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This report evaluates the results of a five year study of fire indications onboard army aircraft. Specifically it evaluates the aircraft fire detection systems. The overall conclusion drawn from the report is that the fire detection systems are unreliable and do not meet the intent of the applicable specifications governing such devices.

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**ARMY
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FIRE-DETECTION
SYSTEMS
OPERATION
AND RELIABILITY**

This report evaluates the results of a July 1993 study of fire indications on board Army aircraft. Although the focus was the aircraft fire-detection system, other areas involving "potential" fire, such as smoke and sparks, were included and evaluated.

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Introduction

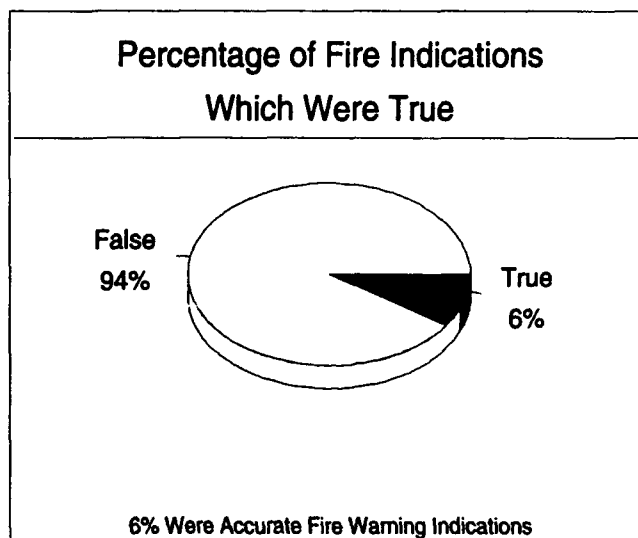
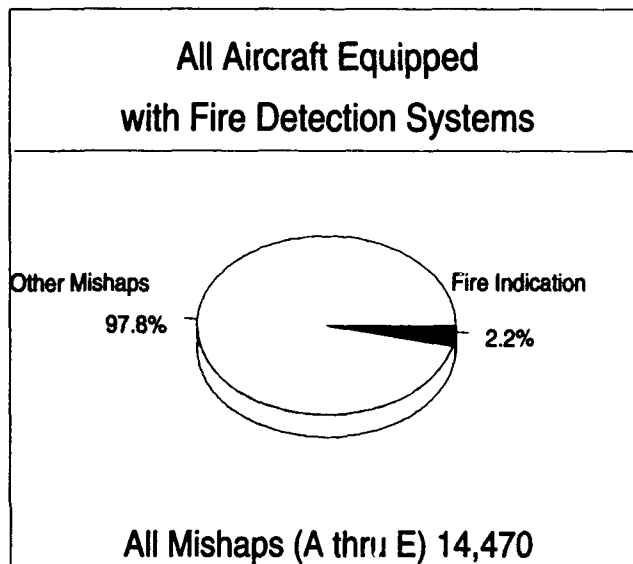
A July 1993 study examined indications of fire on board Army aircraft equipped with fire-detection systems. The study included fiscal years 1988 through 1992 (5 years) and examined 14,470 Class A through Class E mishaps. It should be noted that 14,440 of these were Class E mishaps, most of which were precautionary landings (actions attributed to good judgment).

Indications of fire included smoke in the cockpit, smoke emanating from an engine or auxiliary power unit compartment/bay, shorting, fuel vapors, excessive heat, explosions not associated with impacts, and fire warning indications (fire lights). Not included in the assessment were fires resulting from impacts, smoke and flames emanating from the exhaust stacks, or activation of warning systems by the sun or other illumination.

During the study, there were a total of 331 mishaps relating to fire indications, representing about 2 percent of all mishaps. Of these, 129 were caused from fire warning indications. Of the 129 indications of fire via the fire warning system, 94 percent were false.

This report examines each particular fire-warning-equipped aircraft, the reasons for such a high false-alarm rate, and other causes of fire indications on board Army aircraft.

Readers may ask the significance of smoke and why it is considered part of the study. Smoke and/or fumes (plastic or otherwise) can create a disabling environment (physiological or psychological) to crew members. In addition, failure to turn off, take off line, or shut down the affected item can result in fire. To highlight the consequences of smoke, consider a flight that occurred in Germany on 1 December 1988.



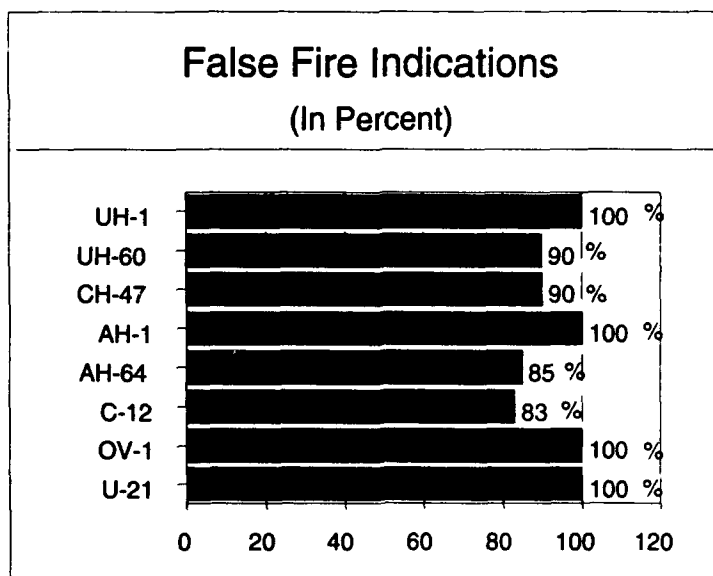
The crew of a Cobra AH-1F was on a night cross-country training flight with the IP in the front (gunners station and on the controls) and the pilot in the back seat. After less than 40 minutes into the flight, they inadvertently went IMC (at night) and contacted the appropriate controlling agency. Shortly after encountering IMC conditions, the crew detected smoke in the cockpit, and shortly after that, the gunners instrument lights went out. The IP passed the controls to the other pilot while he retrieved his flashlight so that he could assume navigation duties, while continuing the conversation with the controlling facility. When he turned on the flashlight, the IP noted their attitude indicator showed a right 40-degree bank and a 7- to 10-degree nose-down attitude.

