SAFETY INVESTIGATION REPORT

HELLENIC AIR FORCE F-16D BLK 50
S/N 93-1084 341SQ/111CW

ALBACETE AFB (ESP), ALBACETE
26 JANUARY 2015

DECLARATION

According to NATO STANAG (STANDARDIZATION AGREEMENT) 3531 and AFSP-1.3, the Safety Investigation Board (SIB) was established on 27 Jan 2015 under the Greek Presidency (Refer to Appendix A), delegated by the involved nations. The involved nations are Spain, France, Germany, Italy, the USA and Greece.

The framework of this investigation is STANAG 3531 and AFSP-1.3.

In accordance with AFSP-1.3, the Safety Investigation Board (SIB) releases the report under the statement: “It is not the purpose of aircraft accident investigation to apportion blame or liability. The sole objective of the investigation and the Final Report is the prevention of accidents and incidents”.

In this regard, any opinion of the mishap investigators as to the cause of, or the factors contributing to, the accident set forth in the accident investigation report may not be considered as evidence in any civil or criminal proceeding arising from an aircraft accident, nor may such information be considered an admission of liability by any state or by any person referred to in those conclusions or statements.

The SIB also states that: “Unless otherwise indicated, recommendations in this report are addressed to the regulatory authorities having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action, if any, is to be taken”.

The involved military material, is by nature subject to information sensitivity and restrictions applied on derived information dissemination. Involved nations are to claim sensitive information that requires protection of confidentiality, integrity, availability and disclosure.

SYNOPSIS

The Hellenic Air Force (HAF) F-16D S/N 93-1084 (here after referred to as the mishap aircraft) of the 341 squadron (SQ), was the number 2 of a 2 aircraft (A/C) formation, taking off for a Tactical Leadership Programme (TLP) Flying Course 2015-1 mission from Albacete Air Force Base (Albacete AFB), Albacete, Spain on 26 January 2015. The mishap A/C crashed at 15:16 local time (14:16 UTC), approximately 7.8 sec after takeoff on runway 27 (RWY 27). The aft seat pilot initiated ejection out of the seat safe ejection envelope. The mishap resulted in the fatal injury of both mishap pilots and the total destruction of the mishap A/C.

The main causes of the mishap were:

- Mishap A/C was not properly trimmed for takeoff as before TAXI, the yaw trim was inadvertent set to maximum right yaw trimming (12^o right), drastically affecting the aerodynamics of the aircraft during takeoff.
-Pilot in command conducted the “Before Takeoff” checklist actions in the parking area (ramp E2) approximately 20 min before takeoff.

After Take-off, pilot stick commands and the resultant control surface outputs were insufficient to maintain the A/C in controlled flight.

Impact and the post impact fire led to the destruction or damage of eight (8) additional A/C and caused fatal injuries to nine (9) French Air Force personnel, numerous injuries and significant damages to ground equipment and to Albacete AFB and TLP infrastructure in the vicinity of Ramp E2 and in front of the TLP hangar.

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1 FACTUAL INFORMATION

1.1 History of the flight

On Monday, 26 January 2015, TLP mission 4, consisting of 22 A/C was scheduled in accordance with the Tactical Leadership Programme (TLP) Syllabus. Mishap A/C (MA) was the number 2 of a 2 ship element (formation) under Call Sign “ARROW 31-32”. The “ARROW” formation was tasked to protect a friendly A/C package and the flight was coordinated with the Mission Commander (MC).

Flight preparation and element brief were in accordance with the mission’s timeline. During the brief, F-16D (two seat model) special procedures were analyzed. The Hellenic F-16s were parked at ramp E2 (Refer to Appendix B).

The MA was loaded with one (1) AIM-9 captive missile on Station 1, one (1) Weapon Pylon on Station 3, one (1) Fuel Pylon with one (1) 370 Gallon External Tank on Stations 4 and 6, one (1) Fuel Pylon with 300 Gallon External Tank at Station 5 (centerline), one 91) Weapon Pylon with one (1) CATM-88B captive missile on Station 7 and one (1) ACMI Pod on Station 9. All External Fuel Tanks were full of fuel.

Normal ground procedures were accomplished in accordance with Technical Order (TO) GR1F-16CJ-1 FLIGHT MANUAL HAF SERIES F-16C/D BLOCKS 50 and BLOCK 52+ AIRCRAFT (here after referred to as the “-1”). The formation conducted the “Before Takeoff” checklist in the parking area (E2). The MA then waited on the ramp for 8 minutes, waiting taxi for takeoff. During that time a slight right roll trim was applied and the yaw trim was set to the full right position (-12º).

The MA taxied and took off with rudder deflection to the maximum right yaw trim position. The MA crashed shortly after takeoff close to shelter D-4 at Albacete AFB, which resulted in the fatal injury of both mishap pilots and the total destruction of the MA.

The impact and post-impact fire led to the destruction or damage of eight (8) additional A/C, caused fatal injuries to nine (9) French Air Force personnel, numerous injuries and significant damages to the ground equipment and to Albacete AFB and TLP infrastructure on the vicinity of Ramp E2 and the front of the TLP hangar.

1.2 Injuries to persons

Injuries	Mishap A/C	Others
Fatal	2 (GRC)	9 (FRA)
Serious		7 (FRA), 10 (ITA)
Minor		14 (FRA), 2 (ITA)
Total	2	42

1.3 Damage to aircraft

The Mishap A/C (MA) was destroyed by impact forces and a post-impact fire.

1.4 Other damage

The impact and post impact fire destroyed or damaged eight (8) more A/C (Refer to Appendix B):

-FRA M-2000D S/N 651(totally destroyed)
-FRA M-2000D S/N 669 (substantially damaged)
-FRA Alpha Jet S/N E047 (totally destroyed)
-FRA Alpha Jet S/N E096 (substantially damaged)
-FRA Rafale S/N B335 (slightly damaged)
-ITA AMX S/N 7193 (totally destroyed)
-ITA AMX S/N 7192 (slightly damaged)
-USA F-15E S/N 202 (slightly damaged)

Significant damages were also caused to ground equipment and to Albacete AFB and TLP infrastructure in the vicinity of Ramp E2 and in front TLP hangar (Refer to Appendix B).

1.5 Personnel information

Both pilots were current and qualified to fly the mission.

The pilot occupying the forward seat was the Pilot in Command (PIC) and he was flying the MA. He was a 36 years old male, a recently certified Instructor Pilot (IP), an experienced pilot and qualified Mission Commander (MC) flight leader qualified, with a total of 1527 flight hours including 940 hours in the F-16C/D BLK50 aircraft. His flight hours for the last day, week and 2 months were 0, 4.0 and 11.7 respectively.

The 32 years old male occupying the aft seat (aft seat pilot, ASP) was a Medium Experienced Pilot and qualified four-ship flight leader, with a total of 1140 flight hours including 536 hours in the F-16C/D BLK50 aircraft. His flight hours for the last day, week and 2 months were 0, 3.3 and 15.0 respectively.

Both pilots were medically qualified to fly the mission.

Their crew rest for the weekend, including Sunday, was in accordance with regulations.

1.6 Aircraft and Maintenance information

1.6.1 General Information - Documentation

F-16D BLK50 S/N 93-1084 was manufactured by Lockheed Martin Aeronautics Company (LM) and delivered to the Hellenic Air Force (HAF) on 7 Jan 1997. Total A/C flying hours (AFH) prior to the accident were 4,056.6 (excluding any fraction during the mishap sortie). The A/C's engine was an F110-General Elecric-129 S/N 538399A. Prior to the accident, Engine Flying Hours (EFH) were 2,166.7 and Total Accumulated Cycles[1] (TAC) 6,235.9.

The last scheduled MA phase inspection (400 hours cycle) was completed on 16 Oct 2014, at 3,984.4 AFH, 72.2 AFH before the mishap. The last scheduled 50 EFH engine inspection was completed on 12 December 2014, at 2,142.1 EFH, 24.6 AFH before the mishap.

An examination of the MA records has been conducted. No deferred maintenance defects had been recorded. All Time Compliance Technical Orders (TCTOs) were complied with or were within rescission dates. All of the Safety TCTOs were accomplished. All documented periodic/hourly inspections were complied with except Rinsing (every 15 days) of the A/C.

A review of the unscheduled maintenance records reveals that the most recent discrepancies included an "AIFF malfunction" (9 Jan 2015) and a "Removal and Installation of FWD side stick grip due to broken DMS switch" (21 Jan 2015). The MA flew 1 sortie (23 January 15) without malfunctions. The history of parts removed and replaced indicated no unusual historical data.

Engine oil spectrometric and chip detector SEM/EDX analysis for 30 days prior to the mishap indicated no discrepancies. Mass and center of gravity of the MA were within the prescribed limits.

A summary of training and medical records for all individuals who performed maintenance on this A/C for the mishap mission and the unscheduled maintenance of the last 15 days revealed they were adequately trained and qualified for the work performed.

In accordance with the technicians who performed the "preflight," "launch" and "End of Runway Inspections" on 26 January 2015 for the MA, no abnormalities were noted.

1.6.2 Selected systems information and analysis

1.6.2.1 Flight Control System (FLCS) Description

[1] Total Accumulated Cycles: A form of life measurement that major engine components are tracked against.

The F-16 uses a digital four-channel, fly-by-wire system which hydraulically positions control surfaces. Electrical signals are generated through a stick, rudder pedals, and a Manual Trim panel. A main component of the FLCS is the flight control computer (FLCC). Redundancy is provided in electronic branches, hydraulic systems, power supplies, and sensor systems (Refer to Appendix C).

Command signals to the FLCC are initiated by applying force to the stick and rudder pedals. These signals are processed by the FLCC along with signals from the air data system, flight control rate gyros, accelerometers, and the Inertial Navigation System (INS). The processed signals are transmitted to the integrated servoactuators (ISA’s) of the horizontal tails, flaperons, and rudder which are positioned to give the commanded response.

