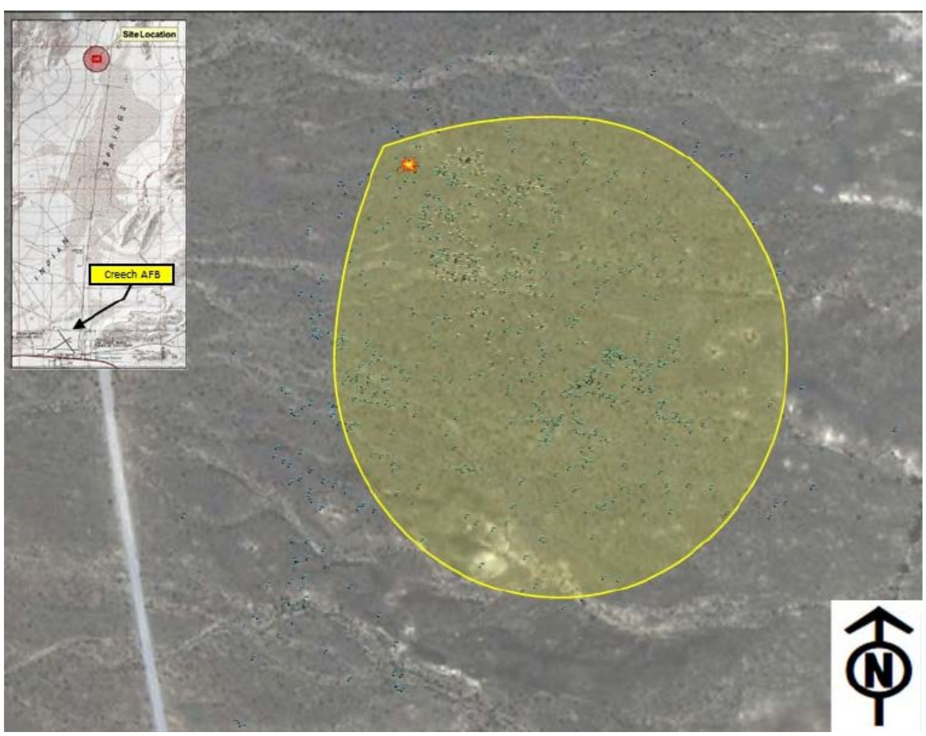


Figure 10: Impact Site and Debris Field (Tab U-6).

f. Egress and Aircrew Flight Equipment (AFE)

Based on recorded audio and analysis of the canopy on impact, the MP did not attempt ejection (Tab U-18). The impact destroyed the ejection seat and only fragments were recovered so no inspection was possible (Tab U-18). There were no overdue inspections for any of the MP's flight equipment (Tab H-9). The MP was current and qualified in the Aircrew Flight Equipment (AFE) continuation training, to include 120-day fit check, Egress, and Hanging Harness (Tab T-4 to T-7). All AFE personnel were qualified on the equipment (Tab H-9). After completion of the Diamond Loop on Takeoff, the MP completed a Foreign Object Damage (FOD) check to ensure he was properly strapped in and to ensure no debris impeded aircraft operations during inverted flight (Tabs V-8.12 and Z-6). The MP did not mention any issues over the radio when he performed his FOD check (Tab Z-6).

g. Search and Rescue (SAR)

At 1029L, the RSO and TB6 made the *"Knock-It-Off"* call to stop the maneuvering for the practice aerial demonstration (Tabs N-4, V-2.13 and V-14.15). TB5 immediately climbed to a safe altitude over the impact site to search for a parachute (Tabs V-2.13 and Z-11). At that time, the RSO called Creech Tower to inform them of the mishap and to send emergency services (Tab Z-11). Approximately one minute after the impact, TB1 cleared TB5 and TB6 to return to Nellis AFB, due to being low on fuel (Tabs V-5.11 and Z-11). Shortly after that, TB1 cleared TB2 and TB3 to return to Nellis AFB while TB1 continued to orbit over the impact site and assumed duties as the on-scene commander (Tabs V-5.11 and Z-11).

At 1033L, Nellis-Creech Fire Dispatch Center received notification via primary crash phone of an aircraft accident (Tab FF-4). Fire Department crews immediately dispatched to the flight line and Thunderbirds practice area (Tab FF-4). After determining that no aircraft were landing at Creech AFB, the crash recovery team traveled to the range and arrived at the crash scene at 1108L (Tab FF-4). The team included the Fire Chief, four different fire trucks, an ambulance, a rescue vehicle and associated personnel (Tab FF-4). The initial response time to the impact site was 35 minutes, with travel over approximately 14 miles on improved and unimproved surfaces (Tab FF-4). After arrival at the crash site, the Fire Chief notified his crew to don personal protective equipment, including self-contained breathing apparatus, and search the impact site for an ejection seat, parachute and/or signs of life (Tab FF-4). After ensuring the site was safe for follow on recovery actions and determining the MP had not survived the mishap, the crash recovery team suspended activities due to darkness at 1956L and left the mishap site under guard by Security Forces (Tab FF-4). The crash recovery team did not report any difficulties as a result of weather, time of day, topography, or civilians at the crash site (Tab FF-3 to FF-7).

h. Recovery of Remains

A team of experts from Nellis-Creech Fire Emergency Services recommenced recovery efforts at 0845L on 5 April 2018 (Tab FF-5). At 1430L, recovery teams departed the mishap site with the MP's remains and arrived at the Nellis AFB Medical Center by 1630L (Tab FF-5).

5. MAINTENANCE

a. Forms Documentation

The Air Force Technical Order (AFTO) 781 series of forms collectively document maintenance actions, inspections, servicing, configurations, status, and flight activities (Tab BB-73). The AFTO 781 forms in conjunction with the Integrated Maintenance Data System (IMDS) provide a comprehensive database used to track and record maintenance actions and flight activity, and to schedule future maintenance (Tab BB-74 to BB-75).

A comprehensive review of the active AFTO 781 forms and IMDS revealed no discrepancies, overdue inspections, or overdue Time Compliance Technical Orders (TCTOs) that would ground the MA from flight operations (Tab HH-3). A thorough review of the active AFTO 781 forms and IMDS historical records for the 40 days preceding the mishap revealed no recurring maintenance problems (Tab HH-3). Additionally, the MA was operating as designed, and there was no indication of mechanical, structural, or electrical failure that would have contributed to the mishap (Tab HH-3).

b. Inspections

The Pre-Flight (PR) Inspection and Basic Post-Flight (BPO) Inspection include visually examining the aerospace vehicle and operationally checking certain systems and components "to ensure no serious defects or malfunctions" exist (Tab HH-3). Phase inspections are a thorough inspection of the entire aerospace vehicle (Tab HH-3). Walk-Around Inspections (WAI) are an abbreviated PR Inspection and are completed as required prior to launch IAW the applicable Technical Orders (TOs) (Tab HH-3).

