FLEET USAGE MONITORING IS ESSENTIAL IN IMPROVING AGING U.S. ARMY HELICOPTER RELIABILITY AND MAINTAINABILITY

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Abstract

The U.S. Army currently has a fleet of approximately 3000 attack, cargo, and utility helicopters with design heritages that range from 20 to 40 years old. Over 2000 of these existing aircraft are scheduled to be upgraded and/or re-manufactured, and another 1000 are planned to be new production aircraft and all are planned to remain in service beyond the year 2030. As shown in Figure 1, these aircraft designs are essentially at mid-life.

The challenge facing the Army Aviation Program Executive Office is to keep these aircraft affordable, available, and safe even while experiencing escalating operational tempos in increasingly harsh and stressful environments. Army helicopters are extremely complex machines that were designed with relatively old design tools, computational techniques, and materials to perform within broad operational usage envelopes defined by distinct flight regimes and duty cycles. These flight regimes are comprised of combinations of aircraft configurations and flight maneuvers. Current Army helicopter system and structural component maintenance, overhaul, and retirement actions are typically scheduled based upon flight hours that were derived from what was presumed to be a worst-case spectrum of helicopter usage. In reality, many Army helicopter structural components are retired for reasons other than fatigue at flight hours that fall far short of design expectations.

This paper describes the approach to bridge the gap between the design assumptions and operational usage by applying current technology to leverage knowledge of actual operations to identify damaging flight regimes and unsafe usage, refine scheduled maintenance requirements, and predict unscheduled maintenance actions. The basic approach is to relate helicopter system failures and maintenance actions to the actual operational usage history. Usage monitoring provides information that can be correlated with discrepancies and failures to establish meaningful usage-related safety and reliability, availability, and maintainability (RAM) trends. As a minimum, the amount of time each airframe, system, and component is exposed to damaging flight regimes, duty cycles, and operational environments will be recorded, evaluated, and correlated with the predetermined, but constantly refined, RAM trend database. Predictive tools will use the correlated information to identify opportunities to improve aircraft operations, maintenance, and logistical planning. This approach provides the basis for a more effective Army helicopter maintenance program that can be tailored to the actual operational usage experience of each individual helicopter, system, and component.

1 Determination of Component Design Replacement Life

U.S. Army helicopter fatigue life-limited structural components are routinely removed, replaced, and retired, for reasons other than fatigue, well before reaching the number of flight hours determined by the manufacturer's calculated retirement times (CRT). The design CRT is based on a design usage spectrum that was derived for each U.S. Army helicopter model to capture the most severe usage that helicopter model can ever be expected to experience. Knowledge of actual operational usage can be used to identify unsafe usage, refine scheduled maintenance actions, and predict unscheduled maintenance requirements. The design regimes are assumed for helicopter usage as a part of the approach to ensure “six-nines” of reliability for life-limited component structural fatigue. While this process, illustrated in Figure 2, has produced an excellent flight safety record, it does not reflect degradation produced by actual operational usage.

Discrepancies between reality and assumptions can result in parts being flown with less than six-nines of safety. In some instances, this can result in unnecessary cost. In others, it can manifest itself in costly overhauls and retirement. This has not gone unnoticed by the U.S. Army, and engineering has long realized that there may be potential for gaining significant cost and safety benefits by monitoring usage of individual life-limited structural components.

2 Use of Regime Recognition to Monitor Component Usage

Aspects of flight that affect the fatigue of components (speed, altitude, bank angle, GW, etc.) can be categorized using “flight regime recognition”. When aircraft was initially designed, each of these regimes was assumed to be performed at a conservative rate that would produce the design life for each fatigue life limited (FLL) critical safety item (CSI). In Figure 3, the CSI replacement time is the point at which the component would be retired. Most parts will average experiencing a flight regime mix that is much less severe that the design flight spectrum and can fly well beyond the design flight hours before accumulating 100% of the design fatigue life. This is shown in the green shaded area of Figure 3. However, there are examples of parts that have experienced usage that is more severe that than the design damage assumptions as shown in the red shaded area of Figure 3. To protect safety, these parts should be removed and replaced prior to achieving the Design Flight Hours. Flight regime recognition would record the actual flight regime history for the aircraft and life-limited components, and the components could be retired at the appropriate time by taking into consideration flight usage.