Before continuing, the reader should consider the following: This crew was flying at night, they went IFR (not a normal mode of flight for most helicopter pilots), there was a short, the lights went out, and the attitude indicator was - - - ? Most of us would consider the attitude indicator as incorrect based on some fairly reliable data (i.e., short, lights out). As it was, the IP made a quick scan of his emergency instruments and realized the indicator was correct. The other pilot had vertigo. The IP took the controls, was given guidance to his airbase, and broke out VFR during the let-down.

As one can readily see, it's not the actual single failure, but the composition of a situation that is the problem—in this case, night, IMC, an electrical short, failed lights, instrument indications, and incapacitation. To effectively manage this, we rely on technology resulting in confidence in our systems. But sometimes that confidence is ill-placed. Take fire-detection systems for instance.

Regarding the exceptionally high false-alarm rate, one wonders if the crew's view of the fire warning light's importance is diluted. Indeed, most pilots in this study (when faced with a warning light or other fire indication) landed as soon as possible. Apache and Chinook pilots (100%) landed as soon as possible regardless of in-flight diagnosis. However, UH-1 and UH-60 pilots were not so inclined. Two UH-1 pilots elected to continue flight for a 5- to 10-minute period (one to reach his destination), and one UH-60 pilot flew to his destination (5 to 10 minutes) with his fire light illuminated. Unfortunately, the Blackhawk pilot had a leaking fuel line, which was misting and subsequently flashing into a small, localized fire.

This study contains an explanation of various systems, some recommendations, and an analysis of each aircraft.



Overview of Systems

Army rotary and fixed wing aircraft have two primary fire-detection systems available: optical detectors and heat-sensing elements. The UH-1, AH-1, OV-1, and CH-47 have heat-sensing elements (commonly called "firewire"), while the UH-60, C-12, and U-21 have optical sensors. The AH-64 uses both. The system on the Comanche is not set.

Optical Detectors

In Army aircraft, optical detectors are placed strategically to view specific pieces of equipment subject to fire. The UH-60's engine is protected by two detectors, while its APU has one. Optical detectors base their operation on wavelengths of light emitted by a fire. A fire generates a hydrocarbon spike at the 4.3-micrometer wavelength. In the case of Army aircraft, we use detectors that see both visible light and the infrared spectrum, which is why red flashlights or the sun can trigger the detectors. Optimally, the detector should see infrared radiation at the 4.3-micrometer wavelength. However, the optical detectors installed in Army aircraft see more light in the visible spectrum and are also affected by aging. These detectors are of a design from the late 1950's, and that design is installed today on all Army aircraft that use optical detection devices.

According to the military specification, MIL-F-23447, a detector shall activate within 5 seconds after seeing a flame. This is based on a test flame. A test flame is conducted using JP-4 or 100-octane fuel in a flat pan having an inside diameter of 5 inches and a depth of 3 inches. The detector must see the flame within 5 seconds from a distance of 48 inches.

Sensing Elements

A second method of detecting fires is the use of sensing elements found in UH-1, AH-1, CH-47, AH-64, and OV-1 aircraft. These elements are either long flexible hollow pressurized tubes or wires made of an outer tube and a center wire or "core." Heat sensors or continuous thermal detectors (wire) in the Huey, Cobra, Chinook, and Apache work on various principles. One element manufactured by Fenwal Aerospace has a solid nickel conductor insulated with a eutectic salt saturated porous ceramic material. This is encased in an Inconel tube. When the temperature increases, the impedance of the insulator decreases, setting off the alarm.

Walter Kidde uses a system consisting of an Inconel tube containing a ceramic-like thermistor in which two conductors are embedded. The thermistor electrical resistance changes between the conductors with temperature. Other systems such as those manufactured by Gravinier, HTL, and Edison employ methods using single cores encased in stainless steel, which measure resistance, capacitance, or a combination of both. However, most of these (e.g., Fenwal, Walter Kidde) can be tailored for a particular temperature.

Military specification MIL-F-7872C, requires that systems indicate a fire within 5 seconds after any 6-inch portion of the sensing element is exposed to 2000°F for 5 seconds or 1500°F for 10 seconds. If, for instance, the heat is removed, the capacitance or resistance normalizes and the fire-warning light will clear.

Another detector is the pneumatic detector. Pneumatic detectors, or tubes pressurized with a reference pressure, have a responder housing (such as Systron Donner systems) that reacts to pressure changing with temperature within its attached tube, whereupon a pre-set pressure threshold gate activates the system. Contrary to myth, pressurized systems are not affected by crushed tubes or pinching. The system is installed in the Apache transmission area and uses three elements, one for each transmission heat exchanger and one for the transmission support area. Additionally, the shaft-driven compressor is protected by an overheat sensor. This gives the Apache the most sophisticated hybrid fire-detection system of all Army aircraft.

Note: Both optical and wire detection ("firewire") systems are additionally required by their respective military specifications to "prevent" occurrences of false warnings (zero percent) resulting from flight operations, loose connections, damage to components, and inadequate maintenance. This is probably an unrealistic goal, but 94 percent is probably below expectations.