The total airframe operating time of the MA at takeoff of the mishap sortie (MS) was 6661.0 hours (Tab D-7). Since its last phase inspection on 26 June 2017, the MA flew 262.4 hours (Tab D-2). The last PR/BPO inspection occurred on 3 April 2018 at 1530L with no discrepancies noted (Tab D-7). A WAI occurred on 4 April 2018 at 0730L with no discrepancies noted (Tab D-7). Prior to the mishap, the MA had no relevant reportable maintenance issues and all inspections were satisfactorily completed (Tab HH-3).

c. Maintenance Procedures

A review of the MA's active and historical AFTO 781 series forms and IMDS revealed all maintenance actions complied with standard approved maintenance procedures and TOs (Tab HH-3).

d. Maintenance Personnel and Supervision

The USAFADS Maintenance Team performed all required inspections, documentations, and servicing for the MA prior to flight (Tab HH-3). A detailed review of maintenance activities and documentation revealed no errors (Tab HH-3). Personnel involved with the MA's preparation for flight had proper and adequate training, experience, expertise, and supervision to perform their assigned tasks (Tab HH-3).

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

Due to the nature of impact, all fluid samples were destroyed and not testable (Tab HH-3). DAS data obtained from the MA indicated that the fuel system, hydraulic system and engine were all operating and responding to the MP's inputs at the time of impact (Tab U-10 to U-13). The samples from the oil and hydraulic fluid recovered from the servicing carts were not analyzed, based on information from a technical report and DAS data indicating that all systems were operating normally (Tab HH-3).

f. Unscheduled Maintenance

Unscheduled maintenance is any maintenance action taken that is not the result of a scheduled inspection and normally is the result of a pilot-reported discrepancy (PRD) during flight operations or a condition discovered by ground personnel during ground operations (Tab HH-3). There were no unscheduled maintenance actions since the last scheduled inspection (Tab HH-3).

6. AIRFRAME, MISSILE, OR SPACE VEHICLE SYSTEMS

a. Structures and Systems

The MA impacted the ground at 57 degrees nose low and 89 degrees left bank into a dry desert with sparse vegetation (Tab U-4). The majority of the MA was broken into pieces ranging in size from a few inches to a few feet (Tab U-5). The largest debris recovered was part of the right wing (Tab U-5). The impact crater measured 33 feet wide, 19 feet long and 3 feet deep (Tab U-5). The debris field was mainly southeast of the impact crater, measuring 1,750 feet by 2,250 feet (Tab U-5).

b. Evaluation and Analysis

(1) MA Data Acquisition System (DAS)

The DAS includes the Enhanced Crash Survivable Memory Unit (ECSMU), which contains non-volatile memory (Tab U-7 to U-8). The ECSMU contains 320MB of flash memory protected by an armored housing assembly for crash protection (Tab U-8). The ECSMU contains flight data such as analog inputs, discrete inputs, and message/warning data (Tab U-8 and U-9). The DAS operated as expected until impact of the MA (Tab U-4).

(2) MA Flight Control Surfaces

All the primary and secondary flight controls liberated from the MA at impact (Tabs U-5 and HH-3). Both wings and one horizontal tail were partially intact (Tab U-5). One rotary actuator that controls leading edge flap movement was still connected to the wing structure (Tab U-15). The DAS data and the position of the leading edge flap rotary actuator confirm the flight controls were responding appropriately to the MP's inputs at the time of the mishap (Tab U-16).

(3) **MA Engine**

The engine was completely broken up on impact (Tab HH-3).

(4) **Hydraulic System**

The hydraulic system supplies hydraulic pressure at 3,000 pounds per square inch (psi), +/- 50 psi (Tab U-10). There are two systems, Systems A and B, that generate pressure from two engine driven hydraulic pumps (Tab U-10). The two systems operate simultaneously and independently to supply pressure to the primary and secondary flight controls should one system fail (Tab U-10). Both flight control accumulators were recovered from the mishap site (Tab U-10). Upon disassembly, there were witness marks left by the pistons in both accumulators, indicating there was hydraulic fluid and pressure on the piston (Tab U-11 to U-12). The witness marks indicate the position the piston was in at the time of impact (Tab U-11 to U-12). Based on the DAS data and the physical evidence of the accumulators, both hydraulic systems were pressurized and providing hydraulic power at the time of impact (Tab U-12).

(5) **Electrical System**

After a thorough search, neither the generator nor any electrical bus components were located in order to perform a physical analysis (Tab U-14). The DAS data showed that the electrical system was supplying power to the aircraft systems and functioning at the time of impact (Tab U-14).

(6) **Escape System**

The MA is equipped with an ejection seat actuated by the pilot pulling the ejection handle located on the forward part of the seat (Tab U-17 to U-18). Once this occurs, the canopy liberates from the aircraft and the ejection seat leaves the aircraft milliseconds later (Tab U-17 to U-18). The largest piece of the canopy was recovered several hundred feet away from the impact site, in line with the debris field (Tab U-18). It had an accordion crush pattern indicating the canopy was secure to the MA at impact (Tab U-18). The ejection seat was destroyed and only fragments were discovered (Tab U-18). The DAS data did not record a "canopy open" in-flight warning (Tab U-18). The MP did not initiate ejection within the period of recorded data (Tab U-18).

7. WEATHER

a. Forecast Weather

On 4 April 2018, forecast for NTTR South had winds out of the south at nine knots and a broken ceiling at 20,000 feet AGL, with good visibility (Tab F-2). The forecast weather did not include precipitation (Tab F-2).

b. Observed Weather

The RSO provided an updated weather status once the MF flew into the range airspace (Tab Z-6). The RSO reported calm winds, greater than 10 miles of visibility, a few clouds at 14,000 feet AGL, a broken ceiling at 19,000 feet AGL, and an altimeter setting of 30.07 inches of mercury, which was substantially similar to the actual recorded weather at Creech AFB (Tabs F-3 and Z-6). The RSO did not observe or report any precipitation (Tabs F-3 and Z-6).

c. Space Environment

Not Applicable.

d. Operations

The MF was operating within prescribed weather requirements for the High Show and pilot weather minimums (Tabs BB-43 and T-8).

8. CREW QUALIFICATIONS

a. Mishap Pilot

The MP was a current and qualified aerial demonstration pilot (Tabs G-5, T-8 and DD-7). With training dating back to 2008, the MP completed Air Force Undergraduate Pilot Training (UPT) and Introduction to Fighter Fundamentals (IFF), obtained initial qualification training in the F-16, and completed two overseas assignments (Tab T-3). The MP completed the Four-ship flight lead upgrade and Instructor Pilot Upgrade, and then he was selected to transition to the F-35 (Tab T-3). Upon selection for the Thunderbirds, the MP attended the F-16 Transition Course (TX) in 2017 and completed the Thunderbirds 70-ride upgrade syllabus with "slightly above average" performance (Tabs G-2 to G-3, G-5, T-8, V-2.4, V-4.3, V-7.3, and V-14.4). The MP was a current and qualified F-16 pilot during his time with the Thunderbirds and displayed a high degree of aptitude for a slot pilot in his first year (Tabs G-5 and V-4.3).