This approach has been developed, demonstrated and/or implemented for six aircraft during the US Army Lead the Fleet Program (AH-64A, AH-64D, CH-47D, CH-47F, UH-60A, and UH-60L) and for a few samples of the USN/USMC AH-1W, CH/MH-46, HH-60H, SH-60B, SH-60F, and USCG HH-60H. These programs have demonstrated the validity of using helicopter flight regime recognition techniques to observe fatigue damage accumulation in life-limited structural components based upon the actual operational usage severity.

Successfully increasing the operational flight hours of life-limited components by applying structural usage monitoring poses additional new challenges and concerns. Analysis of monitored structural usage data typically reveals that the average predicted fatigue life limits of structural components is about two-and-one-half times the design flight hour life limits. This extended operational usage exposes life-limited components to increased time-related environmental degradation, chemical corrosion, sand erosion, operational wear, and general susceptibility to mishaps experienced during normal inspection and maintenance. Knowledge of actual operational usage can be used to identify unsafe usage, refine scheduled maintenance actions, and predict unscheduled maintenance requirements.

3 Assessment of Component Actual Life vs. Predicted Life

As illustrated in Figure 4, Army maintenance records reveal the fact that many FLL CSIs fall far short of achieving the design life expectations. For example, for 96 AH-64A/D, CH-47D/F and UH-60A/L FLL CSI part numbers, the average operational life expectation is only about 25% of the design life values. These parts are removed and discarded for reasons other than achievement of the design fatigue lives. The reasons for the replacements for cause are enumerated in Figure 3. Based upon average number of flight hours experienced per year by these fleet of aircraft, and the replacement cost for parts and labor, the Army would spend about $50M per year for parts should they always achieve their design lives. Since actual operational usage is typically only 40% as severe as the design assumptions, there is a potential for flying the parts 250% of the design flight hours before achieving 100% of the design fatigue life. As shown in Figure 4, his would result in an average annual savings of $30M. However, since the parts on average achieve only 25% of the design fatigue life flight hours, the Army is in reality spending approximately $150M more than would be required had they always achieved the design flight hour values. The potential benefits of FLL CSI structural usage monitoring consist of obtaining information that can be used to modify and improve operational usage, maintenance actions, the physical parts, and/or reassess the parts retirement criteria. If the current average FLL CSI achievement of only one-quarter of the design fatigue life can be improved to one-third of the design fatigue life, the resultant annual savings will be approximately $50M.

4 Evaluation of the Increase in the Severity of Operational Usage

Figure 4 analyses are based upon the peacetime usage of Army helicopters of about 14 hours per month in rather moderate environments. As illustrated in Figure 5, the wartime usage is much more severe than the previous peacetime usage. Deployed aircraft now average flying 40 to 50 hours per month. Not only has the operational tempo greatly increased, but the operational environment is much harsher. Therefore, the potential benefits of understanding the relationship between operational usage and the resultant maintenance actions are even greater.

5 Determination of Component Usage and the Resulting Damage

A sample analysis of the time and number of events an Army UH-60A Black Hawk has spent in damaging flight regimes during operational usage is shown in Figure 6. The Original Equipment Manufacturer (OEM) determined the fatigue life of each UH-60A life-limited, flight-critical component when the aircraft was designed. These component lives were based upon a conservative assumption of the percentage of flight time and number of discrete events that each component could spend in damaging flight regimes. The black bars are an aggregate of the percentage of time or number of events per flight hour in the damaging regimes that the component failure modes were designed to experience. The red bars are the aggregate of the actual monitored usage. Although a large percentage of actual flight time was spent in banked turns, one of the most damaging regime types, the time was spent in the lower aspects of the regime type. For example, most of the banked turns occurred at moderate bank angles that produce relatively mild damage. That resulted in the aircraft experiencing much less operational damage from banked turns than would be produced by the design usage, despite spending nearly three-quarters as much time in banked turns. The actual damage produced by operational usage is shown in Figure 6.

