

## POST - MAINTENANCE FLIGHT TEST AS A MECHANISM OF MOTION IN MIRCE MECHANICS

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MIRCE Mechanics is a part of MIRCE Science that focuses on the scientific understanding and description of the physical phenomena and human rules that govern the motion of functionable system types through MIRCE Space [01]. A full understanding of the mechanisms that influence this motion through MIRCE Space is essential for accurately predicting the functionability performance of functionable system types using MIRCE Science. According to the 5th axiom of MIRCE Science, the probability that a completed maintenance task introduces faults or errors is greater than zero. To reduce the probability of introducing undetected maintenance errors and their consequential impact on the system operational process, the concept of the Post-Maintenance Flight Tests (PMFT) is used in aviation industry. Consequently, the main objective of this paper is to critically assess these types of maintenance verification tests and their impact efficacy on the functionability performance, as understood through the application of MIRCE Science. The physical reality of inducing errors during maintenance and their consequences on post-maintenance flight is illustrated using an incident that regrettably took the lives of two pilots, when their Piper PA 46-350P, N962DA, crashed into the Spokane River on May 7, 2015, following an attempted landing at Felts Field Airport in Spokane, Washington, USA.

Key words: Flight, Functionalization, Maintenance, Motion, Probability

### INTRODUCTION

*“Motion does not mean travel of the ball-type electron along some orbit around the nucleus. Motion is the change in the state of the system “atom” in time.”*  
Werner Heisenberg

MIRCE Mechanics is a part of MIRCE Science that focuses on the scientific understanding and description of the physical phenomena and human rules that govern the motion of functionable system types through MIRCE Space [01]. A full understanding of the mechanisms that influence this motion through MIRCE Space is essential for accurately predicting the functionability performance of functionable system types using MIRCE Science.

According to MIRCE Science, at any instant of calendar time, a given functionable system type could be in one of the following two states:

- Positive Functionability State (PFS), a generic name for a state in which a functionable system type is able to deliver the expected measurable function(s),
- Negative Functionability State (NFS), a generic name for a state in which a functionable system type is unable to deliver the expected measurable function(s), resulting from any reason whatsoever.

The motion of a functionable system type through the functionability states, in the direction of calendar time, is generated by functionability actions, which are classified as:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a system to move to a PFS.

- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a system to move to a NFS.

The motion of a functionable system type through the functionability states is manifested through the occurrences of functionability events, which are classified as:

- Positive Functionability Event (PFE), a generic name for any physically observable occurrence in time that signifies the transition of a functionable system type from a NFS to a PFS.
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence in time that signifies the transition of a functionable system type from a PFS to a NFS.

At the MIRCE Academy a large number of positive functionability actions have been analysed, including maintenance tasks like: overhauls, tests, inspections, visual checks, scheduled maintenance tasks, repairs, replacements, examinations and many others, in order to understand the mechanisms driving the motion of functionable system types out of their negative functionability states. Based on the information available, Knezevic [02] concluded that, from the point of view of the quality of execution, each physically observable maintenance task could be categorised as:

- Successful Maintenance Task (SMT), where all maintenance activities have been completed successfully in the first attempt.
- Faulty Maintenance Task (FMT), where all maintenance activities have not been completed successfully in the first attempt.

By studying numerous maintenance processes regarding the execution of maintenance tasks, in respect to the possibility of detecting maintenance faults and errors, made during the maintenance process, the author grouped them into following two categories: [02]

- Detectable Faulty Maintenance Tasks (FMTD), are those where the faulty activities could be detected during the execution of consisting activities or at the end of the task and corrective action taken.
- Non-Detectable Faulty Maintenance Tasks (FMTND) where faults and errors induced during the maintenance process are not detected during the execution of the constituent activities or at the end of the task and are left for the operational process to detect the maintenance faults and suffer their consequences.

In accordance to the 5th axiom of MIRCE Science [01] each maintenance task completed has a certain probability of belonging to the FMTND category. To reduce the probability of existence of undetected maintenance errors and their consequences on the system operational process, the concept of the Post-Maintenance Flight Tests (PMFT) is used in aviation industry. Consequently, the main objective of this paper is to analyse this type of maintenance tasks and their impact on the motion of functionable system types through MIRCE Space and their consequential impact on the functionability performance, as perceived by MIRCE Science. The physical reality of inducing errors while performing maintenance tasks and their consequences on post-maintenance flight is illustrated using an incident that took the lives of two pilots, when the Piper PA 46-350P, N962DA, crashed into the Spokane River on May 7, 2015, following an attempted landing at Felts Field Airport in Spokane, Washington, USA.

