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# Analyzing Cost Growth at Program Stages for DoD Aircraft

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# Analyzing Cost Growth at PROGRAM STAGES FOR DOD AIRCRAFT

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This research examines Cost Growth Factors (CGF) at various program stages for 30 Department of Defense aircraft programs. From Milestone (MS) B, the authors determine CGFs at the Critical Design Review (CDR), First Flight (FF), Development Test and Evaluation End, Initial Operational Capability (IOC), and Full Operational Capability. They find development

CGFs are significantly larger than procurement CGFs. Additionally, cost growth primarily occurs early in the program. At CDR, which occurs on average at the 12 percent completion point of a program, aircraft programs had already experienced on average 15 percent of their total program cost growth. The first spike in percent of total cost growth occurs at FF, 35 months or ~3 years after MS B. Lastly, the analysis shows that by IOC (approximately 6.5 years after MS B or 48 percent of program completion), an aircraft program realizes 91 percent of its total cost growth.

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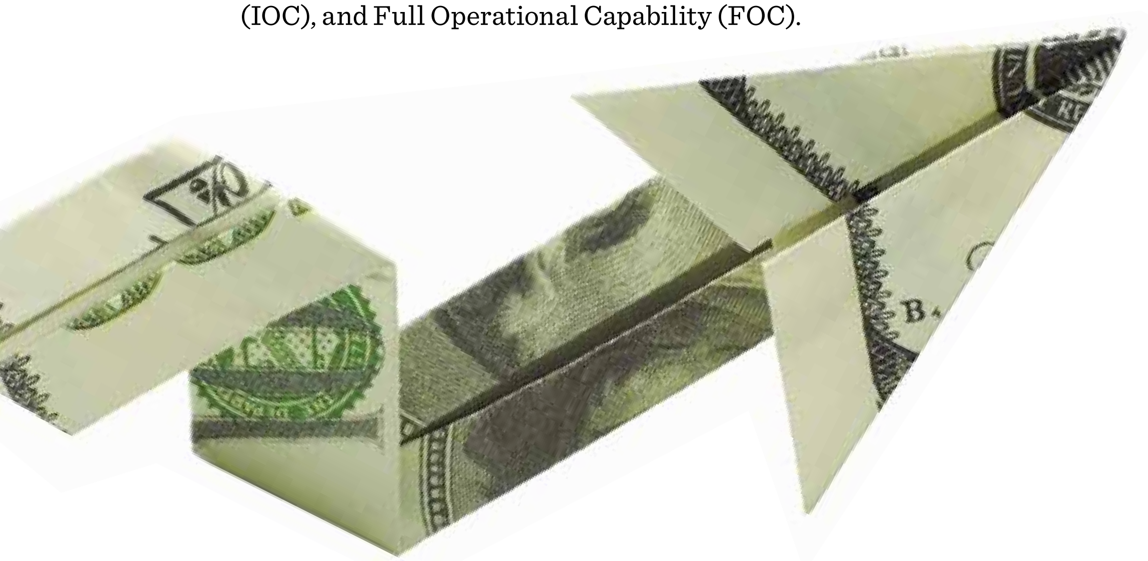
*Image designed by Michael Krukowski*

Cost growth in weapon systems creates challenges for the Department of Defense (DoD) and often forces difficult decisions regarding acquisition funding. [As noted by Cancian (2010), cost professionals sometimes make a distinction between cost growth and cost overrun; cost growth is more general and is the term used here.] Such choices could include removing funding from smaller programs, postponing program development, or eliminating programs altogether. To better understand cost growth, the cost community needs to know when cost growth is most likely to occur. This knowledge might allow for better planning of advanced contingencies when a program will need to draw additional funds from another source, more robust baseline estimates to reflect a truly more realistic depiction of the weapon system's future, or proactive measures in place to mitigate the anticipated spike in cost growth for a program. Supporting this need for knowledge, previous research finds that government decisions account for more than two-thirds of the cost growth experienced in major defense programs (Bolten, Leonard, Arena, Younossi, & Sollinger, 2008). With a total portfolio consisting of 78 programs totaling $1.4 trillion (in Fiscal Year 2015 dollars), even small cost growth percentages have large dollar impacts (Government Accountability Office, 2015). Thus, insight into when cost growth occurs provides valuable data for better informed government decisions that hopefully result in reduced future program costs.

All Major Defense Acquisition Programs (MDAP) are required to pass specific reviews and milestones. Five common stages all major aircraft programs proceed through are: Critical Design Review (CDR), First Flight (FF), Development Test & Evaluation End (DTE), Initial Operational Capability (IOC), and Full Operational Capability (FOC).



Additionally, the Defense Acquisition System has formal milestones (MS A, MS B, and MS C) that all MDAPs must complete. Although previous research has extensively studied cost growth in MDAPs, no one to our knowledge has analyzed cost growth utilizing program stages as benchmarks. Thus, we assess program cost growth from MS B (official program initiation) to CDR, FF, DTE, IOC, and FOC for the MDAP's development, procurement, and total acquisition phases. The analysis is limited to DoD aircraft systems as reported in Selected Acquisition Reports (SAR, 2015).

## Background

Since 1969, MDAPs are required to annually submit SARs to Congress (Drezner, Jarvaise, Hess, Hough, & Norton, 1993; Porter et al., 2009). SARs outline a weapon system's status and report current funding estimates as well as actual expenses incurred. Our research utilizes SAR data to evaluate program cost estimates and actual costs incurred. Three cost estimates exist within SARs: Planning Estimate (PE), Development Estimate (DE), and Current Estimate (CE) (Calcutt, 1993). PEs are the DoD estimate made during the Concept Exploration and Definition stage (current DoD Instruction 5000.02 now refers to this as Materiel Solution Analysis and Technology Maturation and Risk Reduction phases) of the program life cycle. DEs occur at MS B or the start of Engineering and Manufacturing Development phase of the program life cycle. If a program is complete, the final CE is the actual cost of the program (Calcutt, 1993).