Figure 6 shows the aggregate of the damage experienced by the FLL CSI component failure modes for each type of flight regime. This chart is a normalized comparison of the aggregate design damage with the damage experienced in actual operational usage. Figure 6 shows that most of the actual operational damage occurred due to banked turns, ground-air-ground cycles, and forward level flight. It should be noted that although the current U.S. Army Aviation maintenance program is based primarily upon flight hours, there is no identifiable regime that attributes damage to any FLL CSI based upon flight hours. Therefore, flight hours are in effect a non-metric.

The purpose of the fleet usage monitoring is to gain insight into the accumulated damage that each U.S. Army helicopter experiences during operational usage, and to use this information to evaluate overhaul and retirement times, increase safety and operational readiness, and reduce costs.

6 Improvement of Helicopter Usage, Maintenance, and/or Components

Although flight-recorded data indicates the average FLL CSI experiences only 40% of the CWC usage severity, these parts average achieving only 25% of the design flight hours before being retired for reasons other than fatigue. Figure 7 shows that analysis of aircraft usage, in combination with knowledge of the operational environment, provides the information to correlate usage plus environment with actual maintenance actions. The ideal approach is to use regime recognition to monitor each individual helicopter and FLL CSI to obtain a clear picture of actual aircraft and component usage. Regime usage information will be supplemented with recorded location and date/time information to provide the basis for defining the operational environment. Algorithms will then be developed to relate usage and environment to the resultant maintenance actions. This process will provide information to facilitate informed decisions relative to retirement criteria, operational usage, maintenance actions, and parts improvements. Fleet usage monitoring will result in improve safety, reliability, availability, and cost.



Aircraft	Entered Svc	Design Age
CH-47	1961	45+ years
UH-60	1978	28+ years
AH-64	1984	22+ years

- ✓ Average design age ~30 years.
- ✓ 2000 of 3000 Force Mod helicopters will be upgraded to remain in service beyond 2030.