Pitch motion is controlled by symmetrical movement of the horizontal tails. Roll motion is controlled by differential movement of the flaperons and horizontal tails. Yaw motion is controlled by the rudder. Roll coordination is provided by an aileron rudder interconnect (ARI). The ARI function is not available whenever Main Landing Gear (MLG) wheel speed exceeds 60 knots or if Angle of Attack (AOA) exceeds 35 degrees. After takeoff, ARI is activated within 2 seconds after the LG handle is raised (spin down braking system). If the LG handle remains down, 10-20 seconds are required for the MLG wheels to spin down and activate ARI. ARI was not activated during mishap flight.

F-16 uses a roll-rate command system. Roll trim and roll stick inputs are additive. When the aircraft is commanded to roll (by the pilot), the corresponding control surfaces deflect to initiate the roll, then their deflection decreases as the commanded roll-rate is achieved.

Rudder pedal force is summed with yaw trim to form a yaw command signal. Yaw commands vary linearly as function of above mentioned signal.

1.6.2.2 Trim System

The F-16 FLCS uses pitch, roll and yaw trim to reduce pilot stick and rudder pedal forces. Pitch and roll trim inputs may be initiated using either the trim button on the A/C control stick or using the Pitch Trim or Roll Trim wheels on the Manual Trim panel (Refer to Appendix D). Roll trim inputs also command proportional rudder deflection through the ARI function which automatically counters sideslip. Rudder trim is initiated using the yaw trim knob on the Manual Trim panel only.

The Manual Trim panel is located on the aft section of the left console in the FWD cockpit only. Yaw trim input from full left to full right (12 degrees) requires approximately one-half knob rotation (180°) (maximum yaw rudder input by pedals is 30 degrees). Three (3) Compressed O-rings installed between the knob and panel facing to provide the appropriate friction to maintain the yaw trim knob position. There are two (2) safety guards mounted to front and back side of yaw trim knob to protect against inadvertent movement of the knob (Refer to Appendix D).

F-16 is not equipped with a system which provides an advisory to the pilot when mistrimming conditions exist prior to/during takeoff.

1.7 Meteorological information

According to the Meteorological Aerodrome Report (METAR) published and distributed by the meteorological services of Albacete AFB on the 26 January 2015 at 14:00UTC the weather was: "LEAB 261400Z 31009 280V340 CAVOK[2] 11/M04 Q1026 NOSIG". The Terminal Aerodrome Report (TAF) (complement to METAR which reports forecast weather rather than current weather) that was published and distributed by the Agencia Estatal de Meterología (AEMET, Madrid) prediction and meteorological services at 11:00Z time was: "LEAB 261100Z 2612/2621 29008KT CAVOK". Weather condition broadcasted by the Tower of Albacete on the Ground frequency at 14:03:47 UTC to ARROW formation, when they requested TAXI clearance, was that the current wind was 310/8 and the QNH was 1026 hPa (3030 inches Hg). At approximately 14:15:33 UTC, Albacete Tower broadcasted that the local wind was "330/9" during the clearance for Arrow to takeoff on runway 27.

The geographical position of the sun was 32 degrees elevation and 194 degrees bearing relative to Arrow flight's takeoff position. The natural light's intensity was measured as 49480 LUX and characterized as Direct sunlight (32000–100000 lux), according to Photometry.

1.8 Aids to navigation

The Tactical Air Navigation system (TACAN) and Instrument Landing System (ILS) for RWY 27, necessary for instrument departure and approach from and to RWY 27 were operational and functional at the time of the accident. However, due to fair weather conditions, Albacete AFB was under Visual Flight Rules (VFR)/Visual Meteorological Conditions (VMC) status.

The condition of the associated navigational aids was not a contributing factor to the accident.

1.9 Communications

Aeronautical and fixed service communications were effective, functional and operational. Moreover, there were no reported problems or difficulties regarding the communications amongst aircrew, Albacete AFB and TLP.

Communications were not a contributing factor to the accident.

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[2] **C**eiling **a**nd **V**isibility are **OK**; specifically, (1) there are no clouds below 5000 feet above aerodrome level or minimum sector altitude (whichever is higher) and no cumulonimbus or towering cumulus; (2) visibility is at least 10 kilometers (6 statute miles); and (3) no current or forecast significant weather such as precipitation, thunderstorms, shallow fog or low drifting snow.

1.10 Aerodrome information

Albacete AFB (ICAO: LEAB), is located about 4 miles (6 kilometers) south of the city of Albacete. The Base coordinates are: Latitude 38°56'55"N, Longitude 1°51'49"W. The magnetic variation at LEAB is 0.47°W.

There is one runway designated 09/27 with an asphalt surface measuring 2,700 × 60 meters (8,858 feet × 197 feet). Aerodrome’s elevation is 702 meters (2,302 feet) above mean sea level. There is one parallel taxiway north of the main runway. Between the north parallel taxiway and the main runway at the beginning of RWY 27 and RWY 09 there are two leak check areas, used as "hot brakes" and "hydrazine activation or leak" areas for parking A/C in case of such an emergency situation.

There are 4 additional parking areas (Aprons E1, E2, E3 and E4) for A/C operating from LEAB. E2 apron is used by A/C participating in TLP courses and has a capacity of 31 parking spots for fighter sized A/C.

1.11 Flight recorders

1.11.1 Flight Control System Memory - Seat Data Recorder (SDR)

The seat-mounted flight control system (FLCS) data recorder, commonly called the seat data recorder (SDR), was sent to LM Aero for retrieval and analysis of the information in the presence of a Greek SIB member.

The SDR indicated normal functioning of the FLCS and did not record any flight control system maintenance faults (MFLs).

FLCS limiters are provided in all three axes to help prevent departures/spins. In cruise gains, the AOA/g limiter reduces the maximum positive G command as a function of AOA. The maximum AOA depends on the position of the STORES CONFIG switch. In CAT I, the maximum commanded AOA is 25.8 degrees. In CAT III, the maximum AOA varies from approximately 16-20 degrees as a function of GW and G. In takeoff and landing gains, the STORES CONFIG switch has no effect on limiting or gains. Maximum positive G is a function of airspeed and AOA. The STORES CONFIG switch was positioned to the CAT III setting, which was the proper for the MA configuration.

Due to the short duration of the mishap flight there were only two lines of FLCS memory data: The transition of weight-off-wheels (WOW) that begins the recording session, and a stall warning (Low Speed Warning Tone), which occurred 2 seconds after WOW due to AOA reaching 15 degrees with the landing gear handle down position(Refer to Appendix C) .

1.11.2 Crash Survivable Memory Unit (CSMU)

The CSMU is one of the two Crash Survivable Flight Data Recorder (CSFDR) units (the other is the Signal Acquisition Unit). The CSMU data consists of discrete events and analog parameters that are been recorded for the primary purpose of mishap investigation. Recording starts when the main generator comes on line after ground engine start. The CSMU of the MA, damaged by fire, was sent to LM Aero. It was disassembled to remove the data directly from the memory chips in the presence of Greek and French SIB members. Heat damage to one of the eight memory chips in the CSMU resulted in the inability of several lines of data to be decompressed (Refer to Appendix C).

1.11.3 Signal Acquisition Unit (SAU)

The SAU is the non-crash-hardened part of the CSFDR system that processes selected aircraft signals and sends the signals to the CSMU for recording. It contains data for service life monitoring and engine usage data. The SAU also stores Type 5 data, the same as data stored in the CSMU (Type 1 data). The SAU was downloaded successfully by LM Aero and the data was decompressed. Data from the mishap flight and several previous flights was available in this download, allowing data that was not able to be decompressed due to heat damage of CSMU was successfully recovered (Refer to Appendix C).

1.11.4 Other Recorders

The aircraft contained several other line replaceable units (LRUs) that have memory storage devices. They include the Data Transfer Cartridge, (DTC), the Fire Control Computer (FCC), the Engine Monitoring System (EMS) and the Programmable Display Generator (PDG). These LRUs were damaged by impact and /or fire and were not recovered. The only available Air Combat Maneuvering Instrumentation (ACMI) data was those received via datalink (the memory card was damaged and could not be recovered). This data is relatively inaccurate (not precise) and they had been used only at the very beginning of the investigation, until more precise data was received (from SDR and CSFDR).

1.12 Wreckage and impact information

The MA crashed near shelter D-4 close to ramp E2 (Refer to Appendix B), 7.8 seconds (approximately) after WOW. The aircraft was destroyed by impact forces and post-impact fire.

Due to the time required for signal transmissions and processing, the CSFDR cannot store data up to the very instant of impact. Approximately one-half second of data that is in the accumulation and processing phase will not be recorded. As a result, the CSFDR’s last recorded values prior to impact were true heading 329.1 degrees, pitch position at -12.77 degrees and roll position at 87.2 degrees. Assuming these parameters, the RH wing tip should have been the first part of the MA to impact the ground. This has been confirmed by the shape of the initial impact point and the A/C pieces’ distribution (Refer to Appendix B)

After several checks on the runway and within its vicinity, no item relevant to the MA was found. Starting from the taxi and runway area, the canopy was found first, followed by part of the right-hand leading edge flap. For the final location and the state of the major components of the wreckage refer to Appendix B.

All MA ejection seat firing devices that should have been activated had been checked and it has been confirmed that they were properly operating in accordance with the mode 1 seat operation status (KCAS 220knots<250knots, Altitude 2400ft<15000ft). The ejection was initiated out of the seat safe ejection envelope.

1.13 Medical and pathological information

The results of the medical and pathological investigations of the MA pilots were negative regarding their medical condition during the day of the accident. Therefore, there was no evidence that physiological factors or incapacitation affected the flight crewmembers' performance.

The forensic/ pathological examinations did not detect any pathologic factor for the medical condition of the MA pilots. Toxicological examinations were also negative for both pilots.

There was no detection of disease or factors which could impair human performance, such as carbon monoxide, oxygen deficiency, alcohol and/or other drugs. So, there was no evidence that physiological factors or incapacitation affected the performance of MA pilots.

