ACTIVE DUTY C-17 AIRCRAFT COMMANDER FUEL EFFICIENCY METRICS AND GOAL EVALUATION

THESIS

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Abstract

As the largest consumer of fuel in the Department of Defense, the Air Force continually looks for new ways to advocate aircraft fuel efficiency. Optimal metrics and goals are essential components to encourage efficient flying. This research examined two metrics through quantitative statistical and qualitative criteria analysis, picked the most effective metric, and utilized Goal Setting Theory (GST) to couple the metric with an attainable goal aimed at making Aircraft Commander's (AC's) more fuel efficient. The first metric, $M1_{Cargo\ Adjusted}$, uses current sortie planning factors and adjusts these for payload. The second metric, $M2_{Regression}$, uses regression analysis based on flight time and cargo to determine predicted sortie fuel consumption. It was determined that $M1_{Cargo\ Adjusted}$ provided a more robust measure of efficiency that would provide AC's a locus of control over metric results. $M1_{Cargo\ Adjusted}$ was then paired with GST foundational principles of goal specificity, difficulty, and commitment and translated into an efficiency goal aimed at influencing AC behavior and optimizing long-term efficient fuel use.

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Michael J. Schumacher

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ACTIVE DUTY C-17 AIRCRAFT COMMANDER FUEL EFFICIENCY METRICS AND GOAL EVALUATION

I. Introduction

From fiscal year 2014 to fiscal year 2015, the Air Force (AF) experienced a decrease within the Operation and Maintenance (O&M) budget. Although the total force (Active Duty, Guard, and Reserve) garnered a slight increase in the Flying Operations budget ($0.3B), it came at a cost to other O&M components such as Civilian Pay (-$0.2B) , Installation Support (-$0.6B), Training and Recruiting (-$0.2B), and Mobility Forces (-$0.1B) (Air Force Financial Management and Comptroller, 2015). This stagnation is directly related to sequestration and its lasting effects. Cost savings must be realized in all possible areas to mitigate the impact of cuts on mission readiness. One potential area for cost savings is aircraft fuel efficiency.

This thesis focuses on active duty, C-17 Aircraft Commander (AC) fuel efficiency. Specifically, the researcher compares two fuel efficiency metrics (Reiman, 2014:52 and AMC/A3F, 2014:22) to assess their validity and applicability in measuring AC efficiency. Additionally, using goal-setting theory (GST) (Locke and Latham:1990), and the selected metric, a fuel efficiency goal is set for Air Force (AF) AC's to be used in a follow-on motivational experiment.

For the purposes of this paper, Metric 1 and Metric 2 are the focus of analysis will be referred to as $M1_{\text{Cargo Adjusted}}$ and $M2_{\text{Regression}}$. The basis for $M1_{\text{Cargo Adjusted}}$ is found in work by Reiman (2014:52) at the Air Force Institute of Technology that looked at optimal route planning and effective fuel efficiency metrics. $M2_{\text{Regression}}$ is used by Air Mobility Command Fuel Efficiency Office (AMC/A3F, 2014:22) using regression analysis. The basis of $M2_{\text{Regression}}$ is to provide "The pounds of fuel burned per flight hour; referred to as burn rate efficiency"

(AMC/A3F, 2014:6) in order to compare total fiscal year fuel consumption and efficiency trends.

Background

It is important to gain a macro perspective surrounding the need for fuel efficiency. This section will describe the current financial and readiness state of the Air Force (AF), the amount of fuel consumed in the AF, and applicable sections of the AF Energy Strategic Plan. A discussion of these three areas will provide a better understanding of the need for better fuel efficiency and the potential savings associated with this research.

The AF is becoming a smaller, more cost-effective service. Sequestration, voluntary separation programs, and force shaping have constantly reminded Airmen and government civilian employees of the constrained fiscal environment. In September 2013, the Chief of Staff of the Air Force, General Welsh, stated, "Within three to four months, many of our flying units will be unable to maintain mission readiness…we also will probably have to cut up to 550 aircraft, about 9 percent of our inventory" (Pellerin:2013). Due to the length of sequestration, the full effect has yet to be seen and could lead to further reductions.

A major contributing factor to this problem is AF fuel consumption. According to the AF Energy Strategic Plan (USAF, 2013:6), the AF accounts for nearly half of the Department of Defense (DoD) energy consumption, with 81% of that being used in aviation. Further, heavy aircraft fuel expenditures account for approximately 4 billion dollars each year. A small percentage decrease in fuel usage will contribute significant savings and help meet AF priorities.