Fig.1. Army Aviation Force Modernization Aircraft are at Mid Life

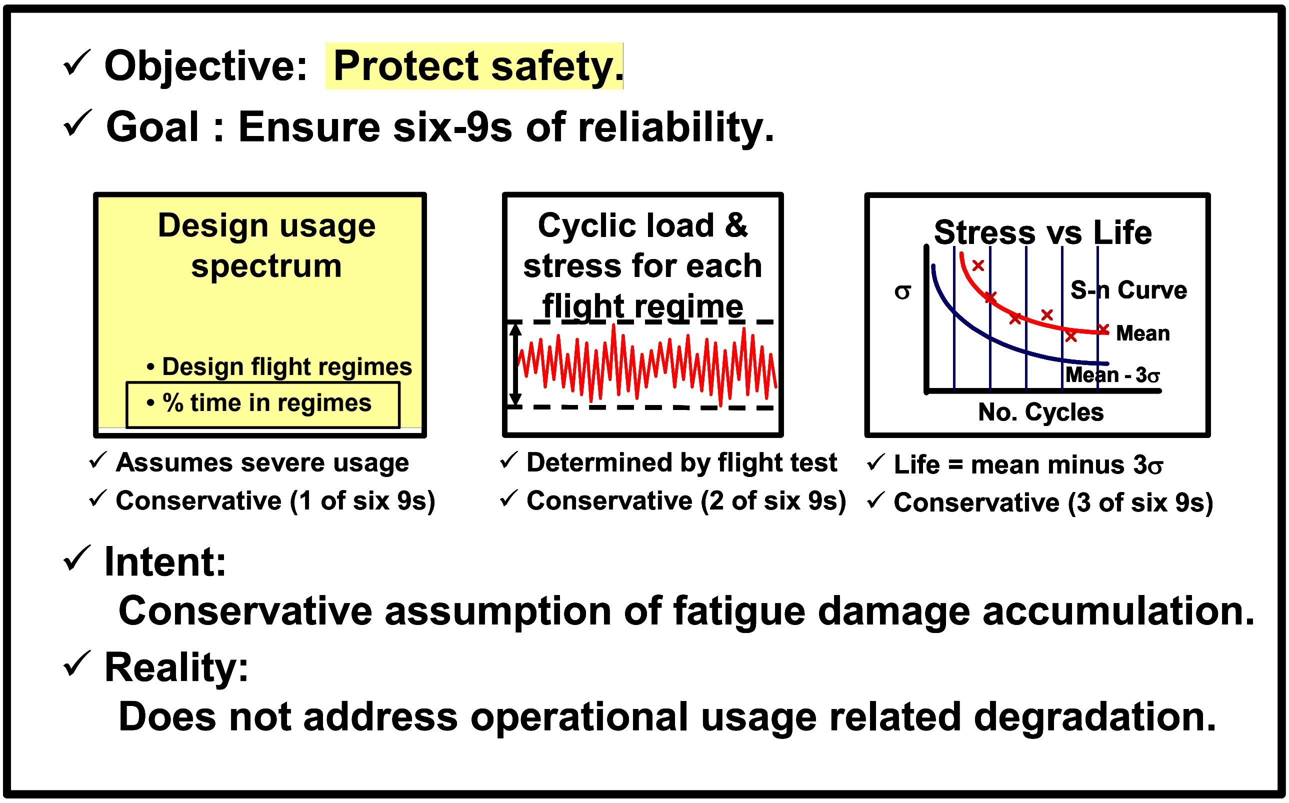

Fig. 2. Fatigue Life Limited Component Replacement is Based upon Conservative Assumptions