Analysts calculate cost growth from a baseline estimate: the PE, DE, or CE. Typically, the DE at MS B is the baseline estimate for cost growth because an MS B decision results in formal program initiation. As formal cost reports materialize, cost growth becomes easier to track, and it is for this reason the estimator measures cost growth from the DE when possible. Our research investigates cost growth as defined as the increase in cost from the DE to the CE or final estimate of the DoD program

Researchers primarily use two common methods for calculating cost growth. The first method (Equation 1) calculates cost growth as a percentage of the original cost estimate. In the first method, the estimated cost is subtracted from the actual cost and then divided by the estimated cost (McNichols & McKinney, 1981). The second method (Equation 2) calculates cost growth as a cost growth factor (CGF). The CGF method divides the cost variance (actual) by the estimate (Arena, Leonard, Murray, & Younossi, 2006). A CGF of 1.0 indicates the program did not go over or under the cost estimate, and the actual cost matched the estimated cost.

If the CGF is greater than 1.0, the program sustained growth, calculated as the CGF – 1.0 to determine the percent cost growth. Conversely, if the CGF is less than 1.0, the program did not sustain cost growth; rather, the program cost less than the estimate. For this article, we use CGF (2) to assess cost growth for DoD aircraft programs.

$$\frac{(Actual—Estimated)}{Estimated} \tag{1}$$

$$\frac{Actual}{Estimated} \tag{2}$$

Previous researchers on DoD MDAP cost growth include Drezner et al. (1993), Christensen (1994), and Arena et al. (2006). Drezner et al. (1993) studied 128 weapon systems utilizing SAR DEs as a baseline. Their research studied CGFs of weapon systems during development, procurement, and total program duration. After accounting for inflation and quantity, they determined individual weapon system cost growth increases on average 2.2 percent per year or about 20 percent through the life of a program. Drezner et al. (1993) also discovered development CGFs were 7 percent greater than procurement CGFs.

Christensen (1994) used Earned Value Management (EVM) data to determine the difference between the original budgeted amount and the estimate at completion. Using EVM in his analysis of cost overrun in DoD weapon systems, Christensen states that cost overruns begin appearing at the 10 percent program completion point. Examining aircraft specific programs, he also discovered that approximately 75 percent of cost overrun occurs by the 50 percent program completion point.

Lastly, the research of Arena et al. (2006) provides information on CGFs for 68 completed programs with similar complexities to programs acquired by the U.S. Air Force. They defined completed weapon systems as systems that have greater than 90 percent production complete. Using SAR reports, Arena et al. divided the data into funding categories, milestones, and commodity type to account for possible changes in correlation with CGFs. The funding categories focused on development and procurement, while the MS category primarily focused on MS B and MS C. The major findings from them include significant cost growth at MS B and MS C, and that completed programs reported 46 percent and 16 percent growth, respectively. The two reported CGFs illustrate cost growth bias decreases as a program moves toward completion.

## Methodology

Our research uses SAR data to analyze cost growth at five program stages: CDR, FF, DTE, IOC, and FOC. Specifically, we focus on DoD aircraft programs, which is defined as a fixed-wing, manned aircraft developed for one or more of the U.S. DoD Service branches. Furthermore, our analysis includes only Acquisition Category I (ACAT I) aircraft programs. All ACAT I programs are MDAPs. An MDAP is a program that is not a highly sensitive classified program and that is designated by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L) as an MDAP; or that is estimated to require eventual expenditure for research, development, test and evaluation, including all planned increments, of more than $480 million (Fiscal Year 2014 constant dollars) or procurement, including all planned increments, of more than $2.79 billion (Fiscal Year 2014 constant dollars) (Acquisition Category, 2015).

Our research utilizes a database originally built by the RAND Corporation for the Air Force Cost Analysis Agency (AFCAA). This database is populated with SAR data on approximately 330 defense acquisition programs dating back to the 1950s and provides annual funding reports by appropriation as well as calculated cost growth measures (Arena et al., 2006). In addition to the SARs, the AFCAA database also includes significant program dates for DoD aircraft programs: MS B, CDR, FF, DTE, IOC, and FOC. In conjunction with the SAR and AFCAA information, we also use *Deagel*. *Deagel* is a nongovernment database that tracks civilian and military aircraft data. If the SAR and AFCAA database lacked a particular stage date for a program, we reference *Deagel*. For the B-1B, F-15E, and T-45, we use *Deagel's* listed dates for IOC, while for the C-17 we use the listed CDR date. Our final dataset includes 30 DoD aircraft platforms.

We normalize all cost data in order to ensure valid comparisons. The two variables with the biggest effect on cost growth are inflation and order quantity (Drezner et al., 1993). The standard approach to account for inflation is to convert all dollars to a single base year value. For each aircraft program, we use the MS B year as the base year for the inflation rates to standardize CGFs. We utilize the Office of the Secretary of Defense Comptroller Appropriation (APN) inflation rates to perform these conversions.

Next we normalize for order quantity. SARs list the quantities estimated and produced for each aircraft program. The quantities each aircraft program produces typically shift throughout a program's life cycle. In order to standardize the units produced for each aircraft program, the units are standardized to the final production amount. The method used in this article is the same method RAND adopted (Arena et al., 2006). The standardization process uses learning curves and first unit cost, which are derived from annual funding data provided in each program SAR. If the quantity reported in the baseline estimate is less than the final quantity, we calculate the cost of units not produced and add that value to the baseline estimate. Likewise, if the final quantity produced is less than the baseline estimate, we calculated the estimated cost of additional baseline units and subtract that value from the baseline estimate (Arena et al., 2006)

Lastly, we compute percentage completion of each program. In order to calculate the percentage completion of a program, it is necessary to first identify program completion dates. We use the final reported SAR to signal program completion. The final SAR identifies when all production is complete. However, the Office of the USD (AT&L) can consider terminating the requirement to report SARs when 90 percent of production units are complete or when a program is no longer considered an ACAT I program (SAR, 2015). Because it is uncertain if termination of SAR reports occurs at 90 percent completion or at final production completion, we use the anticipated date of the last production unit completion (in the last SAR report submitted for the program) as the FOC and calculate the percent of completion based off that date.

## Analysis

Table 1 displays the complete CGFs for the 30 aircraft weapon systems in the analysis. The table outlines the acquisition phase: development (DEV), procurement (PROC), or total (TOT), and the program stages: CDR, FF, DTE, IOC, and FOC for each CGF. The blank fields in Table 1 are attributable to either a program not completing a specific stage at the time of this analysis, the program fell below a SAR reporting threshold and no longer required annual reports, or we were unable to find a recorded date for that stage. For example, the F-35 has yet to complete Development Test & Evaluation and the B-1A fell below a reporting threshold in 1978 and was no longer required to make annual SAR reports; therefore, these fields are blank in Table 1.

