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Effect of Aircraft Age on Maintenance Costs

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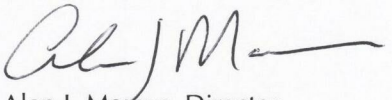

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Effect of Aircraft Age on Maintenance Costs

Peter Francis
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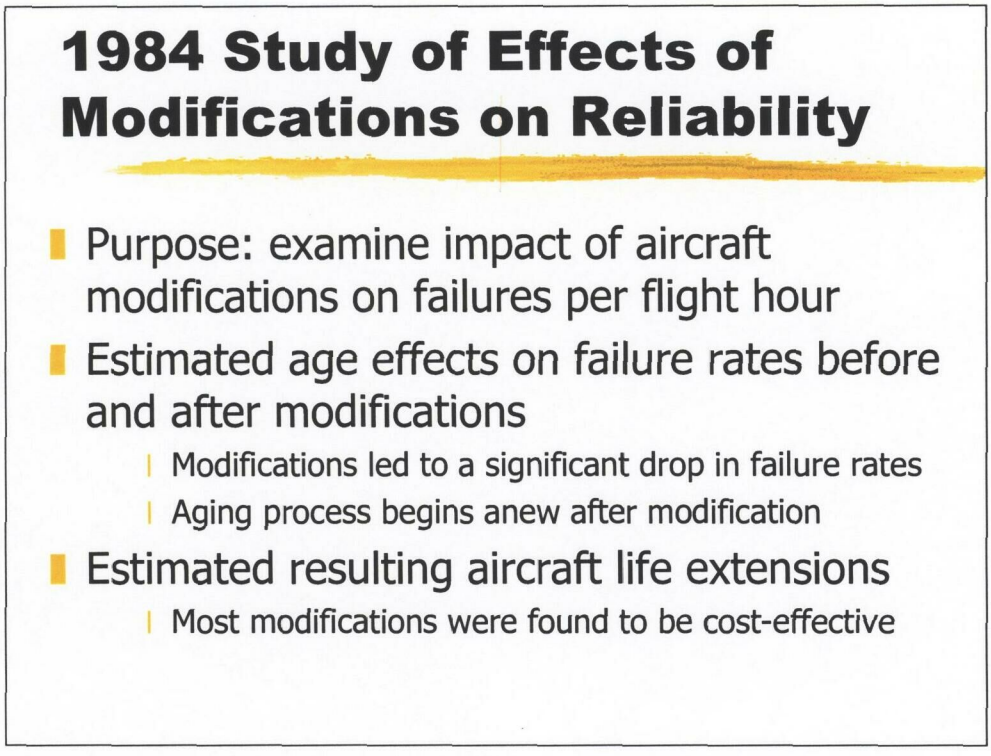
N814 asked us to examine the issue of platform age and its impact on maintenance costs. A brief review of the available literature shows that this topic has been examined before by the Navy, CNA, and other FFRDCs, and that ongoing efforts by NAVAIR should prove useful in developing methods to allow for age-related costs in the budget process. We report on a few publications that present quantitative conclusions on the impact of aging platforms on maintenance and operating costs. This literature review, though far from exhaustive, is meant to convey the idea that this topic has been examined before, and that work in this area is continuing.

We also present some exploratory analyses of two data sets that we created for this purpose. Both use the individual aircraft as the unit of observation. One is organized around individual sorties in a particular month; the other contains summary maintenance labor data and is organized by aircraft, by month, for a 10-year period. Both provide additional evidence that maintenance effort rises with aircraft age.