The MP was current and qualified as an experienced Thunderbirds flight lead (more than 500 hours in the F-16), Operations Supervisor and weather category two pilot (can fly instrument approaches with weather better than or equal to clouds at 300 feet AGL and visibility of 1 NM) (Tab T-8). His total flight time was 1,441.0 hours, with 310.9 of those hours as an instructor (Tab G-12).

On the day of the mishap, the MP's recent flight time in the F-16CM was as follows: (Tab G-6)

MP	Hours	Sorties
Last 30 Days	24.4	20
Last 60 Days	71.9	59
Last 90 Days	92.9	79

The MP's most recent flight prior to the mishap was on 3 April 2018 (Tab V-6.7 to V-6.8). The MP executed the High Show version of the demonstration including the High Bomb Burst Rejoin (Tab V-6.7 to V-6.8). HUD evidence indicated that he completed the High Bomb Burst Rejoin successfully no less than 29 times prior to the mishap (Tabs DD-3 and GG-5 to GG-6).

The MP became a member of the Thunderbirds after a competitive and rigorous selection process (Tab V-14.5). He was an "inspirational" leader who was always positive and put others before himself (Tab V-1.2, V-2.2, V-4.2, V-5.2, V-6.2, V-10.2 and V-11.2). His extended pre-service flight familiarity made him a “highly experienced” and “highly capable” pilot who excelled in his transition to the Thunderbirds (Tab V-2.3, V-5.3, V-6.3, V-8.2, V-13.3 and V-14.3 to V-14.4). In fact, the merger between his positive personality and pilot skills made him a “perfect fit for the Thunderbirds mission” to recruit, retain, and inspire (Tab V-2.2, V-4.2, V-6.2 and V-14.3). A member of his squadron summed up the MP as “just a beautiful human being” (Tab V-10.2).

b. Other USAFADS Pilots

There were no other qualification issues relevant to this investigation (Tabs T-8 and DD-8).

9. MEDICAL

a. Mishap Pilot

(1) MP Qualifications

At the time of the mishap, the MP was medically qualified for flying duty and required no aeromedical waivers (Tab X-3).

(2) MP Health

The MP received his most recent periodic health assessment (PHA) on 12 July 2017, and the PHA revealed there were no disqualifying medical conditions (Tab X-3).

(3) MP Pathology

Of the tested muscle tissue samples, the Armed Forces Medical Examiner Toxicology reported “None Detected” for ethanol or illicit substances to include amphetamines, barbiturates, benzodiazepines, cannabinoids, cocaine, opioids, phencyclidine, sympathomimetic amines, acid, neutral, and alkaline extractable drugs by immunoassay, gas chromatography/full scan-mass spectrometry, and liquid chromatography mass spectrometry (Tab X-4). The muscle sample also indicated “None Detected” for carbon monoxide (Tab X-4). A cyanide analysis was not performed, as no specimen was suitable for testing (Tab X-4).

The MP sustained injuries on impact of the MA that resulted in his immediate death (Tab X-4).

(4) MP Lifestyle

Upon review of multiple witness testimonies and inspection of available personal belongings, no lifestyle factors were found to be causal or contributory to the mishap (Tab X-3). The medical record documented regular time dedicated to physical fitness (Tabs V-2.20 to V-2.21, V-3.7, V-7.13 and X-3).

(5) MP Crew Rest and Crew Duty Time

Due to the nature of the mishap, no 72-hour and 7-day histories preceding the mishap were available to fully evaluate activities, behaviors, sleep and nutritional habits (Tab X-3). Numerous witnesses testified that the MP appeared well rested and ready to fly on the day of the mishap (Tab V-2.9, V-4.10, V-5.8, V-6.8 to V-6.9 and V-14.11).

b. Other Crew Members

(1) Qualifications

There were 15 enlisted personnel and five officers from the unit, in addition to the MP, who were involved with the mishap and performed maintenance, crew chief, or flying duties on 4 April 2018 (Tab X-5). Of these 20 individuals, all were medically qualified for duty and had no disqualifying medical conditions (Tab X-5).

(2) Health

The medical review of the records of the 20-team members revealed no evidence of medical conditions or medication use that could have negatively affected the performance of the MP on the day of the mishap or contributed to the mishap in any way (Tab X-5).

(3) Pathology

The toxicological examinations tested for carbon monoxide, ethanol, amphetamines, barbiturates, benzodiazepines, cannabinoids, cocaine, opiates, and phencyclidine (Tab X-5). All members were negative for carbon monoxide, ethanol and illicit drugs (Tab X-5).

(4) Lifestyle

Based on witness interviews and medical records review, there was no evidence of lifestyle habits that could have negatively affected the duty performance of the Thunderbirds team members involved or on duty during the mishap (Tab X-5).

(5) Crew Rest and Crew Duty Time

A review of the 72-hour and 7-day history of both the USAFADS Director of Operations and the MA DCC revealed no evidence to suggest there were any abnormalities that could have substantially contributed to the mishap (Tabs R-4, R-11 to R-17, and GG-7).

10. OPERATIONS AND SUPERVISION

a. Operations

The scheduled hours of work per duty day in combination with the intensity of work and the number of days worked sequentially (Ops Tempo) for the USAFADS is high (Tab V-6.4 and V-14.6). The number of sorties the MP had during the past 30 days provides evidence for this fact (Tab G-6). However, during the time of the mishap, a majority of the squadron was coming off a week-long break (Tab V-2.8, V-3.3, V-4.9, V-5.6, V-7.5 and V-14.9). During the flight brief, TB1 stressed that the practice demonstration was a training environment for risk mitigation considerations (Tab V-2.11 and V-14.12).

b. Supervision

TB1 did not note anything out of the ordinary for the members of the squadron (Tab V-14.11 to V-14.12). The ORM process in the squadron identified the risk for the flight to be in the "Green" and TB1 assessed the operational risk as being on the low end of the spectrum, with no additional supervision approval required for the flight (Tabs K-6, V-2.10 and V-14.11).

Other supervisory measures implemented included the RSO (Tab BB-23). The RSO acted similar to the Supervisor of Flying (SOF) role (Tab BB-23). The RSO ensured two-way radio communication at all times and ensured the demonstration airspace was clear of traffic, thereby acting as an overall Safety Observer for the demonstration (Tabs V-13.3 to V-13.4 and BB-23).