**TABLE 1. COST GROWTH FACTORS (CGF) FOR 30 AIRCRAFT WEAPON SYSTEMS IN THE ANALYSIS**

| Aircraft Program | DEV CDR | DEV FF | DEV DTE | DEV IOC | DEV FOC | PROC CDR | PROC FF | PROC DTE | PROC IOC | PROC FOC | TOT CDR | TOT FF | TOT DTE | TOT IOC | TOT FOC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A-10** | 1.09 | 1.19 | 1.18 | 1.19 | 1.27 | 1.03 | 1.22 | 1.28 | 1.22 | 1.34 | 1.03 | 1.22 | 1.28 | 1.22 | 1.33 |
| **AV-8B** | 1.00 | 1.01 | 1.21 | 1.20 | 1.30 | 1.00 | 1.03 | 0.98 | 0.86 | 0.92 | 1.00 | 1.03 | 1.02 | 0.91 | 0.98 |
| **B-1A** | 0.96 | 1.15 | | | 1.10 | 1.00 | 1.11 | | | 1.21 | 0.99 | 1.12 | | | 1.20 |
| **B-1B** | 1.05 | 1.05 | 1.17 | 1.16 | 1.31 | 0.99 | 0.98 | 0.96 | 0.96 | 0.98 | 1.00 | 0.99 | 0.99 | 0.98 | 1.02 |
| **B-1B CMUP Comp** | 0.98 | 0.97 | 1.02 | 1.00 | 0.95 | 1.00 | 0.84 | 1.16 | 1.02 | 0.95 | 0.99 | 1.07 | 1.16 | 1.08 | 1.07 |
| **B-1B CMUP JDAM** | 0.85 | 0.80 | 0.77 | 0.77 | 0.77 | 1.05 | 1.09 | 1.05 | 1.05 | 1.02 | 0.94 | 0.90 | 0.88 | 0.88 | 0.87 |
| **B-2 RMP** | 0.88 | 0.81 | 1.02 | 0.93 | 0.93 | 1.00 | 0.99 | 1.14 | 1.06 | 1.04 | 0.93 | 0.89 | 1.07 | 0.99 | 0.98 |
| **C-5 RERP** | 0.87 | 0.97 | 1.00 | 1.02 | | 1.04 | 1.03 | 1.00 | 1.22 | | 1.01 | 0.99 | 1.00 | 1.21 | |
| **C-17** | 1.22 | 1.36 | 1.41 | 1.54 | 1.81 | 1.08 | 1.31 | 1.29 | 1.45 | 1.72 | 1.05 | 1.33 | 1.47 | 1.47 | 1.75 |
| **E-2D** | 1.00 | 1.06 | 1.26 | 1.50 | | 1.00 | 1.09 | 1.31 | 1.27 | | 1.00 | 1.08 | 1.30 | 1.33 | |
| **E-3A AWACS** | | 1.52 | 1.55 | 1.49 | 1.71 | | 1.31 | 1.33 | 1.32 | 1.28 | | 1.38 | 1.41 | 1.28 | 1.43 |
| **E-3 AWACS RSIP** | 1.02 | 1.07 | 1.07 | 1.07 | 1.07 | 1.00 | 1.41 | 1.57 | 2.05 | 2.06 | 1.01 | 1.21 | 1.27 | 1.45 | 1.46 |
| **E-6A** | 1.11 | 1.12 | 1.11 | 1.12 | 1.12 | 0.97 | 0.78 | 0.81 | 0.82 | 0.90 | 1.02 | 0.87 | 0.90 | 0.91 | 0.98 |
| **E-8 JSTARS** | 0.98 | 1.22 | 2.13 | 2.12 | 2.41 | 1.92 | 1.92 | 1.87 | 1.90 | 1.86 | 1.06 | 1.55 | 2.01 | 2.02 | 2.15 |
| **EA-18G** | 1.05 | 1.08 | 1.04 | 1.04 | | 1.05 | 1.04 | 1.04 | 1.02 | | 1.05 | 1.05 | 1.05 | 1.05 | |
| **EF-111A** | 0.97 | 1.38 | 1.48 | 2.10 | 2.10 | 0.92 | 1.53 | 1.62 | 1.62 | 1.62 | 0.93 | 1.48 | 1.60 | 1.79 | 1.79 |
| **F-14A** | 1.32 | 1.32 | 1.47 | 1.48 | 1.83 | 1.03 | 1.03 | 1.19 | 0.92 | 1.18 | 1.08 | 1.08 | 1.24 | 1.02 | 1.29 |
| **F-15** | 0.98 | 0.98 | 1.09 | 1.09 | 1.37 | 1.05 | 1.04 | 1.32 | 1.23 | 1.28 | 1.03 | 1.03 | 1.19 | 1.19 | 1.30 |
| **F-15E** | 1.07 | 1.07 | 1.09 | 1.09 | 1.48 | 1.00 | 1.00 | 1.01 | 1.01 | 1.01 | 1.02 | 1.03 | 1.04 | 1.04 | 1.34 |
| **F-16A/B** | 1.00 | 1.25 | 1.28 | 1.31 | 2.51 | 1.00 | 1.12 | 1.10 | 1.13 | 1.08 | 1.00 | 1.13 | 1.12 | 1.15 | 1.27 |
| **F-18A/B** | 1.08 | 1.11 | 1.15 | 1.15 | 1.36 | 1.02 | 1.11 | 1.33 | 1.35 | 1.45 | 1.03 | 1.11 | 1.29 | 1.31 | 1.43 |
| **F-18E/F** | 0.99 | 0.95 | 0.98 | 0.98 | 0.98 | 1.00 | 1.02 | 0.96 | 0.95 | 1.01 | 1.00 | 1.01 | 0.96 | 0.96 | 1.01 |
| **F-22** | 1.12 | 1.19 | 1.50 | 1.47 | 1.64 | 1.03 | 1.10 | 1.61 | 1.46 | 1.62 | 1.05 | 1.13 | 1.58 | 1.47 | 1.63 |
| **F-22 Inc 3.2B** | 0.99 | | | | | 0.99 | | | | | 0.99 | | | | |
| **F-35 (CTOL)** | 1.25 | 1.24 | | 1.53 | | 1.36 | 1.36 | | 1.82 | | 1.26 | 1.30 | | 1.69 | |
| **F-35 (CV)** | 1.24 | 1.50 | | 1.53 | | 1.36 | 1.66 | | 1.70 | | 1.34 | 1.63 | | 1.62 | |
| **P-8A** | 0.96 | 0.99 | 1.11 | 1.12 | | 1.00 | 1.01 | 0.95 | 0.95 | | 0.99 | 1.01 | 1.00 | 1.00 | |
| **S-3A** | | 1.08 | 1.10 | 1.08 | 1.09 | | 1.00 | 1.02 | 1.00 | 1.06 | | 1.02 | 1.04 | 1.02 | 1.07 |
| **T-6** | 1.02 | 1.02 | 0.84 | 0.86 | 0.90 | 1.00 | 1.00 | 1.42 | 1.44 | 1.47 | 0.99 | 0.99 | 1.13 | 1.36 | 1.41 |
| **T-45** | 1.07 | 1.09 | 1.31 | 1.31 | 1.53 | 1.10 | 1.21 | 1.50 | 1.48 | 1.70 | 1.10 | 1.20 | 1.48 | 1.48 | 1.68 |