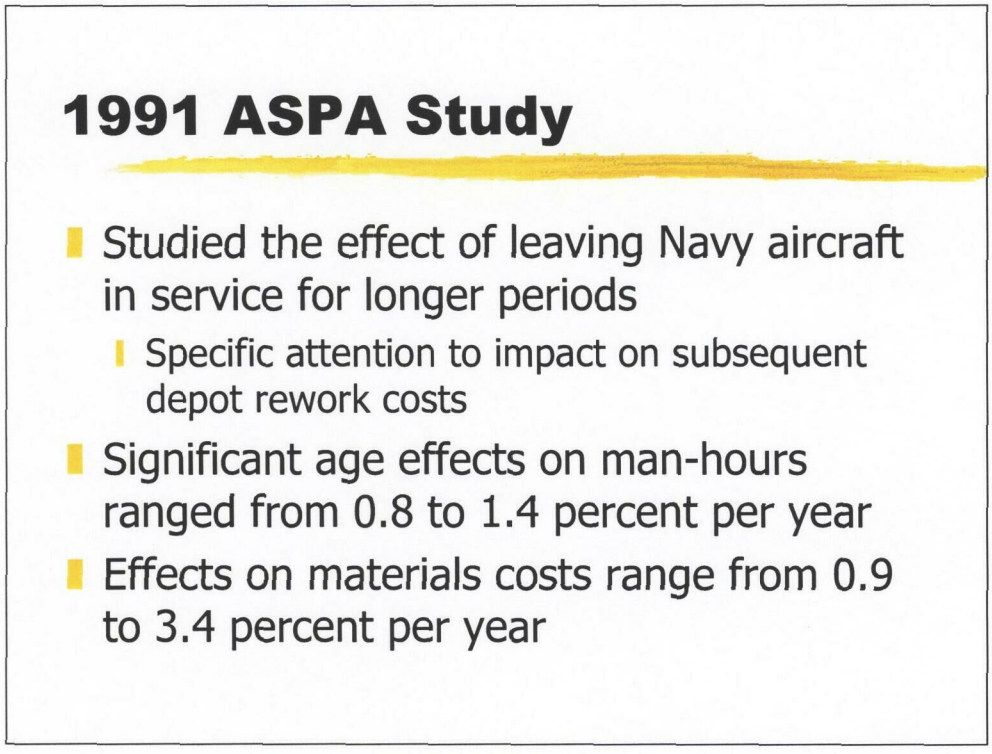
Outline

- Previous analysis
  - CNA research
  - RAND research
  - NAVAIR (NAMO)
- New analysis
  - Maintenance database
  - Sortie database
- Conclusions

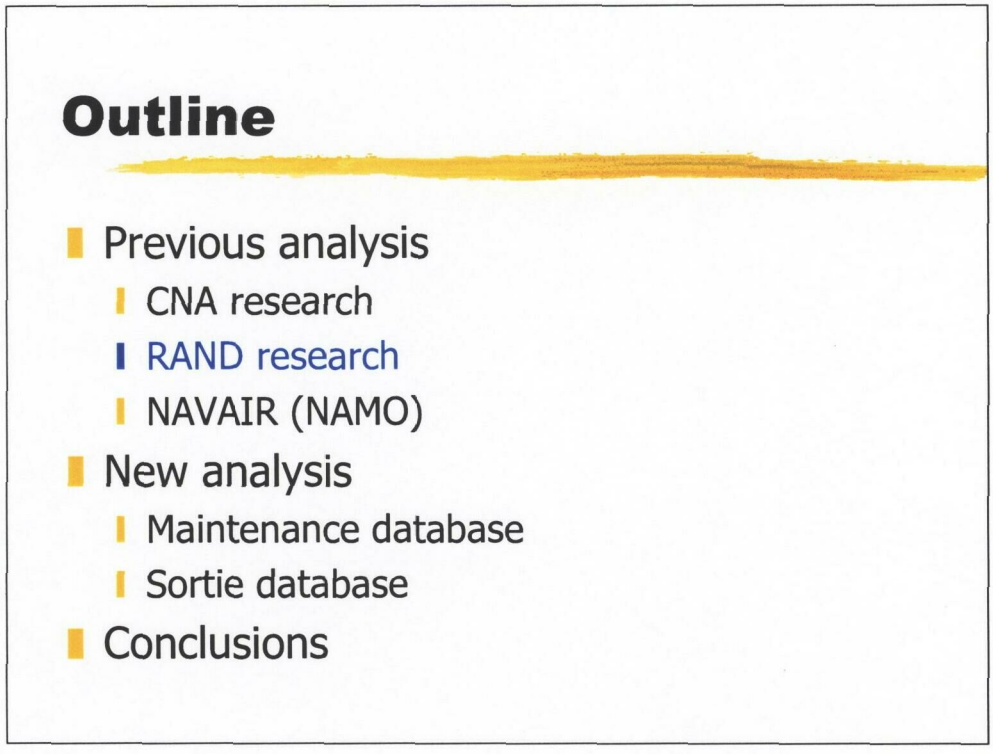
We begin with a look at two CNA research memoranda that quantify the effect of aircraft age on maintenance costs. Both are rather old, and they were not primarily motivated by the particular question of age impacts on maintenance requirements. Nonetheless, they controlled for such considerations while answering other questions and therefore give us an indication of the magnitudes of age-related effects.



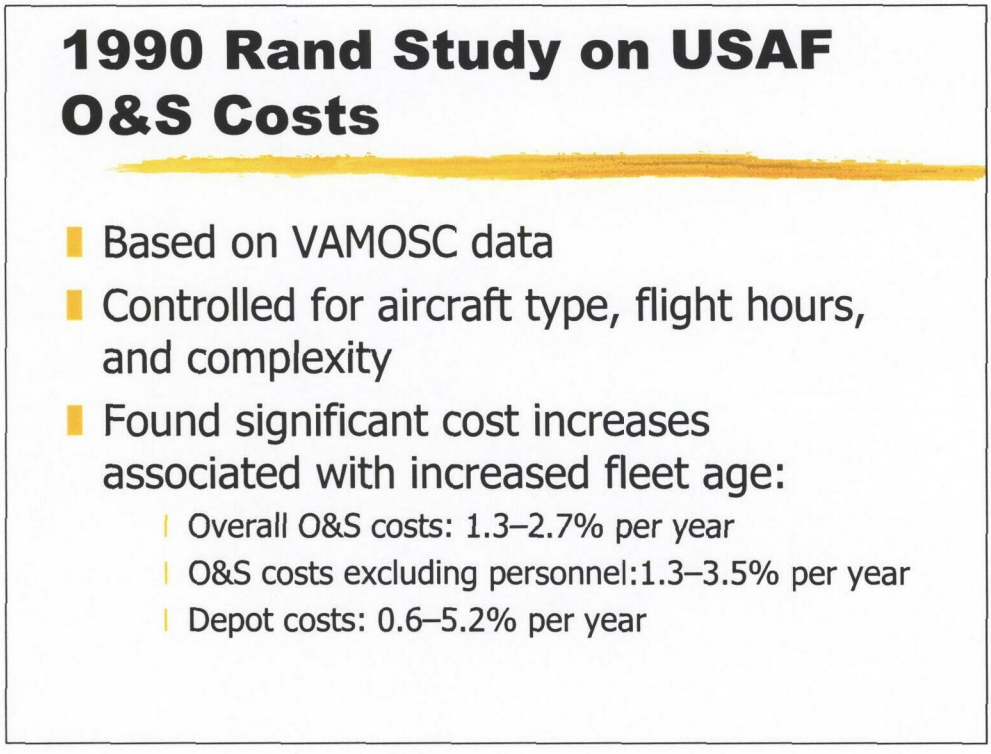
In 1984, a CNA study [1] examined the effect of modifications on four different aircraft models (three fixed wing and one helicopter). As part of this study, analysts estimated age-related changes in failure rates for the aircraft before and after modifications were made. The results are not reported as annual percentage rates of change so it is difficult to compare them to results from later studies, but estimated age effects on failure rates were positive and statistically significant in most cases.