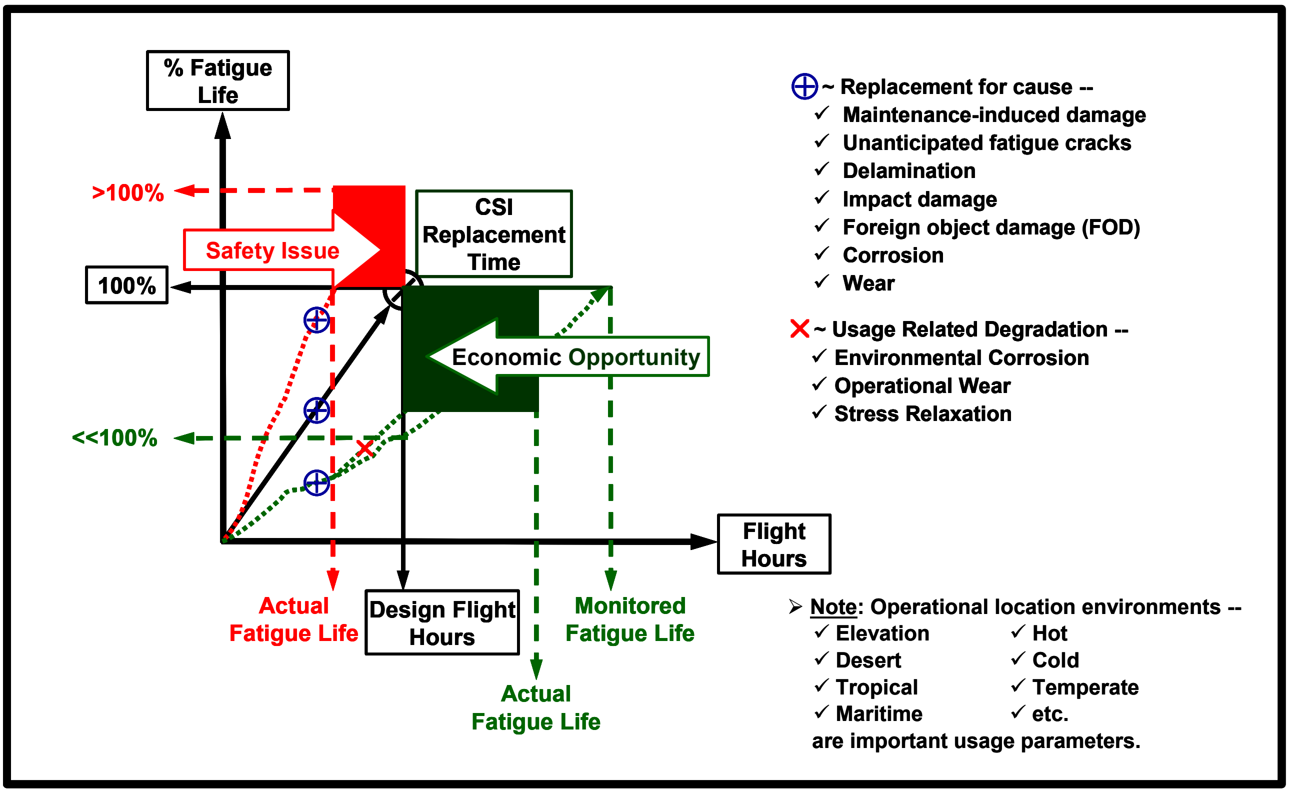

Fig. 3. Usage Monitoring Provides Insight into Component Maintenance Requirements

