

AIRCRAFT COST GROWTH AND DEVELOPMENT PROGRAM LENGTH: *SOME AUGUSTINIAN PROPOSITIONS REVISITED*

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This paper examines two notions that were popularized by Norman Augustine. The first is that growth in the cost of successive generations of tactical aircraft is more an inherent (time-driven) characteristic of such programs than a reflection of changes in their technical parameters. The second is that the design and build phase of aircraft development programs has remained virtually unchanged for 40 years, implying that no systematic relationship exists between the characteristics of a program and the length of its development cycle. Models resulting from this examination, which suggest certain modifications to Augustine's original propositions, are tested against recent data from the F/A-18E/F program.

More than a decade ago, Norman Augustine (1986, p. 143) provided a humorous characterization of growth in the costs of military aircraft:

In the year 2054, the entire defense budget will purchase just one aircraft. This aircraft will have to be shared by the Air Force and Navy 3-1/2 days each per week except for leap year, when it will be made available to the Marines for the extra day.

Augustine actually produced a scatter plot and some trend lines to support this prophecy. Elsewhere in the same publication he wrote (1986, p. 140):

...the cost of an individual airplane has unwaveringly grown by a factor of four every 10 years. This rate of growth seems to be an inherent characteristic of such systems, with the unit cost being most closely correlated with the passage of time rather than with changes in maneuverability, speed,

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weight, or other technical parameters.

Even the most casual observer of the defense marketplace would agree that long-term growth in the costs of tactical aircraft has been substantial. When Augustine says that unit cost has grown by a factor of four every 10 years, which equates to an annual growth rate of 15 percent, he makes no adjustment for the normal increase in manufacturing prices over time—inflation. Other factors having a bearing on aircraft unit costs (besides changes in technical characteristics) are first, the total procurement quantity of a given type and model—the so-called learning-curve effect—and second, the number of units produced in a given year—the production-rate effect.

This article seeks first to disentangle these factors—inflation, technical characteristics, learning, and production rate—from the growth in aircraft costs experienced over a 30-year period (1950–1980). The result constitutes an estimate of the real rate of cost growth, meaning the rate that is associated strictly with the passage of time. That result is then tested against data from a current program, the Department of the Navy's F/A–18E/F, in an effort to see if the same rate of cost growth continues, or—as one would hope—if it has abated to some degree.

Another of Augustine's propositions (1986, p. 356), and one of considerable interest in defense acquisition circles, is the following:

The duration of the design and build phase of aircraft development programs has remained virtually unchanged for 40 years.

This period is approximately the same for government projects, commercial projects, and, for that matter, projects undertaken in the Soviet Union.

Based on a scatter plot showing no trend between months-to-first-flight and year-of-first-flight for a combined set of military and commercial aircraft, this statement strongly implies that no systematic relationship exists between the characteristics of an aircraft program and the length of its development cycle. Historical data examined later in this article suggest that the length of a tactical aircraft development program has been systematically related to a standardized measure of the aircraft's eventual procurement cost. We consider the cost measure to be a proxy for program complexity or sophistication. As with the trend in cost growth, we tested that relationship against recent data from the F/A–18E/F program.

TACTICAL AIRCRAFT COSTS

A consistent source of procurement cost and technical characteristics data (McNichols, 1983) was available for 17 fighter and attack aircraft programs. The oldest of those was the F–89. The year in which its first operationally configured production unit was delivered—the measure of time employed throughout the paper—was 1950. The most recent aircraft is the F–18A; its year of first delivery was 1980. The other programs were the A–4, A–6, A–7, A–10; F–4, F–14, F–15, F–16, F–100, F–101, F–102, F–104, F–105, F–106, and F–111.

Measures of unit flyaway cost—the cleanest quantification of procurement cost—were constructed as follows, with flyaway defined to include airframe, engine, electronic, and armament costs, but not spare parts or other support items. First, to eliminate the learning-curve effect, we focused on the cost of the 100th production unit. Because military aircraft are procured in lots rather than by individual units, the cost of unit 100 can only be approximated. Dividing total annual flyaway cost in the year that included the 100th unit by that year’s procurement quantity gives an approximate unit-100 cost in undeflated dollars. Then, to remove the effects of inflation, we applied a procurement-cost deflator (Office of the Secretary of Defense, 1991) to convert the cost measures to constant fiscal year 1990

dollars. Figure 1 is a plot of approximate unit-100 flyaway cost in millions of 1990 dollars against year of first delivery.