The 57 WG Supplement to ACCI 11-USAFADS Volume 3 prescribes a maxium "target" G of +7.5 G's for all Thunderbirds maneuvers (Tab BB-25). A "target" is a parameter a Thunderbird pilot will attempt to achieve in the performance of a manuever (Tab BB-25). Maneuvers designed with a target G less than the aircraft flight control limits of approximately +9 G's allows for a safety margin if the pilot requires more performance from the aircraft (Tabs V-2.19, V-4.12, V-5.14 to V-5.15, V-6.15 to V-6.16, V-7.12, V-8.20 to V-8.21, V-14.19 to V-14.20, and BB-25). A maximum target G also provides a guard against G-LOC while not restricting the pilot from maneuvering at higher +G's for safety of flight reasons (Tab BB-25). If a Thunderbird pilot exceeds +7.5 G's in a maneuver, 57 WG Supplement to ACCI 11-USAFADS Volume 3 requires the debrief of the maneuver to address maneuver set-up and energy management (Tab BB-25). While witness testimony illustrates it was not uncommon for Thunderbirds pilots to exceed +7.5 G's due to the dynamics of the aerial demonstration, the evidence also illustrates supervisors enforced the required debrief standard (Tab V-2.19, V-3.6, V-4.12, V-5.15, V-6.15 to V-6.16, V-7.12, V-8.20 to V-8.21 and V-14.19 to V-14.20). Flight briefings leading up to and on the day of the mishap included discussions on G awareness, and the organizational culture supported any pilot's decision or request to stop an aerial demonstration practice for problems with G tolerance (Tab V-2.18 to V-2.19, V-4.12, V-6.15, V-7.12, V-8.19 and V-14.19).

11. HUMAN FACTORS ANALYSIS

Loss of Consciousness (Sudden or prolonged onset)

The AIB considered all human factors as prescribed in the Department of Defense Human Factors Analysis and Classification System 7.0 (DoD HFACS 7.0) and found this mishap involved a Loss of Consciousness (Sudden or prolonged onset) (Tab BB-45 to BB-46). This human factor falls under the "physical and mental state"/physical problem (PC300) area of DoD HFACS 7.0, and refers to the mental and physical states of individuals that can result in unsafe situations (Tab BB-46). Specifically, PC304, Loss of Consciousness, is a factor when the individual has a loss of functional capacity or consciousness due to G-induced loss of consciousness (G-LOC), seizure, trauma, or any other cause (Tab BB-46).

a. Effects of Acceleration on the Human Body

The acceleration due to gravity on earth is a constant designated as "g," and it is equivalent to 9.81 meters/second squared (Tab BB-62). "G," on the other hand, is the force experienced by a person due to acceleration measured in multiples of the acceleration of gravity felt at the earth's surface (Tab BB-63). A person standing on their feet on earth therefore experiences a force of +1 G (Tab BB-63). The opposite of +1 G is -1 G, the equivalent to a person standing on their head (Tab GG-4).

Sustained acceleration in the +G direction occurs very often during advanced aerobatic maneuvers, and it has received a great deal of research and attention (Tab BB-64). When a pilot experiences +G acceleration, blood flow in the body will tend to pool in the abdomen and lower extremities, leading to cerebral hypoxia, or lack of oxygen in the brain (Tab BB-66). The eyes and brain are very susceptible to low oxygen levels, and as cerebral blood pressure drops, visual, and then neurologic symptoms develop, which can lead to G-LOC (Tab BB-67).

b. G-LOC Physiology

G-LOC occurs when cerebral blood pressure and oxygen delivery to the brain are insufficient to maintain consciousness (Tab BB-67). Brain tissue has a 4-6 second oxygen reserve and G-LOC may occur if the brain does not receive oxygenated blood before its oxygen reserve is completely consumed (Tab BB-18). G-LOC is divided into two periods: absolute and relative incapacitation (Tab BB-67). Absolute incapacitation lasts anywhere from 2-38 seconds and is defined by unconsciousness (Tab BB-67). Convulsive flailing of the arms and legs can occur in up to 70% of subjects towards the end of absolute incapacitation (Tab BB-18 and BB-67). As G-LOC occurs, aircrew rapidly or over a few seconds unloads to +1 G due to a lack of deliberate flight control inputs during the period of absolute incapacitation, and remain there until the beginning of relative incapacitation (Tab BB-19). Relative incapacitation lasts anywhere from 2-97 seconds and is the period when the pilot regains consciousness "at which point the aircrew may initiate aggressive control inputs in an attempt to recover the aircraft" (Tab BB-19 and BB-67).

c. Protective Measures against +G's

Physiological stresses due to +G's are well known by pilots and there are multiple training tools used to help pilots overcome the effects of +G's, including education on G-protection, proper wear of the ATAGS, performing an Anti-G Straining Maneuver (AGSM), and executing a G-Ex prior to high +G's flight (Tab BB-6, BB-11, and BB-70 to BB-71).

The AGSM includes forcefully exhaling against a closed glottis (back of the throat) while simultaneously tensing leg, arm, and abdominal muscles (Tab BB-70). The purpose of the AGSM is to increase cerebral blood pressure, thereby preventing G-LOC (Tab BB-70). A properly executed AGSM will give pilots the greatest protection against +G's, conferring about +3 G's of extra protection (Tab GG-4 to GG-5).

A properly fitted ATAGS confers about +2 to +2.5 G's of additional protection for pilots and aircrew who are fitted or re-fitted every 120 days to maintain optimum performance (Tabs V-1.2 and BB-70). Physical conditioning is also a key point of +G's protection, given that the muscle tensing phase of the AGSM is very fatiguing, and pilots need to have optimum physical conditioning, especially in the lower extremities, in order to maintain G-endurance (Tabs BB-70 and GG-4 to GG-5). Pilots are also taught to maintain optimum cardiovascular and aerobic fitness to optimize G-tolerance (Tab BB-12).

Executing a G-Ex prior to high +G flight is intended to test personal +G tolerance and assess ATAGS inflation, while also conferring additional physiological protection in the form of a cardiovascular reflex (also known as a baroreceptor reflex) (Tab BB-6 to BB-7, BB-58 to BB-59, and BB-66). When the body is subjected to greater than +1 G, a drop in cranial blood pressure results (Tab BB-18). Pressure receptors in the carotid arteries and aorta sense this drop in blood pressure and send signals to the brain to increase heart rate, contractility, and total peripheral vascular resistance to compensate (Tab BB-66). This cardiovascular reflex takes approximately 10-15 seconds to manifest itself, and lasts for about 10-15 minutes (Tab BB-18). The resultant increase in blood pressure gives the pilot approximately an additional +1 G of tolerance (Tab BB-18).

d. Human Response to –G's

–G is relatively defined as any G less than +1 G, including zero G (Tab BB-64). During any –G maneuver, blood flows rapidly headward, increasing cerebral blood pressure (Tab BB-68 to BB-69). The carotid and aortic baroreceptors sense this increase and rapidly respond by reducing the heart rate and widening the blood vessels in the periphery of the body (Tab BB-48 to BB-49, BB-66, and BB-68 to BB-69). This response is scaled based on the intensity of the –G's experienced, meaning higher –G's result in lower heart rates (Tab BB-56 and BB-68). Symptoms of –G exposure include congestion in the head and face, headache, and reddening of vision (Tab BB-68 to BB-69). Humans are less tolerant to –G's than +G's, and significant cerebral impairment and damage can occur with sustained –G's, especially more than –3 G's (Tab BB-69). Apart from avoiding –G's, there are no known countermeasures to counter the resulting physiological effects (Tab BB-69). Some aerobatic pilots report the only way to compensate for sustained –G's is to relax during the maneuver to avoid further cerebral blood pressure increases (Tab BB-69). If a pilot attempted an AGSM in the –G regime, the result would be a further increase in cerebral blood pressure and a magnification of the symptoms (Tab GG-5).