Findings and Recommendations

The following findings and recommendations are made based on the material contained within this report.

Finding 1

The installed fire detection systems on board Army aircraft provide FALSE fire warnings in over 90% percent of the system activations.

Recommendations

a. Implement actions to modify or replace existing fire-detection systems installed on Army aircraft. New systems, unlike those presently installed, should meet the requirements of both MIL-F-7872C and MIL-F-23447. This can be accomplished by—

(1) Replacing outdated flame detectors currently installed on the UH-60, AH-64, C-12, and U-21 with sensing wire (which use a minimum number of connections), pneumatic detectors, or new generation flame detectors.

(2) Replacing or modifying sense elements used on the AH-1, UH-1, and OV-1 with elements having a minimum number of connections, which account for over 15 percent of all false alarms.

b. The Army should ensure that fire-detection systems intended for use on developing aircraft (e.g., Comanche RAH-66) are representative of modern technology and not carryover hardware from the past (e.g., UH-60, C-12, and AH-64 flame detectors).

c. Require manufacturers of detection systems to warrant their product for greater periods against false alarms, and require performance standards to be met.

d. Develop a program for the CH-47 engine nacelle cowling installation. The cowlings account for over 70% of all CH-47 false alarms due to chaffing against the sense elements.

Finding 2

The pneumatic detectors installed on the AH-64 are poorly installed. The responders for each detector are not secured in place (as required by Military Specification) allowing unnecessary movement which results in potential failure.

Recommendation

Secure the responders using a smaller clamp (i.e., PN MS2133-12 or smaller).

System Evaluations

UH-1 Iriquois (Huey)

The UH-1 was evaluated for fire indications between fiscal years 1988 and 1992. During this period, the UH-1 had approximately 4,300 Class A through E mishaps; of these, 102 (2.3%) resulted from some form of fire indication. The 102 incidents can be broken down as follows:

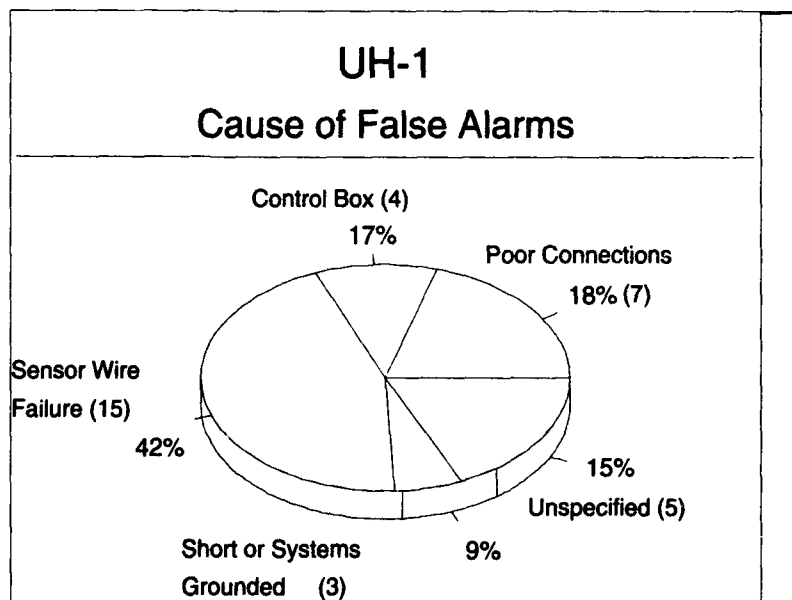
34	Fire warning activations	33%
18	Smoke (seen by the crew or ground crew) at or near the engine compartment	18%
10	Hot starts	10%
8	Shorts related to circuit-breaker switches or rheostats	8%
5	Failed windshield-wiper motors	5%
5	Smoke through the heat ducts	5%
5	Smoke in the transmission area from spilled oil or chaffing	5%
7	Failures (shorts) of instruments, inverters or relays	7%
5	Battery failures	5%
5	Unknown sources of electrical smoke	5%

Evaluating the major indications of fire, several areas stand out. These are fire-warning indications, smoke in or around the engine, hot starts, and windshield wipers. Of these, smoke in and around the engine compartment was the result of residual spilled oil. Of the hot starts, not enough data was available to properly address the issue. This left fire-warning indications and windshield-wiper failures.

The UH-1 fire-detection system is manufactured by Edison; it has two sensing elements, each 215 inches long. The elements have a single-wire core design, which changes resistance as the element is heated. The element is held in place along the cowling by clamps and is interconnected into the system using connectors/cannon-type plugs. In the 34 fire-warning-system activations, the UH-1 crews landed immediately (as required) in all but two cases. All indications were false. The 34 fire-warning activations could be broken down as shown in the chart below.

The data for fire-warning-light indications has remained generally constant for the past 5 years, accounting for about half of all fire indications.

Another area of interest is the windshield wipers, which (by actual numbers) accounted for only 5 percent of the total



fire indications. However, if one considers its extremely limited use (rain), the incidence of failure changes dramatically. This, coupled with the critical phases of flight (IFR on final, during takeoff, night operations) when required, can create problems in the cockpit until the failure is isolated to the wiper motor. *Military Specification, Motors, Direct Current, 28-Volt System, Aircraft, General Specification For*, dated 26 July 1965 and reviewed on 12 December 1987, states in paragraph 3.4.11 (Life of Motor): "The useful life of the motor shall not be less than 1,000 hours." A more realistic time would be years of installation on board the aircraft.

