National Aeronautics and Space Administration

System Failure Case Studies

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FORRESTAL IN FLAMES

On July 29, 1967, a tragic string of events culminated in disaster on the flight deck of the USS Forrestal resulting in the deaths of 134 sailors. As twenty-seven, fully armed combat aircraft were on deck in preparation for a bombing mission over North Vietnam, a wing mounted Zuni rocket was inadvertently launched from an F-4 Phantom. The rocket flew across the flight deck and penetrated an externally mounted fuel tank of an A-4 Skyhawk, flooding the deck with hundreds of gallons of jet fuel which quickly ignited. The fire engulfed the aircraft and spread quickly, fanned by 32 knot winds. One minute and 34 seconds later, one of that same Skyhawk's 1000 pound bombs "cooked off," with an explosion that sent shrapnel, flame, and destruction across the flight deck, wiping out the fire fighting crew, and wreaked havoc below deck. Over the next hour, eight more 1000 pound bombs exploded, each time taking the lives of another valiant team of sailors fighting the blaze. The ship was able to return to Subic Bay, Philippines, but fires continued below deck for over 24 hours.

BACKGROUND: USS FORRESTAL

The USS Forrestal, christened and launched in Newport News, Virginia in December 1954, was the super-carrier of its time. Forrestal was the first ship designed specifically to handle jet-powered aircraft and incorporated the very best technology of the 1950's.

Captain John Beling, a decorated combat veteran of World War II, took command of Forrestal in May 1966. In June of the following year, Forrestal left Norfolk, Virginia with over 5,000 enlisted men and officers, en-route to an area in the South China Sea, off the coast of North Vietnam, called Yankee Station. This would provide the base of operations for air strikes on targets in North Vietnam. During the voyage, a great deal of attention, drilling, and training was devoted to fire prevention and firefighting. Captain Beling even distributed a "case study" of the 1966 fire aboard the aircraft carrier Oriskany (involving magnesium flares) that took the lives of 44 enlisted men and officers.

Weapons Carrier Design: The triple ejector rack (TER) served as a mechanism to launch rockets mounted in pods underneath the wings of fighter and attack aircraft. The TER was designed with two independent safe and arm systems. First was the "pigtail" plug that had to be in place for electrical signals from the cockpit to reach the launcher element within each TER. Operational procedures stated that "the pigtail connector shall not be plugged in to the receptacle until just before takeoff," typically while seated on the catapult with a clear field of fire. The second safeguard was the TER electrical-safety

Deck of the Forrestal engulfed in flames July 29, 1967.

Forrestal in Flames:

134 dead, 161 injured.

Proximate Cause:

- Power surge in F-4 Phantom triggered launch of Zuni rocket while Phantom was parked on deck

Underlying Issues:

- Zuni rocket launcher design flaws
- Combat time pressures resulting in waivers and on-the-fly procedural changes
- Miscommunication of and lack of command line involvement in procedural changes
- Dangerously unstable ordnance
- Insufficient firefighting training and infrastructure

pin or TER-pin. This pin mechanically opened all firing circuits in the launcher, and procedures called for it to be removed immediately before takeoff. The two-fold safety controls were consistent with standard safety philosophy.

Safety Board and Safeguards: On June 29, 1967, on the way to Vietnam, Forrestal's Weapons Coordination Board (WCB) approved a waiver to the requirement concerning pigtail connectors, allowing insertion of the pigtail while the aircraft was parked on the aft flight deck as an operational time saving measure. The WCB logic was that this shortcut was acceptable because the TER-pins were in place until launch. The WCB decision was never forwarded to higher authority for review, as was called for in standard operating procedures.

Every Sailor (must be) a Fire-fighter. Every engineer, a safety engineer.

Additional Time-Saving Initiatives: Unfortunately, flight maintenance crews for certain squadrons, driven by the acknowledged need to save time, had, on their own volition, made similar informal determinations concerning the TER-pin. They reasoned that early removal of the TER-pin would save time and was supported by the logic that the pigtails would be in place until launch. This breach of process discipline went undetected by first-line supervisors at the time.