### **POST-MAINTENANCE FLIGHT TEST**

Post-maintenance flight in the aviation industry is an accepted nomenclature for an assessment of the functionality of a functionable system at the end of the maintenance tasks. It is also known as a "functional check flight," or FCF. These types of flights also apply to production testing of new aircraft as they "roll off" the assembly line. [03]

The objective of this task is to fly the aircraft using normal operating procedures to validate the functionality of the aircraft under test, after completion of the maintenance tasks or manufacturing process. The test is performed in accordance with a defined test plan, with pilots ready to react if a contingency occurs, so that they can get the airplane back on the ground and address the cause of the contingency.

The functional check flight should be carefully planned with an emphasis on risk management before the aircraft leaves the ground. This must include consultations with maintenance staff and, in some cases, representatives of the aircraft's manufacturer, as well as piloting currency, insurance coverage, crew coordination and other Fed-

eral Aviation Authority (FAA) regulations, to name a few. For example, FAR 91.305 regulation states flight-testing must be conducted over open water, or sparsely populated areas having light air traffic. [03]

Post-maintenance test flying can be risky. Even relatively simple owner-performed maintenance chores, like oil changes or brake-pad replacement, have been known to create airborne drama. Whenever an aircraft comes out of maintenance, some sort of test flight should be conducted with the intention of verifying the work performed. In fact and perhaps unsurprisingly, the FAA has a regulation covering post-maintenance test flights, FAR 91.407. Its applicability to a specific situation hinges on the extent to which, if any, work on the aircraft "appreciably changed its flight characteristics or substantially affected its operation." That's a fairly broad definition, and one an owner or operator should think about whenever some maintenance is planned.

### **Is Post Maintenance Flight Testing Necessary?**

Numerous accidents in all types of functionable systems have been maintenance related. It means that as result of an inherent fault or an error that took place during the execution of the maintenance task, functionable systems have experienced transition to a NFS, while in-service. Types, scale and frequencies of the maintenance induced failures and their consequences in commercial aviation can be found in literature. The collection of maintenance error related events, briefly described below, are taken from the report published on 12 August 2002 by the National Transportation Safety Board of the USA, and Civil Aviation Authorities of the UK, thus:

- May 25, 2002. China Airlines B747-200. Structural failure at the top of a climb to cruise altitude resulted in a crash into Taiwan Strait; due to the repair of previous tail strike, when steel doubler that are prohibited by structural repair manual., were used. Toll: 225 killed.
- April 26, 2001. Emery Worldwide Airlines DC-8-71F. Left main landing gear would not extend for landing. Cause was failure of maintenance to install the correct hydraulic landing gear extension component and the failure of inspection to comply with post-maintenance test procedures. No injuries.
- March 20, 2001. Lufthansa A320. Cross-connected pins reversed the polarity of captain's side stick. Post-maintenance functional checks failed to detect the crossed connection. Aircraft ended up in 21° left bank, almost hitting the ground. Co-pilot switched his side-stick to priority and recovered the aircraft. No injuries.
- Feb. 16, 2000. Emery Worldwide Airlines DC-8-71F. Crashed attempting to return to Rancho Cordova, California. Cause was improperly installed right elevator control. Toll: 3 crew killed.