UH-60 Blackhawk

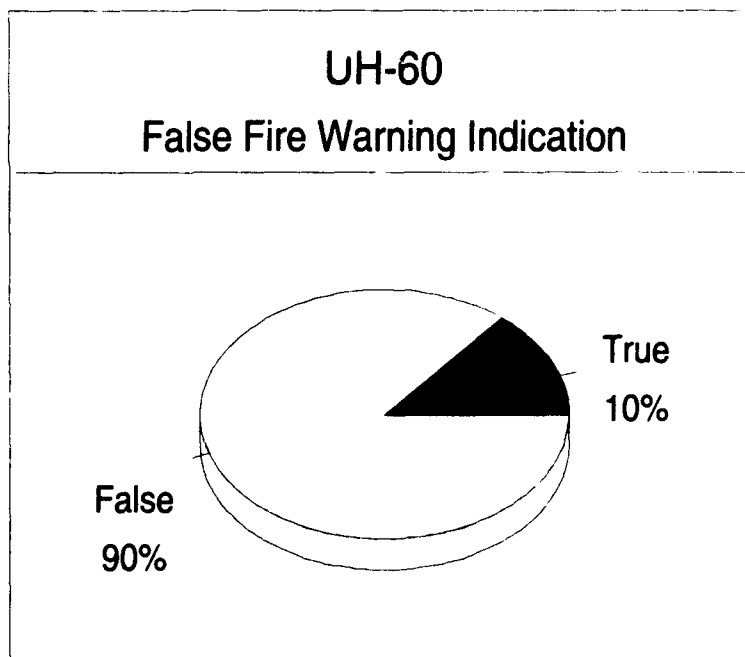
The UH-60 had a total of 2,709 Class A through Class E mishaps between 1988 and 1992 (inclusive). Of these, 86 (3%) resulted from fire indications. These were broken down as follows:

48	Fire-warning indications (engine and APU)	55%
9	Shorts related to overhead panels	10%
7	Compass failures that created smoke	8%
5	Visual indications of smoke from the APU	6%
5	Shorts related to radios or other instruments	7%
3	Overtemperature during engine starts requiring an emergency shutdown	4%
3	Failed starters or alternators	3%
3	Failed windshield-wiper motors	4%
1	APU fire that was not detected	1%
1	Failure related to the environmental control system	1%
1	Visual indication of smoke from the engine	1%

The three most numerous indications of fire were the fire-warning system activation, shorts related to the overhead panel, and compass failures.

The UH-60 fire detection system uses flame detectors manufactured by Pyrotector (since purchased by Walter Kidde). Each engine is protected by two detectors, and the APU compartment is protected by one. As previously mentioned, they operate on the premise of seeing infrared light.

Four (about 10 percent) of the 48 fire-warning-system activations were accurate. Therefore, the false-alarm rate was about 90 percent. Of the four accurately triggered fire-warning activations, one was for the auxiliary power unit (APU) and the other three were for the engine. In two of the three related to the engine, the cause was a leaking fuel line or fitting where vaporizing fuel flashed into a fire. However, due to convective air movement, the fires would self-extinguish and de-activate the fire-warning light. In one of the two cases, the crew landed as soon as possible commensurate with the fire warning annunciation emergency procedures. However, in the second case, the crew considered the light a probable false

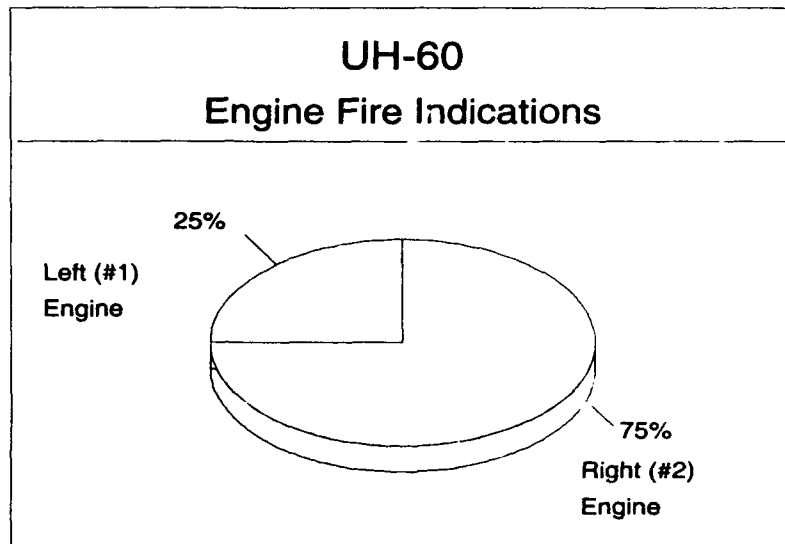


indication and continued flight another 10 minutes (the light annunciated on and off) until they reached their destination.

The causes of the fire indications could be broken down as shown in the chart below.

An assessment could not be drawn from shorts related to the overhead panel because part numbers and specific items of failure were not reported and the information referred only to the general area.

Compass failures accounted for 7 fire indications (8%) during flight and, although seemingly insignificant, in one case the pilot was executing an instrument approach during night IMC. Contending with a primary instrument at such a critical time can increase the crew's workload in several regards. Pilots must isolate the failure, execute the emergency procedure, and, while performing these tasks, fly the aircraft effectively. Weather conditions, illumination, crew rest, and training can adversely impact the crew's effectiveness.



