National Aeronautics and Space Administration

SYSTEM FAILURE CASE STUDIES

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Wire to Wire

On September 2, 1998, Swissair Flight 111, a McDonnell Douglas MD-11 travelling from New York City to Geneva, Switzerland, crashed into the Atlantic Ocean southwest of Halifax International Airport and the island of Nova Scotia. All 229 people on board died--the highest-ever death toll involving a McDonnell Douglas MD-11. The Canadian Transportation Safety Board (TSB) investigation concluded that flammable material used in the aircraft's avionics wiring assemblies allowed a fire to spread beyond the control of the crew, resulting in the loss of the aircraft.

Figure 1: MD-11 aircraft similar to SR 111.

BACKGROUND

Upgraded Aircraft

The McDonnell Douglas MD-11, structurally based on the company's DC-10 design, was significantly upgraded for more economical and efficient operation via automation using avionics. For example, the redesign automated most of the functions that were performed by the flight engineer in the DC-10, thereby allowing for a two-crew cockpit.

Swissair received delivery of the mishap MD-11 in 1991, adding in 1996 an ambitious In-Flight Entertainment Network (IFEN) for the passengers. Marketed by a small Las Vegas-based supplier and rushed through FAA approval and installation, IFEN combined computer, video, and audio technologies to allow passengers to select movies, audio, games, news, gambling, and a moving map through an interactive seat video display.

WHAT HAPPENED?

The Crash

SR 111 departed from New York at 9:18 PM Atlantic time on September 2, 1998 with two pilots, 12 flight attendants, and 215 passengers on board. At 10:10 PM, the Captain and the First Officer detected an unusual odor, then visible smoke in the cockpit. A flight attendant confirmed the smell in the cockpit, noting no such odor aft in the cabin. Immediately, the Captain asked if the source could be the air conditioning system, and the First Officer concurred. Crews had experienced this scenario before, without fire or critical system effects. Having made this assessment, the pilots' actions became deliberate rather than immediate; they remained unaware that an electrical fire raged in the small avionics space above and behind them.

While smoke increased in the cockpit, the crew informed local air traffic control of an urgent (but not immediate) problem, requesting clearance to familiar Boston Logan International Airport, nearly 300 miles away.

Controllers instead offered the crew a heading to the much closer Halifax International Airport in Nova Scotia, only 60 miles away. Now five minutes since detecting smoke, the pilots agreed. Donning oxygen masks against increasing smoke, the pilots began their descent from 33,000 feet to 21,000 feet. The First Officer was at the controls while the Captain would finally begin to work through the Swissair emergency checklist for smoke in the cockpit.

Swissair Flight 111 crashes after a fire ignites in the cockpit attic

Proximate Causes:

- Fire ignited from wiring arc and spread quickly via flammable materials above cockpit
- Detection relied on crew experience; fire became uncontrollable
- Uncontrolled fire caused critical systems failures

Underlying Issues:

- Aircraft Certification Standards allowed flammable materials use in unprotected area
- No regulatory requirement for fire detection/suppression in hazardous area
- Flammability test criteria not stringent enough
- No requirement for integrated in-flight firefighting plan

Figure 2: Actual SR 111 flight path.

The TSB report concluded that the fire grew faster than the crew could have made a safe landing at Halifax, regardless of flying or firefighting actions. Securing non-essential electric power per the emergency checklist thirteen minutes after smoke discovery resulted in much worse smoke, followed by loss of essential flight instruments. This left the crew disoriented, blind, and lost, circling South of Halifax to descend and dump fuel for landing. Declaring an emergency at 10:25 PM, SR 111 received emergency Halifax landing clearance. Controllers heard nothing more from the crew. Six minutes later, seismographic recorders in Halifax recorded aircraft-ocean impact as a seismic event. Only twenty-one minutes elapsed since the pilots first noted the unusual odor.

Proximate Cause

Full results of the very difficult TSB investigation were not made public until 2003. TSB Investigators found an initiating wire arcing event occurred near the In-Flight Entertainment Network power supply unit cable (Figure 3), and easily ignited the flammable insulation blankets in the attic above the cockpit.

The pilots' initial diagnosis of an unusual odor placed it as a benign air conditioning issue. Once the pilots realized that the smoky odor accompanied actual smoke, they declared an urgent situation and requested to land; however, by the time it took them to reroute and land the plane, subsequent systems failures made safe landing at Halifax impossible.