- Jan. 31, 2000. Alaska Airlines MD-83. Crashed in Pacific Ocean near Port Hueneme due to loss of horizontal stabiliser caused by the maintainer failure to lubricate jackscrew assembly that controls pitch trim. Toll: all 88 aboard killed.
- Jan 21, 1998. Continental Express ATR-42. Fire in right engine during landing, due to improper overhaul of lugholes in the fuel/oil heat exchanger. No serious injuries.
- March 18, 1997. Continental Airlines DC-9-32. Failure of maintenance personnel to perform a proper inspection of the combustion chamber outer case, allowing a detectable crack to grow to a length at which the case ruptured, causing uncontained failure of right engine. No injuries.
- Nov. 1996. A320 (operator unknown). Both fan cowl doors detached from No.1 engine during rotation. Doors had been closed but not latched during maintenance. According to AAIB, "Similar incidents have occurred on at least seven other occasions."
- July 17, 1996. TWA Flight 800, B747. Fuel/air explosion due to inadequate maintenance on an aging fleet and noncompliant parts. Toll: all 230 passengers and crew killed.
- July 6, 1996. Delta Air Lines MD-88. Uncontained engine failure on takeoff due to inadequate parts cleaning, drying, processing and handling. Toll: 2 passengers killed, 2 passengers seriously injured.
- June 8, 1995. ValuJet Airlines DC-9-32. Maintenance technicians failed to perform a proper inspection of the 7th stage high compression disk, allowing a detectable crack to grow to a length at which it ruptured. Toll: 1 crew seriously injured.
- Feb. 1995. British Midland B737-400. Oil pressure lost on both engines. Covers had not been replaced from borescope inspection the previous night, resulting in loss of almost all oil from both engines during flight. Diverted and landed safely. No injuries.
- March 1, 1994. Northwest Airlines B747. Narita, lower forward engine cowling dragged along runway. During maintenance, the No. 1 pylon diagonal brace primary retainer had been removed but not reinstalled. No injuries.
- Aug. 1993. Excalibur Airways A320. Un-commanded roll in first flight after flap change. Returned to land safely at Gatwick. Lack of adequate briefing on status of spoilers (in maintenance mode) during shift change. Locked spoiler not detected during standard pilot functional checks. No injuries.
- Sept. 11, 1991. Continental Express Airlines, EMB-120. Horizontal stabilizer separated from fuselage during flight because maintenance personnel failed to install 47 screw fasteners. Toll: all 14 passengers and crew killed.
- Aug. 21, 1990. United Airlines B737. Flashlight left by maintenance, sandwiched between cargo floor and landing gear retract/extend linkage, causing the crew to make a gear up landing. No injuries.
- July 22, 1990. USAir B737. Fuel pump control failure due to improper machining. No injuries.
- June 1990. British Airways BAC1-11. Captain sucked halfway out of windscreen, which blew out under effects of cabin pressure, as 84 of 90 securing bolts were smaller than the specified diameter. Toll: 1 serious injury.
- Aug. 12, 1985. Japan Air Lines B-747SR. Improper repair of aft pressure bulkhead led to sudden decompression in flight that damaged hydraulic systems and vertical fin. Aircraft struck Mt. Ogura. Toll: 520 passengers and crew killed; 4 surviving passengers injured.
- May 25, 1979. American Airlines, DC-10. Separation of No.1 engine and pylon assembly on takeoff at Chicago's O'Hare. Toll: all 298 passengers and crew plus 2 killed and 2 seriously injured on the ground.

Based on the examples presented above, which only "scratching the surface" of the problems related to the faulty execution of maintenance tasks, it seems that the post maintenance flight test could be a good mechanism for detecting the faults prior returning the aircraft to scheduled service. In some extreme cases, the post maintenance flight tests might end in accidents, but the consequences of these occurrences on the environment and flying public should be significantly smaller.

The contra argument could be that each post maintenance flight test prevents the return of the aircraft to its revenue generating purpose, which could have a significant impact on the "bottom line" of the airline. Hence, a rational trade-off has to be made between the benefits of doing the test and the lost revenue sustained while conducting it.

#### **PREPARATION FOR THE POST MAINTENANCE FLIGHT TEST**

The process begins with a thorough understanding of the work that was done on the aircraft. According to many operators, the first question to ask is whether a functional check flight is really necessary for the maintenance that was performed.