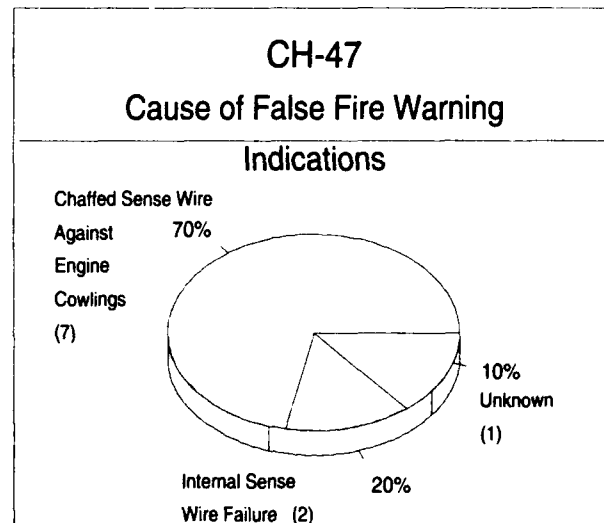
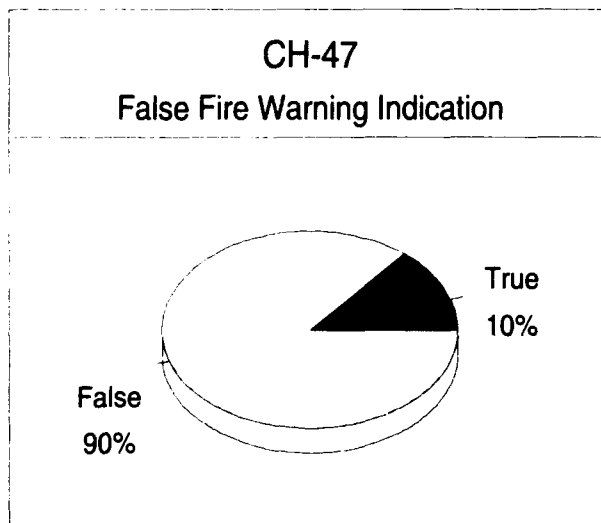
CH-47 Chinook

CH-47 cargo helicopter mishap experience was reviewed for fire indications for the 5-year period FY 1988 through 1992. During this time, 26 such indications represented about 2 percent of all Class A through E mishaps. The causes were as follows:

11	Fire warning activations	42%
3	Combining-gearbox problems	11%
4	Shorts resulting in smoke	15%
2	Smoke coming from the engine nacelle (smoke due to oil/oil lines)	8%
1	Heating system malfunction	5%
2	Smoke in cabin from unknown or unreported source	8%
3	Miscellaneous (1 starter, 1 fuel fumes, and 1 forward transmission)	11%

The CH-47 fire-detection system uses a sensing element manufactured by Fenwal. Each engine has three interconnected elements that are attached to the engine itself. The elements are of a core design whose ceramic-insulated center core resistance changes with heat. Of the 11 fire indications by the onboard system, only one was correct. The other 10 (about 90%) were false indications. The false indications resulted from the following:

7	Chaffed sense wire against engine cowlings	70%
2	Internal sense wire failure	20%
1	Unknown	10%



Seventy percent of the CH-47's high false alarm rate is easily affected by simple precautions (against chaffing) when the engine nacelles are closed.

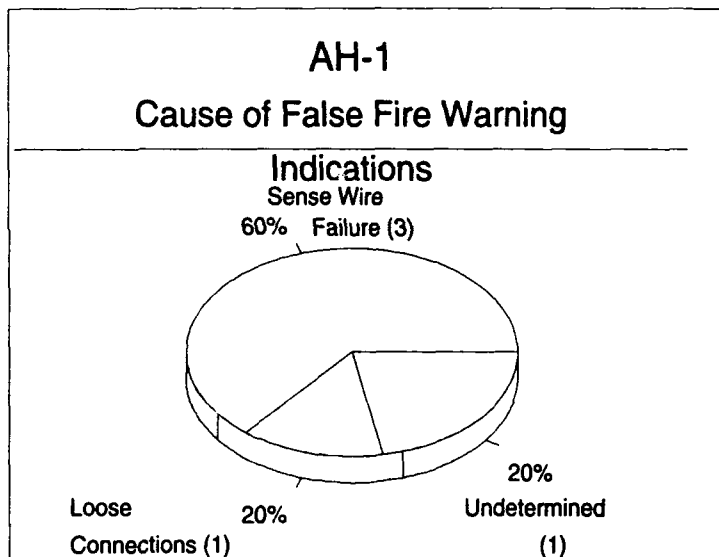
AH-1 Cobra

During FY 1988 through 1992, the AH-1 experienced 24 fire-related incidents, which accounted for less than 1 percent of the AH-1's 3,100 Class A through E mishaps. This is the lowest of all aircraft. The AH-1 sensing element is manufactured by Walter Kidde. The fire indications resulted from the following:

5	Fire warning system activations	20%
7	Starter/alternator failures	29%
4	Environmental control unit failures	16%
2	Shorts (unspecified)	9%
2	Radio failures	9%
4	Miscellaneous (2 smoke-external, 1 transmission-area smoke)	16%

All five activations of the fire-warning systems were false. Of these, 3 (60%) were caused from a wire (fire resistance wire) breakage, 1 (20%) was from a loose cannon plug, and 1 (20%) was undetermined.

Sixteen percent of all fire indications were the result of environmental control unit failures, all of which resulted in smoke in the cockpit. Attack aircraft rely on forced ventilation and their environmental control units. This makes environmental failure events more critical on an AH-1 aircraft than, say, a heater failure on a UH-1, which can be easily vented.