e. The "Push-Pull Effect"

Pilots experience negative impacts when a period of –G flight precedes a pull to the +G regime, known as the "Push-Pull Effect" (Tab BB-56 and BB-69). Because of the peripheral (lower body) widening of blood vessels and accompanying lowered blood pressure that occurs during –G's, a pilot's +G tolerance after sustained –G's will be greatly reduced (Tab BB-48). Whereas pilots confer an extra +1 G of protection through the cardiovascular reflex following a +G pull (as during the G-Ex), this protection is cancelled out if the pilot sustains –G's for several seconds (Tab BB-18 and BB-48). When a pilot rapidly transitions from sustained –G flight to +G flight within several seconds, the body is still in a low blood pressure and low heart rate regime, resulting in a rapid drop in cerebral blood pressure (Tab BB-69). The carotid and aortic baroreceptors will eventually respond to the lowered cerebral blood pressure caused by the initial +G pull, but this response takes about eight to ten seconds (Tab BB-69). This eight to ten second period is approximately two to six seconds longer than the cerebral oxygen reserves (Tab BB-69).

f. MP Exposure to –G's, "Push-Pull Effect"

During the High Bomb Burst Rejoin, the MP experienced a sustained 22 second –G regime, with an increase in –G's to a maximum of –2.06 G's in the last two seconds of that period further intensifying the physiological effects of –G flight (Tab GG-5 to GG-6). The MP then transitioned to a +G regime within one second and took approximately five seconds to achieve +8.56 G's (Tab GG-6). The DAS data shows a reduction in control stick pull and a lack of deliberate flight control inputs following the attainment of +8.56 G's (Tab GG-6). The five-second duration of increasing +G to a max of +8.56 G's put the MP into the G-LOC regime due to reduced blood flow to the brain (Tab BB-67). With the lack of deliberate flight control inputs, the MA rapidly unloaded to a +1 G flight regime, as expected during a period of absolute incapacitation (Tabs BB-67 and GG-6). Five seconds later, a pull back on the control stick with simultaneous throttle advancement was recorded approximately one second prior to impact, providing evidence of a transition from absolute to relative incapacitation (Tabs BB-67 and GG-6). The pertinent mishap times are listed below and illustrated in *Figure 11*:

a. 1028:22L: Beginning of Immelmann (Max +7.9 G's)
b. 1028:36L: Beginning of inverted flight (with 22 sec duration neg G's)
c. 1028:56L: -0.90 G's recorded
d. 1028:58L: Maximum –G's: -2.06 G's
e. 1028:59L: +3.61 G's (5.67 G's/sec)
f. 1029:00L: +6.23 G's (2.62 G's/sec)
g. 1029:01L: +7.75 G's (1.52 G's/sec)
h. 1029:02L: +8.34 G's (0.58 G's/sec)
i. 1029:03L: Max +G's: +8.56 G's (0.21 G's/sec)
j. 1029:04L: Beginning of period of no deliberate flight control inputs
k. 1029:09L: Beginning of renewed flight control inputs
l. 1029:10L: Impact

(Tab GG-6).

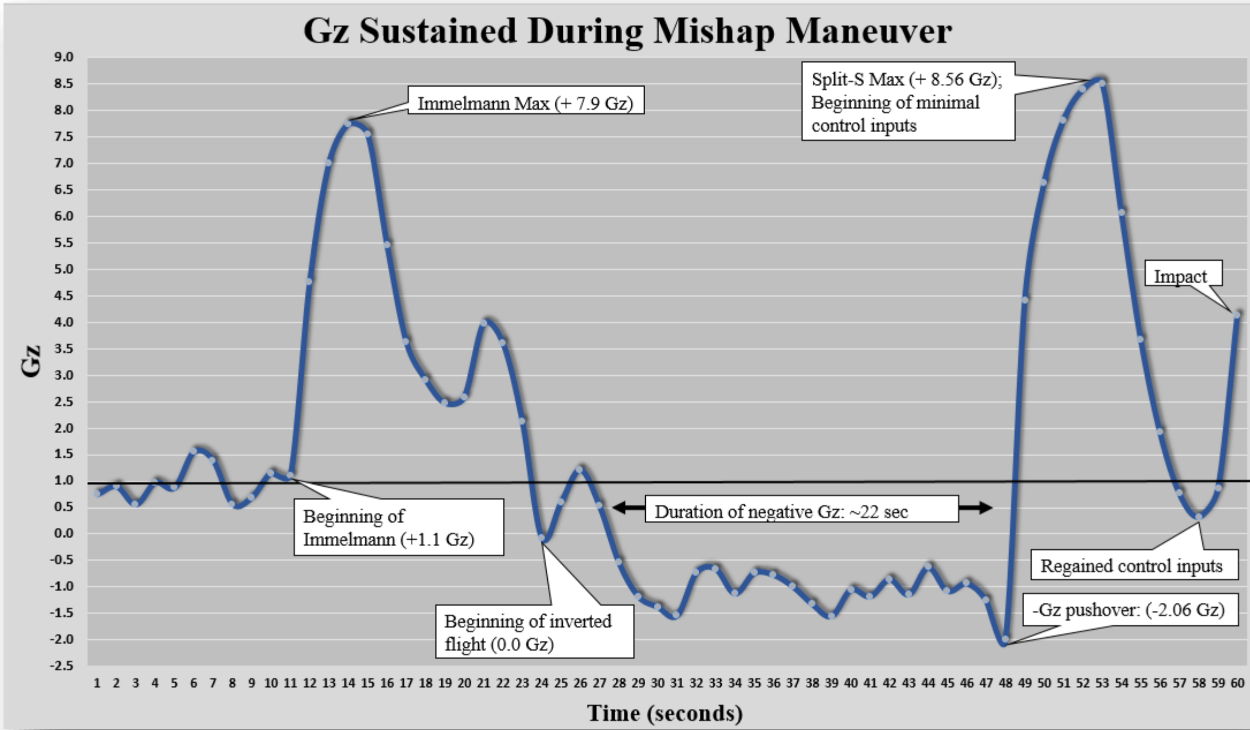


Figure 11. Data Extracted by Medical Member from Mishap Data
(Gz terminology represents measurements of G in the z axis, generally) (Tab Z-7)

g. MP AGSM Effectiveness, Previous Split-S Rejoins, Physical conditioning, ATAGS

A properly executed AGSM confers about +3 G's of additional +G tolerance (Tab GG-4). The MP underwent USAF standard centrifuge training, in 2009, IAW AFI 11-404, Attachment 3, and was graded as average on both his initial and +9.0 G's qualifications (Tabs BB-13 and GG-5). The MP's centrifuge video recordings from those qualifications contained average AGSM performance (Tab GG-3). The MP's physiological records were current at the time of the mishap (Tab G-8). The MP was trained to begin muscle tensing prior to pulling the aircraft into high –G maneuvers (Tab GG-5). Given the –G flight dynamics prior to the mishap maneuver, a properly executed AGSM would have increased the MP's cerebral blood pressure while under –G's, and it would have exacerbated the negative physiological effects of that condition (Tab GG-5). The MA impact destroyed the HUD tape, making a review of the AGSM used during the mishap maneuver impossible (Tab GG-5).