*Note.* Table 1 outlines the Acquisition Phase: Development (DEV), Procurement (PROC), or Total (TOT), and the Program Stages: Critical Design Review (CDR), First Flight (FF), Development Test and Evaluation End (DTE), Initial Operational Capability (IOC), and Full Operational Capability (FOC) for each CGF. AWACS = Air Warning and Control System; CMUP = Conventional Mission Upgrade Program; Comp = Computer Upgrade; CTOL = Conventional Take-off and Landing; CV = Carrier Variant; Inc = Increment; JDAM = Joint Direct Attack Munition; JSTARS = Joint Surveillance Target Attack Radar System; RERP = Reliability Enhancement and Re-Engining Program; RMP = Radar Modernization Program; RSIP = Radar System Improvement Program.

In addition to the CGFs, we calculate the percent of program completion at each stage for all 30 aircraft programs in our database. We plot these CGFs and associated percent program completion in Figures 1–3. Despite the large variability, the points are generally clustered in order of CDR, FF, and finally FOC.

**FIGURE 1. DEVELOPMENT COST GROWTH FACTORS BY PERCENT COMPLETE FOR 30 AIRCRAFT PROGRAMS**

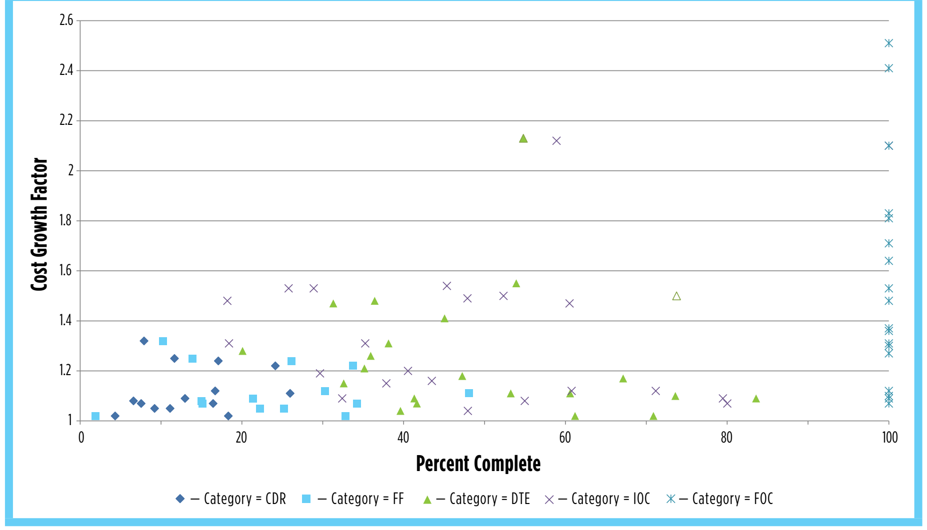



**FIGURE 2. PROCUREMENT COST GROWTH FACTORS BY PERCENT COMPLETE FOR 30 AIRCRAFT PROGRAMS**

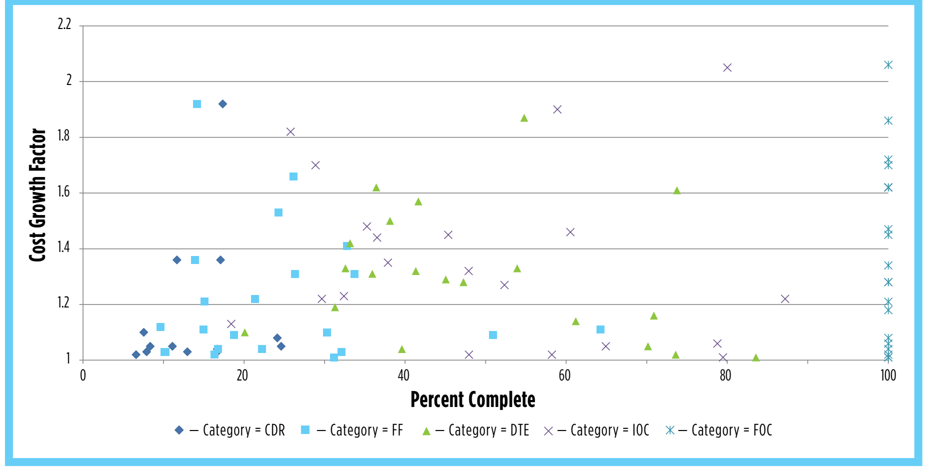
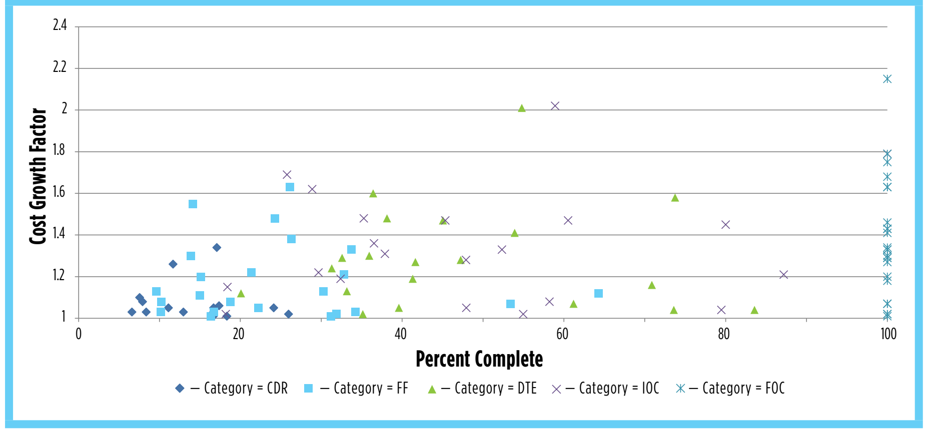
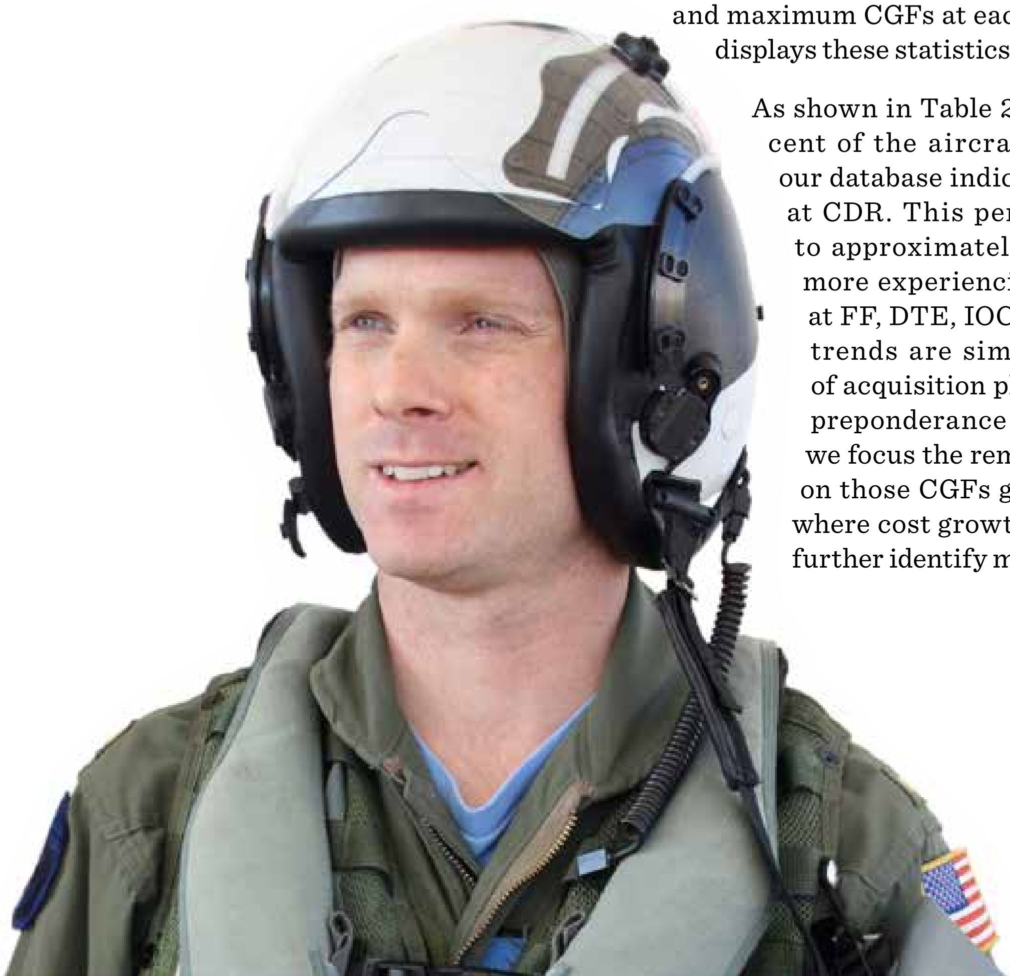



**FIGURE 3. TOTAL COST GROWTH FACTORS BY PERCENT COMPLETE FOR 30 AIRCRAFT PROGRAMS**




To draw more macro trends, we derive summary descriptive statistics using a statistical discovery software called JMP® (Version 11.2). We examine how many programs and the percentage of these that sustain cost growth; the mean, median, standard deviation, and interquartile range (the difference between the 75 percentile and the 25 percentile); and minimum and maximum CGFs at each stage. Table 2 displays these statistics.