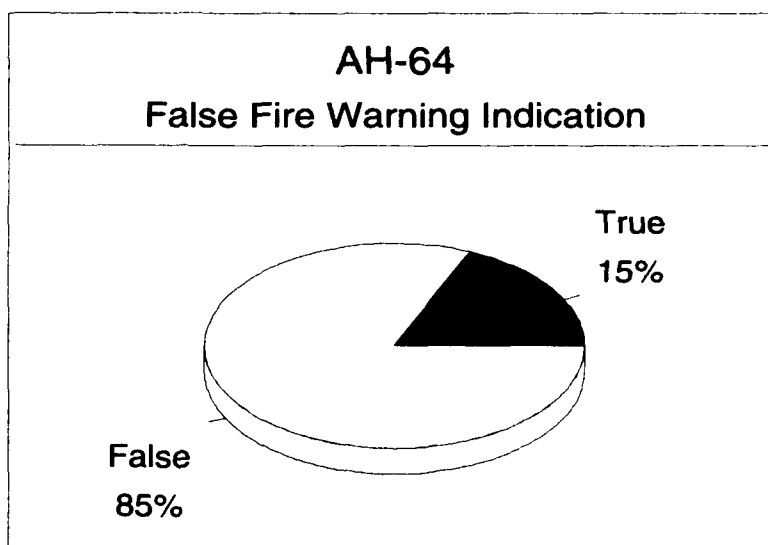
AH-64 Apache

Evaluated during the study were 3,014 Class A through E Apache mishaps. Of these, 99 (3%) related to fire indications. Compared to other aircraft, this figure is about 50 percent higher than the average, but not the highest, and considering its electrical systems, probably very good. The 99 fire-related events could be categorized as follows:

14	Fire warning activations	14%
28	Shaft-driven-compressor failures	29%
20	Environmental control unit failures	20%
13	Starters/alternators	13%
10	Shorts, circuit breakers	10%
10	Miscellaneous (3 turrets, 1 brakes, 1 hydraulics, 1 battery), 1 radio, 1 inverter, and 1 smoke, unknown source)	10%
3	Smoke events (from outside sources)	3%
1	Transmission overheat indication	1%

It should be noted that as a result of all 14 fire-warning indications, the Apache crews landed immediately (unlike the UH-1 and the UH-60). This predisposition is most likely related to the severity of fire consequences on board the AH-64.

The study concentrated on three areas: fire-warning activations, shaft-driven-compressor failure, and the environmental control unit (ENCU).



The Apache has by far the most complex fire-detection system. It uses optical infrared flame detectors, pneumatic overheat-detection elements, and an overheat sensor.

Flame detectors. The AH-64 uses two optical infrared flame detectors in each engine compartment and two in the APU compartment. These detectors are essentially the same as those on the UH-60 Blackhawk. Originally manufactured by Pyrotector, the detectors are now made by the Walter Kidde Aerospace Group. They sense (see) visible and infrared light.

Overheat detectors. The Apache's transmission area is protected by three pneumatic detector elements manufactured by Systron Donner. These detectors are considered highly reliable. One element or loop travels around the transmission and its mast support struts while the other two loops are attached to the left and right transmission heat exchangers. The detectors

use a hydrogen-charged core inside a pneumatic tube filled with a reference gas (usually helium). An increase in heat causes a pressure increase, which activates a switch located in a hemetrically integrated responder assembly. The entire element (loop and responder) is one piece, giving it the advantage (in theory) of minimal false indications due to poor connections, contamination, or moisture. However, in evaluating the Apache pneumatic detectors, it was discovered that at Fort Rucker's Hanchey Army Airfield alone, 44 such elements were replaced on a 130-aircraft fleet between July 1991 and July 1993. This replacement rate showed consistency over the last 12 months, indicating that problems (although not false alarms) continue to exist with the system. The problem was mounting hardware used by the Army.

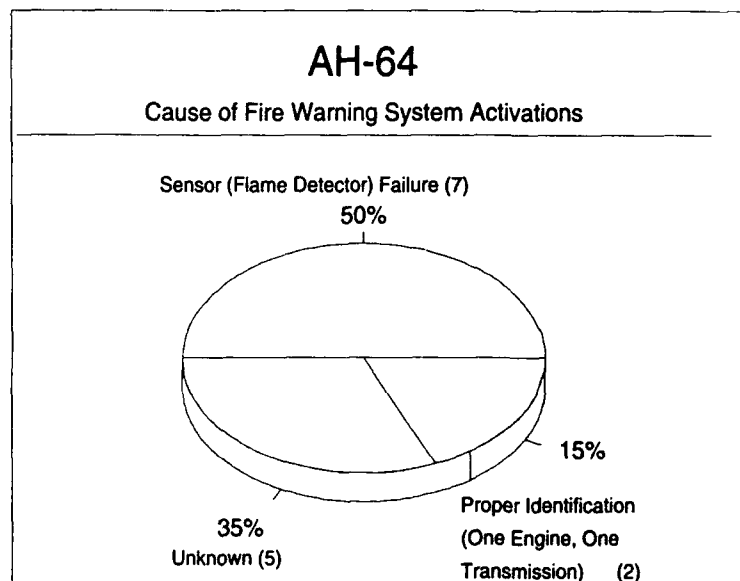
In evaluating the mounting hardware (installed on new production and used in a modification to install upgraded systems) for the Apache pneumatic detector, attention was brought to the hold-down clamp (part number MS21333-13) for the responder assembly of each detector. Ironically, they did not secure the responder assemblies and, in fact, allowed the responders to vibrate, oscillate, and move freely within a containment area. Specifications by the manufacturer, Systron Donner, call for the use of a "responder clamp." Unfortunately, the clamp used (MS21333-13) is simply too big and creates/promotes failure. Military Specification MIL-F-7872C (ASG), *Fire and Overheat Warning Systems, Continuous, Aircraft Test and Installation of*, dated 19 November 1966, with Amendment 1 dated 18 August 1980, and reviewed in September 1987, is specific in its requirements (paragraph 3.6.6, Support Clamps) for sensor security. The AH-64 does not meet that standard.

