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Garrett B. O'Hanlon

Jonathan D. Ritschel
Air Force Institute of Technology

Edward D. White
Air Force Institute of Technology

Gregory E. Brown

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Delineating Operating and SUPPORT COSTS IN AIRCRAFT PLATFORMS

1st Lt Garrett B. O'Hanlon, USAF, Jonathan D. Ritschel, Edward D. White, and Capt Gregory E. Brown, USAF

As the costs of Department of Defense (DoD) Weapon Systems increase, the ability to estimate the Operating and Support (O&S) costs accurately for the various weapon systems has become vital to long-term affordability. This research focuses on the O&S costs of the Air Force fixed-wing arsenal (i.e., platforms) for 1996–2016. First, the Cost Element Structure (CES) for 52 aircraft platforms and seven operational mission categories is analyzed to derive the descriptive statistics per aircraft category through examination of actual historical costs. Second, testing to identify statistical differences within the O&S CES construct across various Air Force aircraft categories is conducted. DoD cost estimators and stakeholders alike can benefit from this research by utilizing the results as cross-checks for predicting O&S costs through analogous-based estimates and as an in-depth analysis into categories of CES costs being incurred.

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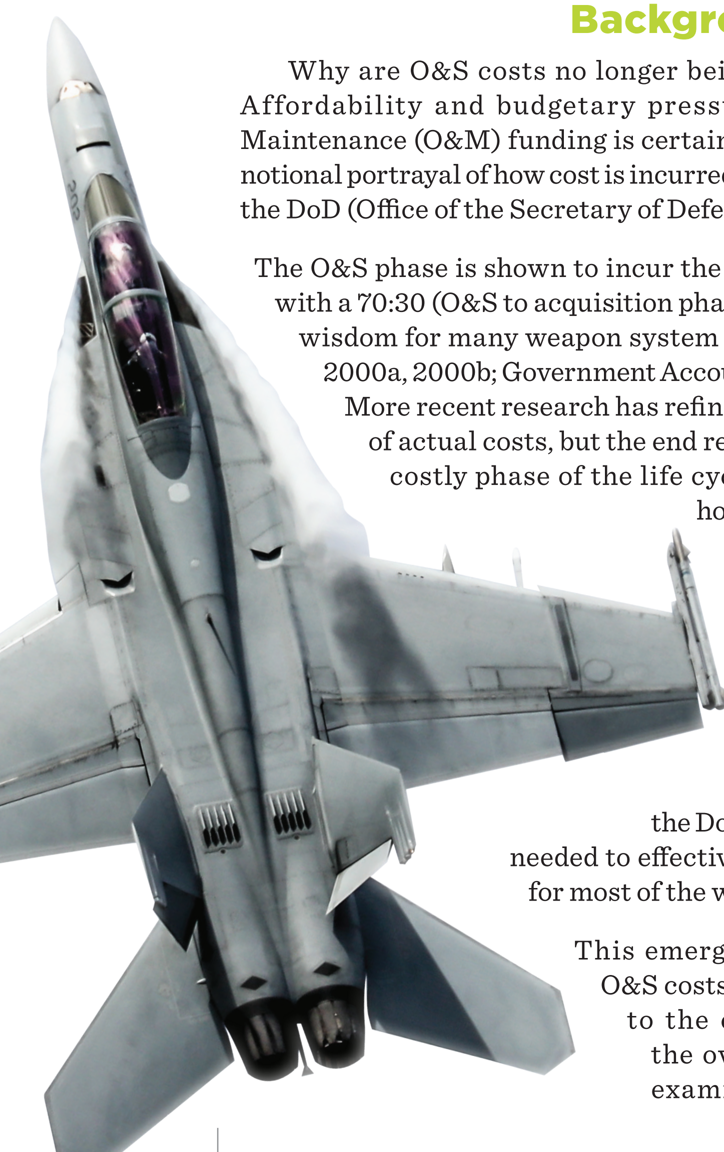
Operating and Support (O&S) costs are receiving increasing attention throughout the Department of Defense (DoD). Historically, defense acquisition has emphasized the near-term costs (i.e., research and development or procurement) at the expense of long-term affordability considerations manifested in a program's O&S costs (Ryan, Jacques, Ritschel, & Schubert, 2013). That paradigm is changing as legislation, such as the Weapon Systems Acquisition Reform Act (WSARA) of 2009, has accentuated the importance of the O&S phase (WSARA, 2009).