As shown in Table 2, nearly 50 percent of the aircraft programs in our database indicate cost growth at CDR. This percent increases to approximately 75 percent or more experiencing cost growth at FF, DTE, IOC, or FOC. These trends are similar regardless of acquisition phase. Given this preponderance of cost growth, we focus the remaining analysis on those CGFs greater than 1.0, where cost growth does occur, to further identify macro trends.

**TABLE 2. DESCRIPTIVE STATISTICS BY ACQUISITION PHASE**

| Phase | Category | Sample Size | Programs w/ Cost Growth | % Programs w/ Cost Growth | Mean | Median | Standard Deviation | IQR | Min | Max |
|---|---|---|---|---|---|---|---|---|---|---|
| DEV | CDR | 28 | 14 | 50% | 1.04 | 1.01 | 0.11 | 0.11 | 0.85 | 1.32 |
| DEV | FF | 29 | 22 | 76% | 1.12 | 1.08 | 0.18 | 0.23 | 0.80 | 1.52 |
| DEV | DTE | 26 | 22 | 85% | 1.21 | 1.13 | 0.27 | 0.30 | 0.77 | 2.13 |
| DEV | IOC | 28 | 23 | 82% | 1.26 | 1.16 | 0.32 | 0.44 | 0.77 | 2.12 |
| DEV | FOC | 23 | 18 | 78% | 1.41 | 1.31 | 0.47 | 0.64 | 0.77 | 2.51 |
| PROC | CDR | 28 | 13 | 46% | 1.07 | 1.00 | 0.19 | 0.05 | 0.92 | 1.92 |
| PROC | FF | 29 | 22 | 76% | 1.15 | 1.09 | 0.24 | 0.26 | 0.78 | 1.92 |
| PROC | DTE | 26 | 20 | 77% | 1.22 | 1.18 | 0.26 | 0.35 | 0.81 | 1.87 |
| PROC | IOC | 28 | 21 | 75% | 1.26 | 1.22 | 0.33 | 0.46 | 0.82 | 2.05 |
| PROC | FOC | 23 | 19 | 83% | 1.29 | 1.21 | 0.33 | 0.61 | 0.90 | 2.06 |
| TOTAL | CDR | 28 | 15 | 54% | 1.03 | 1.01 | 0.09 | 0.06 | 0.93 | 1.34 |
| TOTAL | FF | 29 | 23 | 79% | 1.13 | 1.08 | 0.19 | 0.21 | 0.87 | 1.63 |
| TOTAL | DTE | 26 | 20 | 77% | 1.21 | 1.15 | 0.26 | 0.31 | 0.88 | 2.01 |
| TOTAL | IOC | 28 | 21 | 75% | 1.25 | 1.20 | 0.29 | 0.46 | 0.88 | 2.02 |
| TOTAL | FOC | 23 | 19 | 83% | 1.32 | 1.30 | 0.32 | 0.44 | 0.87 | 2.15 |

*Note.* The Interquartile Range (IQR) represents the difference between the 75 percentile and the 25 percentile.