Systems Failures

In an arcing event such as the TSB found, vaporized copper expands to many thousands of times its formerly solid volume, generating enough heat and pressure to easily ignite nearby flammable materials. Airflow in the area was provided by an air conditioning system fan, and smoke mixed in with the airflow from the cockpit air diffusers. The fire was also likely exacerbated by a failure in the crew oxygen system. This failure not only allowed pure oxygen to fuel the flames in the cockpit attic, but also stopped the flow of oxygen to the pilots' oxygen masks.

Though regulations did call for several fire extinguishers to be present on the aircraft, recovery of these extinguishers could not determine whether any had actually been used. Investigators determined the cockpit overhead material was likely melting at ocean impact due to heat.

As noxious smoke and combustion by-products filled the cockpit, the pilots would have had a difficult time seeing their primary flight instruments, their most reliable cues for stabilized flight. As they turned off non-essential electric power in an attempt to isolate a potential fire source, autopilot was lost. When the pilots lost power to their primary flight instruments due to the fire's progress, their remaining standby instruments' positioning and small size would have made them difficult for the pilots to scan and fly with, even without smoke buildup.

Underlying Issues

Inadequate Aircraft Certification Standards

At the time the MD-11 aircraft were being manufactured, FAA aircraft certification standards for material flammability allowed the use of materials that could be ignited and also sustain or spread a fire. TSB investigators found that certification testing procedures mandated under flammability standards were not sufficiently stringent or comprehensive to adequately represent the full range of potential ignition sources. Nor did the testing procedures replicate the behavior of the materials when installed in combination, or in various locations and orientations, as they are found in typical aircraft installations.

Testing, both prior to and after the incident, showed that metallized polyethylene terephthalate (MPET)[1] covered

Figure 3: Recovered IFEN Cable segment with area of melted copper, indicating an arcing event occurred.

1 PET material is commonly known as Mylar, and may either be metallized or non-metallized.

insulation blankets, installed near the IFEN, were flammable. Investigators believe these blankets were the first to ignite, and that they were also responsible for the subsequent kindling and spread of the fire. Additionally, the hooks, fasteners, and tape around the blankets were found to be combustible contributors to the flames. The TSB report labeled the presence of these flammable materials as the most significant deficiency in the chain of events that ultimately led to the crash.

Aircraft crews were also generally unaware that materials like the flammable MPET blankets were used behind the lining of the interior cockpit. As a result, the pilots did not possess enough system knowledge to diagnose and act upon the actual fire scenario.

Inadequate Fire Detection

The mishap aircraft met existing aircraft regulatory requirements and was consistent with industry standards of the time for smoke and fire detection. One such industry standard was the separation of the plane into three separate fire zone categories (Figure 4): Designated Fire Zones (engines, auxiliary power unit), Potential Fire Zones (cargo compartments, lavatories) and Non-Specified Fire Zones (everything else). Because Designated Fire Zones and Potential Fire Zones have potential ignition sources and flammable materials, they are equipped with built-in fire detection and suppression capabilities. The remaining Non-Specified Fire Zones, such as the cockpit and the “attic” area above the cockpit, were solely dependent upon human intervention for both detection and suppression of an in-flight fire.

Although flammable materials existed in the Non-Specified Fire Zones, the potential for ignition was considered minimal. There was no recognized need to train aircraft crews for firefighting in places other than the interior cabin areas, or to design aircraft to allow for quick and easy access to hidden or enclosed spaces.

Flawed Emergency Fire Plan

At the time of the crash, there was an expectation within the commercial aviation community that an unknown source of odors or smoke inside the aircraft pressure vessel would be discovered quickly, and that proven actions taken to rapidly isolate historic sources would extinguish a fire. Though regulations supplied the pilots with a checklist to follow when smoke was detected, the current configuration of upgraded systems in the aircraft was not considered, nor was the aircraft as a whole. The pilots had to rely on sight and smell alone to detect odor and smoke from unknown sources. This reliance resulted in the misidentification of the initial odor as smoke originating from an air conditioning source. This in turn influenced the crew to spend precious minutes performing navigation and communication tasks that would ultimately prove futile.

Aftermath

From the 1970’s up until the SR 111 fire and crash, rules and regulations concerning fire safety had concentrated on the cabin and other zones with historic fire-hazard risks—but not the cockpit. Although the MPET insulation blankets were not allowed for use in other areas of the aircraft, their use in the cockpit was acceptable. Since the crash of SR 111, regulations have been revised to forbid the use of these blankets. Stricter tests and guidelines for the use of all materials onboard commercial aircraft have also been implemented. Swissair disabled and eventually removed the in-flight entertainment network from its commercial aircraft.