Background

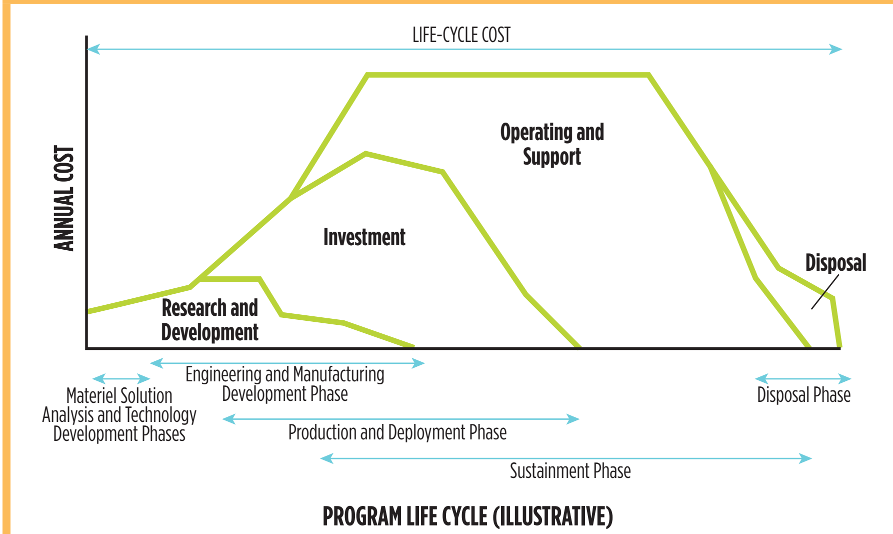


Why are O&S costs no longer being relegated to the background? Affordability and budgetary pressures on future Operations and Maintenance (O&M) funding is certainly part of the answer. Figure 1 is a notional portrayal of how cost is incurred by a typical weapon system within the DoD (Office of the Secretary of Defense [OSD], 2014).

The O&S phase is shown to incur the majority of the cost expenditures, with a 70:30 (O&S to acquisition phases) ratio provided as conventional wisdom for many weapon system types (General Accounting Office, 2000a, 2000b; Government Accountability Office [GAO], 2010, 2012). More recent research has refined the 70:30 ratio through analysis of actual costs, but the end result that O&S is typically the most costly phase of the life cycle for a majority of system types holds (Jones, White, Ryan, & Ritschel, 2014). Therefore, it is imperative to develop accurate O&S cost estimates to ensure long-term affordability for DoD weapon systems. Developing accurate estimates necessitates an understanding of O&S costs. However, the GAO recently reported that the DoD as a whole "lacks key information needed to effectively manage and reduce O&S costs for most of the weapon systems" (GAO, 2010, p. 4).

This emerging emphasis on understanding O&S costs is reflected in the literature. Prior to the enactment of WSARA in 2009, the overwhelming majority of studies examined the acquisition phases (i.e., research and development or procurement) of the life cycle while the O&S phase was rarely analyzed (Ryan, Jacques, Colombi, & Schubert, 2012). That historical fact is changing as a burgeoning post-WSARA literature on understanding O&S costs is developing as demonstrated in the works of GAO (2010, 2012), Ryan et al. (2013), Jones et al. (2014), and Boito, Light, Mills, and Baldwin (2016), among others. The change reflects a recognition that O&S is a key component to affordability where affordability is defined as an "assessment of whether or not the program's costs can be borne within an expected budget level" (Office of the Secretary of Defense [OSD], 2016, p. 19).

FIGURE 1. ILLUSTRATIVE SYSTEM CYCLE



Note. (OSD, 2014).

Affordability decisions require accurate O&S cost estimates. Developing these estimates necessitates that cost analysts be provided the needed tools and historical information to derive the most reasonable and credible O&S estimates for their respective programs. Thus, the purpose of this article is twofold. First, to provide a more refined understanding of the historical composition of the O&S Cost Element Structure (CES) costs in Air Force aircraft platforms, which can serve as a cross-check for cost analysts when developing estimates. Second, to identify statistical differences within the O&S CES construct across various Air Force aircraft categories.

The works of Jones et al. (2014) delineate the relative magnitude of costs between the life-cycle phases of platform categories, which serves as a useful heuristic to cost analysts. This article takes the next step by investigating the relative magnitude of the elements *within* the O&S CES for aircraft platforms. To accomplish this, an understanding of the CES is imperative. The Director, Office of the Secretary of Defense-Cost Analysis and Program Evaluation (OSD-CAPE) publishes an *Operating and Support Cost-Estimating Guide* that details the CES (OSD, 2014). This OSD-CAPE publication defines and outlines the six Level 1 elements of the CES. It further demarcates the six Level 1 CESs into Level 2 and Level 3 subelements (see Figure 2). This type of hierarchy enables the estimators to provide a structural approach to cost estimating that ensures completeness of potential O&S costs.

FIGURE 2. PARTIAL COST ELEMENT STRUCTURE HIERARCHY

SECOND-LEVEL/THIRD-LEVEL O&S COST ESTIMATING SYSTEM

1. UNIT-LEVEL MANPOWER
- 1.1 Operations
- 1.2 Unit-Level Maintenance
- 1.3 Other Unit-Level

2. UNIT OPERATIONS
- 2.1 Operating Material
- 2.2 Support Services
- 2.3 Temporary Duty
- 2.4 Transportation

3. MAINTENANCE
- 3.1 Consumable Materials and Repair Parts
- 3.2 Depot Level Reparables
- 3.3 Intermediate Maintenance (External to Unit-Level)
- 3.4 Depot Maintenance
- 3.5 Other Maintenance

4. SUSTAINING SUPPORT
- 4.1 System-Specific Training
- 4.2 Support Equipment Replacment and Repair
- 4.3 Sustaining/Systems Engineering
- 4.4 Program Management
- 4.5 Information Systems
- 4.6 Data and Technical Publications
- 4.7 Simulator Operations and Repair
- 4.8 Other Sustaining Support

5. CONTINUNING SYSTEMS IMPROVEMENTS
- 5.1 Hardware Modifications
- 5.2 Software Maintenance

6. INDIRECT SUPPORT
- 6.1 Installation Support
- 6.2 Personnel Support
  - 6.2.1 Personnel Administration
  - 6.2.2 Personnel Benefits
  - 6.2.3 Medical Support
- 6.3 General Training and Education
  - 6.3.1 Recruit and Initial Officer Training
  - 6.3.2 General Skill Training
  - 6.3.3 Professional Military Education