Overtemperature detector. The shaft-driven compressor (SDC) also has an overtemperature detector, which activates at about 350 degrees. When activated, it will illuminate the SDC annunciator. However, because it is parallel wired with the SDC pressure switch, the SDC fail light cannot be attributed to one symptom (pressure) or the other (heat).

In all SDC failures, the SDC light illuminated in 30 percent of the failures.

Of the 14 fire-warning activations from the fire-detection system, two fires were properly (system)

identified and one of those two properly extinguished. The AH-64 has the lowest false-alarm rate of helicopters—about 85 percent. Its breakdown is as follows:



7	Sensor (flame detector) failures	50%
5	Unknown (not reported) failures	35%
2	Proper identification (1 engine, 1 transmission)	15%

Another area reviewed was the shaft-driven compressor. The SDC provides pressurized air to the pressurized air system (PAS). The SDC is driven by the transmission accessory gearbox and has an input speed of over 12,000 rpm. Its single-stage compressor wheel turns in excess of 85,000 rpm.

The SDC fail light illuminated in 30 percent of all SDC failures. In 1993, the trend of SDC failures (which resulted in a fire indication to the crew) was about 25%, a slight increase over 1992.

However, the natural question arises as to how SDC failures have been progressing over the last 5 years (fire and nonfire related), and the table to the right breaks that down into the average time between failures of the shaft driven compressor.

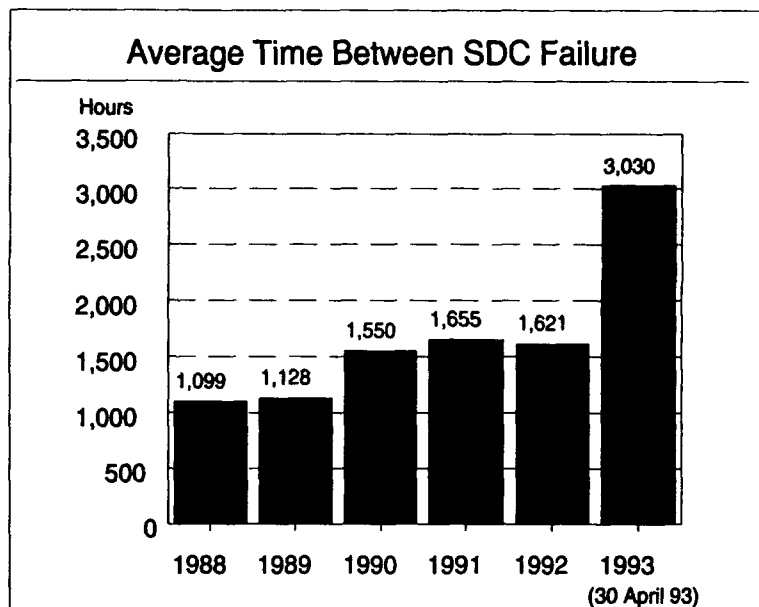
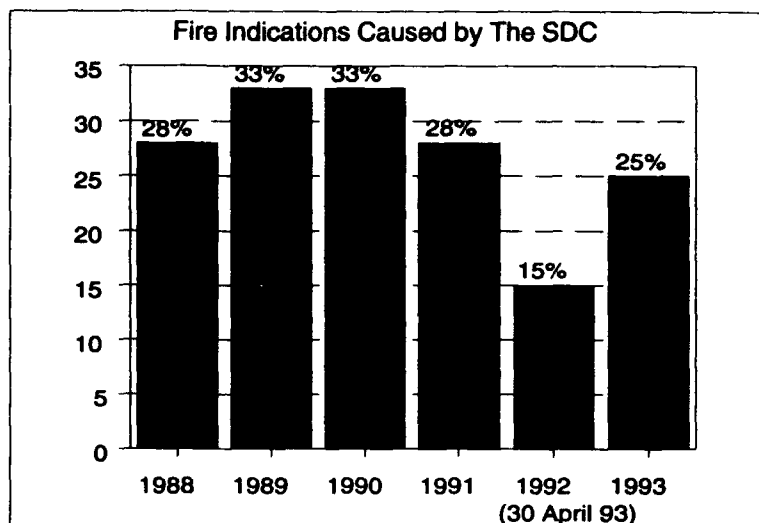
As one can see, the mean time between failure has increased almost three fold since 1988 and is attributable to recent modifications. It should be pointed out that according to unconfirmed information, the

Apache is available without the SDC. The Army has replaced an estimated 300 SDCs at a cost of over \$5.5 million during the last 5 years, and in 1993, we should spend about \$600,000 on them.

The last area explored was the AH-64 ENCU failures. Those accounted for 20 percent of all failures during the 5-year period and on a yearly basis accounted for the following total of all fire indications:

1988	1989	1990	1991	1992
20%	5%	30%	21%	24%

The ENCU failures indicate a general leveling over the years with the primary cause of failure stemming from internal turbine cooling fan failure in about 50 percent of the cases. On initial



review of the ENCU, one does not appreciate the criticalness of its failure until the cockpit fills with smoke through the vents. In several cases, pilots had to be evacuated after landing for treatment of smoke inhalation. In three cases the crews were tested for toxic effects of the smoke.

Finally, and on a side note of all shorting events, the heating blanket (for the nose gearbox) accounted for 40 percent of all shorts.