Generally speaking, most maintenance procedures on modern aircraft do not require flight checks. Maintenance departments rely on the Aircraft Maintenance Manual (AMM) for guidelines on post-maintenance flight testing, as it gives a specific direction on checking the components that have to be flight-tested. The task cards for the event will cover the specific things the flight testing shall include. For example, once a hot-section inspection has been completed, and assuming no deterioration was discovered, runs can be conducted on the ground. After major overhauls, rigorous operating cycles will be con-

ducted in test cells by the engine manufacturer or repair station that did the work before returning powerplants to customers, necessitating only routine check flights after the engine was reinstalled and signed off. [03]

After a major engine maintenance action is completed a static takeoff engine power check will be performed in accordance to the Airplane Flight Manual (AFM) to verify that power and temperature limits were within proper parameters. However, there are some scheduled maintenance actions that require extensive, carefully planned evaluation flights. For example the Gulfstream has an electrical load-shedding system that drops off non-essential equipment to reduce the electrical load on the airplane in an emergency. Testing this feature has to be done in the air because there are designated trip-level altitudes where certain functions will be performed by the systems, so it is impossible to do these tests on the ground. The electrical system does this only in the case of a contingency, and there are certain steps that the flight crew has to perform to make it happen.

Another test, requiring in-flight evaluation, is an Auxiliary Power Unit (APU) start at altitude. In the case of: flap maintenance, it is essential to do a flight test to electrically load the APU and check they are working properly. Although all possible checks are done on the ground, there are some things that have to be checked out in the air, For example "flap rigging" is one of them.

In addition to the AMM and AFM, other references for planning a PMFT include the Aircraft Owner's Manual (AOM) and various customer support services offered by the original equipment manufacturer (OEM) including advice, publications and training from the OEM flight operations departments. Typically, the factory checklist is used for this purpose. In addition, a Flight Risk Assessment Tool (FRAT) sheet is used in Safety Management System (SMS) for normal as well as maintenance test flights that will be completed prior to flying.

According to Esler [03] the most generic rules for the preparation of PMFT are as follow:

1. Rule 1: Think how to prepare for and fly a safe PMFT. In other words, do the "homework" by; studying every source of information available in communication with the aircraft's OEM. If there's a choice among flight crews, obviously the best and most experienced pilots should be selected, especially those with the greatest time in the aircraft type, as they should be intimately familiar with the aircraft's performance envelope and proclivities. Depending on the extent of the maintenance task, the test pilot will sit down with the maintenance department personnel to determine what was done on the airplane and what they expect from flying staff. A lot of times, maintenance technicians are taken on the flight, typically, one of those who performed the maintenance task. Typically, a director of maintenance (DOM) oversees all maintenance on company-operated aircraft; it is their responsibility to prepare a thorough briefing on

what was done and what systems were affected. The DOM also prepares a check flight item summary with a list of what is necessary to look for and what checks that additionally have to be done together with normal flight operational checks.

2. Rule 2: Rely on the maintenance personnel to brief the flight crew and explain everything that was done to the aircraft and how it will be verified on the PMFT. If necessary maintainers should work with the DOM to plan the flight, keeping everyone involved with the maintenance action in the loop. Conducting post-maintenance flight checks safely requires pilots experienced in the aircraft, intensive preparation and cross-communication with the maintenance provider, and adherence to risk management principles
3. Rule 3: Plan the PMFT around the maintenance that was performed on the aircraft with an emphasis on risk management and an understanding that the flight should be collaboration between the cockpit crew and maintenance staff. Prior to the flight it is necessary to thoroughly brief all personnel involved and prepare for possible emergencies. The flight should be carried out under Air Traffic Control (ATC) control with radio contact maintained at all times. The flight crew and maintenance personnel should hold a preflight briefing and cover emergency situations that may occur during the intended flight that are related, or may not be related, to the maintenance performed. If an incident or problem arises on the flight, the crew and maintenance technicians will assess and determine if the flight can be continued or a return to base is required.
4. Rule 4: Make sure the aircraft documentation is up to date, even before going into the airplane. It is important to spend some time reviewing the folder containing all the aircraft documents and all the paperwork to be sure that:
  - there are no open write-ups,
  - that everything has been signed off,
  - that all the dates (maintenance, inspection and overhaul) have been complied with
  - that all the squawks have been addressed and signed off,
  - that the weight and balance is correct and other things that make the airplane legal to fly.