Note. (OSD, 2014)

Documenting relative magnitudes of costs incurred by CES for various platform categories provides the cost analyst a point of comparison for current and future O&S estimates. In other words, a cross-check provides credibility to an estimate. [Note: See the GAO (2009) *Cost Estimating and Assessment Guide* for discussion on the process to develop credible cost estimates.] For example, consider a cost analyst completing an estimate on a new fighter platform. If the estimate for CES 2.0 Unit Operations, is 5% of the total estimate cost while the historical interquartile range for fighter platforms is 14–22%, then a signal is provided to the estimator that more scrutiny is warranted in that element (e.g., perhaps missing components of CES 2.0 in the estimate).

Research Methodology

The data used in this research originates from the Air Force Total Ownership Cost (AFTOC) database. AFTOC is the Air Force's derivative of the Visibility and Management of Operating and Support Costs system, which allows for the extraction of actual O&S costs per cost element for the total Air Force inventory. Data span from 1996 (the first year of available AFTOC data) through 2016. The year 2017 is omitted due to the unavailability of actual costs for the entire year at the time of this analysis.

AFTOC provides both base-year and then-year dollars. Costs are normalized with OSD inflation indices to base-year 2016 in order to remove the effects of inflation.

Analysis is conducted at the Mission Design System (MDS) level. The initial pull from the AFTOC database contains 274 MDS where each aircraft model series or "variant" is a separate MDS. To be included in the final dataset, there must be a Total Active Inventory (TAI) of 10 in at least 1 year of cost data. Additionally, the analysis is limited to fixed-wing aircraft. Gliders, helicopters, ground unit vehicles, and other non-fixed-wing platforms are not included. The analysis is conducted on a Cost per Flying Hour (CPFH) basis for normalization in accordance with the literature (Boito, Keating, Wallace, DeBlois, & Blum, 2015). Therefore, the data are screened to exclude programs that are not incurring flying hours greater than 100 hours per year. Lastly, MDS that are phasing out with fewer than 10 years of available cost data are omitted; likewise, platforms phasing in with fewer than 5 years of available cost data are also omitted. This brings the total MDS for analysis to 52 (Table 1). The 52 remaining MDS are then grouped based on AFTOC designation into seven operational mission categories: Bomber, Fighter/Attack, Reconnaissance, Special Duty, Trainer, Transport/Tanker, and Unmanned Aerial Vehicle/Drone (UAV/Drone) (Table 2).

> **"Understanding where the majority of costs reside is important. This signals to cost analysts to allocate time and resources to developing these parts of the estimate.**

TABLE 1. DATASET SCREENING

Screen	Number Removed	Remaining MDS
AFTOC		274
MD TAI <10	128	146
Non-Fixed Wing	26	120
Flying Hours <100	30	90
Phase-in/out		52

TABLE 2. PROGRAMS SELECTED BY AIRCRAFT CATEGORY

Aircraft Categories/Platforms		
Reconnaissance	**Trainer**	**Fighter/Attack**
E-3B	AT-38B	A-10A
E-3C	T-1A	A-10C
E-8C	T-6A	F-15A
U-2S	T-37B	F-15B
Transport/Tanker	T-38A	F-15C
C-5A	T-38C	F-15D
C-5B	**Special Duty**	F-15E
C-5C	AC-130U	F-16A
C-17A	EC-130E	F-16B
C-21A	EC-130H	F-16C
C-130E	MC-130E	F-16D
C-130H	MC-130H	F-22A
C-130J	MC-130P	F-35A
HC-130N	WC-130H	F-117A
KC-10A	WC-130J	OA-10A
KC-135D	**Bomber**	**UAV/Drone**
KC-135E	B-1B	MQ-1B
KC-135R	B-2A	MQ-9A
KC-135T	B-52H	

Research Design

Once the final dataset is collected and screened, the data are standardized. All costs are normalized for Level 1 elements, Level 2 subelements, and Level 3 subelements by their respective CPFH. As shown in Equation 1, the CPFH is derived by dividing each element/subelement cost by the annual flying hours (annual flying hour data come from AFTOC by MDS). Each element/subelement cost is then aggregated to derive the total O&S cost for that respective year per flying hour in order to facilitate the development of individual ratios by CES element.

$$CPFH = \frac{Element\ or\ Sub\text{-}Element}{Annual\ Flying\ Hours}\ \text{Equation} \qquad (1)$$

Next, descriptive statistics are utilized to characterize the O&S cost data by calculating the means, medians, standard deviations and interquartile ranges (the difference between the 75th percentile and the 25th percentile) for individual platforms (MDS) and operational mission categories. The operational mission category designation for an MDS comes from AFTOC. For example, the B-1 is designated as a bomber in AFTOC. Then, testing is conducted between the categories to determine differences across all seven categories. The data are first tested for normality with the Shapiro-Wilk's test. Because the data are found to be nonnormal, the rank-based nonparametric Kruskal-Wallis test is employed. The null hypothesis of the Kruskal-Wallis test is that all medians are statistically the same; the alternative hypothesis is that at least one median is statistically different. A threshold of $\alpha = 0.05$ is employed. If a difference is detected, then the Steel-Dwass multiple comparison test identifies which medians are statistically different. The level of significance for the Steel-Dwass test is set at an $\alpha = 0.00238$. This alpha value is calculated utilizing the Bonferroni Correction, which limits the possibility of a Type I error. All tests are conducted in JMP Pro Version 12.