The ASP suffered serious fatal injuries after he ejected from the MA, one-half second before the front seat pilot did.

PIC was found to have suffered fatal injuries, due to the crash on the ground, having ejected almost one second before impact.

1.14 Fire

At 15:15 local time (14:16 UTC) the emergency signal was activated by the control tower. The accident created a massive fireball that was visible from tens of kilometers away and affected several fueled A/C on the parking ramp (Refer to Appendix B).

Albacete AFB complied with NATO standards set in STANAG 3712, regarding fire protection levels and firefighting means.

Although Albacete AFB firefighters' reactions were immediate, due to the magnitude of the fire, they had to request additional assistance from the civilian terminal of the airport, as well as from Albacete (city) emergency services.

1.15 Survival aspects

Once the fire extinguished, Explosive Ordinance Disposal (EOD) services secured the area by removing the explosive materials.

After the accident, the hydrazine fuel tank was found to be distorted and some hydrazine had leaked to the ground after the accident (Refer to Appendix B). As a result of the hydrazine fuel tank's deformation, it could not be put inside the available transportation container. HAF hydrazine decontamination team specialists packed and secured the hydrazine fuel tank in an alternative salvage drum and the contaminated soil collected from the crash site in a spill kit container. These containers were shipped to Greece on 5 February 2015, where the contained hydrazine was neutralized. No further hydrazine contamination was detected at the crash site and a "HYDRAZINE DECONTAMINATION CERTIFICATE" was issued and provided to the Spanish Authorities.

1.16 Tests and research

Mishap pilots' personal flight suite and flight equipment were in accordance with SOP's.

After the accident, the HAF conducted interim checks of their F-16 fleet, without findings. These checks inspected FLCS system, flight control surfaces, engines and Weight on Wheels switches. Special emphasis was given to the inspection of Manual Trim Panel (of those on A/C and in reserve) and Yaw Knob rotational friction.

The MA's fluid samples (oil, fuel and hydraulic fluid) collected at the crash site and samples from ground equipment that serviced the MA were sent to the Instituto Nacional de Tecnica Aeroespacial (INTA) in Spain for analysis. The sample volume was insufficient to perform a complete analysis and in most cases it was only possible to perform an extraction of particles for observation under a microscope. Significant contamination was present due to exposure to the crash site's conditions even though most of the samples were considered acceptable.

The fuel sample collected from the refueling truck (S/N:EA-8048-3) which had serviced the MA and from the refueling track (S/N:EA-8048-3) which had been initially refilled from the same Albacete AFB fuel tank were sent to INTA. The test results indicated that the fuel was suitable for use.

In accordance with data analysis from General Electric, the MA engine showed full agreement with the Transient Cycle Model. This indicates it was responding as expected and commanded by the PIC. The throttle was positioned to After Burner (A/B) during takeoff and remained in A/B through impact.

A portion of the Manual Trim panel was recovered and sent to LM Aero for analysis. In addition, the Yaw Trim knob to include the mated yaw trim "stop" and separated potentiometer were recovered and provided to LM Aero as individual components.

The yaw trim potentiometer is identical to the pitch and roll potentiometers, but has modifications that make it uniquely identifiable as the yaw trim. A close inspection of the yaw trim hardware revealed that all existing damage was the result of ground impact. Proper positioning of the yaw trim knob in respect to the potentiometer shaft was confirmed through visual examination (Refer to Appendix C).

The PITCH and ROLL TRIM control wheels and their associated gear train assemblies were inspected and the observed damage was due to the ground impact. The position of the pitch trim wheel and the needle indicator indicated pitch trim was centered. The position of the roll trim needle was considered unreliable due to the gear train separation at ground impact, allowing needle shaft rotation.

LM Aero performed multiple flights using the hardware and software configuration of F-16D 93-1084 and the reported takeoff wind at its Handling Quality Simulator (Refer to Appendix C). The first objective was to repeat the takeoff profile with results as close as possible to those observed in the mishap event. Once that was achieved, a variety of changes were made in order to evaluate how changes in the configuration or pilot response to aircraft performance affected the pilot's ability to safely takeoff. Following is a summary of that testing:

-Full right rudder trim, 1.5 dots right roll trim, full aft and left stick following takeoff: A/C rolled right and was not recovered.

-Full right rudder trim, 1.5 dots right roll trim, AOA reduced after takeoff, left roll stick to counter right roll: A/C was recovered from right roll during takeoff.

-Full right rudder trim, 1.5 dots right roll trim, left rudder added after takeoff: A/C continued takeoff without incident.

Several scenarios, under a variety of changes to configuration and surfaces position were evaluated to 116CW Aircrew Training Device (ATD) F-16 C/D BLK52+ADV which led to similar results.

LM Aero also prepared flight animation products for use in the investigation. Recorded data was converted from a table format to a Visual Animation Description. Flight animations included the MA's flight profile, stores configuration and articulated flight control surfaces, background imagery for visual orientation, pilot control stick and throttle inputs and emulation of cockpit instrumentation and displays.

SIB members performed physical tests to check the inadvertent movement of the yaw and roll trims at manual trim panel. This investigation showed that the existence of the three (3) compressed O-rings and the two (2) safety guards make the inadvertent movement of the yaw knob difficult. However, a blocked object (such as TLP checklist) between the yaw knob and the safety guard can cause the same roll and yaw trim movements as recorded in the MA.

1.17 Organizational and management information

The HAF is an autonomous organization operating under national legislation, following international quality standards and NATO regulations. In this regard the HAF has evolved training, qualification and standardization procedures applied to Air Operations and Maintenance including A/C and personnel involved to mishap flight.

The mishap aircraft was equipped and maintained in accordance with HAF regulations and approved procedures. The involved personnel fulfilled training, medical and evaluation national and NATO standards. There was no HAF, NATO or TLP safety breach concerning rules, regulations and/or standardization procedures that could have contribute to mishap.

Tactical Leadership Programme (TLP) is a multinational headquarters based on Albacete AFB. Ten NATO nations participate in the Programme. Its main objective is to increase the effectiveness of participating nation air forces in the field of tactical leadership and conceptual and doctrinal initiatives in support of the Supreme Allied Commander Europe (SACEUR), Supreme Allied Commander Transformation (SACT) and national missions.

1.18 Additional information

1.18.1 Normal Procedures

Normal Procedures section of the -1 provides the actions required for normal operation of the aircraft. It is required that the pilot has complete knowledge and understanding of Emergency Procedures and Operating Limitations sections, in order to operate the A/C correctly/safely.

The Normal Procedures section directs the yaw trim is to be set and checked three times. During “Cockpit Interior Check” it should be set to the center position, during “After Engine Start” it is to be functionally checked with the crew chief and should be set to center position and during “Before Takeoff” the pitch and yaw trim are checked to ensure they are in the center position and to set the roll trim as required.

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Roll trim should be set prior to takeoff to prevent wing drop in the event asymmetric stores are carried. The amount of roll trim required for various asymmetric store configurations weights is to be calculated in accordance with TO GR1F-16CJ-1-1.

F-16 A/C roll trim authority is possible to be exceeded at or near to takeoff speed even when the asymmetric moment is less than aircraft takeoff limits.

When ARI activates after takeoff, roll trim for asymmetric stores causes a rudder input that can cause aircraft yaw away from the wing with the asymmetric store (heavy wing). This yaw is easily controllable through pilot rudder inputs.

1.18.2 End of runway inspection

The “End of Runway Inspection” is in accordance with TO GR1F-16CJ-6WC-1-11 and it is performed by authorized technicians immediately prior to takeoff at a designated location usually near the departure end of runway. In accordance with HAF regulations these requirements are not applicable to A/C on alert and/or when special approval has been issued by a supervision authority (Tactical or Support Commands). During TLP courses A/C are not on alert status and was no designated location other than the end of runway. TLP flights were accomplished under normal ground procedures.

At Albacete AFB there is a “leak check area” between the north parallel taxiway and the RWY 27 dedicated for "hot brakes" and "hydrazine activation or leak" areas in case of an emergency. This area fulfills the requirements for an area where the “End of Runway Inspection” is intended to be conducted (Refer to Appendix B).

Under TLP ground safety rules (“Engineering Joining Instructions”), “no driving on the taxi ways or runway will be permitted unless escorted by TLP staff or host Base” and “no vehicles are allowed to be driven on the parking ramp during launch and recovery operations”. HAF maintenance personnel conduct the “End of Runway Inspection” while A/C are in the parking area (ramp E2), before A/C taxi for takeoff, in order to avoid delays and to follow TLP safety rules. This change to normal HAF procedures was adapted by all Greek participating squadrons over the previous few years, resulting in it being accepted as common procedure. The decision for accomplishing the “End of Runway Inspection” at ramp E2 was a HAF personnel decision in order to facilitating the execution of the daily scheduled flights.

The “End of Runway Inspection” is an inspection mainly performed by the technician (crew chief) without pilot interaction and without the use of an interconnection cord. During the “End of Runway Inspection” the only checks performed of the rudder area are limited to checks for leaks and physical damage. There is no obligation to check the rudder’s position. From their position during this inspection, crew chiefs are unable to define when a rudder disposition is a result of pedal inputs or other means.

1.18.3 Previous Incidents

The HAF has not had similar incidents reported. This does not rule out the possibility of that yaw mistrimming during takeoff incidents have occurred in the past, just that they were not reported, since A/C configuration and other factors may have not produced lesser magnitude effects.

Research for previous incidents revealed that there were similar incidents recorded by other users. Differences to A/C configuration (symmetrical), low gross weight and different A/C type (F-16C model), produced different results (ejection and return to controlled flight). A concise reference is as follows:

ON 12 June 1994 an F-16A aircraft crashed while taking off. The pilot ejected safely prior to the aircraft crashing.