It is necessary to stress the PMFT cannot start until the airplane has been signed back into service, that it is truly airworthy. Then it is necessary to perform the exterior preflight inspection. This is rather a straight forward task, but takes time to look at everything. . To do the job properly it is necessary to touch everything physically, use the flashlight as a pointing device as much as it is used as an illumination device, as it keeps pilots attention focused on what they are looking at, that something is what it is, and not what they are expecting it to be. This process will typically take 2 hrs or so pilots are advised

not to try to “rush through it”. Finally, when the flight crew turn the airplane on, that is, strike the battery switches, to make sure that all the lights come on as they’re supposed to. It is necessary to be sure that: the APU start and stop lights come on; the enunciators function; all the lights come on, including the one showing that the enunciators are armed! Then and only then pilots are advised to go through all the function checks, to make sure everything has its proper form and function, before the aircraft is moved on. It is considered best practice to take maintenance representative on the ensuing check flight since maintainers “take as much pride in what they do as the pilots do” and in case things go wrong .

5. Rule 5: Before launching on a PMFT, work out a plan for handling contingencies that could happen as a result of the performed maintenance tasks. If something unplanned occurs on the functional check flight, the response should be clear: It is necessary to make an assessment, take corrective action if possible, decide whether to continue the flight, and if not, especially if the aircraft is at risk land as quickly as possible, in accordance with the preemptively prepared risk-management plan and the duties assigned to each crew member, including the maintenance personnel “riding along”. Whether there is a glitch to be corrected or all goes well on the PMFT and the aircraft is deemed safe and ready for reentry to service, the last task is to conduct a post-flight review of the operation. The object here is to learn from the experience, exchange information and points of view, to help avoid problems in the future.
6. Rule 6: Debrief after the PMFT and review the entire post-maintenance verification process. Encourage feedback from all involved, identify any faults and errors that were made, and update/correct operations manual and SMS accordingly.

In summary any functional check flight is an extraordinary event, which cannot be treated as a normal flight! Nothing should be assumed. When accelerating down the runway, as soon as the flight controls become effective, the pilots need to make sure that they get the proper response to their inputs for all three axes. Whenever someone performs a task, he or she must always perform one operation at a time (e.g. move one switch), wait, and observes the outcome. If all is OK, then they can perform the next task. It is also vitally important, as always, to work as a team.

### **AN EXAMPLE OF MAINTENANCE INDUCED CATASTROPHIC ERROR**

Arguably, among the most challenging and potentially hazardous flights a pilot undertakes are post-maintenance test flights. The National Transport Safety Board (NTSB) database contains dozens of incidents in which post-maintenance flights ended up tragically, often because the pre-flight chores were rushed or carelessly executed. This paper looks at an incident that took the lives

of two pilots, when Piper PA 46-350P, N962DA, crashed into the Spokane River on May 7, 2015, following an attempted landing at Felts Field Airport in Spokane, Washington, USA. [04, 05, 06].

Rocket engineering company personnel had just completed several maintenance tasks including an annual inspection. The accident flight was to be a post-maintenance test flight, and was expected to take about 40 minutes. Weather conditions were good. Eleven minutes after making the initial call to ATC, the airplane began the takeoff roll. Almost immediately after takeoff, the aircraft began a climbing turn, 10 deg. to the right, as recorded by radar. After flying on that heading for about 1.5 miles, the airplane began a more aggressive turn to the right, reaching 1,000 feet. The airplane’s turn radius then tightened to about 700 feet, and within 45 seconds it completed almost two spiralling turns, while descending about 700 feet. Control tower personnel later told investigators that during this period the airplane was banking about 90 degrees to the right and descending, and they assumed that it was about to crash. However, moments later the bank angle began to reduce, and the airplane appeared to recover. The airplane then began a meandering climb to the east, and about 2.5 minutes later the pilot reported, “We are trying to get under control here, be back with you.”

The Piper eventually over flew the town of Newman Lake, about 11 miles east of the airport, having climbed to about 5,600 feet mean sea level (MSL) and the pilot reported, “Things seem to be stabilizing.” When asked his intentions by the tower controller he replied, “We are going to stay out here for a little while and play with things a little bit, and see if we can get back.” Then the airplane began a gradual left turn, and the pilot requested and was approved for a straight in landing for Runway 22R. The airplane became aligned with the runway about 7 miles east of the airport, and a short time later the controller asked the pilot the nature of the emergency, to which he responded, “We have a control emergency there, a hard right aileron.” The flight progressed, and a few minutes later the pilot reported that the airplane was on a 3-mile final. The Piper remained closely aligned with the runway centreline throughout the remaining descent, and control tower personnel observed that it appeared to be flying in a 20 deg, right-wing-low attitude as it neared the runway threshold. A tower controller later reported that as the still airborne airplane passed Taxiway D, the engine sound changed, as if the pilot was attempting to perform a go-around. Suddenly, the airplane began a sharp roll to the right and crashed into the river just north of the airport.