Results

Descriptive Statistics

The first set of results is portrayed in Table 3. It depicts the mean percentages, standard deviation, and interquartile ranges for the entirety of the aircraft examined in this analysis. The specific definition of each individual CES element in Table 3 can be found in the OSD-CAPE (2014) *Operating and Support Cost-Estimating Guide*. The final dataset is comprised of 52 aircraft platforms and 916 rows of aircraft data from AFTOC. Starting at CES Level 1, it shows that the first three elements—1.0 Unit-Level Manpower, 2.0

Unit Operations, and 3.0 Maintenance—constitute the largest percentage of the mean aircraft costs over the years of 1996–2016, consuming 82.38% of total expenditures. Understanding where the majority of costs reside is important. This signals to cost analysts to allocate time and resources to developing these parts of the estimate.

TABLE 3. AIRCRAFT O&S COST PERCENTAGES

Level	Mean	Std Dev	Median	IQR
1.0 Unit-Level Manpower	**31.46%**	**13.02%**	**31.97%**	**17.88%**
1.1 Operations	27.21%	16.69%	23.80%	25.44%
1.2 Unit-Level Maintenance	51.62%	17.32%	52.36%	22.93%
1.3 Other Unit-Level	21.17%	10.62%	18.73%	13.12%
2.0 Unit Operations	**19.58%**	**8.28%**	**18.25%**	**9.29%**
2.1.1 Energy (Fuel, POL, Electricity)	57.85%	23.27%	60.77%	33.52%
2.1.2 Training Munitions & Expendable Stores	4.11%	8.17%	0.03%	4.21%
2.1.3 Other Operational Material	6.69%	5.41%	5.49%	5.34%
2.2 Support Services	21.75%	20.51%	14.92%	23.31%
2.3 TDY	8.28%	6.99%	6.32%	7.38%
2.4 Transports	1.33%	3.34%	0.31%	0.85%
3.0 Maintenance	**31.35%**	**12.10%**	**30.31%**	**14.59%**
3.1.2 Repair Parts	13.74%	14.69%	10.18%	13.30%
3.2.1 DLR Fly	33.39%	25.55%	34.24%	50.03%
3.2.2 DLR NonFly	0.30%	1.27%	0.02%	0.14%
3.4.1 Aircraft Overhaul/Rework Depot Repair	15.33%	18.77%	6.80%	55.62%
3.4.2 Missile Overhaul/Rework Depot Repair	0.33%	1.43%	0.00%	0.00%
3.4.3 Engine Overhaul/Rework Depot Repair	6.54%	9.96%	1.56%	10.26%
3.4.4 Other Overhaul/Rework Depot Repair	0.55%	1.48%	0.07%	0.47%
3.5 Other Maintenance	0.30%	1.66%	0.00%	0.05%
3.6 Interim Contractor Support	0.73%	3.93%	0.00%	0.30%
3.7 Contractor Logistics Support	28.17%	79.41%	5.61%	66.13%
3.8 Other Contractor Support	0.61%	3.32%	0.00%	0.20%
4.0 Sustaining Support	**1.94%**	**2.80%**	**1.31%**	**1.87%**
4.2 Support Equipment Replacement & Repair	19.48%	26.07%	7.27%	30.39%
4.3 Sustaining/Systems Engineering	46.40%	35.15%	43.95%	71.27%
4.4 Program Management	5.67%	25.15%	0.00%	1.37%
4.6 Data & Technical Publications	9.59%	15.56%	1.02%	0.01%
4.7 Simulator Operations & Repair	15.17%	23.50%	0.54%	27.80%
4.8.1 Other Sustaining Support (Testing)	3.70%	10.38%	0.00%	0.11%
5.0 Continuing System Improvements	**9.05%**	**8.78%**	**6.60%**	**9.35%**
5.1 Hardware Modifications	83.13%	30.53%	95.02%	30.66%
5.2 Software Maintenance	16.87%	26.10%	2.36%	21.64%
6.0 Indirect Support	**6.62%**	**7.96%**	**4.28%**	**4.34%**
6.1 Installation Support	68.11%	24.69%	73.34%	27.58%
6.2 Personnel Support	5.45%	7.32%	3.67%	5.02%
6.3 General Training & Education	26.44%	25.23%	20.51%	27.72%

Note. DLR = Depot Level Repair; IQR = Interquartile Range; POL = Petroleum, Oil & Lubricants; Std Dev = Standard Deviation; TDY = Temporary Duty.

Analysis on the subelements to the six CES Level 1 elements delineates further where costs are being incurred. The subelement percentages are calculated in relation to their corresponding Level 1 element, rather than to the total O&S costs. For example, CES 2.1.1 Energy constitutes on average 57.85% of the total 2.0 Unit Operations costs. This allows for a quick assessment of cost elements that are large cost carries and directs the cost analyst's attention to that area.