Table 3 shows the mean and median CGFs for the five program stages (CDR through FOC) and their associated acquisition phases. Table 4 lists the mean and median percent complete and associated percent of total cost growth for each stage. (Note: 100 percent at FOC does not mean that the program has realized 100 percent cost growth; instead, it indicates that whatever cost growth the program will achieve, 100 percent of that cost growth is realized by FOC.) Equation (3) displays the formula necessary to calculate percent of total cost growth, where *Stage* serves as either the CDR, FF, DTE, IOC, or FOC stage. Table 4 also lists the average months from MS B and associated percent of total cost growth at each stage, again for both the means and medians.

$$\frac{(Stage—1)}{(FOC—1)} \tag{3}$$

**TABLE 3. MEAN AND MEDIAN COST GROWTH FACTOR (CGF) AT TOTAL ACQUISITION PROGRAM PHASES**

| Program Stage | Mean CGF | Median CGF |
|---|---|---|
| DEV CDR | 1.12 | 1.09 |
| DEV FF | 1.19 | 1.14 |
| DEV DTE | 1.26 | 1.18 |
| DEV IOC | 1.34 | 1.20 |
| DEV FOC | 1.56 | 1.43 |
| PROC CDR | 1.16 | 1.05 |
| PROC FF | 1.22 | 1.11 |
| PROC DTE | 1.31 | 1.30 |
| PROC IOC | 1.37 | 1.32 |
| PROC FOC | 1.37 | 1.28 |
| TOTAL CDR | 1.08 | 1.05 |
| TOTAL FF | 1.18 | 1.12 |
| TOTAL DTE | 1.29 | 1.26 |
| TOTAL IOC | 1.35 | 1.31 |
| TOTAL FOC | 1.40 | 1.34 |

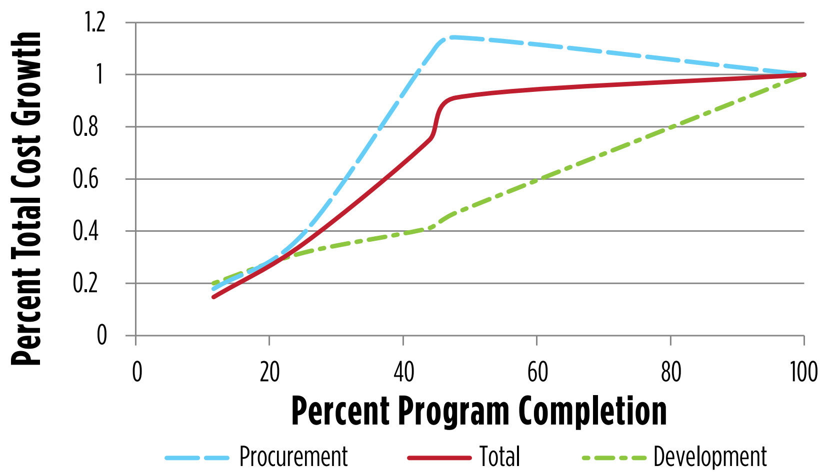
*Note.* CDR = Critical Design Review; DEV = Development; FF = First Flight; DTE = Development Test and Evaluation End; FOC = Full Operational Capability; IOC = Initial Operational Capability; PROC = Procurement.

**TABLE 4. AVERAGE TIME COMPLETE (PERCENT AND MONTHS) AND AVERAGE PERCENT COST GROWTH AT TOTAL ACQUISITION PROGRAM PHASES**

| Program Stage | Mean % Complete | Mean Months Complete | Median % Complete | Median Months Complete | Mean % Cost Growth | Median % Cost Growth |
|---|---|---|---|---|---|---|
| DEV CDR | 13 | 24.1 | 12 | 17.2 | 22 | 20 |
| DEV FF | 26 | 43.6 | 25 | 34.5 | 33 | 32 |
| DEV DTE | 49 | 81.3 | 44 | 74.1 | 47 | 41 |
| DEV IOC | 51 | 88.9 | 48 | 78.1 | 60 | 47 |
| DEV FOC | 100 | 185.8 | 100 | 176.0 | 100 | 100 |
| PROC CDR | 13 | 24.1 | 12 | 17.2 | 44 | 18 |
| PROC FF | 26 | 43.6 | 25 | 34.5 | 59 | 39 |
| PROC DTE | 49 | 81.3 | 44 | 74.1 | 83 | 107 |
| PROC IOC | 51 | 88.9 | 48 | 78.1 | 101 | 114 |
| PROC FOC | 100 | 185.8 | 100 | 176.0 | 100 | 100 |
| TOTAL CDR | 13 | 24.1 | 12 | 17.2 | 19 | 15 |
| TOTAL FF | 26 | 43.6 | 25 | 34.5 | 45 | 35 |
| TOTAL DTE | 49 | 81.3 | 44 | 74.1 | 72 | 75 |
| TOTAL IOC | 51 | 88.9 | 48 | 78.1 | 86 | 91 |
| TOTAL FOC | 100 | 185.8 | 100 | 176.0 | 100 | 100 |

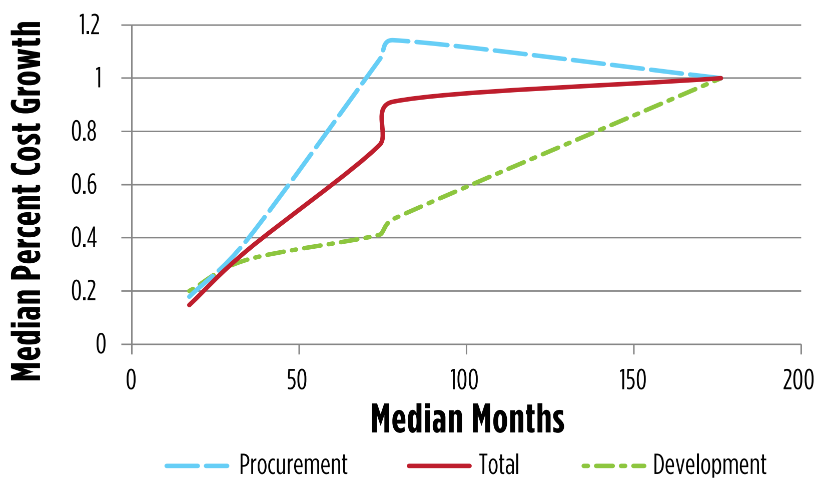
*Note.* CDR = Critical Design Review; DEV = Development; FF = First Flight; DTE = Development Test and Evaluation End; FOC = Full Operational Capability; IOC = Initial Operational Capability; PROC = Procurement.