Takeoff roll appeared normal until the pilot disengaged nosewheel steering at approximately 60 to 70 knots, at which time the aircraft yawed to the right. The pilot then reengaged nosewheel steering and the aircraft came back to the left while still on the runway. At 90 to 100 knots the pilot again disengaged nosewheel steering without encountering further problems. Immediately upon takeoff at about 150 knots the A/C yawed to the right approximately 20 to 30 degrees and began what felt to the pilot like an uncoordinated right roll (a roll with either too much or not enough rudder). Several witnesses said the aircraft abruptly pitched up. The aircraft continued to increase yaw and pitch in what appeared to be a rudder roll (rolling the aircraft by using the rudder and without the use of aileron) to approximately sixty degrees of bank plus or minus ten degrees when the pilot ejected.

According to the followed investigation, the aircraft crashed because it was not properly trimmed for takeoff. Due to the surprising nature of the 20 to 30 degree yaw maneuver immediately after takeoff-the pilot could not maintain control and ejected. The most likely reason for incorrect trim was the pilot's failure to return the TRIM/AP (trim/autopilot) switch to the NORM position during the “After Engine Start Check” and failure to ensure the Yaw Trim knob was in the center position prior to takeoff in accordance with the -1.

The rudder trim was determined to be right of center based on pilot and witness testimony of the yaw maneuvers on the runway and immediately after takeoff, as well as examination of impact and burn marks on the rudder and tail control' surfaces' and examination of the rudder actuator.

Since immediately after takeoff the wheels have not yet spun down to below 60 knots, the pilot did not have the advantage of the Aileron-to-Rudder Interconnect (ARI) when he attempted to roll out of the bank. The ARI would have provided an appropriate rudder deflection for coordinated flight when roll inputs were made to the ailerons, although it would not have corrected for sideslip due to the right trim condition. The pilot stated that he did not use forward stick because he reacted instinctively to a perceived rolling sensation without pitch. The pilot did use aileron to attempt to roll out of the bank but did not recall whether he continued to maintain rudder inputs after takeoff.

On <u>19 November 1997</u> an F-16C experienced several yaw excursions, the first of which occurred during takeoff roll and at lift-off during a check flight at Lockheed Martin Tactical Aircraft Systems (LMTAS).

The pilot had verified that the yaw trim knob was centered prior to flight. After disengaging Nose Wheel Steering (NWS) during takeoff roll, the pilot noted that the aircraft drifted right approximately 50' prior to lift-off. He compensated for this right drift tendency with left rudder until shortly after lift-off. Crash Survivable Flight Data Recorder (CSFDR) data indicates that the rudder went from approximately 6 degrees right at lift-off to 12 degrees right very shortly after lift-off, and then returned to neutral within approximately 10 seconds as the pilot applied control inputs to counter the undesired yaw. Twelve degrees rudder displacement is the full authority of the yaw trim. Several other yaw excursions occurred in flight, and the pilot noted that the yaw trim knob was very sensitive/easy to move.

The investigation determined that the Night Vision Imaging System (NVIS)-modified Manual Trim Panel (MTP) did not have the three required O-rings on the shaft under the yaw trim knob. The purpose of these O-rings is to provide a friction force to keep the yaw trim knob in the pilot-selected position. A check of a second NVIS-modified Manual Trim Panel in the modification hangar at LMTAS revealed that it also was missing the required O-rings.

LMTAS activated the Crisis Management Team (CMT) process to address the issue of these improperly assembled NVIS MTP's. The reason for the concern was the mishap potential associated with abnormal yaw trim knob position. TCTO 1F-16-2144 had been issued to verify the existence of the three (3) O-rings and the appropriate friction.

In accordance with maintenance documentation, TCTO 1F-16-2144 was accomplished on MA. Additionally HAF performed various checks on Manual Trim Panels after the accident. Special emphasis was given to Manual Trim Panel checks (both on A/C or / and shop) and no abnormalities found at Yaw Knob rotation friction and the existence of the three O-rings.

Additionally, there was a similar inadvertent movement of the yaw trim knob caused by misrouted Helmet Mounted Cueing System (HMCS) wiring interference, reported by an F-16 pilot in 2015.

1.18.4 Previous Flight

Analysis of the previous (Friday 23 January 2015) flight (same pilot, A/C and configuration) showed that the pilot used left rudder inputs to maintain runway alignment during takeoff, after disengagement of the nose wheel steering.

Prior to WOW, left rudder inputs were also reduced and the rudder returned to the neutral position. Aft control stick force of 27 pounds was applied for rotation, which is almost the same amount of force for rotation at mishap flight.

The wind was from 330 degrees with gusts from 20 to 35 knots, producing a right wing down (RWD) moment.

The takeoff technique used by the PIC was essentially the same between the previous flight and the mishap flight.

1.18.5 Trim System – Other A/C Types

According to F-16 bibliography there is no need to induce any yaw trim for takeoff, regardless of A/C configuration. Moreover, yaw trimming in training flights is limited to small trim inputs (less than 4 degrees) and in this perspective the ability of yaw trim setting to a level of 12 is not necessary for training flights.

Other A/C (i.e. M-2000, F-15, F-18) equipped with digital flight control do not allow takeoff with trims settings out of takeoff position and use a mistrimming warning indication to notify the pilot. Moreover, there is a dedicated switch (takeoff trim switch) which sets pitch, roll & yaw surfaces to takeoff position.

1.18.6 Flight characteristics specification

Taking into consideration flight simulator tests and flight characteristics from the corresponding section of the -1 (Departures), the assumption is that the magnitude of the A/C behavior caused by rudder mistrimming depends on the following factors:

-A/C Gross Weight. A heavy weight A/C configured with stores has reduced resistance to yaw departure (from controlled flight) when compared to a clean F-16C-model (single seated model).

-External stores configuration. An A/C configured with stores, especially a centerline store, has reduced resistance to yaw departure, relative to a clean C-model.

-F-16 type. F-16D (two seat model) with a centerline 300 gallons fuel tank has reduced departure resistance relative to a clean C-model.

-Asymmetry loading. A left-wing heavy asymmetric F-16 is more susceptible to yaw departure, relative to a clean C-model.

-Cross wind.

2 ANALYSIS

2.1 Chronology of Selected Events Based on SDR and CSFDR Data

SDR time starts at weight-off-wheels during takeoff. CSFDR time starts when the system is powered prior to engine start (MAIN PWR switch to BATT) and this happens approximately at 14:44 Local time (13:44 UTC). The event used for correlating the SDR and CSFDR times was weight-off-wheels at takeoff. This event caused recordings by both systems. (Refer to Appendix C).

Table 1 contains a summary of significant events extracted from the CSFDR and SDR data. The table shows CSFDR time in minutes:seconds.fs and contains only listings applicable to the mishap flight. In the pitch and roll axis, the CSFDR records both the stick command inputs and the resultant flight control surface positions. In the yaw axis, the CSFDR records the position of the rudder, but does not record pilot commanded or system generated inputs. Therefore, the recorded rudder values in the CSFDR will reflect only the position of the rudder surface.

The values listed are those recorded and therefore, approximate because they do not include the associated value range for each parameter. This is further discussed in the footnotes for rudder values towards the end of this table. For reference purposes positive flaperon (wing trailing edge control surface used as both a flap and an aileron) and horizontal tail values are trailing edge down, and positive rudder deflection values are trailing edge left. Positive side stick control values are aft and right commands. The CSFDR data was processed using Integrated Ground Software (IGS), which truncates time to the nearest one-hundredth of a second.

Time (mm:ss)	CSFDR Time (mm:ss.fs)	Event/Remarks
	01:24.75	CSFDR Begins Recording
	7:39.75	FLCS Checks complete; rudder neutral, left roll trim established Left Flap: 18 degrees; Right Flap: 20 degrees Rudder: 0 degrees; Roll Stick: -0.5[3](left) roll stick appears in the data to be a biased value and represents no pilot control lateral stick inputs.
	11:54.75	Right roll trim applied Left Flap: 18 degrees; Right Flap: 16 degrees Rudder: 0 degrees; Roll Stick: -0.5

[3] -0.5 lbs. (left) roll stick appears in the data to be a biased value and represents no pilot control lateral stick inputs.

Time (mm:ss)	CSFDR Time (mm:ss.fs)	Event/Remarks
	11:54.75 To 12:27.94	Fuel Quantity Check
	12:40.69 To 12:40.94	Right Yaw Trim Applied Rudder: -11 degrees (right)
	32:07.38	Application of takeoff power Throttle PLA 89 degrees
	32:09.75	Timed Recording Left Flap: 18 degrees; Right Flap: 14 degrees Rudder: -17 degrees (right) Roll Stick: -1.0 lb. (left)
	32:11.38	Application of Max A/B Throttle PLA 136 degrees
	32:18.81	Maximum (ground) rudder input Rudder 17 degrees (left)
	32:21.44	Maximum (ground) rudder input Rudder 17 degrees (left)
	32:22.81	Rudder Reversal Rudder -3.0 (right)
	32:23.31	Maximum (ground) rudder input Rudder 17 degrees (left)
	32:24.19	Rudder Reversal Rudder -3.0 (right)
	32:24.75	Timed Recording KCAS 148; Left Flaperon 18; Right Flaperon 14 Rudder 14 degrees (left) Roll stick -1.0 lb. (left)
	32:25.44	Rudder Reversal Rudder -9.0 (right)
	32:26.06	Rudder Reversal Rudder 15.0 (left)
	32:26.88	Application of Aft Stick for Rotation Aft Stick 20.0 lb. Roll Stick -4.5 lb. (left)
0:00	32:28.25	WOW KCAS 192 AOA 4.75 Pitch 7 degrees (nose up) Roll -1.4 degrees (left wing down) Pitch stick 12 lb. (aft) Roll stick -12.5 lb. (left) Left Flap 6 Right Flap 20 Rudder -7.0 (right)

Time (mm:ss)	CSFDR Time (mm:ss.fs)	Event/Remarks
0:02	32:30.25	DFLCS STALL WARNING[4]. AOA > 15 degrees with landing gear handle down. Flight manual defines this as low speed warning horn.
	32:30.44	CSFDR AOA Exceeds 15 degrees AOA 15.12 Roll 38 degrees (right)
	32:30.88	Maximum Roll Stick Input Roll Stick: -22 lb. (left) Pitch Stick 31.5 lb. (aft)
	32:31.13	Maximum Pitch Stick Input Pitch Stick: 37.0 Lb. (aft)
	32:32.35	CANOPY OPEN WARN (ejection) KCAS 220 AOA 18.1 Pitch -2.8 Roll 68.9 degrees (right) Roll Stick -10.5 lb. (left) Left Flaperon -18; RightFlaperon 20 Rudder -10 (right)
	32:34.94	Last full recorded record AOA 17.23; Pitch -7.0; Roll 73.1 degrees (right) Left Flaperon -8 Right Flaperon -20
Due to the time required for signal transmissions and processing, the CSFDR cannot store data up to the very instant of impact. Approximately one-half second of data that is in the accumulation and processing phase will not be recorded.		