Table 4 portrays the mean percentages (per Level 1 element) by aircraft category. These results create a top-level, relative-magnitude cross-check for analysts when developing O&S cost estimates. The categories' cumulative cost for the first three elements is as follows: Bomber—76.97%, Fighter/Attack—87.42%, Reconnaissance—86.49%, Special Duty—82.18%, Trainer—64.61%, Transports—84.73%, and UAV/Drone—83.27%. As noted previously, a significant amount of the O&S cost is incurred in these first three elements.

TABLE 4. MEAN PERCENTAGES BY CATEGORY TYPE

CES	Bomber	Fighter/Attack	Reconnaissance
1.0 Unit Manpower	25.85%	33.78%	31.83%
2.0 Unit Operations	15.17%	17.68%	14.13%
3.0 Maintenance	35.95%	35.96%	40.53%
Subtotal	76.97%	87.42%	86.49%
4.0 Sustaining Support	4.96%	1.57%	1.74%
5.0 Continuing System Improvements	16.06%	7.14%	9.00%
6.0 Indirect Support	2.01%	3.86%	2.77%
Total*	**100%**	**99.99%**	**100%**

Note. *Each category may not sum to 100% due to rounding.

The cost driver for the Bomber category is element 3.0 Maintenance, with an aggregate mean percentage of 35.95%. Continuing System Improvements (element 5.0) also constitutes a large percentage for the Bomber category at 16.06%. This result is driven by the newer bomber platforms (B-1B and B-2A), which reflects the complexity of their integrated software packages. The Fighter/Attack category is comprised of 15 platforms. The three fighter platforms (F-117, F-22, F-35) that are maintained by Contractor Logistics

Special Duty	**Trainer**	**Transport/Tanker**	**UAV/Drone**
42.82%	10.13%	32.18%	31.92%
15.29%	27.50%	22.72%	21.48%
24.07%	26.98%	29.83%	29.87%
82.18%	64.61%	84.73%	83.27%
0.84%	3.40%	1.79%	0.57%
10.05%	7.80%	8.84%	11.18%
6.92%	24.17%	4.64%	4.98%
99.99%	**99.98%**	**100%**	**100%**

Support (CLS) have a maintenance mean percentage of 46.4%, which is well above the Fighter/Attack category mean of 35.96%. This finding of higher CLS costs is consistent with previous literature analysis of contracted versus organic-maintained platforms (Ritschel & Ritschel, 2016). A second item of interest is that the two newest fighter platforms—the F-22A and the F-35A—are incurring costs one standard deviation away from the mean for element 5.0 Continuing System Improvements. This is important for cost analysts when conducting new platforms' estimates and may lead to the assumption that newer platforms will start incurring more O&S costs in element 5.0 in comparison to legacy aircraft.

The Reconnaissance category incurred the highest percentage for 3.0 Maintenance at 40.53% when compared to the six other categories. Similar to the Fighter/Attack category, this result is largely driven by the CLS subelement. Element 2.0 Unit Operations is found to be the lowest of all the categories. This result is driven by subelement 2.1.1. Energy, where the U-2S aircraft is approximately one standard deviation below the mean. According to the Air Force's U-2 Fact Sheet Internet page, the U-2S's "long and narrow wings give the U-2 glider-like characteristics" and its fuel-efficient General Electric F118-101 engine allows the aircraft to stay airborne for extended periods of time without refueling (Af.mil, 2015).

The Special Duty category is comprised of eight aircraft that are variants of the C-130 Hercules utilized for different missions. The Special Duty category incurred the highest ratio of element 1.0 Unit-Level Manpower with a mean of 42.82%. The OSD-CAPE (2014) *Operating and Support Cost-Estimating Guide* defines element 1.0 as the cost of operators, maintainers, and other support manpower assigned to operating units (may include military, civilian, and/or contractor manpower) (OSD, 2014). Therefore, Special Duty platforms tend to have more operating unit personnel when compared to other categories.

The Trainer category only accumulated 64.61% of total expenditures for the first three elements, while element 6.0 Indirect Support comprised 24.17%. Further investigation finds that 6.0 Indirect Support—specifically 6.3 General Training and Education—comprised 82.30% of the 24.17%. This is unique to the Trainer category because of the specific mission for the Air Force's Pilot Training Program utilizing these specific aircraft. Additionally, the Trainer category recorded the lowest mean percentage of the seven categories in 1.0 Unit-Level Manpower at 10.13%.

"As a result of the Kruskal-Wallis for all six CESs, the null hypothesis is rejected, and it is thereby determined that statistically significant differences exist between aircraft categories.

The UAV/Drone category is similar to manned aircraft in that the majority of its total expenditures (83.27%) occur in the first three elements. However, unlike other categories, the majority of element 2.0 Unit Operations (21.48%) is not consumed in 2.1.1 Energy, which makes it different from the other aircraft categories. Instead, the majority of the costs occur in element 2.2 Support Services. AFTOC provides examples of cost types that are incurred in 2.2 such as food services, lease costs for special facilities, and transportation of personnel and material to remote operating sites for operations, maintenance, or support.

Analysis of Categories

The second set of results compares the medians of the seven aircraft categories by CES. Individual tests are run for each of the six elements corresponding to Level 1 of the CES. The medians are compared for the categories by performing nonparametric testing: the Kruskal-Wallis and Steel-Dwass tests in JMP. As a result of the Kruskal-Wallis for all six CESs, the null hypothesis is rejected, and it is thereby determined that statistically significant differences exist between aircraft categories. Because the Kruskal-Wallis test does not identify where these differences occur, the Steel-Dwass test is conducted on each of the six CESs. Results from individual Steel-Dwass tests found multiple differences between aircraft categories within the six CESs. A summary count of the number of differences is provided in Table 5.