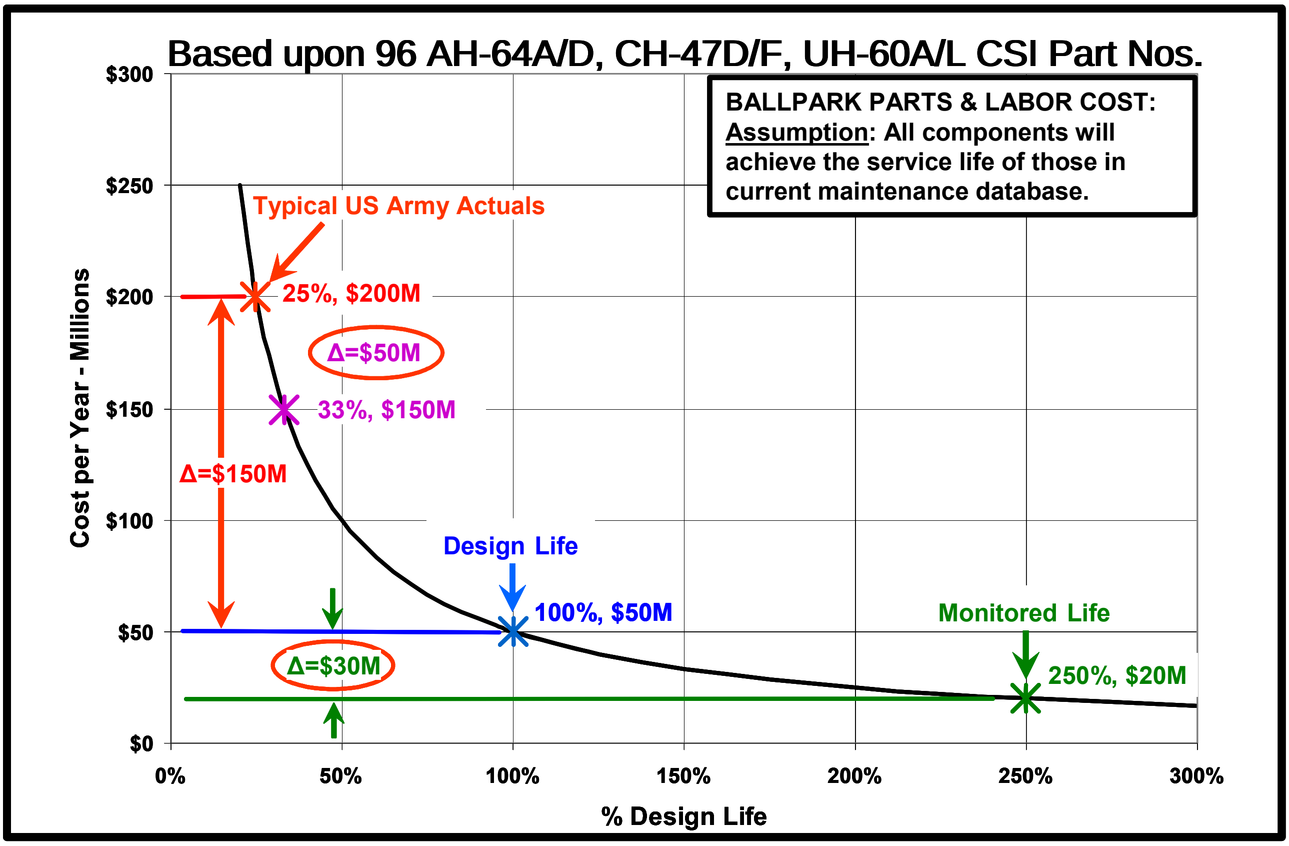

Fig. 4. Army Helicopter CSIs Fall Far Short of Achieving Design Life Expectations