Table 1: Chronology of Selected Events

2.2 Sequence of Events

2.2.1 Flight Preparation

Flight preparation and element briefs were in accordance with the mission timeline. During the element brief, F-16D (two seat model) crew coordination procedures, such as stick interference, control stick switch position, ejection mode selection, intercommunication as well as trim procedures for HARM missile, were all addressed.

TLP provided participants with three checklists. Those checklists were additional flight equipment, carried in the A/C in accordance with SOP's and should be stored in the stowage compartment (map case) located in the right console. The PIC took his flight bag in the cockpit and stored it in this compartment, leaving no vacant space. This action prevented

[4] AOA > 15 degrees with landing gear handle down. T.O. GR1F-16CJ-1 defines this as the Low Speed Warning Tone.

further use of the storage compartment and storage of the three TLP checklists. Checklists are designed to be used anytime during flight if needed. In this regard, the possibility of a checklist temporary being placed on the FWD left cockpit console cannot be excluded.

During the mass brief, a 10 min delay in take off time was given by TLP.

2.2.2 Step to Taxi

Normal ground procedures were accomplished in accordance with TO GR1F-16CJ-1 FLIGHT MANUAL HAF SERIES F-16C/D BLOCKS 50 and BLOCKS 52+ AIRCRAFT (-1). The non standard procedure was that the A/C was moved about a meter forward from the parking position and the “End of Runway Inspection” was performed by the maintenance personnel.

Under TLP ground safety rules ("Engineering Joining Instructions"), “no driving on the taxi ways or runway will be permitted unless escorted by TLP staff or host Base” and “no vehicles are allowed to be driven on the parking ramp during launch and recovery operations”. HAF maintenance personnel performed the “End of Runway Inspection” while the MA remained at parking area (ramp E2), before MA taxied for takeoff, in order to avoid delays and to follow TLP safety rules. This change to normal HAF procedures was adapted by all Greek participating squadrons over the previous few years, resulting in it being accepted as common procedure. Other nations participating in TLP Flying Course 2015-1, had no similar provisions for inspection such the “end of runway inspection”.

The change to the “End of Runway Inspection” order consequently led the pilot to perform the “Before Takeoff” checklist very early, approximately 20 min before takeoff.

At 10:59,1 (CSFDR time) the MA moved about a meter forward and maintenance personnel proceeded to accomplish the “End of Runway Inspection”. After completion of that inspection, as derived from CSFDR analysis, the PIC proceeded the “Before Takeoff” checklist actions (those which can be checked by CSFDR analysis i.e. Flight controls – Cycle, Fuel Check), while in the parking area (ramp E2).

At approximately 11:54.8 CSFDR time, a right wing down roll trim was set inconsistent with the MA configuration. In accordance with -1, A/C should have been trimmed with 1,7 dots left wing down in order to counter the asymmetrical load (8,530 ft-lbs). At the same time the fuel system check was performed (the fuel check switch is located on the lower front instrument panel). Until that point a left wing down roll trim (correct) was set.

Just after fuel check completion (12:40.7) right yaw trim was set to the full right yaw trim position (12°) rapidly and remained in that position for the whole duration of taxi, take off and flight. Both trims (yaw and roll) seem to have been unintentionally moved by an object. SIB investigators showed that movement of a blocked checklist across the trim panel can cause the same near simultaneous roll and yaw trim movements as recorded if done so in a particular manner.

At 21:21,9 (approximately 15:05 local time, 14:05 UTC) the MA started to taxi from E2 to the departure end of RWY 27. Scheduled taxi time was at 14:56 local. During the Mass Brief, a 10 min delay was given by TLP.

After taxi from E2, the MA stopped and waited for takeoff at the "leak check" area (between the north parallel taxiway and the main runway at the beginning of RWY 27) for 3:20 minutes (from 27:21 to 30:42 CSFDR time). This time is sufficient for "Before Takeoff" checklist procedures to be accomplished. However none of the procedures (i.e. Flight Controls – Cycle, Fuel Check) monitored via CSFDR were reaccomplished. It is important to emphasize that the Trim Check (pitch and yaw trim centered and roll trim as required) is part of the "Before Takeoff" procedures. In the absence of a voice data recorder the SIB does not have sufficient data to determine whether the ASP asked for confirmation that the "Before Takeoff" checklist had been accomplished while waiting for takeoff.

2.2.3 Take Off to WOW

At 30:42 (CSFDR time) the MA started to taxi onto RWY 27 to perform a rolling takeoff. At 32:09.7, the MA was almost aligned with RWY 27 and the throttle was placed to MIL power. At 32:10.9, the throttle was placed to minimum A/B and to maximum A/B for takeoff at 32:11.4 and the rudder position remained at -12^{o} (right).

Time deconfliction between the lead A/C (ARROW 31) was 23 sec, in accordance with briefed 20 sec.

While nose wheel steering was engaged, the PIC made left control inputs on three separate occasions to maintain runway alignment. After nose wheel steering manual disengagement (66Kts, 32:17.0), the PIC used four separate left rudder inputs to keep the MA aligned with the runway. Three of the inputs were of maximum rudder command and the fourth almost to maximum, taking into account that the full right yaw trim position (-12º) limited the maximum left yaw trim position to 18º (30º L-12º R = 18º L maximum left rudder deflection).

Aft Stick force (20 lbs) was applied at 32:26.9 for A/C rotation during takeoff. During rotation, and prior to weight off wheels (WOW), left rudder inputs were reduced and rudder returned towards the right, being recorded at -7º (right) at WOW 32:28,2, in accordance with the right yaw trim setting.

The previous flight CSFDR analysis (same pilot and A/C configuration) showed that the pilot used left rudder inputs to maintain runway alignment during takeoff, after nose wheel steering disengagement in order to keep A/C aligned with the runway, taking into account the asymmetry load (RWD) from CATM-88 missile (8,530 ft-lbs). Prior to WOW, left rudder inputs were also reduced and the rudder returned to its neutral position. The assumption, based on CSFDR data from both flights, is that the PIC used the same takeoff technique as that of the previous sortie, in accordance with -1.

At nose wheel steering disengagement speed (66 Knots) the rudder surface was not aerodynamically effective and large yaw pedal inputs resulted in small corrections in order to compensate for the asymmetry and to keep the A/C aligned with the runway. In this regard and taking into account previous flight rudder corrections, similar actions after steering disengagement were considered normal by the PIC and prevented the PIC from noticing the MA mistrimming.

Once the rudder became effective, the quick acceleration through 100 knots put the pilot into a speed regime for which it is generally considered safer to continue a takeoff (lacking a flight control or engine failure) than perform a high speed abort.

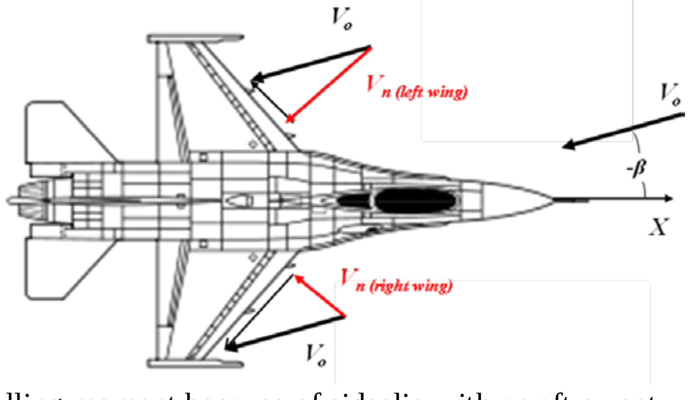
2.2.4 WOW to crash.

At WOW (32:28.25), stick forces applied were 12 lbs aft and 12.5 lbs left. Surfaces position showed that FLCS responded to PIC commands to continue takeoff. The right roll trimming instead of calculated 1.7 dots to the left (to the maximum of 6), was easily compensated by the applied left stick force.

Prior to WOW, left rudder inputs were reduced and the rudder returned to the right. Rudder nose to the right (negative) angle was -7º (right) at the time of WOW, increased to -10º at 0:32:29.31, the first second following WOW, which was the maximum recorded right rudder displacement (after WOW) and kept to that magnitude up to impact. Rudder position caused the nose to swing rapidly to the right, producing a sideslip. By comparing the MA ground track and its true heading during the first second following WOW (when AOA and roll angle were very low) the initial sideslip was determined to be approximately 12º. After that moment, combination of all data, increasing AOA and roll angle, ground track and true heading could not help to calculate the exact magnitude of the sideslip.