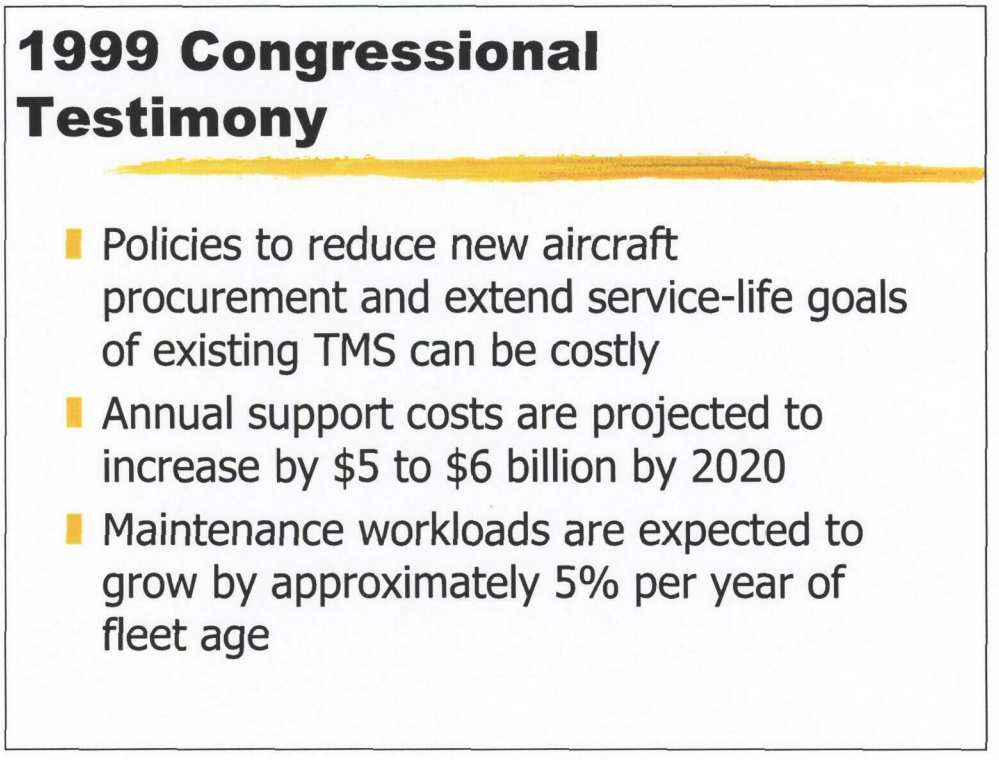
In 1990, another CNA study [2] looked at the impact of the ASPA inspection program on depot rework costs. Age effects were not the primary focus of the paper, but in assessing the effect of the ASPA program, it was necessary to control for them. In most cases, statistically significant age effects were found, and when the estimated effect was statistically significant, it was always positive. Significant estimates ranged from 0.8 to 1.4 percent per year of age for labor hours, and from 0.9 to 3.4 percent per year for material costs.



RAND produced two research documents that quantify the effect of aircraft age on operating and maintenance costs. Both are based on Air Force data. The first is a 1990 research note; the second is a summary of testimony given in 1999 before the House Armed Services Committee.



The RAND research note [3] estimated cost relations for various categories of operating and support (O&S) costs. It reports results for various model specifications and so doesn't offer one "right" cost escalation rate. Still, because it reports significant real increases in costs for most categories, even after controlling for flying activity and aircraft characteristics, it offers strong evidence that age effects are important.



Dr. Raymond Pyles testified before the House Armed Services Committee on February 24, 1999, about the effects of aging fleets on Air Force O&S costs. He told the committee that RAND studies estimated that these costs could easily rise by $5 to $6 billion per year by 2020 if the Air Force continued to follow its current policies, which include a reduction in procurement of new aircraft and extensions of the service-life goals of existing models. If we extrapolate from data given in the testimony, it appears that RAND expects maintenance workloads to rise by about 5 percent per year.