ESTIMATING THE RATE OF COST GROWTH

Before proceeding further, a quick analysis of the data in Figure 1 is instructive. A simple regression of cost—actually the logarithm of cost—on the time variable provides an estimate of the rate of annual cost growth before the effects of technical characteristics and production rate are accounted for. The regression resulted in an estimated growth rate of 5 percent per year. Although that estimate easily passed tests of statistical significance, the time variable—year of first delivery—explained less than 40 percent

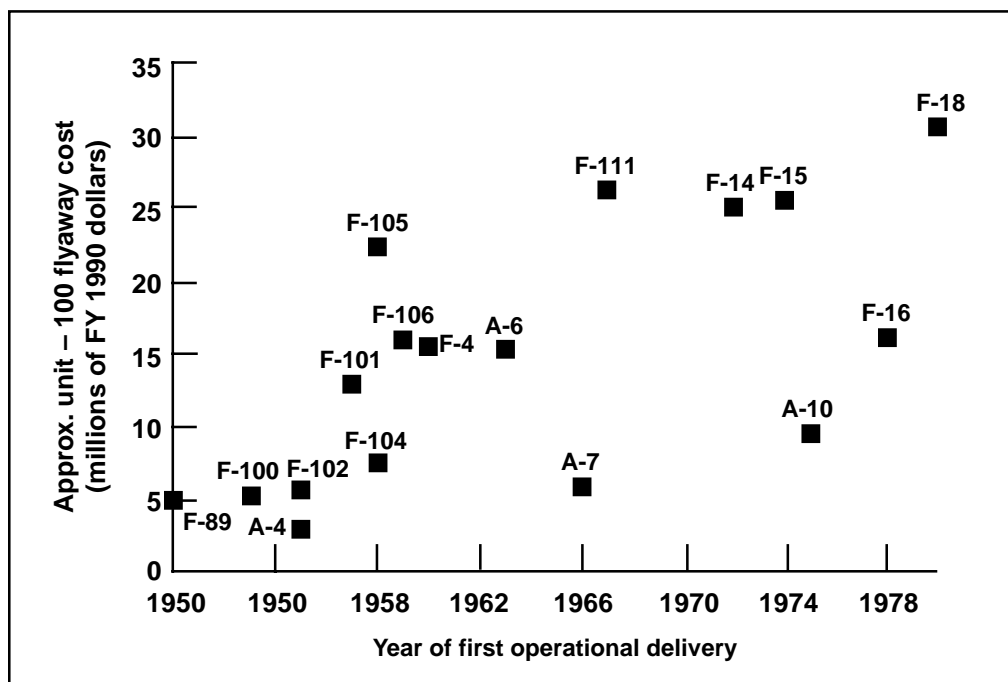


Figure 1. Flyaway Cost Versus Year of First Delivery

of the variation in cost among the 17 aircraft.¹ This relatively low level of explanatory power is consistent with the notion that other factors are systematically influencing cost.

The next step was to bring technical characteristics and production rate into play. That was done by adding three additional predictor variables to the regression model:

- aircraft empty weight (thousands of pounds);
- maximum speed at altitude (knots); and
- production rate in year of unit 100.

Augustine had mentioned maneuverability as another technical characteristic, but even if the requisite data were available—and they were not—maneuverability is a difficult characteristic to quantify.

Results of the regression of cost on weight, speed, production rate, and time were quite satisfactory.² All measures of statistical significance were unambiguously high, and the four predictor variables explained more than 90 percent of the variation in cost. Other results of note were:

- The estimated annual rate of real cost growth declined to slightly more than 3 percent.
- A 10-percent increase in empty weight is estimated to lead to an increase in cost of roughly 7 percent.
- A 10-percent increase in maximum speed is estimated to lead to a cost increase of about 6 percent.

- A doubling of annual production rate is estimated to lead to a reduction in unit cost of roughly 25 percent.

