

AGING AIRCRAFT

*USAF Workload and
Material Consumption
Life Cycle Patterns*

Raymond A. Pyles

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1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138

1200 South Hayes Street, Arlington, VA 22202-5050

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SUMMARY

The Air Force is now passing through a period of transition. Throughout the Cold War, when the force-structure and force-age profiles were roughly constant, Air Force planners and programmers could rely on the retirement of older aircraft to free up the maintenance funds and capacity for both newer aircraft and the growing demands of the remaining aging fleets. Relying on retirement is no longer a part of current plans for the force structure. Instead, some aircraft fleets will have unprecedentedly long service lives. The straight-lining (i.e., zero-growth forecasting) of maintenance-related budget requirements beyond the next year or two underestimates future maintenance requirements, often substantially. Since the U.S. government uses a 6-year forecast to plan expenditures, those longer-term maintenance-budget shortfalls can be resolved only by reprogramming funds from other initiatives or accepting decreased aircraft availability for operations and training. Near-term budgeteers and programmers need to know the consequences of funding maintenance at various levels in the face of growing workloads.

But funding ever-increasing annual maintenance workloads and material consumption is not the only problem. Maintenance requires both human and material capital, which must be acquired and trained, to develop the maintenance capacity needed for those growing workloads. Facility and equipment upgrades may take two to three years to develop. Once funds are available, hiring a new employee and training him or her to a journeyman skill level takes even longer. Expanding capacity by hiring contractors may take still longer, because contractors face those problems plus a steep learning curve when they accept an unfamiliar workload. Planners of

maintenance workload capacity and personnel need to know the approximate sizes of the workloads as much as six to ten years in advance so that they can acquire funds in time to develop sufficient capacity.

Finally, there is the problem of replacing an aircraft fleet because its operating costs or its availability is no longer acceptable. Typical lead times for developing and fielding an initial operating capability for an aircraft design range from ten to 15 years. Once an initial operating capability has been fielded, it may take ten to 20 more years to replace a large fleet at modern production rates. Air Force force-structure planners need to know when total operating costs or fleet availability will reach unacceptable levels.

The analysis reported here proposes models for forecasting age-related maintenance and modification workload and material consumption patterns to aid capacity, funding, and force-structure planners develop cost-effective, realistic plans to sustain older fleets while evaluating cost-effective fleet-replacement plans.

ANALYTIC APPROACH

Two conceptual models of workload and material consumption growth over aircraft service lives were posited, one for maintenance, another for modification. The models build on previous research into age-related maintenance and modification workload growth. Both conceptual models allowed for both growth and decline at different ages, but the modification model allowed for episodic surges when major modifications were required.

In contrast to the approaches in many previous studies, the analytic approach used here sought to distinguish long-term age-related growth from other life-cycle events that may obscure or exaggerate measured workload growth. For example, during a platform's early life, "infantile" failures caused by design or manufacturing errors and initial "honeymoon" periods, when many aircraft components have not yet begun to fail, may change workloads dramatically, but they may have little relationship to the cumulative effects of material degradation as a platform enters its second and higher decade of service. Alternatively, exogenous events, such as changes in accounting systems, how the force is organized, size or posture of the

wing or maintenance organization, skill levels, or maintenance procedures, may also affect workloads and hide or exaggerate the apparent effects of age.

In addition, most previous studies based their forecasts of future workloads on either linear- or compound-growth equations. Over the long periods now envisioned for retaining Air Force aircraft, the two equations yield substantially different forecasts. Compound equations imply continuously accelerating exponential workload growth; the linear equation implies more-modest, constant growth. Thus, it is important to test for the presence of acceleration in order to forecast workloads far into the future.

To complicate the forecasting issue still further, the maintenance conceptual model forecasts that, as a direct consequence of the design-life limits introduced by the original design and manufacturing processes, total workloads and material consumption must ultimately decelerate. If so, early- and mid-life growth may overestimate later-life growth. Again, we need to test the available historical data for that possibility in order to forecast far into the future. Thus, the study used regression analysis to address five questions:

1. Do older fleets experience higher maintenance or modification workloads and material costs?
2. If workloads and costs are higher, how rapidly do they grow with age?
3. Do different platforms experience different rates of growth?
4. Do different maintenance activities experience different growth patterns?
5. What are the prospects for continued growth? Will the growth accelerate, decelerate, or remain the same?

The answers should make it possible to improve forecasts of future maintenance and modification workloads and material consumption, and their associated costs. To answer the questions, we examined life-cycle patterns for the following workload and cost-growth categories:

- Base-level on-equipment (mostly flightline) maintenance

- Base-level off-equipment (mostly component repair) maintenance
- Base-level periodic aircraft inspections
- Base-level special inspections
- Base-level demands for depot-level reparable component repairs (DLR repairs)
- Base-level consumption of General Stock Division (GSD) material
- Base-level replacement of support equipment
- Planned programmed depot maintenance (PDM) of aircraft
- Planned depot engine overhaul
- Contractor logistics support (CLS), priced on an annual per-aircraft basis
- CLS priced on a per-flying-hour basis
- Depot-level modifications installed as part of a Time-Change Technical Order (TCTO)
- DLR replacement and modernization.

Data were not available to examine life-cycle workload and cost patterns for the following:

- Unscheduled depot-level maintenance (UDLM; sometimes called speedline maintenance), in which unexpected repairs are made to damaged aircraft
- Over-and-above depot-level maintenance, in which defects discovered during PDMs are repaired
- Modification-kit design and fabricate costs
- Software maintenance.