Fig. 5. Army Helicopters are Experiencing Increasingly Harsh Usage

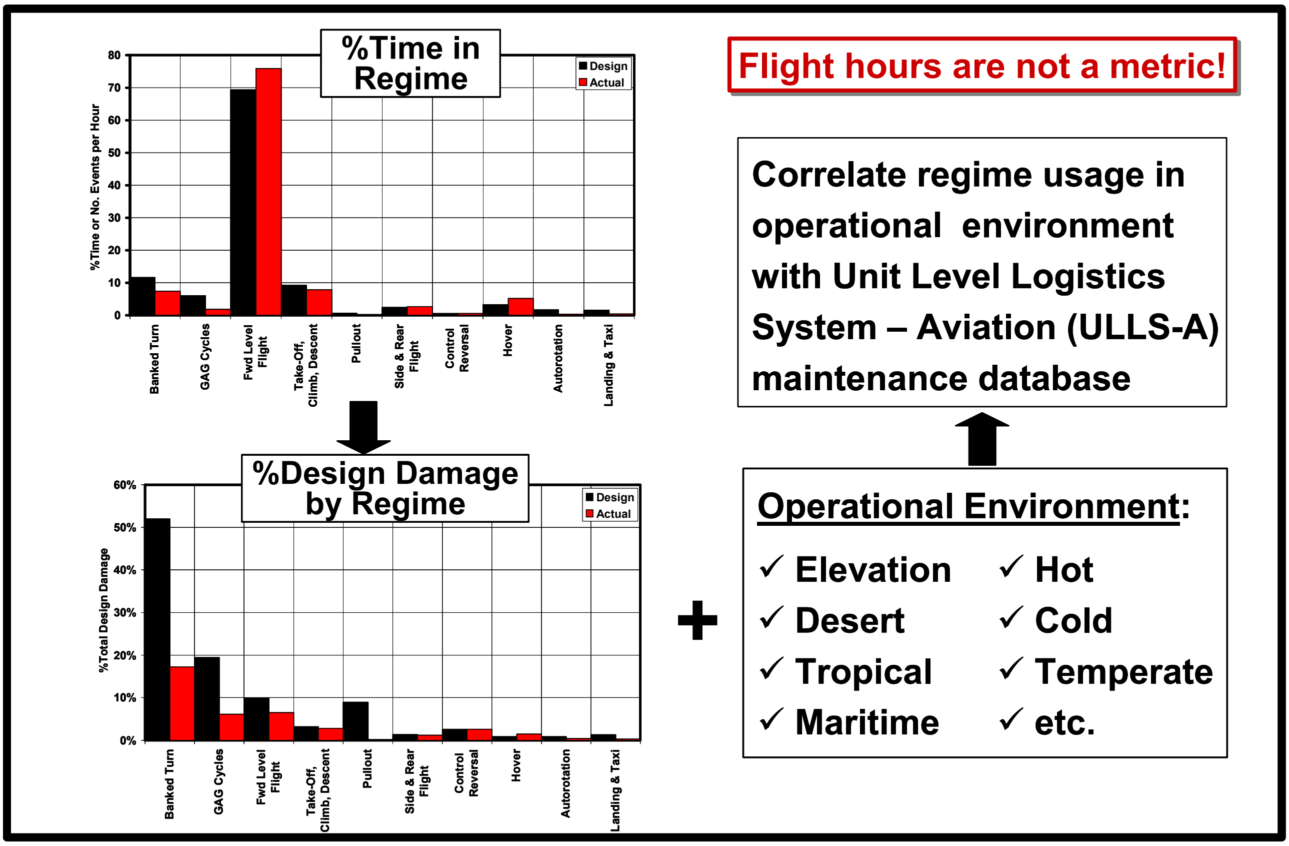

Fig. 6. A/C Maintenance Actions Are Correlated With Usage

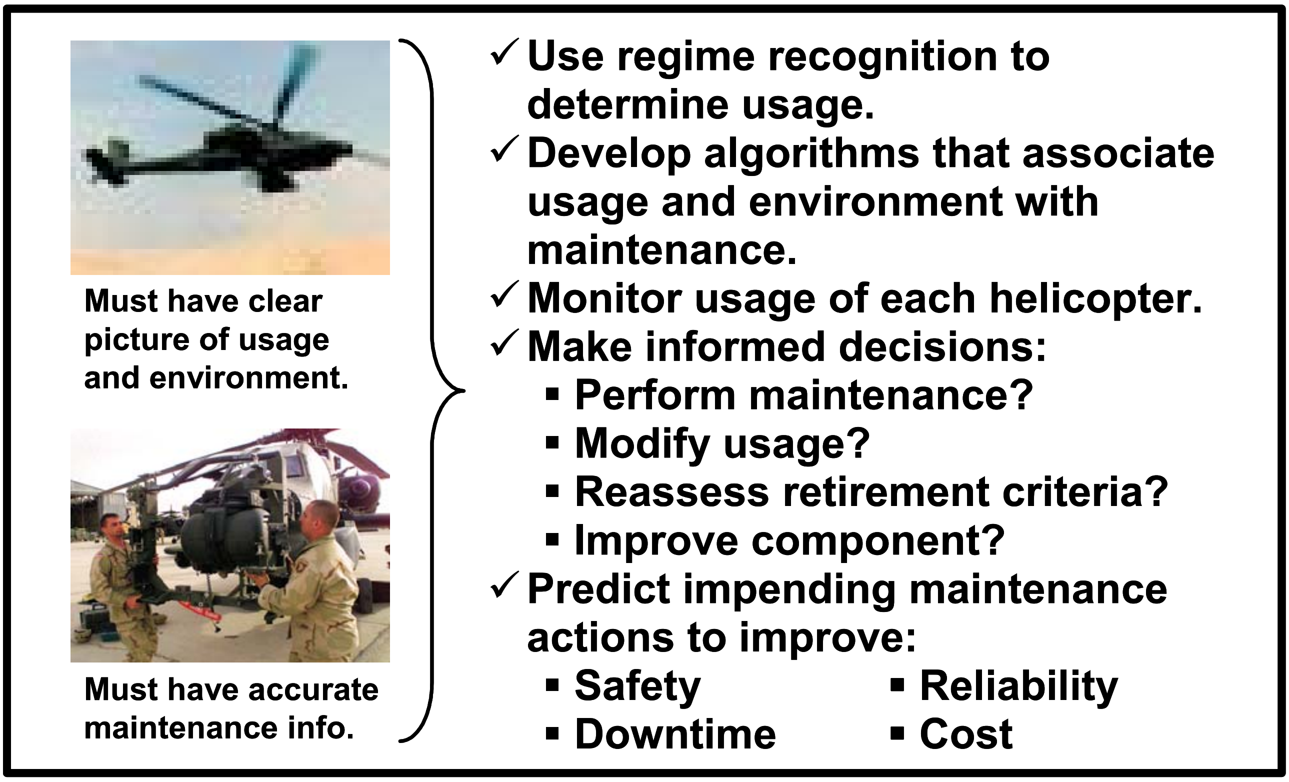

Fig. 7. Helicopter Maintenance is Driven by Usage and Environment