The AIB obtained 39 HUD tapes recorded during the January-March 2018 training season, including 29 High Bomb-Burst Rejoin maneuvers, 17 of which included audio from the intercom of the MP during flight (Tab GG-5 to GG-6). The audio recordings of the MP's AGSM were average with a slightly fast AGSM breath exchange (approximately every 1-2 seconds vs. recommended 3 seconds) (Tab GG-5). The MP underwent a routine HUD tape review by the Thunderbirds Flight Surgeon on 24 March 2018, which noted an adequate AGSM (Tab GG-6). *Table 1* shows the analysis of the recorded High Bomb Burst Rejoins (Tab GG-5 to GG-6).

Date	–G flight Duration	Max –G	G recorded 1-2 sec prior to Split-S	G-onset rate, 1st second of Split-S	Duration of Split-S from beginning of pull to Max +G	Max +G during Split-S
29 Jan 2018	22 sec	-1.8	-0.9	4.5 G's/sec	3 sec	+7.7
30 Jan 2018 (1)	19 sec	-2.5	+0.2	2.8 G's/sec	4 sec	+6.0
30 Jan 2018 (2)	19 sec	-1.5	+0.1	2.7 G's/sec	7 sec	+6.6
31 Jan 2018	23 sec	-2.2	-0.2	4.2 G's/sec	3 sec	+5.9
1 Feb 2018 (1)	16 sec	-2.7	0.0	0.6 G's/sec	6 sec	+6.2
1 Feb 2018 (2)	17 sec	-1.4	+0.5	2.4 G's/sec	7 sec	+5.8
2 Feb 2018	18 sec	-1.6	-1.0	2.8 G's/sec	4 sec	+6.8
5 Feb 2018 (1)	23 sec	-1.8	-0.8	1.9 G's/sec	3 sec	+6.8
5 Feb 2018 (2)	20 sec	-2.2	-1.7	5.5 G's/sec	3 sec	+7.3
6 Feb 2018	16 sec	-2.1	-0.8	3.4 G's/sec	3 sec	+6.9
15 Feb 2018	23 sec	-1.9	-1.3	5.2 G's/sec	3 sec	+6.9
20 Feb 2018 (1)	19 sec	-1.9	-1.0	3.6 G's/sec	3 sec	+6.3
20 Feb 2018 (2)	20 sec	-1.7	-0.9	4.7 G's/sec	4 sec	+7.3
21 Feb 2018 (1)	20 sec	-1.4	-0.4	4.6 G's/sec	3 sec	+7.2
21 Feb 2018 (2)	19 sec	-1.9	-0.8	4.9 G's/sec	4 sec	+7.6
22 Feb 2018	19 sec	-1.6	-0.3	4.9 G's/sec	3 sec	+7.6
28 Feb 2018 (1)	20 sec	-2.2	-1.0	5.2 G's/sec	4 sec	+8.0
28 Feb 2018 (2)	22 sec	-2.0	-0.3	5.0 G's/sec	3 sec	+7.8
5 Mar 2018 (1)	25 sec	-1.6	-0.4	5.6 G's/sec	3 sec	+7.9
5 Mar 2018 (2)	23 sec	-2.0	-0.4	4.2 G's/sec	3 sec	+7.0
6 Mar 2018 (1)	20 sec	-1.4	-0.5	5.2 G's/sec	4 sec	+7.6
6 Mar 2018 (2)	22 sec	-1.9	-0.1	5.6 G's/sec	3 sec	+8.4
7 Mar 2018	18 sec	-2.1	-0.0	3.4 G's/sec	6 sec	+6.6
8 Mar 2018 (1)	21 sec	-2.2	-0.7	4.2 G's/sec	6 sec	+8.0
8 Mar 2018 (2)	25 sec	-1.5	+0.1	2.0 G's/sec	4 sec	+5.5
16 Mar 2018 (1)	20 sec	-2.2	-1.0	5.0 G's/sec	4 sec	+8.0
16 Mar 2018 (2)	20 sec	-1.5	0.0	5.8 G's/sec	3 sec	+8.5
17 Mar 2018 (FAA Cert)	19 sec	-2.0	-0.6	4.6 G's/sec	3 sec	+7.4
19 Mar 2018 (COMACC Cert)	17 sec	-2.5	-0.5	3.8 G's/sec	3 sec	+6.3
4 Apr 2018 (Mishap Maneuver)	22 sec	-2.06	-2.06	5.67 G's/sec	5 sec	+8.56

Table 1: MP High Bomb Burst Rejoin recorded G's (Tabs BB-5 and GG-5 to GG-6).

Table 1 illustrates that, during the mishap maneuver, the level of the –G's recorded in the 1-2 seconds prior to the pull for the Split-S and the maximum +G's attained during the pull for the Split-S was higher than any previously recorded and available Split-S maneuvers, predisposing the MP to reduced +G tolerance due to the "Push-Pull Effect" (Tab BB-50 and BB-57). Furthermore, the mishap Split-S did not have any recorded lessening of the –G's prior to the control stick pull to +G for the Split-S, as previously recorded Split-S maneuvers did (Tab GG-5).

The MP had a reputation for exceptional fitness and had executed many successful high +G maneuvers in the weeks leading up to the mishap (Tabs V-2.20 to V-2.21, V-6.17 and GG-5 to GG-6). Physical fitness is not protective against the physiological effects of –G's (Tab BB-69).

The MP's ATAGS inspections were current (Tab H-10). His ATAGS was a size Large-Long, but based on TO 14P3-6-141, paragraph 4.1, the Table 4-1 sizing chart and the MP's waist circumference and height, the MP should have been in a size Medium-Long ATAGS (Tab H-10). However, the above TO also states that a pilot may change to the next higher or lower ATAGS size based on individual fit (Tab H-10). Given this information, the MP was within TO guidance regarding ATAGS fit and therefore no evidence suggests the larger size ATAGS was a factor in the mishap (Tab H-10).