TABLE 5. CES DIFFERENCES BY AIRCRAFT CATEGORY

Level	Bomber	Fighter/Attack	Reconnaissance
1.0 Unit-Level Manpower	4	3	2
2.0 Unit Operations	2	4	4
3.0 Maintenance	4	3	3
4.0 Sustaining Support	5	4	2
5.0 Continuing System Improvements	4	2	1
6.0 Indirect Support	5	4	5
Total	24	20	17

Table 5 conveys how many times a category was statistically different from another category per cost element. The Trainer category was the most significantly different category, with 32 instances. In contrast, the UAV/Drone category resulted in the least statistically different results when compared across the other six categories, with a total of 15 statistically different instances. For any given CES, the maximum amount of times a difference can be found for any given category is six because there are seven categories in total. This occurs four times. Three of the four occurrences are in the Trainer category (CES 1.0, CES 2.0, and CES 6.0). This provides caution to the cost analyst that the trainer aircraft O&S profile is very different than other aircraft platforms. The only other instance where complete divergence is found is the Transport/Tanker category at CES 3.0 Maintenance.

As shown in Table 5, identification of differences is important. Understanding the direction of these differences is also useful. Table 6 is a color portrayal of the Steel-Dwass test for all six OSD-CAPE CESs. The categories that are highlighted in red have median values that statistically incur more expenditures in the respective element per total O&S cost when compared to the category highlighted in gray. The categories that are highlighted green are statistically indistinguishable when compared to the corresponding category highlighted in green.

Several interesting observations may be drawn from Table 6. First, while the mix of platform categories where differences are found varies, the number of differences are consistent across CES 1, 2, and 3. Second, CES 5.0 Continuing System Improvement, has the most platform categories where

Special Duty	Trainer	Transport/Tanker	UAV/Drone
5	6	3	1
4	6	5	3
5	5	6	3
5	5	4	5
2	4	2	0
5	6	4	3
26	**32**	**24**	**15**

statistically indistinguishable median values occur. Lastly, CES 6.0 Indirect Support, has the largest number of divergences. This result is reasonable given the nebulous nature of indirect support allocations. As detailed in the CAPE *Operating and Support Cost Estimating Guide*, indirect support costs are installation and personnel costs allocated on "a per capita or some other basis," which can be ambiguous for cost estimators (OSD, 2014, pp. 6–16).

Discussion and Conclusions

The growing importance of O&S consideration in the DoD is apparent. It is reflected in legislation such as WSARA and the subsequent product support assessment, which cautioned that the "lack of an affordability requirement and adequate visibility of operating and support costs has been a long-standing barrier to effectively assessing, managing, and validating the benefits or shortcomings of product support strategies" (DoD, 2009, p. 13). At the same time, high-profile programs such as the F-35 have received significant attention in the media and the DoD for their large O&S cost projections (Capaccio, 2017; Mizokami, 2017). Meanwhile, divestiture decisions within the DoD for the U-2/RQ-4 Global Hawk are framed not only by relative capability performance of the platforms, but also by their expected O&S costs (Pomerleau, 2016).

Thus, understanding the historical nature of O&S costs is a necessary step to help bridge the knowledge gap and provide informed analysis on affordability considerations. Cost estimates are only as good as the data upon which they are based. Coupling the work of Jones et al. (2014), which delineated the percentage of life-cycle cost by phase, with the breakdown of the O&S phase by percentage of CES presented here, is a positive step towards improving the DoD's estimating capability. Future cost estimates can then be improved through new research into developing predictive (perhaps parametric) models for each CES element.

TABLE 6. RESULTS OF STEEL-DWASS TESTS

1.0 Unit-Level Manpower

Level	Level
Transport/Tanker	Trainer
Special Duty	Fighter/Attack
Special Duty	Bomber
Fighter/Attack	Bomber
Transport/Tanker	Bomber
UAV/Drone	Trainer
Special Duty	Reconnaissance
Special Duty	UAV/Drone
Bomber	Trainer
Reconnaissance	Trainer
Special Duty	Trainer
Special Duty	Transport/Tanker
Fighter/Attack	Trainer
Reconnaissance	Bomber
UAV/Drone	Bomber
UAV/Drone	Transport/Tanker
UAV/Drone	Reconnaissance
Transport/Tanker	Reconnaissance
Reconnaissance	Fighter/Attack
UAV/Drone	Fighter/Attack
Transport/Tanker	Fighter/Attack

2.0 Unit Operations

Level	Level
Trainer	Fighter/Attack
Trainer	Special Duty
Transport/Tanker	Special Duty
Transport/Tanker	Reconnaissance
Trainer	Reconnaissance
Transport/Tanker	Bomber
Trainer	Bomber
Transport/Tanker	Fighter/Attack
UAV/Drone	Special Duty
Trainer	UAV/Drone
Fighter/Attack	Reconnaissance
Fighter/Attack	Special Duty
Trainer	Transport/Tanker
Fighter/Attack	Bomber
UAV/Drone	Fighter/Attack
UAV/Drone	Reconnaissance
UAV/Drone	Bomber
Special Duty	Reconnaissance
Special Duty	Bomber
UAV/Drone	Transport/Tanker
Reconnaissance	Bomber