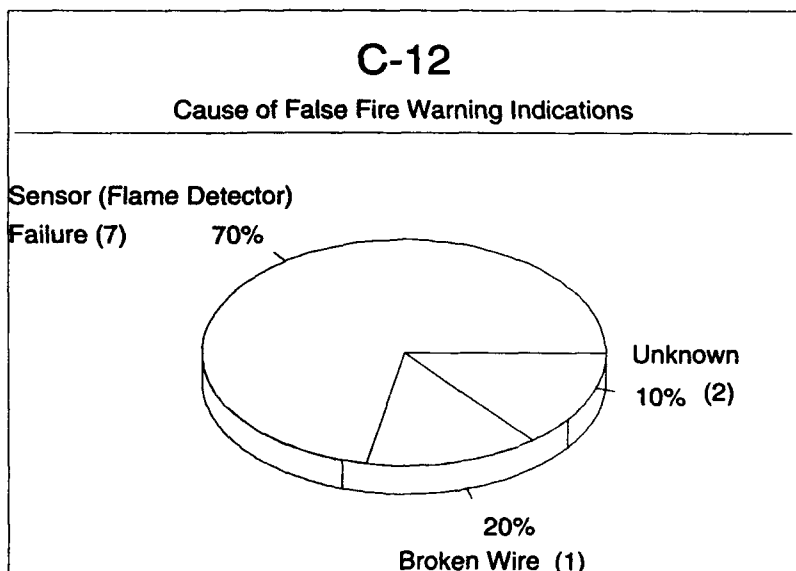
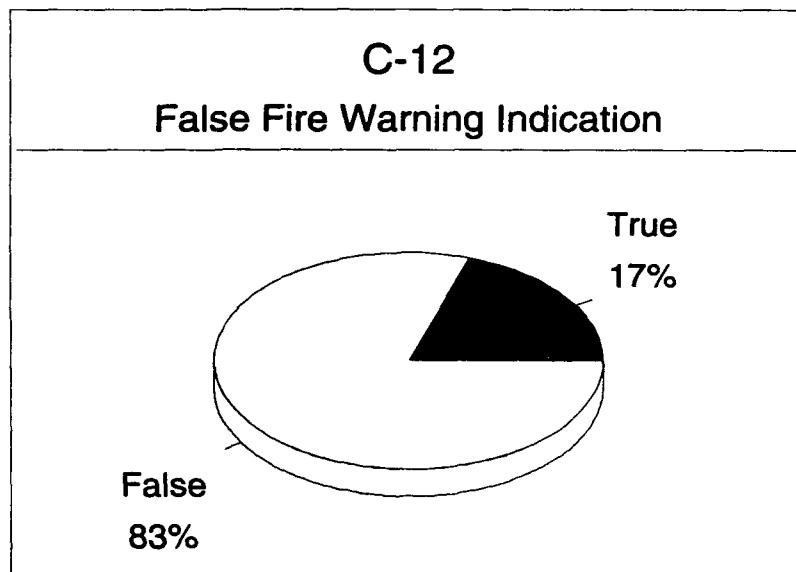
C-12

During the 5-year study period, Army C-12 crews were alerted to 27 indications of fire. During this same period, the C-12 had a total of 610 Class A through E mishaps, making fire indications more than 4 percent of all C-12 mishaps, the highest of all aircraft. Of the 27 fire indications, the actual breakdown is as follows:

12	Fire warning system activations	44%
4	Smoke (oil in the engine compartment)	15%
4	Forward blower motor failures	15%
4	Shorts (1 console, 2 behind cockpit, and 1 unknown)	15%
3	Unknown	11%

The C-12 has flame detectors made by Pyrotector. Each engine has three. They operate on viewing infrared light from the fire. Of the 12 fire-warning indications, two were true (one oil and the other a burned-out starter generator) while the remaining 10 (83%) were false.

The forward blower motor/fan is a weak link for the Army C-12. Unfortunately, its failure results in smoke and fumes into the cabin and cockpit. It is not considered a critical failure as on the AH-64 and AH-1 in that the C-12 offers a much more stable and thereby manageable platform from which to work.



OV-1 Mohawk

An evaluation of the Mohawk shows that during the study period (FY 1988 through 1992), the aircraft had 530 Class A through E mishaps. Of these, 16 (3%) related to fire indications. The breakdown is as follows:

2	Fire warning system activations	12%
10	Smoke in the cockpit	62%
2	Engine de-ice failures	12%
1	Oil spilled in engine area	6%
1	Actual fire (#2 engine)	6%

Smoke in the cockpit stands out as a high percentage of both fire indications and as measured against other aircraft—the highest rate of smoke incidents of all aircraft. Smoke in the OV-1 cockpit can be broken down as having been caused from inverters/radio failures (40%), environmental ducts (30%), and unspecified (30%).

It should be noted that with the small size of the OV-1 cockpit compared to other aircraft (and radio/electrical storage in proximity to the occupied space) the effect of smoke and detection of fumes is greater.

The OV-1 uses fire detection elements manufactured by Walter Kidde in each engine. The system has a ceramic-like thermistor in which two conductors are embedded. The resistance of the insulating thermistor changes with temperature. Regarding fire warning systems, the two activations of the system were false due to poor connections. The one incident of an actual fire did not activate the onboard system due to the fire's location. However, the OV-1 Mohawk is only one of two aircraft whose fire-detection system does not account for the highest percentage of fire indications. The other aircraft is the Apache.

U-21

During the 5-year study priod, the U-21 experienced 476 Class A through E mishaps, of which eight (1.7%) related to fires or fire indications. These eight could be broken down as follows:

3	Fire warning system activations	37%
3	Electrical shorts (non-specific)	37%
1	Smoke in the cockpit	13%
1	Fumes through the heating vents	13%

The U-21 uses optical detectors (flame detectors) like the C-12 and rotary wing aircraft. Each engine has three detectors (manufactured by Pyrotecor) that are sensitive to the infrared wavelength. Of the three times the warning system for fires activated, all were false and all were attributed to faulty flame detectors.