Multiple regression analyses were conducted for each workload and material consumption category in turn, using available historical data for multiple United States Air Force (USAF) aircraft. Depending on the available data, control variables were entered for aircraft fly-away cost, calendar year, major operating command, basic aircraft

mission (e.g., fighter, bomber, cargo), several break-in periods (e.g., infantile-failure or honeymoon periods), in addition to the aircraft age and an age–flyaway cost interaction term. For engine workloads, engine weight was used instead of flyaway cost. We used a stepwise approach to eliminate statistically nonsignificant terms and so that a simple linear relationship that retained any significant terms could be identified.

A post-hoc test was then performed to detect any acceleration or deceleration. It added a second-order term centered on age 20 years. That age was chosen to minimize any correlation between the linear and second-order terms. If the second-order term was statistically significant, acceleration (or deceleration) had been detected in that workload or material consumption category.

Statistical tests (Cook’s distance and leverage) were also performed to detect the presence of any data points that might have an undue influence on the resulting equations. When those tests indicated some possibility of undue influence, we removed the offending points so that we could observe the effects on the stepwise regression reductions. When those results yielded a substantially different relationship, both results were reported and the implications discussed.

LATE-LIFE GROWTH FINDINGS¹

Maintenance workloads and material consumption generally exhibited late-life growth as aircraft aged, but the rate of that growth depended on both the aircraft’s flyaway cost and the workload category. Long-term, late-life growth was found in all base-level and depot-level maintenance workloads and material consumption categories except base-level periodic inspections, per-flying-hour contractor logistics support, and depot modification workloads.

Often, growth rates depended on the aircraft flyaway costs: More-expensive aircraft experienced higher growth rates. Of course, growth rates in engine overhaul workload depended not on aircraft

¹See Chapter Five, “Summary of Findings” and “Summary of Major Age-Related Findings” sections and Tables 5.42 and 5.43.

flyaway cost but on engine weight: Heavier engines exhibited higher rates of growth.

Little evidence was found for the accelerating growth implicit in the compound-growth equations. The only exceptions were PDM workloads, for which a second-order term centered on age 20 was significant. This finding indicates that PDM workload growth does accelerate, at least through the 40 years of experience available to date.

Except for General Support Division (GSD) consumable materials, no workload or material consumption category exhibited any late-life deceleration. Even the GSD result may be illusory. The available GSD data end about the age of the peak consumption. Thus the second-order deceleration may only reflect a prolonged honeymoon period for some long-lived consumable parts.

Finally, depot-level aircraft modernization workloads (TCTO workloads) exhibited a statistically significant surge during the period between 20 and 25 years of age. This surge may reflect the limits of the designers' ability to forecast operational performance requirements. As a result, the Air Force may find it necessary to reinvest periodically to keep retained aging platforms operationally viable as operating environments evolve.

OTHER WORKLOAD AND COST FINDINGS

Where data were available, all workload and cost categories were affected by differences across Major Operating Commands (MAJCOMs; e.g., Air Combat Command, Air Mobility Command) and early-life honeymoon or infantile-failure periods.

Such early-life transitions pose an especially difficult problem for those who would predict later-life growth. This analysis found both honeymoon and infantile-failure patterns, depending on the workload category. Honeymoon effects' low initial workloads would cause later-life growth rates to be overestimated; infantile failures would cause such rates to be underestimated. In either case, forecasters of late-life workloads can improve their forecasts by discounting such early-life transitions. (See Chapter Five "Findings

for On-Equipment (Flightline) Workloads” section for an example of both infantile failures and a honeymoon period.)

The causes of differences in base-maintenance workloads across MAJCOMs cannot be determined from these data. While some of those differences may reflect variations in operating environments or maintenance philosophies, they may also reflect different reporting practices. In any case, the large differences found in this study may hide or exaggerate the effects of age in other studies, if the MAJCOMs’ fleets have different ages. (See Chapter Five “Findings for On-Equipment Workloads” for an example of differences between commands.)

IMPLICATIONS FOR PLANNING²

Obviously, the growth rates and life-cycle workload patterns reported here can be translated into estimates of future aircraft availability and cost, based on the planned evolution of the USAF force structure. Work is under way to develop a long-term forecasting tool suitable for future maintenance and modification costs for alternative force-structure plans. Computational approaches are also being developed to forecast aircraft availability from aggregate maintenance or workload data. Those improved forecasts are an essential element for planning during the period of transition to an older force through which the Air Force is now passing.

IMPLICATIONS FOR MAINTENANCE POLICIES AND PRACTICES³

Despite the analytic results reported here that should improve workload and cost forecasts, considerable uncertainty remains about how future maintenance and modification workloads may grow. First, some statistical uncertainties are inherent in the forecasting equations developed in this study. The size of those uncertainties generally grows as one extrapolates beyond the ages at which the Air Force has operated aircraft. This study estimates the size of those

²See Chapter Six, “Six Strategies” section.

³See Chapter Six, “Facing Demand and Supply Uncertainties” section.

uncertainties for each workload or material consumption category. Perhaps more important, the study identifies a number of factors (new material deterioration processes and natural limits to workload growth) that could emerge as those fleets age further. Those factors represent nonstatistical (sometimes called structural) uncertainties that, if they emerge, could dwarf the statistical uncertainties. In light of those uncertainties, the Air Force needs to adopt a twin policy of

- improving its understanding of the causes of workload changes
- reducing its susceptibility to unexpected changes.

Age does not directly cause the measured workload patterns. It is only a correlate of many other material-deterioration and maintenance-response processes that change over time. The Air Force might be able to mitigate the workload growth if it better understood the underlying causes and potential remedies.

That improved understanding will take time to develop. Until the causes and remedies are better understood, the Air Force will need to hedge against those uncertainties. Such hedging strategies might include contingency plans for replacing older fleets, maintaining several fleets with overlapping capabilities to minimize the risk of early retirement, or developing spare maintenance capacity to ensure against the effects of unexpected maintenance workload growth for older fleets.