3.0 Maintenance

Level	Level
Transport/Tanker	Special Duty
Transport/Tanker	Trainer
UAV/Drone	Special Duty
Bomber	UAV/Drone
Reconnaissance	Trainer
Reconnaissance	Transport/Tanker
Bomber	Trainer
Reconnaissance	Special Duty
Bomber	Special Duty
Fighter/Attack	Transport/Tanker
Fighter/Attack	Trainer
Bomber	Transport/Tanker
Fighter/Attack	Special Duty
UAV/Drone	Trainer
Trainer	Special Duty
Reconnaissance	Fighter/Attack
UAV/Drone	Transport/Tanker
Reconnaissance	Bomber
UAV/Drone	Reconnaissance
Fighter/Attack	Bomber
UAV/Drone	Fighter/Attack

4.0 Sustaining Support

Level	Level
Trainer	Special Duty
Trainer	Fighter/Attack
Transport/Tanker	Special Duty
Trainer	Reconnaissance
Bomber	UAV/Drone
Bomber	Reconnaissance
Special Duty	UAV/Drone
Trainer	UAV/Drone
Bomber	Special Duty
Fighter/Attack	Special Duty
Fighter/Attack	UAV/Drone
Transport/Tanker	UAV/Drone
Bomber	Fighter/Attack
Trainer	Transport/Tanker
Bomber	Transport/Tanker
Transport/Tanker	Reconnaissance
Special Duty	Reconnaissance
Reconnaissance	Fighter/Attack
Trainer	Bomber
Transport/Tanker	Fighter/Attack
UAV/Drone	Reconnaissance

TABLE 6. RESULTS OF STEEL-DWASS TESTS (CONTINUED)

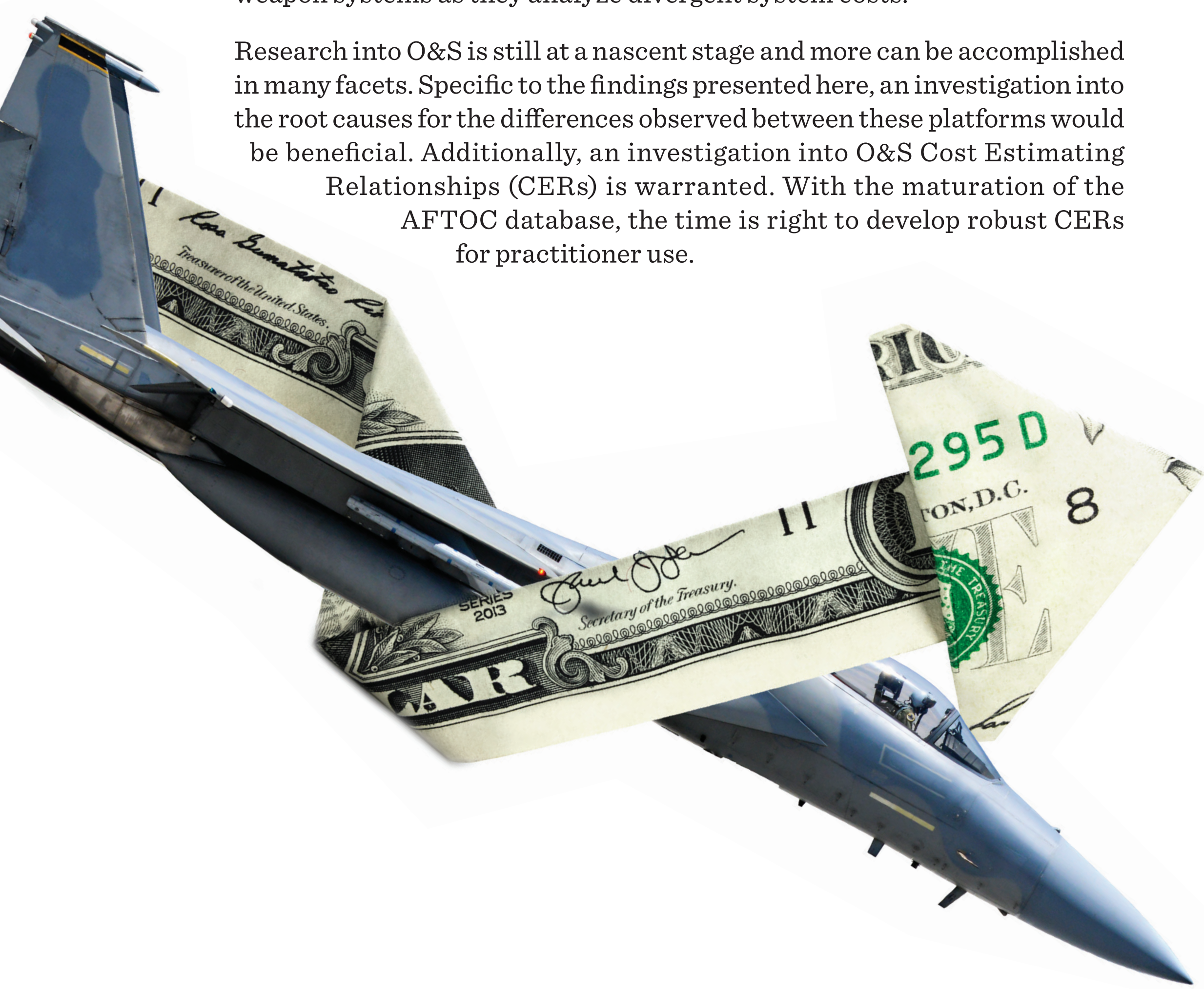
5.0 Continuing System Improvements		6.0 Indirect Support	
Level	Level	Level	Level
Transport/Tanker	Trainer	Trainer	Fighter/Attack
Bomber	Reconnaissance	Transport/Tanker	Bomber
Special Duty	Trainer	Fighter/Attack	Bomber
Bomber	Special Duty	Trainer	Special Duty
Bomber	Trainer	Transport/Tanker	Reconnaissance
Bomber	Fighter/Attack	Trainer	Reconnaissance
Bomber	Transport/Tanker	Special Duty	Fighter/Attack
Special Duty	Fighter/Attack	Trainer	Bomber
UAV/Drone	Transport/Tanker	Special Duty	Reconnaissance
UAV/Drone	Fighter/Attack	Special Duty	Bomber
UAV/Drone	Trainer	UAV/Drone	Bomber
Reconnaissance	Fighter/Attack	UAV/Drone	Reconnaissance
Special Duty	Reconnaissance	Trainer	UAV/Drone
UAV/Drone	Reconnaissance	Special Duty	Transport/Tanker
UAV/Drone	Special Duty	Fighter/Attack	Reconnaissance
Transport/Tanker	Fighter/Attack	Trainer	Transport/Tanker
Transport/Tanker	Reconnaissance	Transport/Tanker	Fighter/Attack
UAV/Drone	Bomber	UAV/Drone	Fighter/Attack
Trainer	Reconnaissance	Reconnaissance	Bomber
Transport/Tanker	Special Duty	UAV/Drone	Transport/Tanker
Trainer	Fighter/Attack	UAV/Drone	Special Duty