AF strategic energy priorities support research pertaining to the consumption issue. Two priorities will be addressed (USAF, 2013:15) including: 1) Reduce Demand: “Increase energy efficiency and operational efficiency for AF systems and processes without losing mission capabilities", and 2) Foster an Energy Aware Culture: "Integrate communication efforts using training and education opportunities to increase awareness of energy impacts to mission." Analyzing fuel efficiency metrics, determining efficiency goals, and influencing AC's to attain those goals has the potential to both reduce demand and change the culture of fuel usage in the AF.

Problem Statement

> *Ensuring AF AC's are focused on fuel efficiency is paramount to sustaining resources and reducing costs. Currently, fuel efficiency metrics are not utilized to influence behavior while flying. Without a well-defined metric in place for efficiency, goals cannot be set or attained. The researcher will compare two efficiency metrics, select the most useful one, and use that metric to set an efficiency goal for all AF AC's. This goal will be the cornerstone for a follow-on experiment assessing the effect of publicly or privately provided feedback on AC's fuel efficiency.*

Research Questions

1. *From a metric criteria perspective, is* $M1_{\text{Cargo Adjusted}}$ *or* $M2_{Regression}$ *a more adequate measure of fuel efficiency for Aircraft Commanders (AC's)?*

2. *From a metric comparison perspective, how do Wings/Individual AC's perform?*

3. *Which metric should be provided to AC's and for what purpose?*

4. *Using goal theory literature, how can the chosen metric be presented as a goal for AC's? What efficiency goal can be set for AF AC's?*

Assumptions

Various assumptions must be made in order to properly focus the research. These include: 1) fuel tracker data will be correctly filled out by AC's and entered into the tracking system, 2) the effects of Advanced Computer Flight Plan (ACFP) wind and temperature errors are normally distributed with a mean of zero, 3) tail degrade data in ACFP is accurate, and 4) Air Traffic Control (ATC) biases placed in ACFP by flight managers are accurate. A closer look at these four assumptions will lay the foundation for the research and provide the reader an understanding of factors impacting the study.

First, data accuracy and integrity constitute a key assumption. AC's are responsible for manually tracking fuel consumption and inputting that data into the Fuel Data Tracker for analysis. The possibility exists, as in all data, that the information is erroneously entered which could skew the comparison results. Although the assumption of accuracy is made, outliers will be addressed in the research to help control for entry errors.

Next, an assumption exists that ACFP errors for wind, temperature, and tail degrade adjustments are normally distributed with a mean of zero. ACFP allows flight managers to add fuel for instances of uncertain weather. The assumption is that the current flight manager policies for adding fuel are adequate and do not skew the results.

Finally, ATC biases are assumed to be accurate. Flight managers attempt to control for ATC issues such as hold-down fuel at certain locations. The assumption is that the hold-down fuel is warranted and not excessive. Too much allotted fuel against the ACFP plan could significantly benefit an AC from an efficiency perspective.

The aforementioned assumptions account for factors outside of the researcher's control and give a framework for performing the experiment and analyzing the data. While all factors cannot be controlled and accounted for, these assumptions set boundaries for the research. These assumptions will be revisited and reevaluated throughout the study.

Limitations

Ample opportunity exists for the scope to become too large in such a restricted timeframe. Identifying limitations will ensure the scope is controlled and a quality product is presented that can be utilized for follow-up research.

The first limitation is that AC's in training status will not be evaluated; the focus will be on Special Assigned Airlift Missions (SAAM). Due to the conflicting priorities of training requirements and safety of flight versus fuel efficiency, it was determined that training missions should be a separate research project. A specific, defined mission set allows for concise evaluation of each metric and provides a clear comparison.

Another limitation is that only active duty Boeing C-17A Globemaster will be evaluated. It was chosen because it has the highest airlift fleet fuel consumption and thus, a large data set. Additionally, Guard and Reserve Wings will not be evaluated. Cultural and procedural differences may exist that would be difficult to standardize with the active duty components.

Methodology

Statistical analysis comprises the majority of the methodology in this thesis. Regression analysis, comparison of means, trend analysis, and analysis of variance are some of the methods that will be utilized in determining the best metric to use. Additionally, qualitative analysis is used based on effective metric criteria using weighted decision matrices. Finally, analysis of GST literature provides the required techniques for designing and selecting a goal.

Follow-On Experiment

A brief and tentative description of the follow-on experimental research is important to understand prior to the literature review and methodology sections. To motivate efficient flying, classic GST provides a solid framework for research. An applicable example of GST comes from an article from Latham and Locke (1979) in which the researchers evaluated logging companies to find truck-loading efficiencies. Despite managerial encouragement to fully load the trucks, the drivers only averaged 60% capacity due to fear of being monetarily fined for being overweight. Management came to an agreement with the union that the researchers would set a goal of 95% and post each driver's accomplishment toward that goal but would take no actions, positive or negative, based on truck loads. They utilized goal-setting methods coupled with feedback to influence logging crew performance. With the implementation of goal theory, loads averaged 80% and 70% the first two months and then settled at approximately 94% for the remainder of the evaluation period.