**FIGURE 4. MEDIAN PERCENT TOTAL COST GROWTH VERSUS MEDIAN PERCENT PROGRAM COMPLETION**




*Note.* Applies to development, procurement, and total acquisition phases for 30 aircraft programs included in the database.

**FIGURE 5. MEDIAN PERCENT TOTAL COST GROWTH VERSUS MEDIAN MONTHS FROM MS B**



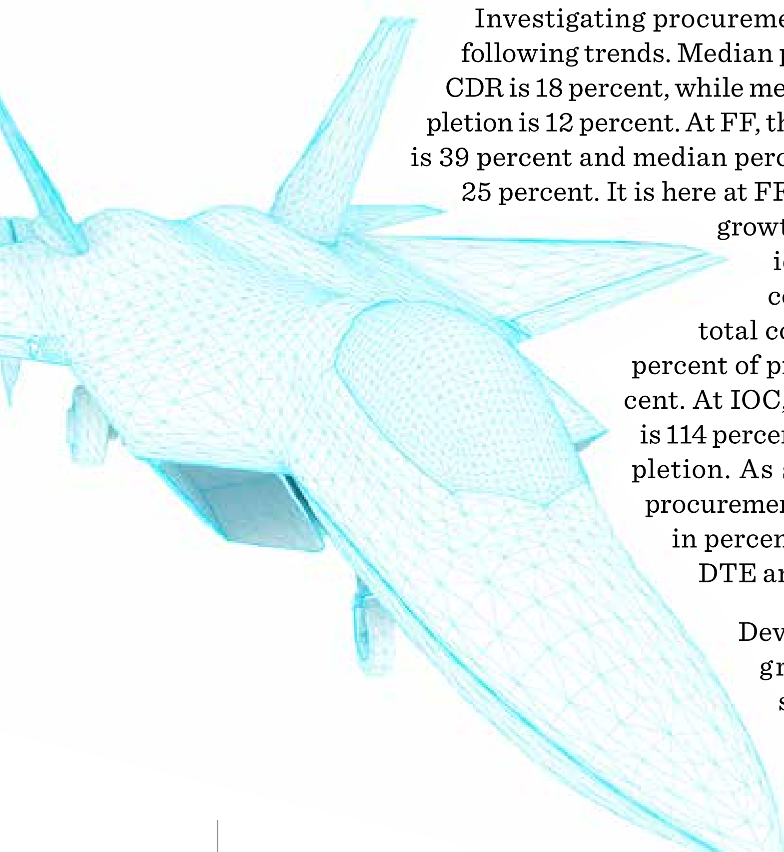

*Note.* Applies to the development, procurement, and total acquisition phases for the 30 aircraft programs in the database.

Due to some large CGFs affecting the means as seen in Table 2, we primarily address the median values from Tables 3–4 and macro trends of those medians illustrated in Figures 4–5 in the following analysis. Investigating just the FOC stage in Table 3, the median CGFs for the development, procurement, and total acquisition phases are 1.43, 1.28, and 1.34, respectively. Therefore, we find that the median CGF for the development phase is significantly greater than the CGF for either the procurement phase or total acquisition phase. With respect to program cost growth, these CGFs correspond to 43 percent, 28 percent, and 34 percent total cost growth for the development, procurement, and total acquisition phases.

According to Table 4, the four program stages of CDR, FF, DTE, and IOC all occur before 50 percent schedule completion. Since IOC is typically the last stage (sometimes DTE has a later date) with a median percent completion of 48 percent, we further analyze these results. For the procurement phase, we find the median CGF represents 114 percent of total realized cost growth at IOC. Thus, the procurement phase realizes all of its cost growth by IOC, despite IOC representing only the 48 percent program completion point. This is not all that surprising given development is mainly complete, and most actual production costs are collected and understood by the time full rate production begins. Additionally, we find that the median CGF at IOC (114 percent) is greater than the median CGF at FOC (100 percent). Visually, this peak is seen in Figure 4. A similar trend holds for the total acquisition phase, whereby 91 percent of total realized cost growth occurs at IOC. This trend for total is not as pronounced as procurement since it also accounts for development costs, which has a much smaller percent of total realized cost growth of 47 percent at IOC. With respect to actual time at IOC, Table 4 shows the median time from MS B to IOC is 78.1 months or 6.5 years. Overall, the descriptive analysis suggests that by IOC, which typically occurs 6.5 years after MS B, a program realizes 91 percent of its total cost growth.

Besides investigating trends seen at IOC, we also assess descriptive trends at CDR, FF, and DTE. For both CDR and FF, the median percent of total realized cost growth for development, procurement, and total acquisition are relatively similar, unlike those at IOC. The percentages for CDR are 20 percent, 18 percent, and 15 percent, while for FF the percentages are 32 percent, 39 percent, and 35 percent, respectively. For DTE, these percentages start to diverge with median development, procurement, and total acquisition program cost growth at 41 percent, 107 percent, and 75 percent, respectively. Thus, DTE is found to be a pivot point for cost growth.

Investigating the association of median cost growth percentage to median schedule completion percentage at CDR, we find they are relatively comparable (Table 4). For CDR, the median schedule completion percentage is 12 percent, while the median percentages of total realized cost growth for development, procurement, and total acquisition are 20 percent, 18 percent, and 15 percent, respectively. For FF, this association is again somewhat comparable, but starts to weaken. At FF, the median schedule completion percentage is 25 percent, while the median percentages of total realized cost growth for development, procurement, and total acquisition are 32 percent, 39 percent, and 35 percent, respectively. At DTE, this association further weakens. The median percent of total cost growth is 75 percent, while the total percent of program completion is 44 percent. This is primarily because of the rapid increase of procurement cost. Why this occurs, we do not know; indeed, such rapid increase of procurement cost might suggest an area for future studies and investigation. As discussed previously regarding IOC, 91 percent of total cost growth occurs at 48 percent schedule completion. Overall, we see a steep rise in percent of total cost growth between FF and IOC, primarily attributable to procurement cost.