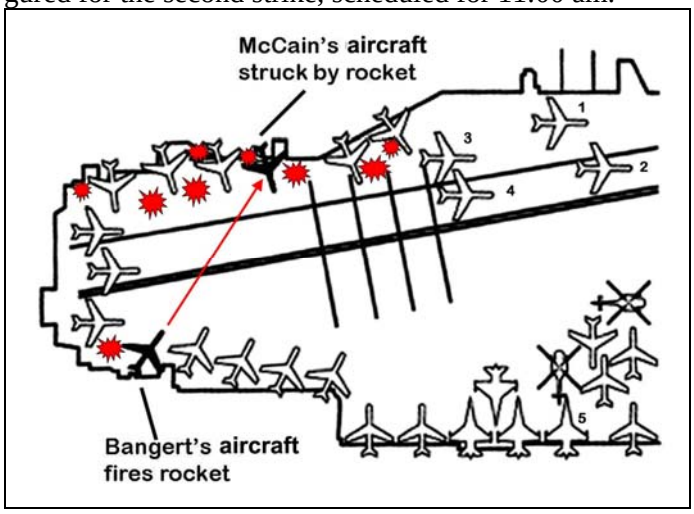
Forrestal crew fights to quell the raging jet-fuel fires.

Ordnance Supply and Management: On the evening of Friday, July 28, 1967 the Forrestal accepted a load of dangerous 1000 pound "B"-bombs, some manufactured as early as 1935, rusty, poorly stored and maintained, and notoriously sensitive to heat and impact. The Forrestal was used to using the newer H-6 model, designed to withstand high heat and vibration. Captain Beling had protested but was told that no alternative ordnance was available. It was the B-bombs or nothing. Pressed to launch air strikes the next morning as part of the major US air offensive, the Captain reluctantly accepted the weapons.

What Happened?

The Accident

The next morning, the Forrestal launched the first strike of 37 aircraft between 7:00 am and 7:50 am. The strike force returned by mid morning. and the deck was reconfigured for the second strike, scheduled for 11:00 am.



Arrangement of aircraft at the time of the rocket misfire.

By 10:51 am, all of the 27 aircraft assigned to the strike were manned and engaged in pre-flight checks, with some beginning to start their engines. Pilot Jim Bangert was in the cockpit of his F-4 Phantom. He had started his starboard engine providing internal power and was prepared to switch from the tractor external power supply. His ground crew had just inserted the pigtails in accordance with the waiver procedures (and under the assumption the TER-pin was still in), effectively arming the six and-a-half foot long, five inch diameter Zuni rockets.

At 10:51:21, he hit the power cutover switch, and one of his Zuni rockets blazed across the deck, chest high, severely burning members of Bangert's ground crew, severing a man's arm on its way across the deck and ripping open a loaded fuel tank of an A-4 Skyhawk (piloted by John McCain, now US Senator from Arizona). Hundreds of gallons of JP-5 fuel spewed onto the flight deck and ignited directly beneath the wing mounted 1000 pound B-bomb payload. One minute and 34 seconds later, the B-bomb exploded.

The initial blast killed five of the eight members of Damage Control Team #8, specifically trained for flight deck firefighting. The other three were severely injured. Twenty-two others died in the initial blast. Lt. McCain had successfully egressed his burning aircraft and was en-route to the island when the bomb went off. He was hit by several pieces of shrapnel, but his wounds were minor. In the next half hour, eight more 1000 pound B-bombs exploded with horrific effect. Before the fires were under

control, a total of 134 men were killed and 161 injured. Over 20 aircraft were lost.

Proximate Cause

Attempting to change-over his F-4 Phantom to internal power, Pilot Jim Bangert hit the power cutover switch which, due to an electrical relay design deficiency, initiated a power surge to his Zuni rocket launcher. Independently and without each other's knowledge, the WCB and maintenance crews had compromised both redundant ordnance launch prevention systems – insertion of the pigtail and removal of the TER-pin – by performing those functions significantly before take-off, allowing the not-uncommon power surge to cause the Zuni rocket to fire.

Underlying Issues

This system failure was the result of multiple factors which included design deficiencies (frequent and unexplained power-on surge during aircraft change-over from a start-up power cart to internal power), intentional and unintentional lowering of safety barriers, unrecognized lapse in process discipline, and hazardous ordnance.

Zuni Launcher Design Issues: Captain Beling questioned the intrinsic design safety of the LAU-10 safety and ignition system (which included the pigtail and TER-pin). His testimony before the investigation board stated, "It is evident that Forrestal's ordnance personnel never had a safe system to work with and never had the technical information needed to design prudent, sailor-proof rocket loading and arming procedures." It was noted that only two months earlier (May 1967) a Zuni rocket misfired from an F-8A Crusader sitting on the deck of the carrier Hancock. Fortunately, the rocket missed personnel and other aircraft; the exact cause of the misfire is still unknown.