On the day of the mishap, the MP's DCC remembers the MP donning his ATAGS properly (to include engaging the comfort zippers) (Tab V-9.6). The DCC also testified to connecting the ATAGS to the port on the left console in the MA as the MP strapped in and checked all other straps, connections, and switches (Tab V-9.3 to V-9.4). The MF accomplished G system tests prior to takeoff (Tab V-2.17, V-6.14, V-7.10 to V-7.11 and V-14.18). The MP also attained +7.9 G's in the Immelmann just prior to the mishap rejoin, with deliberate flight control inputs thereafter, making it likely the MA's G system was working properly during the mishap rejoin (Tabs Z-7 and DD-7 to DD-8).

12. GOVERNING DIRECTIVES AND PUBLICATIONS

a. Publicly Available Directives and Publications Relevant to the Mishap

(1) AFI 51-503, *Aerospace and Ground Accident Investigations*, dated 14 April 2015 (Incorporating Change, dated 12 March 2018)
(2) AFI 11-404, *Fighter Aircrew Acceleration Training Program*, dated 9 June 2017
(3) AFI 11-202V3, *General Flight Rules*, dated 10 August 2016
(4) AFI 11-2F-16V3, *F-16 Operations Procedures*, dated 13 July 2016 (Incorporating Change 1, dated 26 May 2017)
(5) AFPAM 11-419, *G Awareness for Aircrew*, dated 17 October 2014

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

b. Other Directives and Publications Relevant to the Mishap

(1) 57th Wing Supplement to ACCI 11-USAFADSV3, *Operational Procedures-Thunderbirds*, dated 3 January 2018

(2) TO 00-20-1, *Aerospace Equipment Maintenance Inspection*, dated1 April 2016
(3) DOD Human Factors Analysis and Classification System 7.0
(4) Banks RD, Grissett JD, Turnipseed GT, et al. The "Push-Pull Effect." *Aviation, Space, & Environmental Medicine.* 1994; 65: 699-704
(5) Banks RD, Grissett JD, et al. "The Effect of Varying Time at –Gz on Subsequent +Gz Physiological Tolerance (Push-Pull Effect)." *Aviation, Space, & Environmental Medicine.* 1995; 66: 723-727
(6) Goodman LS, LeSage S. "Impairment of Cardiovascular and Vasomotor Responses During Tilt Table Simulation of "Push-Pull" Maneuvers." *Aviation, Space, & Environmental Medicine* 2002; 73: 971-979
(7) Slungaard E, McLeod J, et al. "Incidence of G-Induced Loss of Consciousness and Almost Loss of Consciousness in the Royal Air Force." *Aerospace Medicine and Human Performance*. 2017; 88(6) 550
(8) Davis JR, Johnson R, Stepanek J, Fogarty JA. *Fundamentals of Aerospace Medicine, 4th Ed.* 2008, Lippincott Williams & Wilkins, Philadelphia, PA; pp. 83-95

c. Known or Suspected Deviations from Directives or Publications: None.

17 August 2018

CASE A. CUNNINGHAM
Brigadier General, USAF
President, Accident Investigation Board

STATEMENT OF OPINION

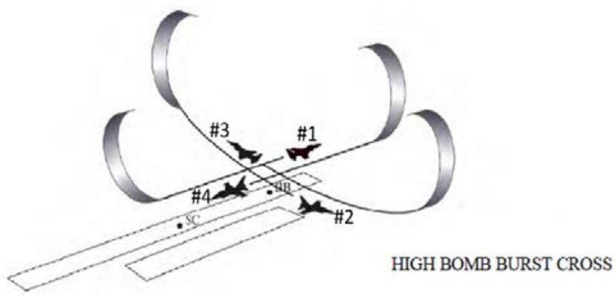
F-16CM, T/N 91-0413
Nevada Test and Training Range
4 April 2018

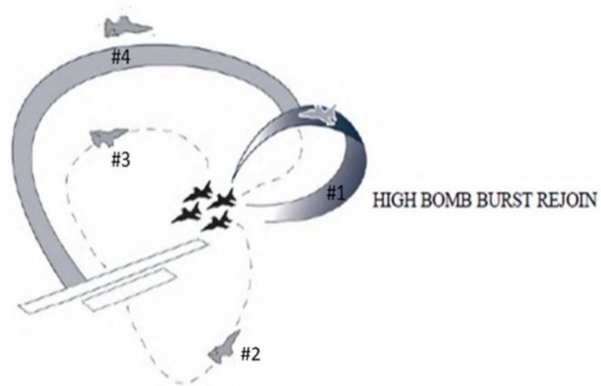
Under 10 U.S.C. § 2254(d) the opinion of the accident investigator as to the cause of, or the factors contributing to, the accident set forth in the accident investigation report, if any, may not be considered as evidence in any civil or criminal proceeding arising from the accident, nor may such information 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 4 April 2018, the mishap pilot (MP), flying F-16CM tail number (T/N) 91-0413, assigned to the United States Air Force Air Demonstration Squadron, known as the "Thunderbirds," 57th Wing, Nellis Air Force Base (AFB), Nevada (NV), engaged in a routine aerial demonstration training flight at the Nevada Test and Training Range (NTTR) near Creech AFB, NV. During the training flight, at approximately 1029 local (L) time, the mishap aircraft (MA) impacted the ground and fatally injured the MP, without an ejection attempt.

The mishap mission was planned and authorized as a practice of the "High Show" version of the Thunderbirds aerial demonstration and was flown in the Thunderbirds practice area in the south part of the NTTR. The mishap flight (MF) was a formation of six F-16CMs (Thunderbirds #1-6), the standard Thunderbirds aerial demonstration flight. Thunderbird #4 was the MA/MP. The mishap occurred after the "High Bomb Burst Cross" and during the "High Bomb Burst Rejoin," an aerial demonstration maneuver performed by the Thunderbirds in the F-16 for the past 35 years. During this maneuver, Thunderbird #1, the lead pilot/aircraft (TB1), executed 5/8 of a loop before rolling to wings level (Half Cuban Eight) as the MP flew the MA above TB1 in the opposite direction in inverted flight at no lower than the prescribed altitude of 5,500 feet above ground level (AGL). As TB1 completed the Half Cuban Eight and continued a descent, the MP initiated a descending half-loop (Split-S) to "rejoin" with TB1 into the Slot position (directly behind TB1) as Thunderbird #2, the left wing pilot, and Thunderbird #3, the right wing pilot, affected their own rejoins from their respective sides of the formation. The MP's execution of the Split-S subjected him to a significant force due to acceleration measured in multiples of the acceleration of gravity felt at the earth's surface, abbreviated as "G" or G-Force. The MA impacted the ground during the Split-S portion of the High Bomb Burst Rejoin and fatally injured the MP, without an ejection attempt. The two diagrams on the next page illustrate the MF's transition from the High Bomb Burst Cross to the High Bomb Burst Rejoin.





I find by a preponderance of evidence the cause of the mishap was the MP's G-induced loss of consciousness (G-LOC) during the Split-S portion of the High Bomb Burst Rejoin. Additionally, I find by a preponderance of evidence two factors substantially contributed to the mishap: (a) the MP's diminished tolerance to +G's induced by the physiology of exposure to –G's ("Push-Pull Effect") and (b) an associated decrease in the effectiveness of the MP's Anti-G straining maneuver (AGSM) under those conditions.