The movement of the MA's nose to the right during the sideslip produced an aerodynamic right wing down rolling moment. The recorded roll was approximately 7º at the first second following WOW and increased dramatically to approximately 33º in the following second. The roll continued increasing bank until the MA impacted the ground. The main causes of the rolling moment were as follows:

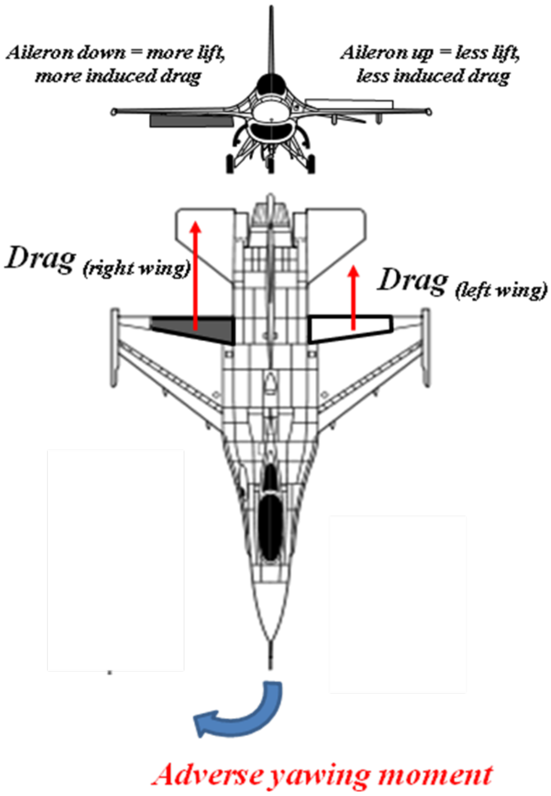
-The F-16 is equipped with an aft-swept wing. In all aft-swept wing A/C, during sideslip, the upwind wing toward the velocity vector (left in MA) produces more lift than the downwind wing as the normal vector of the velocity (the one perpendicular to the leading edge of each wing – $V_{n\ (left\ wind)}$) is increasing. The "spanwise" vector of the velocity produces no lift. The opposite happens to the other wing (right in MA).



Rolling moment because of sideslip with an aft-swept wing

- The fuselage blocked some of the airflow over the right (downwind) wing during the side slip and reduced the lift produced by this wing. The MA was equipped with a center line tank and longer canopy as it was a two-seat model (F-16D). Both factors additively contributed to the airflow blockage as mentioned above.

Although the right roll moment was decreased approximately at 2.5 sec after WOW (from approximately 22 degrees/second to 6.6 degrees/second), left control stick inputs were insufficient to cease the right roll. Due to the MA lack of desired response, PIC increased the left control stick command. At 2.6 seconds following WOW (32:30.88), the maximum value (which is the maximum available) left roll stick input was recorded (-22 pounds)[5]. This left roll control stick input, without ARI activation (no automatic rudder to offset adverse sideslip due to roll surface deflections), enhanced the nose right sideslip due to increased drag generation from the wing. The result was additional MA's yaw to the right (adverse yaw). Additive to the sideslip factors were the asymmetric store on right wing and the 9 knot wind from 330º (60º right from the nose).



Adverse yawing moment due to aileron deflection

Immediately after WOW, the MA AOA increased at a rate that, caused the DFLCS Stall Warning AOA tone to sound (Low Speed Warning Tone sounds with AOA > 15 degrees with the landing gear handle down) approximately 2 seconds after WOW, as recorded by SDR. The AOA continued to increase to its maximum recorded value of 18.6º[6]

[5]DFLCS maximum is about +/-18 pound but pilot stick forces may exceed that which is accepted by the DFLCS

[6] With gear/flaps down, the DFLCS allows a max AOA of 21 degrees.

just4.3 seconds after WOW (32:32.56). The AOA increase was primarily the result of aft control stick input (force), but the increasing sideslip would likely tend to increase AOA as well. After commanding the maximum left roll input, the PIC instinctively responded to abnormal MA behavior and applied aft control stick input as a reflex action (ie, stick in the lower left corner). 2.9 seconds following WOW (32:31.13) aft pitch stick force increased from 12 pound (at WOW) to the maximum of 37 pounds[7] and sustained until ejection started. A clear indication of the reflex response of the PIC is the substantial increase of the aft stick force to 18 pounds at 1.6 seconds following WOW (32:29.88), in comparison to 6.5 pounds 0.25 seconds earlier.

Maximum aft stick input combined with maximum left roll input and an 8,530 ft-lb right wing heavy asymmetry likely increased the nose right sideslip condition.

The MA response could be characterized as a high nose right sideslip condition that induced a right rolling moment of greater magnitude than could be overcome by the available commandable roll (in the opposite direction) considering the effects of the inactive ARI and high AOA condition with the landing gear down.

LM Aero used a Handling Quality Simulator to evaluate the effect of varied inputs to safely takeoff a simulated F-16D Block 50 of the same configuration of the MA. By using full right rudder trim, 1.5 dots right roll trim, the test pilot reduced the AOA (by applying forward control stick input) after takeoff and use left roll to lever the A/C. Under these conditions the test pilot managed to recover the A/C from right roll and to continue takeoff. Although this is an indication that with the reduction of AOA the accident could have been prevented, we cannot consider this scenario because the corrective actions were taken in the early stages immediately after takeoff, with a pilot aware of the scenario and expected aircraft response.

In the mishap flight corrective actions such as an AOA reduction were unlikely, because of the normal reaction time necessary for the PIC to realize and react to the given situation. Taking into account that the presence of the ASP could have increased the PIC's reaction time (due to situation being similar to "stick interference" and consequently the need for communication with ASP), one can assume that only reflex-type stick commands (aft and left) could be expected by from the PIC until 2.5 seconds after WOW. At that time the roll angle was already 45^{o}, the AOA was almost 16^{o} and the MA recovery seemed unachievable. One must take into consideration that the PIC had to react in the unforgiving altitude of no more than 60 feet. The fact that the landing gear was left in the down position can be considered as a clear indication of the surprising nature of the problem.

The above reflex pull applied to the control stick is the normal action expected by an average pilot especially when operating a fly-by-wire fighter type A/C. The PIC had no clear indication of yaw departure or any other out of control situation, which are marked by much more severe characteristics. In accordance with the -1 and the description above, these characteristics are not, consequently, related to takeoff/gear down conditions. Although there was a low speed warning tone two seconds after WOW, the MA attitude and altitude, led to a

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[7] DFLCS maximum is about 32 lbs but pilot stick forces may exceed that which is accepted by the DFLCS.

strong instinct to “pull to cope”. However, the aft stick input and AOA increase were detrimental to MA’s recovery.

Moreover, the PIC having no clear indication for the cause of the MA’s abnormal situation and being conditioned during the previous flight to believe that during the takeoff phase only minor rudder corrections were needed and allowed, he was not in a position to consider that the rudder input was a proper corrective action.

The PIC did not attempt to modify his reaction and continued to apply the same control stick inputs until the ejection. This highlights that the PIC did not attempted to eject earlier while the MA was in the ejection envelope.

The use of rudder during takeoff (when ARI is not available) is described in the -1 as an input to provide coordinated flight and to control yaw. However, all rudder inputs are described in the -1 as light and smooth and not in the context of countering the magnitude of this particular situation.

LM Aero used the Handling Quality Simulator to evaluate the effect of rudder correction during takeoff. Specifically, they used full right rudder trim, 1.5 dots right roll trim and added left rudder after takeoff. Under these conditions, the test pilot managed to recover the A/C from the right roll and the A/C continued takeoff as expected. Recovery and normal takeoff were possible because the main cause of the accident was eliminated at a very early stage. For this simulation, the pilot’s reaction time was not taken into account.

The CSFDR, by design records additive command inputs to the pitch and roll axis. The recorded CSFDR data (max aft and left applied forces) indicates that the ASP did not apply any competing inputs to the PIC inputs for the entire duration of the flight.

According to the CSFDR, the MA air speed increased 1.7 seconds following WOW to 208 Knots (from KCAS 192 Knots at WOW). The engine was running at MAX A/B for the entire flight duration. High drag caused by sideslip and high AOA did not allow the airspeed to increase normally. The highest recorded value was 220 knots, 5.7 seconds following WOW (0.7 seconds before the Canopy Open warning, which marked the beginning of the ejection sequence) and while the MA was in a descent.

The increasing right bank angle consequently decreased the perpendicular component of the produced lift. According to the CSFDR data, approximately 3.5 seconds following WOW (32:31.75 CSFDR time) the produced lift was inadequate to compensate for the MA’s weight, thus resulting in the MA’s descent. At 6.38 seconds following WOW (32:34.63) the Canopy Open warning light was recorded, indicating the opening of the canopy during the ejection sequence (approximately 0.3 seconds pass from the pulling of the ejection hand to the canopy jettison). At this point, the roll angle was 68.9 ^{o}, the pitch angle was -2.8 ^{o} (descending) and force was still being applied to the control stick (9 pounds aft and 10.5 pounds left), most likely by the PIC. At 6.63 seconds following WOW (32:34.88) until impact, no further control stick forces were recorded.

At 7.19 seconds following WOW (32:35.44), the last values for pitch (-12.7 ^{o}) and roll (87.2 ^{o}) were recorded. Two more recordings were made (the last of them at 7.31 seconds following WOW - 32:35.56), however with less significant data. Due to the time required for signal transmissions and processing, the CSFDR did not store data up to the very instant of impact. Approximately 0.5 sec of data, which occurred in the accumulation and processing phase, was not recorded. In this regard, the impact time can be placed by estimation at 7.8 seconds following WOW (32:36:00).

2.3 Main Factors Involved with the Accident

2.3.1 Aircraft and Maintenance

Maintenance records indicated that the aircraft was equipped and maintained in accordance with existing procedures and there was no evidence that A/C maintenance contributed directly to the mishap.

The "End of Runway Inspection" was not conducted at the end of the runway (EOR) area, but on the parking ramp (E2) as was routinely done by HAF F-16 at TLP.

Maintenance personnel verified that no abnormalities were found during preflight inspection or during the A/C launch.