Operational Time Pressures Driving Official and Unofficial Changes in Safety Procedures: The official WCB decision to allow early insertion of pigtails to save time in an operational war fighting scenario removed the first critical barrier to disaster. The unofficial practice of removing TER-pins prior to the last minute effectively removed the second critical safety barrier. First line supervisors with certain squadrons were either unaware or participating in practices which deviated from safety requirements, specifically, removing TER-pins prior to take-off position.

Safety Management Communication & Leadership: The lack of line management (command) visibility into and involvement with the WCB process as well as oversight of operational crew practices was also a contributing factor. The accountability concern extends to all management levels within both sea and air wing chains of command.

Hazardous Ordnance: The time pressures to support the 1967 air offensive coupled with logistical supply issues resulted in Navy upper management decisions to use obsolete weapons that had been stored in open-air sheds in the Philippines since the end of World War II. Some of the bombs were in crates labeled 1935.

Half the ship's crew and none of the Air Wing crew had attended firefighting school.

Inadequate Firefighter Training, Infrastructure & Equipment: Despite Captain Beling's efforts to accelerate firefighting training in the year before deployment, many of the crew remained untrained, especially in jet-fuel fires. With Damage Control Team #8 decimated, untrained sailors valiantly fought jet-fuel fires with water hoses (the wrong thing to do) rather than foam. Only half the ship's crew and none of the Air Wing crew had attended firefighting school in the previous three-year period. In addition, Air Wing sailors (40% of the Forrestal crew) were not trained to use an oxygen breathing apparatus and were not well oriented to Forrestal damage control processes and equipment. Numerous problems were also identified related to flight deck "foam station," design, operational readiness and training for foam station operators.

The crew continue to fight the blaze that killed 134 sailors.

Aftermath

The investigation board chaired by Admiral Massey issued a 7,500 page report which concluded that "the deaths and injuries resulting from the fire aboard the Forrestal on July 29, 1967 were caused by the negligence and inefficiency of the Headquarters, Naval Air Systems Command." At the same time, the report provided over 30 findings and recommendations addressing shortfalls in damage control process design and damage control equipment, as well as poor training and execution of damage control functions. The Chief of Naval Operations, Admiral Moorer, empanelled a follow up investigation into Navy-wide aircraft carrier safety led by retired

Admiral James Russell that concurred with the Massey report, as well as citing the need for better personal protective equipment.

Applicability to NASA

The belief in a redundant system that is in actuality compromised or ineffective is a tragic lesson that NASA learned during the Space Shuttle Challenger mishap. All can benefit from a reminder to never remove a safety critical barrier in a high-consequence environment without a full understanding of the status of remaining controls. Operating with one safeguard requires careful deliberation and approval by accountable management at appropriate levels as well as verification that the secondary barrier is, in fact, effective and has been implemented.

Another important thematic lesson involves the need to elevate safety critical waivers, deviations, or exceptions to senior management levels within organizations potentially affected by the departure from requirements. That is, leadership and management must implement processes that ensure their ongoing and real-time knowledge, understanding, and visibility into critical details of hazardous activities and operations.

USS Forrestal in action.

Design and test project teams are reminded of the need to understand hardware/software electro-mechanical system behavior in off-nominal and transient upset environments. The power change-over, believed to have been an initiating event, clearly was an operating environment in which the LAU-10 system should have been design-hardened to withstand power-on transients and verified through extensive testing. Understanding material properties, detonation hazards, and shelf-life characteristics is underscored by the use of B-bombs with unknown (only anecdotal) properties, manufacturing and storage history. The case further instructs teams to maintain focus on configuration management and record keeping for pyrotechnics, propellants, batteries, pressure vessels, and other hazardous materials and systems. What are the shelf-life constraints? Does the hazard risk increase with time? Communication, training, and safety leadership are also resonant themes for NASA.

Questions for Discussion

- Why was the Zuni rocket launch system not immediately placed in a "hold – do not use status" until the May 1967 Hancock inadvertent firing was understood and corrected? Was it the demands and/or constraints of war? Or failure to fully understand the consequences?
- What approaches are you using to verify hazard controls in safety critical systems you employ? How do you ensure reliance on redundant systems doesn't cause complacency?
- How can NASA prevent the evolution of "informal waivering" of safety requirements in the interest of expediency?
- Any waiver, even an official waiver, can increase risk. What steps does your group take to understand and mitigate risks resulting from requirements waivers? Are these waivers and their acceptance rationale revisited on a routine basis?

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