Investigating procurement costs further, we find the following trends. Median percent of total cost growth at CDR is 18 percent, while median percent of program completion is 12 percent. At FF, the percent of total cost growth is 39 percent and median percent of program completion is 25 percent. It is here at FF that the percent of total cost growth begins to increase more rapidly than percent of program completion. At DTE, percent of total cost growth is 107 percent and percent of program completion is 44 percent. At IOC, percent of total cost growth is 114 percent at 48 percent program completion. As seen in either Figure 4 or 5, procurement experiences a large increase in percent of total cost growth around DTE and IOC.

Development percent of total cost growth does not behave the same way as procurement cost growth (Table 4). At CDR, median percent of total cost growth is 20 percent at 12 percent program completion. FF percent total cost growth is 32 percent at a program completion percentage of 25 percent. For both CDR and FF, the percent of total cost growth compared to percent of program completion is not too different, ~7–8 percent. However, at DTE the percent of total cost growth is 41 percent and at IOC the percent of total cost growth is 47 percent. Both of these percentages of total cost growth are less than the percent of program completion and far less than the percent of total cost growth experienced with procurement at the same reviews.

Overall, the descriptive analysis highlights some macro trends. Procurement and total program cost growth display similar trends. Both experience the majority of their cost growth prior to the program being 50 percent complete. At IOC, median percent of total realized cost growth is 91 percent at 48 percent program completion with respect to overall total acquisition cost. For procurement acquisition only, 114 percent of total realized cost growth occurs at 48 percent program completion. The development phase is different. For development acquisition, only 47 percent of total program cost growth occurs at 48 percent program completion. Additionally, for procurement and total acquisition costs, a large spike in median percent of total program cost growth occurs around FF whereas development cost growth follows a steadier, more linear path.

## Conclusions

Building a database of 30 aircraft programs comprised of information gathered from the SARs, we investigated how CGFs change from CDR to FOC for development, procurement, and total acquisition phases. Despite there being much variability from program to program, as evident in Figures 1–3, noticeable trends soon emerge as we aggregate the data to means and medians. As seen in Tables 2 and 3, over half to three-fourths of the aircraft programs experience median cost growth ranging from 28 percent for procurement to 43 percent for development. Thus, we find that development CGFs are significantly larger than procurement CGFs. These results are comparable to Drezner et al. (1993), who discovered development CGFs were 7 percent greater than procurement CGFs. For our database, the average difference was approximately 15 percent.

As previously discussed, the median percent of program completion at IOC is 48 percent and the median percent of total cost growth for total acquisition is 91 percent. Therefore, we identify the CGF of an aircraft program at IOC to be very close to the CGF at program completion.

When comparing development to procurement, procurement is the primary contributor to overall cost growth. With respect to when this cost growth occurs, the major spike in cost growth occurs between FF and DTE. At FF, the median percent of total cost growth is 35 percent at 25 percent program completion. When looking at DTE, median total cost growth is 75 percent at 44 percent program completion. Thus, at DTE, there is a major spike in percent of total cost growth, which could be attributed to a program actually needing to display some capability for the aircraft. From Figure 3, we see DTE does not necessarily occur before IOC for every program. Because of this, DTE can occur after IOC depending on where IOC is identified in a program's Capability Development Document (CDD). Due to shifts in IOC, the point of greatest CGF could occur at DTE or IOC.

Investigating further into development and procurement, we find significantly different results for percent of total cost growth versus percent of program completion. For development, median percent of total cost growth at IOC is 47 percent whereas median percent total cost growth for procurement is 114 percent. With this information, we are likely to see development cost growth after IOC, but do not expect to see any procurement cost growth after IOC. Although not always, as first noted in Figure 1, IOC typically occurs after DTE. Therefore, this would indicate minimal development costs accrued after IOC. That is not what the data indicated. This is therefore another area for future research to delve into this counterintuitive finding. The median CGFs for procurement costs spike at DTE and IOC, then slowly decrease at FOC. A similar trend holds for total acquisition costs, but the FOC CGFs are slightly higher due to development costs being more linear during a program's schedule.

With respect to possible limitations, we noticed some discrepancies when identifying IOC dates. This is because programs are not required to report IOC at a certain point in the program's schedule. The Defense Acquisition University's *ACQuipedia* (Initial Operational Capability, 2015) defines IOC:

> In general, attained when some units and/or organizations in the force structure scheduled to receive a system 1) have received it, and 2) have the ability to employ and maintain it. The specifics for any particular system IOC are defined in that system's CDD and Capability Production Document.

IOC dates reported by aircraft programs in this research are consistent with the DAU definition, where some aircraft programs report IOC earlier in the schedule than other aircraft programs. This inconsistency of reporting could affect our findings. However, given the magnitude of median cost growth at IOC, we doubt our findings would change drastically.

Overall, our research quantified the CGFs for 30 aircraft programs at CDR, FF, DTE, IOC, and FOC. We determined the median CGFs at FOC for development, procurement, and total acquisition to be 1.43, 1.28, and 1.34, respectively. These results are comparable to previous findings. Arena et al. (2006) found total CGFs for development, procurement, and total to be 1.58, 1.44, and 1.46 respectively, while Drezner et al. (1993) found total CGFs for development, procurement, and total to be 1.25, 1.18, and 1.20, respectively. Additionally, Christensen (1994) uses EVM data to identify cost overrun beginning as early as 10 percent of program completion. Consistent with Christensen's findings, we identify a median cost growth of 15 percent for total acquisition costs at CDR, which occurs at a median program completion of 12 percent. Additionally, the first spike in percent of total cost growth occurs at FF—35 months or approximately 3 years after MS B. Lastly, our analysis identifies the amount of time from MS B to each program stage. The median time from MS B to IOC is 78 months or 6.5 years. Therefore, approximately 6.5 years after MS B, a program sustains about 91 percent of its total program cost growth. We submit that understanding a typical cost growth pattern of an aircraft program allows for better timing of program initiation to mitigate funding poaching from other systems when or if cost growth spikes.

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