Data from the SDR and the CSFDR, in conjunction with crash site findings have been evaluated and the following conclusions have been made:

- The SDR did not record any flight control system maintenance faults (MFLs). This indicates normal functioning of the FLCS.
- The electrical system was operating properly until impact.
- The CSFDR data did not indicate any Hydraulic System A or System B Low signal. Therefore, in conjunction with the normal operation of the FLCS system (as shown in by the SDR data), it can be concluded that both hydraulic systems were providing normal hydraulic pressure to the flight control system.
- The EPU (a self-contained system which provides emergency hydraulic pressure to system A and emergency electrical power) was not commanded on at the time of the mishap.
- In accordance with the CSMU data analysis from General Electric, the engine was responding as commanded by the PIC.
- No mechanically induced yaw trim error was noted.
- The right wing down asymmetry was at 8,530 ft-lbs with the maximum allowed being 25,020 ft-lbs.

Mass and center of gravity of the mishap A/C were within limits.

In light of the above, it is considered that all aircraft systems were operating properly following engine start and there was no evidence of any defect or malfunction in the aircraft itself that could have contributed to the accident.

2.3.2 Pilots

Both pilots were current and qualified to fly the mission. Flight preparation and element's brief were in accordance with Standard Operating Procedures (SOPs). In addition to their standard flight equipment, pilots carried three extra check lists handed from TLP.

Moreover, the PIC stored his flying bag in the stowage (map case). This action could not facilitate the use and storage of the three TLP checklists.

All normal ground procedures up to the “Before Taxi” checklist were accomplished in accordance with SOPs and the -1. As done by all Greek participating squadrons over the previous few years, the “End of Runway Inspection” was performed while the A/C was in the parking area (ramp E2), before taxi, instead of in an area close to the departure end of the runway, This change led the pilot to accomplish the “Before Takeoff” checklist earlier in the launch sequence than normal, leaving a time window of 20 minutes between the “Before Takeoff” checklist and takeoff.

The “Before Takeoff” checklist is intended to be the last action before takeoff and ensures proper configuration of the A/C control surfaces for takeoff. In this regard the mean time of 20 minutes could place the A/C at risk of an inadvertent/unnoticed configuration change.

After “Before Takeoff” checklist accomplishment and while the MA was still on ramp E2 waiting to taxi, roll and the yaw trim settings appeared to be moved inadvertently. Yaw trim was set to full right deflection (-12º) rapidly and remained as such, for the duration of taxi, take off and flight.

The yaw trim knob is protected by two safeguards installed in front of and to the rear side of the knob. Three O-rings are installed on the shaft under the knob to provide sufficient friction and to maintain the knob’s position. For these reasons, it is not easy to unintentionally move the knob. However, after performing tests to examine the possibility of the knob being moved by an object, it was shown that a checklist positioned between the front safeguard and the knob could possibly move both roll and yaw trim knobs if moved at the correct angle. In this manner it is possible to move the yaw trim knob to the maximum right position.

At the time available from taxi to takeoff, the MA waited 3:20 minutes for takeoff at the departure end of RWY 27. This time was adequate to accomplish the “Before Takeoff” checklist actions. This is to highlight that a verification check of trim position on the trim panel is included in the “Before Takeoff” checklist. According to the CSFDR analysis, no recordable actions were taken and the MA took off not properly trimmed.

After nose wheel steering disengagement, the PIC made left control inputs on four separate occasions to maintain runway alignment. The MA showed similar takeoff roll handling and behavior to the A/C (with similar configuration) previously flown by the PIC. Taking into account the previous flight, the necessity for increased rudder corrections did not cause the PIC to notice the nature and the magnitude of the problem.

Moreover, once the rudder became aerodynamically effective, the quick acceleration through 100 knots put the PIC into a speed regime in which it is generally considered safer to continue the takeoff (unless lacking a flight control or engine failure) rather than perform a high-speed abort.

Flight simulation tests at LM Aero showed that the most effective action to counter sideslip is the rudder application. Releasing aft control stick pressure and decreasing A/C AOA were essential to regaining A/C control in this situation. However, the combination of low altitude, high gross weight, high right rolling moment, and minimal time available (less than two seconds), the only action to be consider by an F-16 pilot who was totally surprised by this type of the problem would be ejection in a timely manner.

2.3.3 Systems (Trim panel)

The Manual Trim Panel is located on the left console of the forward cockpit, out of the pilot's field of vision. On the ground there are numerous checks during normal ground procedures combined with a NOTE and a WARNING against mistrimming. While the A/C is airborne there is no need to visually check the Manual Trim Panel.

Normal ground procedures detailed in the -1 include a NOTE referring to G-suite interference (during flight) and one WARNING in the "Before Takeoff" checklist procedures which mentions serious control difficulties during takeoff may be caused by a mistrimming of the A/C with respect to yaw. There is an additional more WARNING not applicable to HAF BLK 50 A/C concerning HMCS interference.

The safety measures applied to the Manual Trim Panel in order to protect Yaw Trim Knob from unintended movements (O-rings and safety guards), the existence of a related NOTE and WARNING, the F-16 incident of 2015 and the physical tests performed by SIB all showed that unintended rotation of Yaw Trim Knob is an issue of concern.

The fact that this unintended yaw knob rotation is uncommon, especially rotation of this severity, did not lead flight training and HAF Flight Safety structures to deal with this issue at an appropriate level. This is reinforced by the fact that there is no related emergency procedure and no previous recorded incidents in HAF. Although, by definition, a -1 WARNING "could result in personal injury or loss of life if not carefully followed", the word difficulty in the description refers more to the complexity than to the danger and consequently the notion to the pilot is that ultimately he can cope with the problem. Additionally, a yaw mistrimming has to be combined with a numerous other critical factors (heavy gross weight, asymmetric configuration, two seat model, all available stations to carry fuel tanks (4,5 and 6) loaded, cross wind, etc.) in order to reach a fatal level.

Other A/C equipped with digital flight controls address this issue by providing an advisory to the pilot when yaw trim is out of the center position, effectively preventing takeoff of a mistrimmed A/C. Moreover, some aircraft have a dedicated switch (Takeoff Trim Switch) which sets pitch, roll & yaw trim surfaces to the takeoff position.

According to the F-16 bibliography, there is no need for the A/C to be yaw trimmed for takeoff, regardless of configuration. Moreover, yaw trimming during training flights is limited to small trim inputs (less than 4 degrees) and in this perspective, the ability of yaw trim setting to a level of 12 is not necessary for training flights. In light of the above and according to Operational Risk Management (ORM), the ability of the yaw trim to be set to 12 degrees deflection constitutes an unnecessary risk during training flights.

3 CONCLUSIONS

3.1 Findings

-All aerodrome navigational aids, aeronautical and fixed service communications were operating normally at the time of the accident.

-The runway in use for takeoff was RWY 27, the METAR was CAVOK and wind was 9 knots, from 330º. This means that the cross wind component was 7.8 Knots from the right side.

-Both pilots were current, medically qualified and eligible to fly the mission. Their crew rest was in accordance with regulations.

-Both pilots' flight suites and flight equipment were in accordance with regulations. Flight preparation and the element brief were in accordance with mission's timeline. During the briefing, F-16D (two seat model) crew coordination procedures were addressed.

-TLP equipped participants with three checklists. Those checklists were additional flight equipment intended to be carried in the A/C.

-PIC took his flight bag and stored it in the stowage (map case) in the cockpit. This probably did not facilitate the stowage and use of the three checklists provided by TLP.

-From flight preparation through the "Before Taxi" checklist, normal ground procedures were performed in accordance with the -1 and SOP's.

-The "End or Runway Inspection" was performed on ramp E2 instead of an area near the end of the runway. This change to normal procedures was adopted by all Greek participating squadrons for the previous few years and became common practice.

-The change to "End of Runway Inspection" order led the pilot to change his standardization order and consequently the "Before Takeoff" checklist was conducted earlier in the launch sequence than normal. This procedural change modified the standard pilot's habit patterns.

-After the "End of Runway Inspection" was completed, both mishap pilots performed the "Before Takeoff" checklist actions while in the parking area (ramp E2). The Trim Check (pitch and yaw trim centered and roll trim as required) is among the "Before Takeoff" checklist actions.

-Before taxi, both yaw and roll trim settings were inadvertently modified. Roll trim was set slightly to the right (inconsistent with the configuration) and yaw trim was set rapidly to the maximum right position (-12º) and remained in that position throughout the remainder of the MA's operation.

-Following SIB findings, the unintended trim knob movements were most likely caused by an object moving between a trim knob safety guard and the yaw trim knob (on the Manual Trim Panel), such as a TLP checklist.

-After taxi, the MA stopped the A/C and waited for takeoff at the leak check area (between the north parallel taxiway and the main runway at the beginning of RWY 27) for 3:20 minutes. This time was adequate to accomplish “Before Takeoff” checklist procedures. However, none of the procedures (i.e. Flight Controls – Cycle, Fuel-Check, etc.) monitored via CSFDR were reaccomplished and the PIC did not return the yaw trim knob to the center position prior to takeoff.

-The SIB does not have sufficient evidence to determine whether the ASP asked for “Before Takeoff” check list reconfirmation while waiting for takeoff.

-While the nose wheel steering was engaged, the PIC made left control inputs on three separate occasions to maintain runway alignment.

-After nose wheel steering manual disengagement (66Kts, 32:17.0), the PIC used four, separate left rudder inputs to keep the MA aligned with the runway. Three of these inputs were at maximum rudder deflection command and the fourth almost to the maximum, taking into account that full right yaw trim position (-12º) limited the maximum left yaw trim position to 18º.

-Analysis of the previous flight (Friday 23 January 2015) (same pilot, A/C and configuration) showed that the pilot used left rudder inputs to maintain runway alignment during takeoff, after manual nose wheel steering disengagement.

-Taking into account the rudder corrections used during the previous flight, the similar actions after steering disengagement during the mishap flight were considered by the PIC to be normal and prevented him from noticing the mistrimming of the MA.