The fact that the weight, speed, and production rate variables were found to play important roles in the model suggests that the accompanying growth-rate estimate—3.3 percent to be exact—is more reliable than the estimate of 5 percent produced by the first regression. There the time variable was almost certain to be picking up some of the effects of the other variables excluded from that model.³

THE F/A-18E/F AS A TEST CASE

The results just described are drawn from 17 different aircraft programs over a 30-year period. That is a substantial experience base. On the other hand, two decades have passed since the last entry to that database occurred. Is it reasonable to assume that the relationship that prevailed then remains in effect today—especially in light of the sweeping changes in technology that have taken place since 1980? Fortunately some new data—from the F/A-18E/F program—provide at least partial insight into that question.

The F/A-18E/F is a high-performance tactical aircraft designed to meet Navy and Marine Corps fighter escort, interdiction, fleet air defense, and close air support mission requirements, and to counter the advanced threat of the first part of the next century. The program was initiated in July 1987 in response to a directive from the Secretary of Defense to the Secretary of the Navy. The Defense Acquisition Board approved entry into Engineering and Manufacturing Development in May



The databases most recent tactical aircraft – the F-18A

1992. Low-rate initial production began in March 1997, with delivery of the first operational unit occurring in December 1998.

The program's most recent *Selected Acquisition Report* (SAR) (Department of the Navy, 1998) provides weight, speed, production rate, cost, and delivery-date information.⁴ The approximate unit-100 flyaway cost reported there is \$49 million in constant fiscal year 1990 dollars.⁵ When the regression results described in the preceding section are combined with the relevant technical and programmatic information, the comparable cost prediction (fiscal year 1990 dollars) is \$65 million.⁶

From a practical standpoint, the big difference in those two numbers—more than 30 percent—might suggest that the long-term rate of cost growth has abated to some degree. Statistically, however, things are less clear. One way of looking at the statistical picture is to note that the lower bound of a 90-percent confidence interval placed around the \$65 million prediction is less than \$44 million. This

means that the SAR cost is well within the uncertainty limits of the original regression.⁷ Another statistical look comes from noting that changing the annual growth rate from 3.3 percent to 3.0 percent would result in a prediction of exactly \$49 million. Such a change is easily within the noise of the original estimate. This observation also serves as a reminder of a lesson well known by all: Small changes in rates of compound growth can make huge differences over long periods of time.

TACTICAL AIRCRAFT DEVELOPMENT PROGRAM LENGTH

As noted earlier, the length of a new aircraft's development program—defined here as the time between program initiation and delivery of the first operational unit—has been a variable of considerable interest in Defense acquisition circles for a long while. Drawing from a database of acquisition milestones developed at RAND

(Rothman, 1987), this section examines an empirical relationship between that variable and the eventual procurement cost of the aircraft in question. In fact, the same cost measure employed in the preceding sections—approximate unit-100 flyaway cost in constant 1990 dollars—proves to be a reliable predictor of development-program length. Predictive accuracy is improved considerably when the presence of inherited technology is taken into account.

The RAND database, which was also the source of the year-of-first-delivery data used in the cost analysis, includes fixed-wing aircraft, helicopters, and tactical missile systems. The aircraft programs examined here differed a bit from those on which the cost analysis was based. Here all fixed-wing aircraft in the

database were included, provided complete cost and development-program data were available. The absence of complete data eliminated the A-4 and F-106, but the B-47, B-52, and S-3 were added, having been previously excluded because the cost analysis was restricted to fighter and attack aircraft. The result was a sample that consisted of 18 programs.