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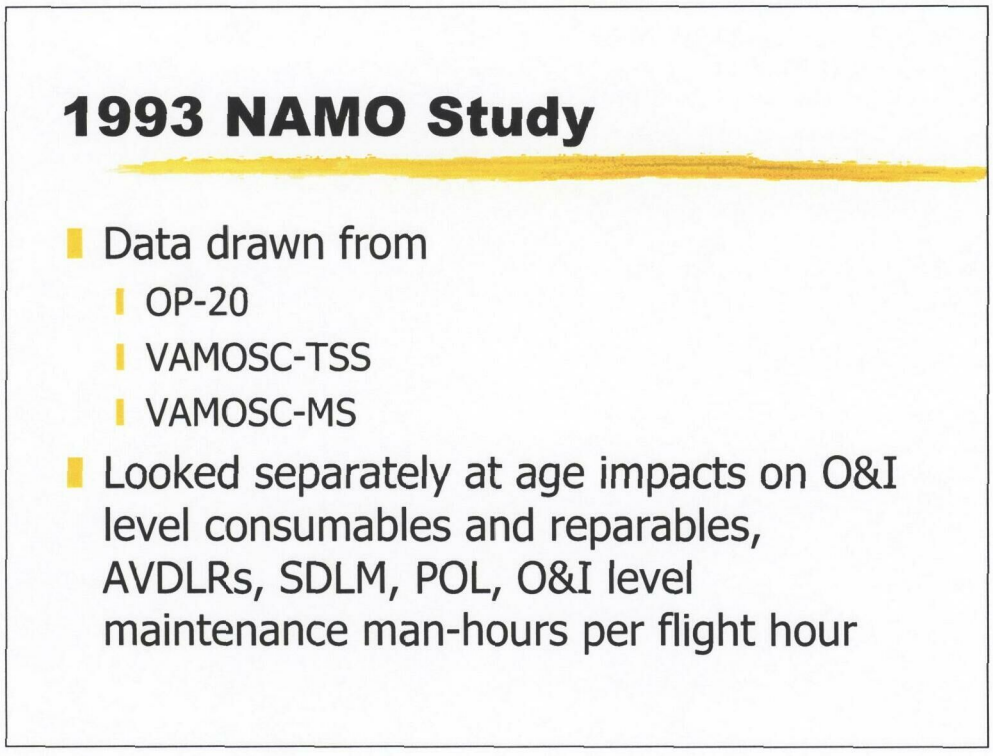
We now turn to a study published in 1993 by the Naval Aviation Maintenance Office (NAMO). (This office was later absorbed into NAVAIR.) Dr. Stoll, who was one of the authors, told us that this work has been pursued and extended since the publication of the 1993 paper. He was not at liberty to send us the most recent results, but he is seeking permission to do so. We hope to report on this work in later versions of this briefing.



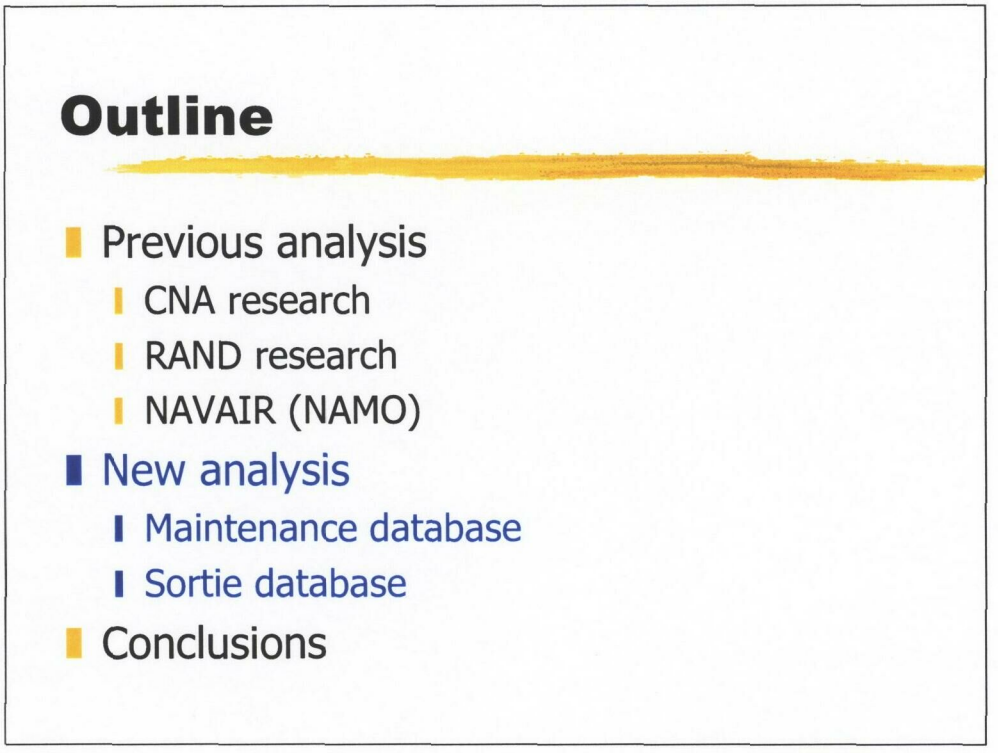
The NAMO study [4] drew data from several sources (see list above) and estimated real (inflation-adjusted) growth rates in various cost categories including organizational- and intermediate-level consumables and reparables; aviation depot-level reparables (AVDLRs); scheduled depot-level maintenance (SDLM); petroleum, oils and lubricants (POL); and maintenance man-hours per flight hour. The data used covered a 10-year period (FY 1983 through FY 1992). Separate calculations were done for individual type/model/series (TMS) and averages over the fleet.