-Once the rudder became aerodynamically effective, the quick acceleration through 100 knots put the PIC into a speed regime in which it is generally considered safer to continue a takeoff (except if lacking a flight control or engine failure) rather than perform a high speed abort.

-Left control inputs were applied during rotation for takeoff to counter the right wing heavy asymmetry and the slight right wing down roll trim setting.

-Prior to WOW the left rudder inputs were reduced and rudder returned toward the right. Aft control stick force applied was normal for takeoff.

-During the entire mishap, the MA landing gear was in down position, the engine operated in MAX A/B and the ARI was not available (due to landing gear handle being down and MLG wheel speed being above 60 knots groundspeed).

-Immediately after WOW, the MA sideslipped rapidly as a result of the full right yaw trim setting. The nose-right sideslip aerodynamically produced a right wing down rolling moment.

-The 7.8 knots, right cross wind during takeoff was a contributing factor to the sideslip but not a critical one.

-The fact that the unintended rotation of the trim knobs is uncommon, especially of this severity and there are no related emergency procedures nor previously recorded incidents of this type in HAF did not lead flight training and HAF Flight Safety structures to deal with this issue at an appropriate level.

-The PIC instinctively reacted by applying maximum aft and left control side stick inputs.

-Maximum aft and left roll stick commands, along with an 8,530 ft-lbs right wing heavy asymmetry, increased AOA, reduced directional stability and likely increased the nose right sideslip condition (without ARI protection). Approximately 2 seconds after WOW, a DFLCS Stall Warning AOA was recorded by the SDR (Low Speed Warning Tone, AOA > 15 degrees with landing gear handle down).

-The PIC's control stick commands and the resulting control surface inputs were insufficient to counter the right roll due to adverse sideslip and high AOA. The PIC's effort to regain control of the MA (maximum aft and left stick inputs) continued until ejection.

-The most effective action to counter sideslip was the application of left rudder. Releasing aft stick pressure and decreasing A/C AOA would contribute to regaining control of the A/C. However, the PIC's behavior was as should have been expected from an average pilot, taking into account the circumstances of the low altitude, the A/C's high gross weight and the high right rolling moment in combination with the very limited time available.

-At 6.38 seconds following WOW the Canopy Open warning light activated, indicating the canopy opening during the ejection sequence. At that point there was still aft and left forces applied to the control stick.

-Ejection was initiated out of the seat safe ejection envelope. MA impacted the ground approximately 7.8 sec after WOW close to shelter D-4, south of TLP ramp E2. The mishap resulted in the fatal injury of both mishap pilots and the total destruction of the MA.

-After impact, the MA pieces and the subsequent fire (fireball) continued along the MA's ground track and led to the destruction or damage of eight more A/C parked at ramp E2 and TLP hangar, fatal injuries to nine French Air Force personnel and numerous other injuries. Significant damage was caused to the ground equipment and the airport infrastructure in the vicinity of ramp E2.

-MA was configured with an AIM-9 captive missile on Station 1, a Weapon Pylon on station 3, a Fuel Pylon with a 370 Gallon External Tank on Stations 4 and 6, a Fuel Pylon with a 300 Gallon External Tank on Station 5 (centerline), a Weapon Pylon with CATM-88B captive missile on Station 7 and an ACMI Pod on Station 9. All external fuel tanks were full of JP-8 fuel.

-The mass and center of gravity of the aircraft were within prescribed limits.

-No deferred maintenance defects had been recorded. The MA flew last sortie (23January 2015) without any noted malfunctions. The history of parts removed and replaced indicated no unusual historical data.

-All individuals who performed maintenance on MA for the mishap mission and the unscheduled maintenance of the last 15 days were adequately trained and qualified for the work performed.

-No abnormalities were noticed during the “Preflight”, “Launch” and “End of Runway Inspections” of the MA on 26 January 2015.

-The maintenance records indicated that the aircraft was equipped and maintained in accordance with existing HAF regulations and approved procedures.

-The seat-mounted flight control system data recorder (SDR), as well as Crash Survivable Flight Data Recorder (CSFDR) units (SAU and SCMU) were recovered at the crash site and sent to LM Aero for retrieval and analysis. Data from the mishap flight and several previous flights was available in these downloads.

-All aircraft systems were operating properly following engine start and there was no evidence of any defect or malfunction in the aircraft that could have contributed to the accident. The engine was responding as commanded by the PIC. The aircraft was structurally intact before impact.

-The Manual Trim Panel is located on the left console of the forward cockpit, out of the pilot’s field of vision. While the A/C is airborne, there is no need to visually check the panel. While on the ground, there are numerous checks during normal ground procedures required by the -1. The -1 lists a NOTE and a WARNING against mistrimming.

-There are safety measures used on the Manual Trim Panel to protect the yaw trim knob from being moved unintentionally (O-rings and safety guards). Moreover, a number of NOTES and WARNINGS in -1 refer to the proper setting of the yaw trim. However, a previous incident report and physical tests performed by the SIB showed that unintended rotation of yaw trim knob is possible.

-Other A/C types have systems/methods to prevent takeoff with improper trim settings. Moreover, there is a dedicated switch (Take Off trim switch) which sets pitch, roll & yaw trim surfaces to the takeoff position.

3.2 Causes

The **main** causes of the accident were:

-The MA was not properly trimmed for takeoff. Before taxi, the yaw trim was inadvertently set to maximum right deflection (12^{o} right), drastically affecting the aerodynamics of the aircraft during takeoff.

-The PIC accomplished the “Before Takeoff” checklist actions while at parking area (ramp E2) approximately 20 minutes before takeoff.

<u>Contributing</u> factors to the accident:

- The Manual Trim Panel design does not prevent all inadvertent movement nor does the A/C have a method/system of notifying the pilot if the A/C is mistrimmed prior to takeoff.

-The coexistence of a number of critical factors led the accident to a fatal level. The factors mentioned above are: heavy gross weight, asymmetry configuration, two seat model, external fuel tanks (mainly centerline) and cross wind.

- The fact that this unintended rotation of the yaw trim knob is uncommon, especially of this severity, did not lead HAF flight training and Flight Safety structures to deal with this issue at an appropriate level. This is reinforced by the fact that there are no related emergency procedures and no previous recorded incidents of this type in the HAF.

- Loose objects in the cockpit, such as checklists not properly stowed, could cause the inadvertent movement of the yaw trim knob.

-The “End of Runway Inspection” was performed at ramp E2 instead of a location near the end of the runway. This procedural change left an open window for the PIC to deviate from standard procedures.

4 SAFETY RECOMMENDATIONS

-HAF to submit a core Engineering Project Request (EPR) under the Falcon 2020 contract for LM Aero to conduct a trade study on how to best control the yaw trim during takeoff.

-LM Aero to identify how to best address the issue of neutralizing or preventing yaw trim inputs during takeoff, and/or providing an advisory to the pilot when certain yaw trim conditions exist.

-HAF to enhance the pilot’s procedures in the view of “Before Takeoff” checklist procedures to be the last actions taken before takeoff.

-HAF to submit AF FORM 847 to Technical Coordination Group (TCG) to add a description in the -1 section VI, FACTORS AFFECTING FLYING CHARACTERISTICS describing the flight characteristics and effect of A/C mistrimming for takeoff.

-HAF to enhance the pilot’s and technician’s procedures in the view of “End of Runway Inspection” to be performed at designated locations as close as possible to the end of the runway.

-HAF to enhance the pilot’s procedures in the view of stowing objects in cockpit in accordance with SOP’s.

APPENDICES

“A” Safety Investigation Board Members

“B” Crash Site and Damages

“C” LM Aero Report of F-16D 93-1084

“D” Manual Trim Panel

ABREVIATIONS

A/B	After Burner
A/C	Aircraft
ACMI	Air Combat Maneuvering Instrumentation
AFH	Aircraft Flying Hours
AFB	Air Force Base
AFSP	Allied Flight Safety Publication
AIM	Air Intercept Missile
AOA	Angle of Attack
ARI	Aileron Rudder Interconnect
ASP	Aft Seat Pilot
ATD	Aircrew Training Device
CATM	Captive Air Training Missile
CSFDR	Crash Survivable Flight Data Recorder
CSMU	Crash Survivable Memory Unit
DEU	Germany
DTC	Data Transfer Cartridge
EFH	Engine Flying Hours
EOD	Explosive Ordnance Disposal
EPR	Engineering Project Request
EPU	Emergency Power Unit
ESP	Spain
FCC	Fire Control Computer
FLCC	Flight Control Computer
FLCS	Flight Control System
FRA	France
FWD	Forward
GRC	Greece
GW	Gross Weight
HAF	Hellenic Air Force
HARM	High-speed Anti-Radiation Missile
HMCS	Helmet Mounted Cueing System
IGS	Integrated Ground Software
ILS	Instrument landing system
INS	Inertial Navigation System
IP	Instructor Pilot
ISA	Integrated Servoactuator
ITA	Italy
LG	Landing Gear
LM	Lockheed Martin Aeronautics Company
LRU	Line Replaceable Units
MA	Mishap Aircraft
MFL	Maintenance Fault Listing
MLG	Main Landing Gear
NATO	North Atlantic Treaty Organization
ORM	Operational Risk Management
PDG	Programmable Display Generator
PIC	Pilot in Command
RWY	Runway
SACEUR	Supreme Allied Commander Europe
SACT	Allied Commander Transformation
SAU	Signal Acquisition Unit
SDR	Seat Data Recorder
SEM/EDX	Scanning Electron Microscope/ Energy Dispersive X-Ray
SOP	Standard Operational Procedures
STANAG	Standardization Agreement
TAC	Total Accumulated Cycles
TACAN	Tactical air navigation system
TCG	Technical Coordination Group
TCTO	Time Compliance Technical Orders
TLP	Tactical Leadership Programme
TO	Technical Order
TWR	Tower
UTC	Coordinated Universal Time
VMC/VFR	Visual meteorological conditions/ Visual meteorological conditions
INS	Inertial Navigation System
WOW	Weight-Off-Wheels