Regulations governing commercial operators’ Smoke/Fumes of Unknown Origin procedures have also been changed so that, when smoke is detected either by sight or smell, the appropriate action is to immediately land at the nearest suitable airport. Actions must be initiated and the procedure managed within an appropriate time limit. Accessibility to all parts of the aircraft pressure vessel is now mandated so the crew can gain access to put out fires as needed. Operators’ policies and training procedures have been revisited to better educate flight crews about potential risks involving smoke and fire hazards.

This incident brought another issue to the forefront of the aviation community: the use of polyimide insulation on aircraft wiring. Although known for its resistance to abrasion and fire, polyimide insulated wiring has less resistance to arc tracking than other insulation types. The US Navy came to this conclusion in 1987, and immediately ordered

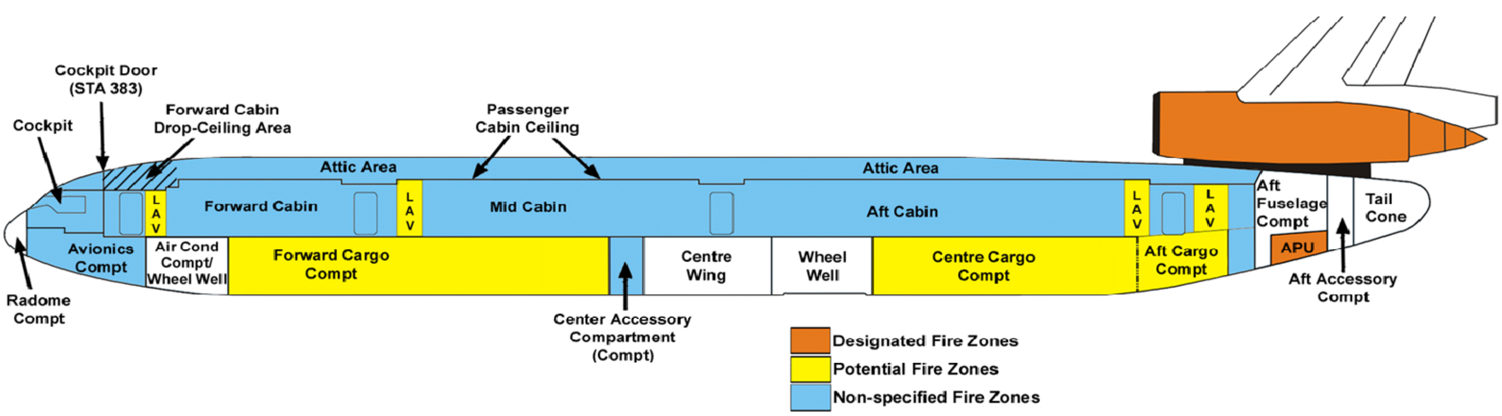

Figure 4: Diagram of MD-11 Fire Zone Designations

the removal of this vulnerable wiring from all of its planes. Similarly, NASA found that a wiring fault tied to polyimide insulation led to an in-flight anomaly shortly after the take off of STS-93. As a result, new international standards to separate and/or protect dissimilar insulation materials from abrasion have come into use.

For Future NASA Missions

When many factors conspire to defeat the large safety margin afforded by time-tested standards, extensive government oversight controls, a commercial aircraft and expert crew, we can readily perceive much smaller margins available to NASA and future commercial space hardware builders and operators. Sheer consideration of mass, propulsion and other limitations within a totally unforgiving environment implies that safety cannot simply be designed and built in; it must synchronize to changes in the system, and be created at the pointy end by the operators on a pre-emptive and reactive level.

Human-rating of commercial space hardware during an epoch when NASA is itself designing and building new launch systems and spacecraft is an effort that will require diligent effort to apply wisdom—be it the hands-on experience of a few engineers or an aviation lesson from decades past. Deciding upon a set of essential safety requirements applicable across industrial and national borders, while incredibly challenging, may be less difficult than verifying the effective and reliable application of those requirements versus the twin forces of economic efficiency and proprietary innovation. Achieving such verification will come down to earthbound humans exercising skills of diligence and vigilance, governed by core values of teamwork and integrity. They will create safety and mission success as a result.

Figure 5: Memorial dedicated to Swissair 111, near Peggy's Cove, Nova Scotia

Questions for Discussion

- Do your design and sustainment requirements address historic failure modes, or include new ones as the system evolves?
- What risk assumptions underpin your testing scope? Have they evolved as the system has changed?
- What cues do your operators have for time-critical problems? Do their decision priorities stem from system/environment knowledge or past success?
- What material selection hazards exist versus all credible energy transfer modes in the current system? What choice is the best trade?

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