1993 NAMO Study: Results

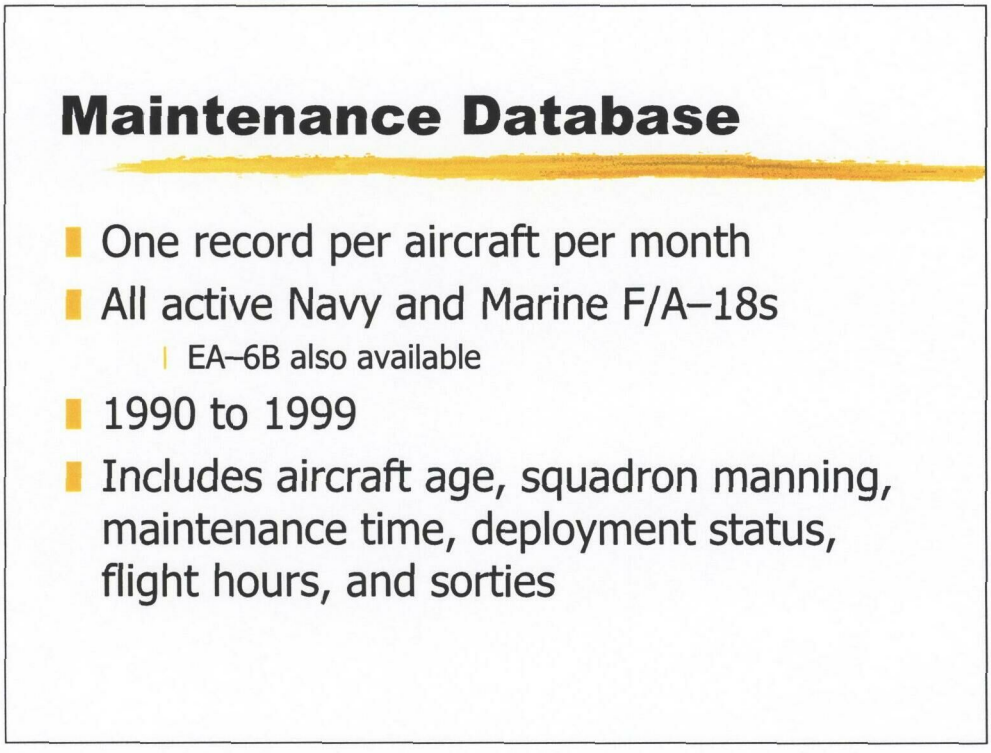
Cost category	Percent change per year of average age
O&I level spares	4.38
AVDLR (fixed wing)	5.3
SDLM (E-2C)	7.94
POL	0.59
O&I level labor	4.17

There was considerable variation in the trends for individual TMS and across differing data sources, but the general upward drift in costs was detectable almost everywhere. Some categories (such as POL) saw only minor changes, while others (E-2C SDLM, for example) increased significantly.

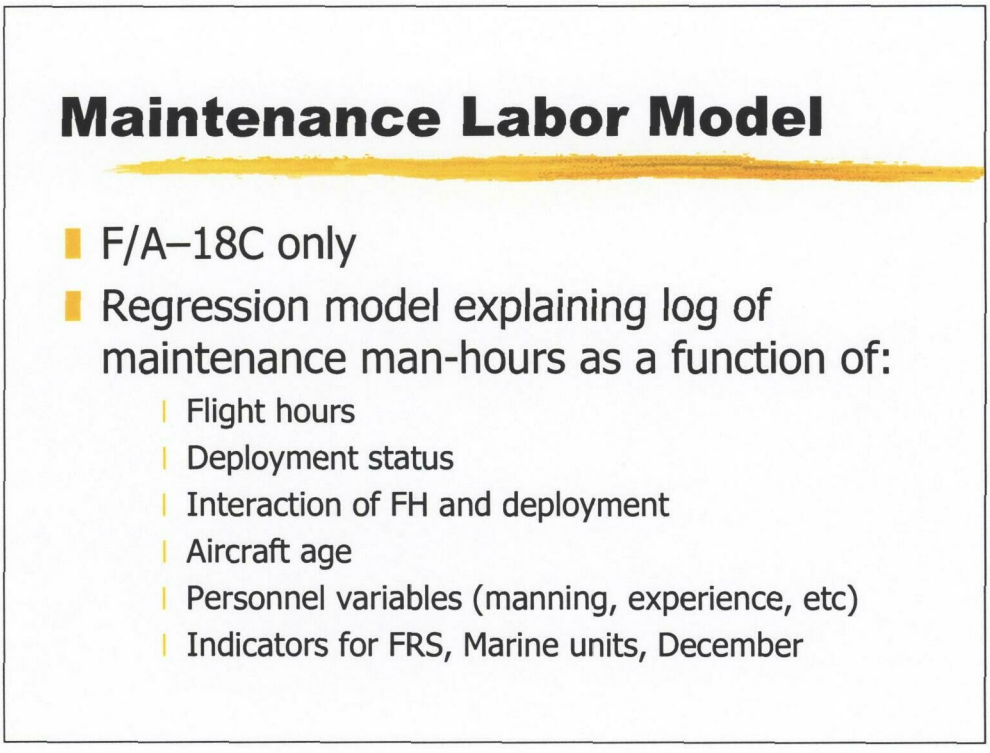
The study concludes that age-related cost increases are clearly evident and recommends that these be taken into account in the budgeting process, as well as in estimates of life-cycle operating costs for new systems. Unfortunately, these recommendations have, so far as we are aware, never been implemented.