Rescue operations, which started immediately, quickly turned into recovery operations. The river was about 25 feet deep at the accident site, and all major airframe components sank within a few minutes of impact. Divers recovered the airplane over a two-day period during the week following the accident. The fuselage sustained crush damage and fragmentation from the firewall through to the right-side emergency exit door. The en-

gine remained attached to the firewall, and the propeller hub with all four blades remained attached to the engine gearbox. All blades were bent about 90 deg aft, 8-12 in from their roots. Both wings had separated from the airframe at their roots, with the right wing separating into two sections outboard of the main landing gear. The horizontal stabilizer had detached from the tail cone.

The 64-year-old pilot-in-command, held a commercial certificate with ratings for airplane single-engine land, multiengine land, rotorcraft-helicopter, and instrument airplane and helicopter, along with a flight instructor certificate for airplane single-engine land. He also held a repairman, experimental builder certificate, and was rated in the Bell 212 helicopter and Lockheed L-382 (C-130 Hercules) airplane. Rocket Engineering told investigators the pilot had an appointment for his FAA medical examination at 0800 on the morning following the accident, and therefore chose to do the flight test that evening instead of the following day (Friday). The pilot's wife also stated that he typically did not work on Fridays but would do so if the work schedule required it.

The pilot-rated passenger held a private pilot certificate with an airplane single-engine land rating, issued in 2010. He had accumulated a total of about 122 hours of pilot-in-command flight experience. He was employed at Rocket Engineering as a customer service and sales representative.

The accident aircraft was manufactured by Piper in 1996 as a PA-46-350P equipped with a Lycoming TIO-540-AE2A 350-hp turbocharged piston engine. It was modified by Rocket Engineering in 2007 under a JetProp LLC STC, which included the installation of a 560-hp Pratt & Whitney Canada PT6A-35 turboprop engine.

The airplane was brought to the facilities of Rocket Engineering on April 17 for an annual inspection. During the period leading up to the accident, routine maintenance was performed, along with the replacement of the four aileron cables in the wings and an aft elevator cable. The mechanic who performed the work stated that the aileron and elevator cables were replaced during the three-day period leading up to the accident.

The owner reported that he had decided to pick up the airplane on May 5; however as the work progressed, he was informed that the airplane would not be ready in time, and the date was pushed back to May 7 (accident day) and then May 8. He had made plans to travel from Los Angeles the afternoon of May 7, and was en route via a commercial airline when the accident happened.

The airplane's primary flight controls are conventional, and operated by dual control wheels and rudder pedals through a closed-circuit cable system. The ailerons and rudder are interconnected through a spring system located under the main cabin.

An aileron is mounted on the outboard trailing-edge section of each wing via a series of hinges. Movement of each aileron is controlled through a yoke and pin assembly that interfaces with a sector wheel mounted in each

wing forward of each aileron. Each sector wheel is connected to, and driven by, one aileron drive cable and one balance cable. In each wing, both the balance and drive cables are terminated with identical ball swage fittings, and each swage fitting inserts into one of two identically sized receptacles in the sector wheel. Both cables are approximately the same length outboard of the pressure vessel seals, which are located about 1 in apart vertically at the wing root.

In each wing, both cables are routed to the fuselage along the wing trailing edge, and pass through their respective pressure vessel seals in the wing root. Inboard of the pressure vessel seals, the left and right balance cables connect to one another after passing through a centre pulley, while the drive cables are routed forward via pulleys to the control wheel assembly in the cockpit. The balance and drive cables are aligned vertically at the pressure vessel seals and diverge about 3 inches laterally at their respective pulley positions. The sector wheel design is unique within the Piper fleet to the PA-46.