Through analysis of 52 aircraft platforms across seven operational mission categories, this research informs DoD portfolio managers and cost analysts as to how cost is incurred in the OSD-CAPE CES. The research finds that 82.38% of all O&S costs are incurred in the first three elements: 1.0 Unit-Level Manpower, 2.0 Unit Operations, and 3.0 Maintenance. Identifying these large cost carriers is important to the cost analyst when it comes to allocating time and resources for developing estimates. For affordability assessments, it highlights the areas that warrant additional scrutiny. Additionally, the delineation of costs discovered between the various CESs and the measures of dispersion provided are invaluable to cost professionals. At a minimum, it provides a relative-magnitude cross-check as estimates are developed.

“Not only has this type of analysis not been previously explored in the O&S arena, but it provides context for portfolio managers into identifying differences between categories of weapon systems as they analyze divergent system costs.

The second portion of the research statistically tested the relationships between seven aircraft category's CES elements in comparison to one another. Trainers are found to be the most significantly different category with 32 instances, while the UAV/Drone category had the least amount with only 15 statistically different instances. This information is valuable to cost estimators and stakeholders across the DoD. Not only has this type of analysis not been previously explored in the O&S arena, but it provides context for portfolio managers into identifying differences between categories of weapon systems as they analyze divergent system costs.

Research into O&S is still at a nascent stage and more can be accomplished in many facets. Specific to the findings presented here, an investigation into the root causes for the differences observed between these platforms would be beneficial. Additionally, an investigation into O&S Cost Estimating Relationships (CERs) is warranted. With the maturation of the AFTOC database, the time is right to develop robust CERs for practitioner use.



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Author Biographies

1st Lt Garrett B. O'Hanlon, USAF,

is a cost analyst at the Air Force Life Cycle Management Center, Hanscom Networks Infrastructure Division, at Hanscom Air Force Base, Massachusetts. 1st Lt O'Hanlon holds a Bachelor of Science (BS) in Economics from the Air Force Academy, and a Master of Science (MS) in Cost Analysis from the Air Force Institute of Technology (AFIT).

(E-mail address: Garrett.OHanlon@us.af.mil)

Dr. Jonathan D. Ritschel

is an assistant professor of cost analysis in the Department of Systems Engineering and Management at AFIT. He received his BBA in Accountancy from the University of Notre Dame, his MS in Cost Analysis from AFIT, and his PhD in Economics from George Mason University. Dr. Ritschel's research interests include public choice, the effects of acquisition reforms on cost growth in DoD weapon systems, and economic institutional analysis.

(E-mail address: jonathan.ritschel@afit.edu)

Dr. Edward D. White

is a professor of statistics in the Department of Mathematics and Statistics at AFIT. He received his BS in Mathematics from the University of Tampa, an MAS from The Ohio State University, and PhD in Statistics from Texas A&M University. Dr. White's primary research interests include statistical modeling, simulation, and data analytics.

(E-mail address: edward.white@afit.edu)

Capt Gregory E. Brown, USAF,

is the chief of cost analysis, Fighter-Bomber Directorate, Air Force Life Cycle Management Center, Wright-Patterson Air Force Base, Ohio. He holds a BA in Economics and a BS in Business-Finance from Colorado State University, a Graduate Certificate in Applied Statistics from Penn State University, and an MS in Cost Analysis from AFIT.

(E-mail address: Gregory.Brown.34@us.af.mil)