A similar experiment will be performed on active duty C-17 AC's. Appropriate goals will be set based on an effective metric and feedback will be provided through multiple methods (private and public). The feedback will provide a performance measurement and should influence how the AC's perform and how much fuel is expended.

Conclusion

The AF needs a fuel efficiency metric that provides a locus of control to AC's that makes them believe they have the power to influence the results of the metric. Once a metric is established that accomplishes this, goals can be set and behavior influenced through motivation. The end result of this sequence results in AF AC's flying more efficient sorties and ultimately influencing budgetary spending.

II. Literature Review

Introduction

A significant amount of previously published research primarily focuses on alternative fuels, aircraft modification, cargo compartment utilization, tankering adjustments, and efficient route planning. This section will focus on the literature that pertains to fuel efficiency in the AF and the theories that are addressed and utilized in the research. Specifically, a functional review will examine strategic energy priorities (DoD and AF), previous efficiency research, efficiency metric construction, and GST literature.

Strategic Energy Priorities

The strategic requirement for fuel efficiency can be found in DoD and AF publications. In the "Defense Budget Priorities and Choices Fiscal Year 2014", energy is stressed as an important investment area to reduce risk and cost associated with consumption (Department of Defense, 2014:7). Emphasizing the importance of efficiency, the publication states:

> DoD is the single largest consumer of energy in the U.S., spending about $22 billion per year on energy. Additionally, energy needs continue to constrain the U.S. military's operational capabilities. Large energy consumption creates long logistic tails that are vulnerable to attack. This energy demand constrains the capabilities of our ground, air, and sea forces at home and abroad. For example, refueling needs limit the abilities of our soldiers, range of our aircraft, and the time-on-station of our ships. (Department of Defense, 2014:31)

The "Air Force Energy Strategic Plan" discusses the need for, and priority of, fuel efficiency in the Air Force. Four priorities are detailed in the plan including: "improve resiliency, reduce demand, assure supply, and foster an energy aware culture." Although all of the priorities relate to fuel efficiency in some manner, the second priority of demand reduction is most relevant in this research. Specifically, it sets a goal to reduce fuel consumption with an objective to garner a 10% efficiency improvement by 2020 (Department of the Air Force, 2013:13).

Previous Fuel Efficiency Research

A significant amount of research has been completed in response to the fuel consumption issue in the DoD and AF. The bulk of the research to date has focused on technical responses to this need. While an in-depth critique will not be performed on these initiatives, it is important to give the reader a brief synopsis of work that has been done outside of the behavioral realm.

Alternative fuels have received significant attention in recent years, both in the DoD and civilian sector. For example, Heliman and Stratton (2014:1) contrasted various alternative fuels for feasibility. Daggett et al. (2006:1-8) evaluated the possibility of replacing or supplementing current fuels with synthetic options. Finally, Nicholson’s (2009:1-61) work was primarily focused on cost-effectiveness of replacing petroleum-based fuel with biodiesel. Fuel efficiency is a constant point of evaluation in the study of alternative fuels. The tradeoffs with various alternative fuels are important when determining the feasibility of replacement.

Aircraft Modification is another area that has received attention from an efficiency standpoint. The KC-135 provides a sound illustration of this focus area. Multiple design changes in the cargo compartment of the KC-135 over a 50 year period have left the aircraft with a shifting center-of-gravity issue contingent on the amount of fuel in the aircraft. In response to this problem, excess fuel was added. Using additional fuel to control the center-of-gravity is extremely inefficient and expensive. Morrison (2010) and McKee (2013) evaluated potential fixes to this issue including adding cockpit armor or specially designing weights to properly balance the aircraft without using added fuel.

In addition to aircraft design changes, operational changes have also exhibited the potential for savings from an efficiency standpoint. Reiman et al. (2013) from the Air Force Institute of Technology (AFIT) examined space utilization in an aircraft's cargo compartment. They evaluated the method in which 463L cargo pallets were being utilized and evaluated whether any changes could be made to the pallet system to optimize cargo capacity on aircraft. Ultimately, it was determined that modifying the pallets to make them stackable optimized the space and allowed more effective loading of cargo, and thus, more effective flying from a fuel efficiency perspective.