Based on program descriptions in the milestones database, two of the aircraft were singled out as having benefited from inherited technology, thereby causing each to experience an abbreviated development cycle. North American's F-100 Super Sabre evolved from its F-86 Sabre. In addition, the firm had invested one year of its own in development before working with the Air Force. Grumman's F-14 inherited engines and avionics from the



The B-52 Bomber

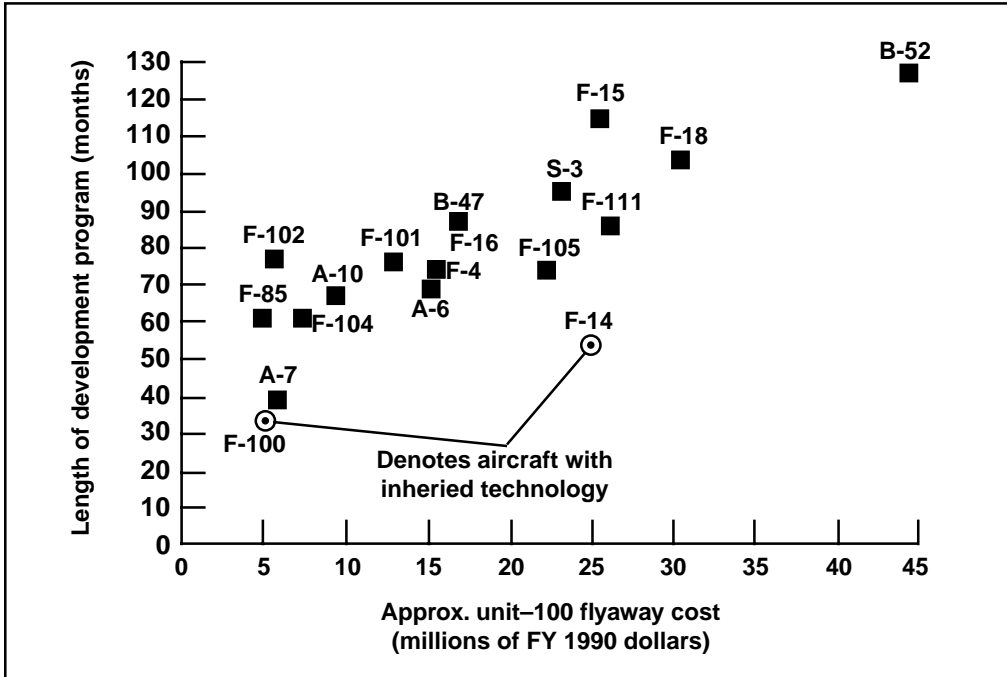


Figure 2. Development-Program Length Versus Flyaway Cost

canceled F-111B program, enabling Tomcat development and production to proceed rapidly. Those two programs are highlighted in Figure 2, which is a plot of development-program length (in months) versus flyaway cost.

The data in Figure 2 were analyzed statistically by a strictly linear regression model with program length as the dependent variable. The predictors were flyaway cost and a dummy variable defined to have a value of one for the F-100 and F-14 and zero otherwise. Results are shown in Table 1.

The first equation is a simple regression of program length on cost. In Equation 2, the dummy variable representing inherited technology is introduced. Its presence increases the model's explanatory power (\bar{R}^2) from 0.601 to 0.799, and

decreases the standard error of estimate (SEE) from 15.2 to 10.8 months. The *t*-ratios shown in parentheses indicate that each of the estimated regression coefficients is significant at better than the 0.005 level. Values of the coefficients in the preferred (second) equation may be interpreted as follows:

- Each increase of \$1 million in the standardized measure of aircraft cost leads to a 1.7-month increase in the length of the development program.
- Inheritance of technology from predecessor programs can shorten the development cycle significantly. For the two aircraft considered here, the development cycles appear to have been reduced by about 3 years (33 months).⁸

Table 1. Regressions with Development-Program Length as the Dependent Variable

Equation	Constant	Cost	Dummy	\bar{R}^2	S.E.E.
1	45.707 (6.535)	1.798 (5.195)	—	.601	15.2
2	50.709 (9.239)	1.714 (6.943)	-33.147 (-4.097)	.799	10.8

A similar question arises here as arose in the cost analysis: Does this historical relationship remain in existence? Again the F/A-18E/F provides a test case. That program officially began in July 1987, with December 1998 being the date for first delivery. That period spans 137 months. Substituting the SAR flyaway cost (\$49 million) into Equation 2 leads to a predicted development-program length of 135 months. The closeness of these two numbers speaks for itself. In generating this prediction, the technology dummy was not activated, meaning the variable was set to zero. That treatment seems appropriate in light of the fact that the F/A-18E/F has an altogether different airframe and propulsion system than the predecessor F-18 aircraft, and it is also designed to accommodate avionics growth.