We created two datasets for the purpose of identifying the effects of platform age on maintenance resource requirements. Both are organized around individual airframes rather than aggregated statistics for a TMS. One contains monthly organizational maintenance and utilization data by airframe going back 10 years; the other has information about every individual F/A–18 sortie flown during June 1996 together with maintenance information on the plane before and after the sortie. In both cases, we were able to establish statistically significant positive relationships between aircraft age and maintenance requirements.



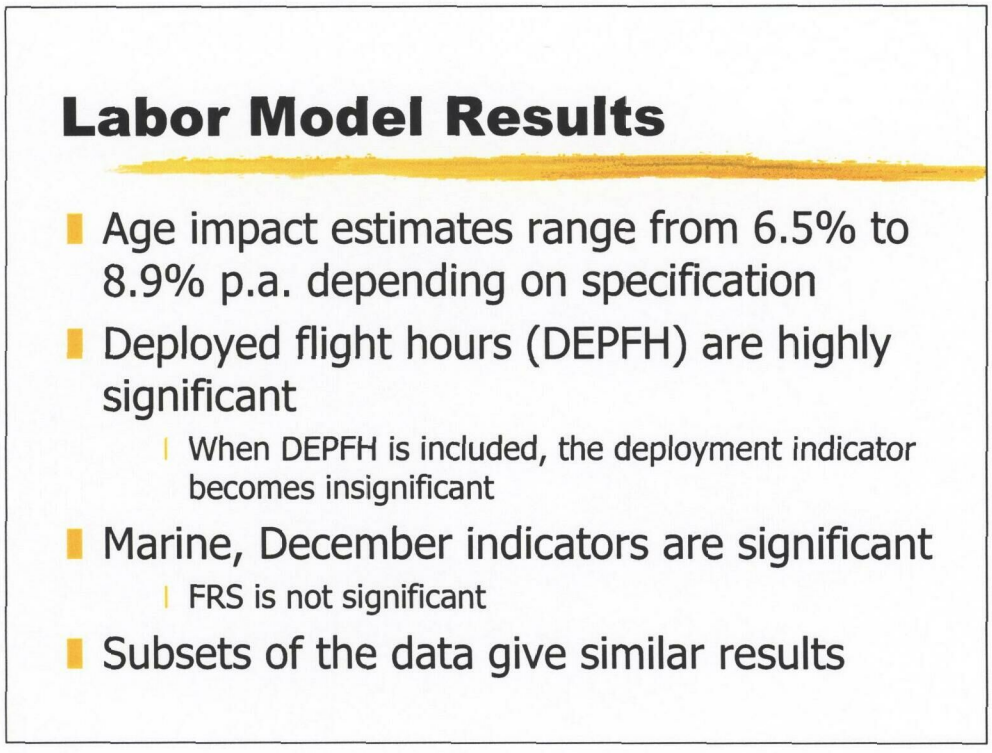
This database contains monthly data on F/A–18s in Navy and Marine Corps service, including fleet replacement squadrons (FRSs). It covers all F/A–18s from 1990 to 1999. Data on EA–6Bs from 1993 on are also available, but we did not use them in our modeling efforts because we could not get acceptance dates for most of the planes now in service. Each observation includes the total number of sorties, flight hours, and maintenance time for the unit taken from AV3M data. It also includes squadron personnel data, such as enlisted manning and the proportion of people who have prior experience with the appropriate TMS. We also included general information about the aircraft such as the model of aircraft, when it began service, and whether the aircraft was deployed for that month.



In our modeling efforts, we looked at F/A–18Cs only because they are the most numerous among the available data. This still allows for a very large sample size: almost 27,000 observations. If we include the manning variables, we are limited to about 16,200 observations—still a good-sized sample. (We have fewer observations because we do not have the personnel data for Marine and FRS units.)

Most of the included variables are self explanatory, but two merit comment. The interaction term—flight hours times the deployment indicator—is meant to capture the effect of carrier operations on breakdown rates. Catapult launches and arrested landings are hard on an airframe, so we would expect to see higher maintenance requirements associated with more deployed flight hours. The December indicator variable was put in because of the suspicion, brought out in an examination of summary statistics, that there is a lower level of maintenance activity at that time of year because of seasonal factors.

The dependent variable is the log of maintenance man-hours. The logarithm transformation is used to permit the interpretation of the age parameter estimates as annual percentage increases.