The NTSB said that four aileron cables were replaced during the maintenance operation. "Post-accident examination of the airplane revealed that the aileron balance and drive cables in the right wing had been misrouted and interchanged at the wing root. Under this condition, both the left and right ailerons would have deflected in the same direction rather than differentially. Therefore, once airborne, the pilot was effectively operating with minimal and most likely unpredictable lateral control, which would have been exacerbated by wind gusts and propeller torque and airflow effects."

The sections of the two interchanged cables within the wing were about equal lengths, used the same style and size of termination swages, and were installed into two same-shape and -size receptacles in the aileron sector wheel. "In combination, this design most likely permitted the inadvertent interchange of the cables, without any obvious visual cues to maintenance personnel to suggest a misrouting. The maintenance manual contained specific and bold warnings concerning the potential for cable reversal," said the Safety Board [06].

"Although the misrouting error should have been obvious during the required post-maintenance aileron rigging or function checks," said the Safety Board, "the error was not detected by the installing mechanic. The installing mechanic reported that he had another mechanic to verify the aileron functionality, that other mechanic denied that he was asked or that he conducted such a check. The mechanic who performed the work also signed off on the inspection; as the federal regulations do not require an independent inspection by someone who did not perform the maintenance." [06]

The pilot did perform a pre-flight check; the pre-flight checklist included confirmation of "proper operation" of the primary flight controls from within the cockpit. "Although the low-wing airplane did not easily allow for a differential check of the ailerons during the walk-around,"

said the Safety Board, “both ailerons could be seen from the pilot’s seat; therefore, the pilot should have been able to recognize that the ailerons were not operating differentially.”

In analysing the circumstances of the accident, the Safety Board observed that the accident occurred at the end of the business day, and the airplane had been undergoing maintenance for a longer-than-anticipated period. The airplane’s owner was flying in from another part of the country via a commercial airline to pick up the airplane the following morning. The accident pilot, who was an engineer at the company and typically flew post-maintenance test flights, was assisting with returning the airplane to service. As he had an appointment with an FAA medical examiner the next morning (Friday), “It is likely that the mechanic and pilot felt some pressure to be finished that day so the owner could depart in the morning and the pilot could attend his appointment.”

In summary, the Safety Board determined the probable cause(s) of this accident to be: “The mechanic’s incorrect installation of two aileron cables and the subsequent inadequate functional checks of the aileron system before flight by both the mechanic and the pilot, which prevented proper roll control from the cockpit, resulting in the pilot’s subsequent loss of control during flight. Contributing to the accident was the mechanic’s and the pilot’s self-induced pressure to complete the work that day.” [06]

Unfortunately, the significant causal factors involved in this accident are repeated several times each year. Pressure to get the job done; inspection/installation-unfriendly designs; and rushed pre-flight inspections are all potential killers. The record shows that post-maintenance flights should never be considered “routine.” They are fraught with hazards that can kill the unwary crew.

## CONCLUSIONS

According to the 5th axiom of MIRCE Science, the probability that a maintenance task completed contains a faults or errors is greater than zero. Hence, MIRCE Mechanics, as a part of MIRCE Science, focuses on the scientific understanding and description of the physical phenomena and human rules that govern the motion of functionable system types though MIRCE Space [01]. A full understanding of the mechanisms of the motion is essential for accurate predictions of functionability performance of functionable system types facilitated by MIRCE Science.

To reduce the probability of existence of undetected maintenance errors and their consequences on the system operational process, the concept of the PMFT is used in aviation industry. Thus, the main objective of this paper was to analyse this type of maintenance tests and their impact on the functionability performance in aviation, on one hand, and to inform functionability engineers and managers in other industries to consider similar tests, on the other.

The physical reality of inducing errors during maintenance and their consequences on a post-maintenance flight is illustrated through an incident that took the lives of two pilots, when their Piper PA 46-350P, N962DA, crashed into the Spokane River on May 7, 2015, following an attempted landing at Felts Field Airport in Spokane, Washington, USA

Arguably, among the most challenging and potentially hazardous flights a pilot can undertake are post-maintenance flights tests The NTSB database contains dozens of incidents in which post-maintenance flights ended up tragically, often because the pre-flight chores were rushed or carelessly executed. Hence, the closing question is:

“Could the probability of the detection of maintenance induced errors be increased by appropriate design solutions, rather than leaving them to be detected during the potentially risky PMFT?”

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