SUMMARY AND CONCLUDING REMARKS

This article has focused first on the rate of long-term growth in tactical aircraft costs that cannot be attributed to normal inflation, learning-curve and production-rate effects, and changes in aircraft technical characteristics. That growth rate was estimated to be slightly more than 3 per-

cent per year, a result quite a bit lower than what one obtains by examining a simple cost versus time relationship. The suggestion has been made that this otherwise unexplained cost growth may represent investment in increased aircraft service lives.⁸ That is certainly an interesting and promising hypothesis, but one that was not tested here.

Compared with the highly detailed aircraft cost models that are presently available, the single regression equation used here constitutes at best a rough-and-ready device for predicting costs. And, of course, these results incorporate no experience with low-observable technology. Nevertheless, when combined with current information from the F/A-18E/F program, they build something of a bridge between past and present, suggesting the possibility of a decline in cost growth, albeit unconfirmed statistically.

The rough-and-ready characterization given to the cost equation is equally applicable to the empirical relationship between procurement cost and development-program length. Still, tools such as these can serve two useful purposes. They may on occasion provide independent corroboration of estimates based on detailed program information, and they may also emit

Navy photo by Photographer's Mate 2nd Class Robert Baker.



An S-3 Viking, attached to Air Anti-submarine Squadron Three Three (VS-33), takes off from the flight deck of USS John C. Stennis (CVN 74) in the San Diego Harbor.

early warning signals concerning optimistic projections of program outcomes. Re-

cent experience suggests that the latter possibilities are hardly remote.



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ENDNOTES

1. References here and later in the article to the percent of variation in the dependent variable explained by the regression reflect adjustments for degrees of freedom in the analysis.
2. The model is linear in time and in the logarithms of all other variables.
3. The technical term for this is specification bias.
4. The speed value given in the *Selected Acquisition Report* is for an altitude of 10,000 feet with intermediate rated thrust. That is a different measure than maximum speed at altitude, which is the measure used in the database from which the regression equation was developed. Therefore, for purposes of this test, we used the database's speed for the F/A-18A/B, 990 knots. A comparison of aircraft weight and engine thrust data between the A/B and E/F models suggests that this is a reasonable number.
5. Two comments are in order concerning this cost. First, strictly speaking it is an estimate in that unit 100 has not yet been constructed. However, the cost is taken from budget submission data and is therefore a "budget quality" estimate. Second, because unit 100 falls in the lot that includes units 99 through 140, the best approximation of the cost of that unit can be obtained by averaging the lots that include units 63 through 98 and 99 through 140. That result is the \$49 million reported above. For comparison, the cost drawn from the lot containing units 99 through 140 is \$48 million.
6. The prediction equation is $\ln(\text{cost}) = -4.281 + 0.7125\ln(\text{weight}) + 0.6187\ln(\text{speed}) - 0.3911\ln(\text{prod. rate}) + 0.0326(\text{time})$. Values of the predictor variables are weight = 30.196, speed = 990, production rate = 39 (a two-lot average as explained in note 8 above), and time = 1998 - 1900 = 98.
7. The standard error of estimate used in calculating the confidence interval was 0.211, measured in natural logs.
8. Readers with a keen statistical interest will note the existence of a potential problem in this regression model. As the dependent variable in the earlier regressions, flyaway cost—the predictor variable here—is subject to both measurement and other types of unsystematic error. The consequences of errors in a predictor variable are developed in virtually all econometrics texts—see, for example, Greene (1990, pp. 293–300). They may be summarized as follows: The small-sample parameter estimates obtained by the method of ordinary least squares (OLS) will be biased (not equal on average to the true parameter values), and the bias will not vanish as the sample becomes increasingly large. An approach that is frequently well suited for this situation

is estimation by the method of instrumental variables (IV). That method was employed here, with the ranks (from 1 to 18) of the observations on the cost variable serving as its instrument (Durbin, 1954). In this case, the OLS and IV estimators produced virtually identical results. For that reason, the issue was pursued no further.

9. This was suggested by William D. O'Neil, Vice President, Acquisition, Technology, and Systems Analysis Division, The CNA Corporation.