These models allowed us to estimate the effects of aircraft age on maintenance activity. Key results are as follows:

- Age impacts were always positive and highly statistically significant. The estimated effects varied from 6.5 percent to 8.9 percent per year of aircraft age for the full datasets, and ranged higher for some subsets of the data.
- The interaction term between flight hours and deployment was very important, with coefficients ranging from four to seven times as large as the coefficients for nondeployed flight hours. If we include the interaction term in the regressions, the deployment indicator becomes statistically insignificant.
- Indicator variables for Marine units and the month of December were both negative and statistically significant. The Marines report fewer maintenance man-hours for all ages of aircraft.
- We tried the models on various subsets of the data to check whether the effects varied over the time period covered. We looked at 1990–1994, 1995–1999, and 1996 alone. In each case, the age parameter was statistically significant and positive, and in no case did it come in at under 6 percent. Thus, we are confident that age effects are detectable in the data even when the time spans covered are very short.

Sortie Database

- One record per plane per sortie
- All active Navy and Marine F/A–18
- One month (June 1996)
- Includes data about the flight, the most recent maintenance action, the first subsequent maintenance action, and the position in the deployment cycle

This database is organized by plane and sortie. Because of the large number of sorties flown, we limited the database to a period of one month (June 1996), and only included F/A–18s. The flight-related information comes from the flight records in the AV3M data. This includes the time of day the sortie started, the amount of time flown, and whether the plane landed on a carrier. This was combined with data on the most recent maintenance action, the most recent scheduled maintenance, and whether there was an unscheduled maintenance action after the sortie. The database also has data about the aircraft itself, including the date it began service, its squadron ID, the series, and whether it was deployed at the time of the sortie.

Unscheduled Maintenance Model

- Probit model (0-1 dependent variable) for whether aircraft required unscheduled maintenance after a sortie
- F/A–18Cs only (3,595 observations)
- Explanatory variables
  - Aircraft age
  - Carrier-based sortie

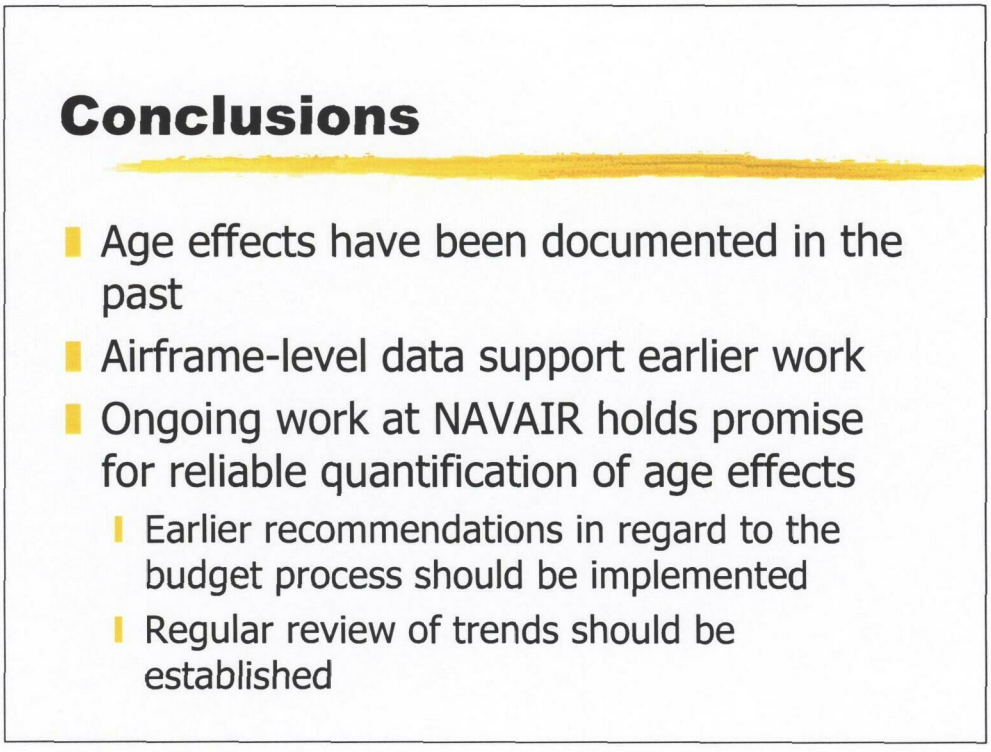
We created this database to see whether we could find evidence of increased maintenance requirements associated with aircraft age. Scheduled maintenance, though important, is predictable and easy to forecast. Hoping to find evidence of a greater propensity toward unscheduled maintenance as age increases, we estimated a model in which the dependent variable was of the binary (0-1) type, with 1 representing a sortie that was followed by an unscheduled maintenance action. We again restricted our attention to F/A–18Cs, and limited the explanatory variables to the plane's age, whether the sortie was off a carrier, and how long it was since the last depot-level maintenance was conducted.

Unscheduled Maintenance Model: Results

- Age and catapult launch are positive and significant at the 5% level
  - Increase of one year in age increases the probability of an unscheduled maintenance action after a carrier sortie by 0.8%
  - There is a 3.5% increase in the probability of unscheduled maintenance after a carrier sortie (compared to land-based)

Both aircraft age and carrier basing had the expected effect of increasing the likelihood of unscheduled maintenance after a sortie. For a carrier-based sortie, a one-year increase in age raises the probability of an unscheduled maintenance action by 0.8 percent. Carrier-based sorties have a 3.5 percent higher probability of resulting in unscheduled maintenance than land-based ones. (Note that these marginal effects are calculated for a representative aircraft; in general, these calculations will vary according to the values of the explanatory variables.)