I developed my opinion by carefully considering the standard of proof for the preponderance of evidence and the requirements for causes and substantially contributing factors as I analyzed available flight data, the Lockheed Martin crash report, the mishap animation created from the Data Acquisition System (DAS), witness testimony, engineering analysis, and other information provided by technical experts. I further studied academic research on human factors relevant to the mishap and reviewed Air Force technical orders, regulations, and guidance.

2. CAUSE

I find by a preponderance of evidence the cause of the mishap was the MP's G-LOC and associated states of absolute and relative incapacitation. During these states, the MP was unable to apply appropriate flight control inputs to avoid the MA's impact with the ground or attempt an ejection.

a. Loss of Consciousness

As he initiated the Split-S at 1028:59L, the MP selected idle power on the engine throttle and pulled back on the control stick to drop the nose of the MA toward TB1 to affect the rejoin. This operation took the MA from -2.06 G's in inverted flight to a maximum of +8.56 G's at 1029:03L. Approximately one second later at 1029:04L, the MP experienced a G-LOC and stopped providing deliberate flight control inputs with the MA at 68 degrees nose low. The MP began a period of absolute incapacitation with the MA accelerating through 356 knots calibrated airspeed (KCAS) and rapidly descending through 6,556 feet mean sea level (approximately 3,510 feet AGL).

For approximately the next five seconds, the MP remained in a state of absolute incapacitation and made no deliberate flight control inputs with the MA accelerating through 415 KCAS at 60 degrees nose low and 406 feet AGL. At 1029:09L, the MP began deliberate flight control inputs as he transitioned from absolute to relative incapacitation. The MA impacted the ground at 1029:10L with the MA at 57 degrees nose low with 89 degrees of left bank at 419 KCAS, fatally injuring the MP.

The five seconds of consciousness the MP experienced after initiating the pull for the Split-S corresponds with the four to six second reserve of oxygen in the brain. The physiological impact of the pull to +8.56 G's drained the blood away from the MP's brain, causing the G-LOC to occur. The MP then stopped flying the aircraft as he entered a state of absolute incapacitation. During this state, he was unable to maneuver the aircraft as he had in all of the other times he successfully completed the maneuver. The transition to a period of relative incapacitation one second prior to ground impact enabled the MP to begin deliberate flight control inputs but his condition still included considerable confusion based on the known physiology of G-LOCs. In this short period of relative incapacitation, the MP was unable to attempt an ejection.

3. SUBSTANTIALLY CONTRIBUTING FACTORS

I find by a preponderance of evidence two factors substantially contributed to the mishap: (a) the MP's diminished tolerance to +G's induced by the physiology of exposure to –G's ("Push-Pull Effect") and (b) an associated decrease in the effectiveness of the MP's AGSM under those conditions.

a. "Push-Pull Effect"

The "Push-Pull Effect" results from a relaxed subject's exposure to –G's, the "push," prior to the onset of +G's, the "pull." Under –G conditions, the subject experiences a decrease in blood pressure, widening of the blood vessels, and a lowered heart rate. These three factors reduce the subject's resting +G tolerance in an amount directly related to the magnitude and duration of the preceding –G's.

Prior to initiating the pull for the Split-S, the MP spent approximately 22 seconds between -0.5 G's and -2.06 G's during inverted flight. In the last two seconds of the 22 second period, the –G's increased from -0.90 G's to -2.06 G's before a rapid transition to a maximum of +8.56 G's during a five-second pull on the control stick. These actions left the MP physiologically disadvantaged for the rapid onset of +G's in two specific ways. First, the effects of the sustained –G's resulted in lowered blood pressure, widened blood vessels, and lowered heart rate, negatively affecting the MP's resting +G tolerance. Second, the increasing –G's in the two seconds prior to the +G pull further slowed the MP's heart rate, magnifying the negative effect on his resting +G tolerance. The resulting outcome was more vascular space created by the widened blood vessels for the blood to flow away from the brain at the onset of the +G's and a lowered heart rate and blood pressure making it more difficult for the body to counter that dynamic.

b. AGSM

In preparation for the onset of +G's during flight, aerospace physiology instructors teach pilots to "get ahead of the +G's" by starting the AGSM before the onset of +G's. The AGSM involves squeezing the muscles of the lower body along with an inhalation of air to prepare for a forced exhalation against the back of the throat before pulling back on the control stick for rapid onset

+G's. These actions result in an increase in blood flow to the brain, inflation of the lungs, and increased chest pressure. A timely and well-executed AGSM places the pilot in a better position to tolerate the physical effects caused by the increase in +G's and can add up to +3.0 G's to a pilot's resting +G tolerance. The effects of the AGSM along with the effects of an additional +2.0 to +2.5 G's protection provided by the CSU-22/P Advanced Technology Anti-G Suit (ATAGS) worn by the Thunderbirds pilots provides coverage up to the maximum +G capability of the F-16.

Although the cockpit video tape was destroyed in the mishap, I deduced from available evidence that the MP's execution of the AGSM did not provide adequate coverage for the rapid onset of +8.56 G's for two specific reasons. First, the physiological effects of the –G's experienced in the two seconds prior to the pull left the MP unable to get ahead of the rapid onset of the +8.56 G's. Timely execution of the AGSM would have created more pressure in the MP's head at the same time his body fought to lessen that pressure and would have increased the negative physiological effects of flight in the –G regime. Second, the combination of a delayed AGSM and the decrease in the MP's resting +G tolerance from the "Push-Pull Effect" lessened the overall additive +G coverage factor to compensate for the +8.56 G's the MP experienced in the pull.

I studied 29 recorded cockpit videos of the MP's successful execution of the Split-S portion of the High Bomb Burst Rejoin. In these other instances, the MP countered the physiological effects of the "Push-Pull Effect" and the +G's of the Split-S through a combination of two techniques. First, he decreased the –G's in the two seconds prior to the pull for the Split-S, causing his heart rate to increase before the pull. The decrease in –G's also provided an opportunity to "get ahead of the +G's" with a timely AGSM. Second, the MP generally flew the maneuver with a lower attained maximum +G than he experienced during the mishap. His average maximum +G in the 29 recorded cockpit video instances was +7.1 G's. In the five other recorded instances where he met or exceeded +8.0 G's in the pull (none greater than the +8.56 G's he experienced in the mishap), a decreased –G in the two seconds prior to the pull left him better positioned for a timely and effective AGSM.

4. CONCLUSION

I find by a preponderance of evidence the cause of the mishap was the MP's G-LOC during the Split-S portion of the High Bomb Burst Rejoin. Additionally, I find by a preponderance of evidence two factors substantially contributed to the mishap: (a) the MP's diminished tolerance to +G's induced by the physiology of exposure to –G's ("Push-Pull Effect") and (b) an associated decrease in the effectiveness of the MP's AGSM under those conditions.

17 August 2018

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Brigadier General, USAF
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