These results should be viewed as preliminary. They are sufficient, however, to satisfy us that the kinds of age-related maintenance cost effects described in the earlier research papers can be identified in airframe-level data. Thus, we take these results as confirmation of the earlier studies.

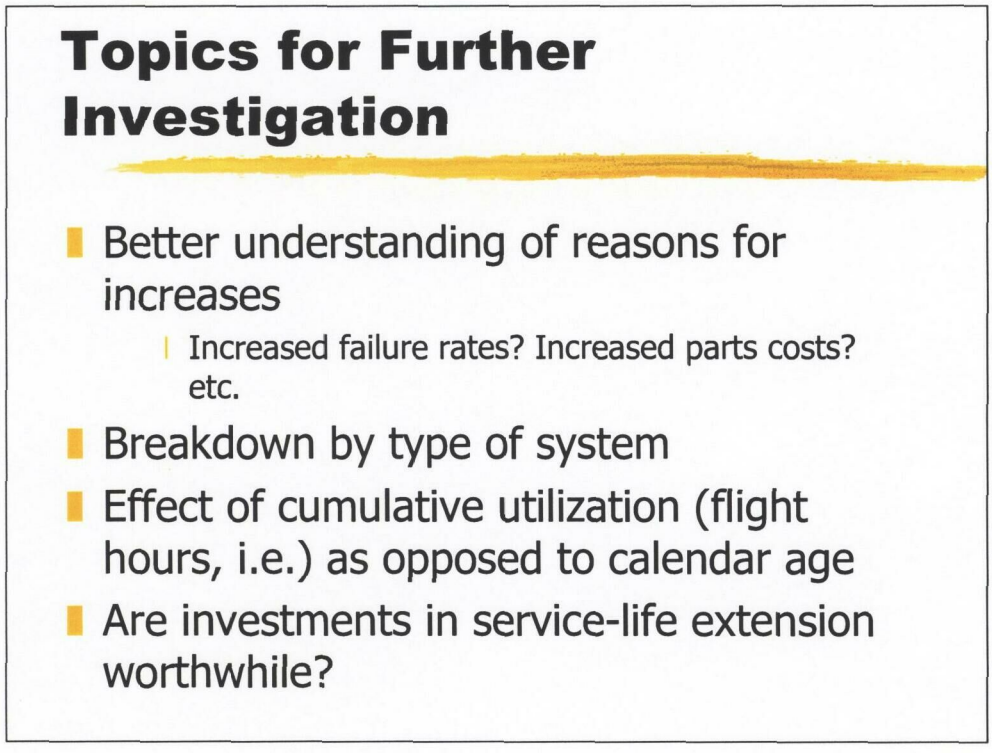


These are our principal conclusions:

First, many different analysts, including some who work for the Navy, have documented the fact that aircraft age affects maintenance costs. These results are not news.

Second, our own analysis of airframe-level data generally supports the conclusion that aging aircraft will require higher maintenance expenditures. The work reported here should be viewed as exploratory, but the robustness of the age effects that we find gives us confidence that further work to refine estimates of age effects and learn more about their causes would be fruitful. (Suggestions for further research are given on the next page.)

NAVAIR is apparently still working on this question. Their earlier work appears to be reasonable, and their recommendations on incorporating age effects in the budgeting process are sensible. We suggest that their proposals, updated where appropriate, be given serious consideration. We also recommend that aging effects be periodically revisited empirically because it isn't clear that these effects can't or won't get worse.



If the Navy wants to know more about this topic, it could pursue several lines of inquiry. Possibilities include (but are not limited to) the following:

- It could be useful to gain a better understanding of the mechanism by which age affects maintenance requirements. Does this come about because of higher failure rates? Different kinds of failures? Increases in parts costs?
- In a similar vein, it would be useful to know which systems in an aircraft are most prone to age-related problems. We speculate that avionics would be less likely to show such effects than mechanical systems or structural members, but that is something that should be confirmed empirically.
- Most of the work cited herein used calendar age as the age metric, but cumulative flight hours (or possibly sorties) may be a better measure.
- Updating the analysis of some of the questions addressed in earlier studies might be worthwhile, since the platforms examined in those earlier papers are now out of service. For example, the question of the cost-effectiveness of service-life extensions could be revisited.

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References

[1] Samuel D. Kleinman. *Effects of Aircraft Conversaion on Reliability,* 1984 (CNA Researach Memorandum 83–1937.10)

[2] Robert A Levy. *ASPA and the Effect of Deferred Depot Maintenance on Airframe Rework Cost,* 1990 (CNA Research Memorandum 90–174)

[3] Gregory G. Hildebrandt and Man-bing Sze. *An Estimation of USAF Aircraft Operating and Support Cost Relations,* 1990 (RAND Research Note N–3062–ACQ)

[4] Laurence Stoll and Stan Davis. *Operating and Support Cost Elements,* 1993 (Naval Aviation Maintenance Office)

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