Metric Development

The next area of review will describe previously developed fuel efficiency metrics. $M1_{\text{Cargo Adjusted}}$ takes existing fuel tracker data collected at AMC and transforms the data into an efficiency score through excel formulas. The metric formulation adjusts fuel consumption as planned by ACFP for the actual payload. Details of the underlying formulations can be found in Appendix B while the Excel® methodology to compute the metric can be found in Chapter III.

$M2_{\text{Regression}}$, developed by AMC/A3F (2014), is regression-based fuel efficiency metric. To obtain a predicted fuel efficiency value, five independent variables are used in the regression including cargo weight (lbs), cargo weight squared (lbs^2), flight time (hrs), flight time squared (hrs^2), and cargo weight multiplied by flight time (lbs X hrs). Cargo weight also includes onloaded and offloaded in flight fuel. The dependent variable is total fuel consumed (lbs). The equation that AMC utilizes for all fuel efficiency regressions is shown in Equation 1(2014:22) and specific coefficient values are shown in :

$$Fuel\ Consumption = m_1\ x\ lbs\ x\ hrs + m_2\ x\ hrs^2 + m_3\ x\ lbs^2 + m_4\ x\ lbs + m_5\ x\ hrs + m_6 \quad (1)$$

Table 1: C-17 SAAM Regression Coefficients (AMC/A3F, 2014)

Intercept	707.94
Weight	67.29
Weight Squared	-0.56
Time	16414.87
Time Squared	-27.80
Weight * Time	30.13

A metric criteria model will be employed in this thesis to compare, contrast, and judge the metrics to determine which metric should be used for future motivational research. The Air Force Sustainment Center published "The Metrics Handbook" which provides a comprehensive guide on evaluating and selecting appropriate metrics. The definition of metrics, attributes of effective metrics, and the metric development process will all provide insight into how the researcher will evaluate the metrics in the remaining chapters of this thesis.

Beginning with the definition of metrics, Nowak states that they are, "a measurement made over time, which communicates vital information about the quality of a process, activity, or resource…continuous improvement of the way we do business" (Nowak, 1992:2-1). With the definition set, the handbook defines several attributes that are essential to effective metrics (Nowak, 1992:2-1):

1) It is accepted as meaningful to the customer.
2) It tells how well organizational goals and objectives are being met through processes and tasks.
3) It is simple, understandable, logical, and repeatable.
4) It shows a trend.
5) It is unambiguously defined.
6) Its data is economical to collect.
7) It is timely.
8) It drives the appropriate action.

Finally, Nowak (1992:3-1) describes the development process in terms of a "metric package." This package consists of the operational definition, the measurement (data), and presentation of the metric. Using this package in an 8-step development process allows full evaluation and implementation of a particular metric.

For the purposes of this thesis, the researcher will evaluate each metric based on the Metric Handbook model (slightly adjusted), determine the most effective metric for the purposes of future motivational research, and provide a development outline to properly guide future research with the selected metric.

Goal-Setting Theory

Once the metrics are evaluated and the appropriate one selected, an effective fuel efficiency goal must be set. GST has a long history and has proven effective in motivating individuals and teams from a performance perspective. Over 400 laboratory studies have been performed studying GST:

> These studies showed that specific, high (hard) goals lead to a higher level of task performance than do easy goals or vague, abstract goals such as the exhortation to ‘‘do one’s best.’’ So long as a person is committed to the goal, has the requisite ability to attain it, and does not have conflicting goals, there is a positive, linear relationship between goal difficulty and task performance. Because goals refer to future valued outcomes, the setting of goals is first and foremost a discrepancy creating process. It implies discontent with one’s present condition and the desire to attain an object or outcome (Locke, E. and G.P. Latham, 2006:265).

The background of GST requires a look at the definition of goals, core model findings, goal attributes (content/intensity), moderators, goal mechanisms, and feedback. Each of these is pertinent to understand in order to set a realistic, attainable goal for C-17 AC’s. Beginning with the definition, Latham and Locke (2002:705) describe a goal as “the object or aim of an action…to attain a specific standard of proficiency, usually within a specified time limit.” This definition is frequently repeated throughout the literature and suggests that a goal focuses an individual (or team) toward a specific action with the aim of achieving a higher standard or performance level than previously attained.

With the definition set, Figure 1 provides an illustration of the core model components of GST that will be discussed, as well as their relationship to each other (Latham and Baldes, 1975:123). In summary, the model demonstrates that ***specific, difficult goals*** will lead to performance, satisfaction, and commitment in a cyclical fashion based on moderating variables and mechanisms. GST posits that specific, difficult goals lead to higher performance results than easy, vague goals. "Do your best" goals contain broad ranges of acceptable performance leading to ambiguity in what a worker believes is satisfactory (Locke, 1968:157 and Locke et al., 2002:706).

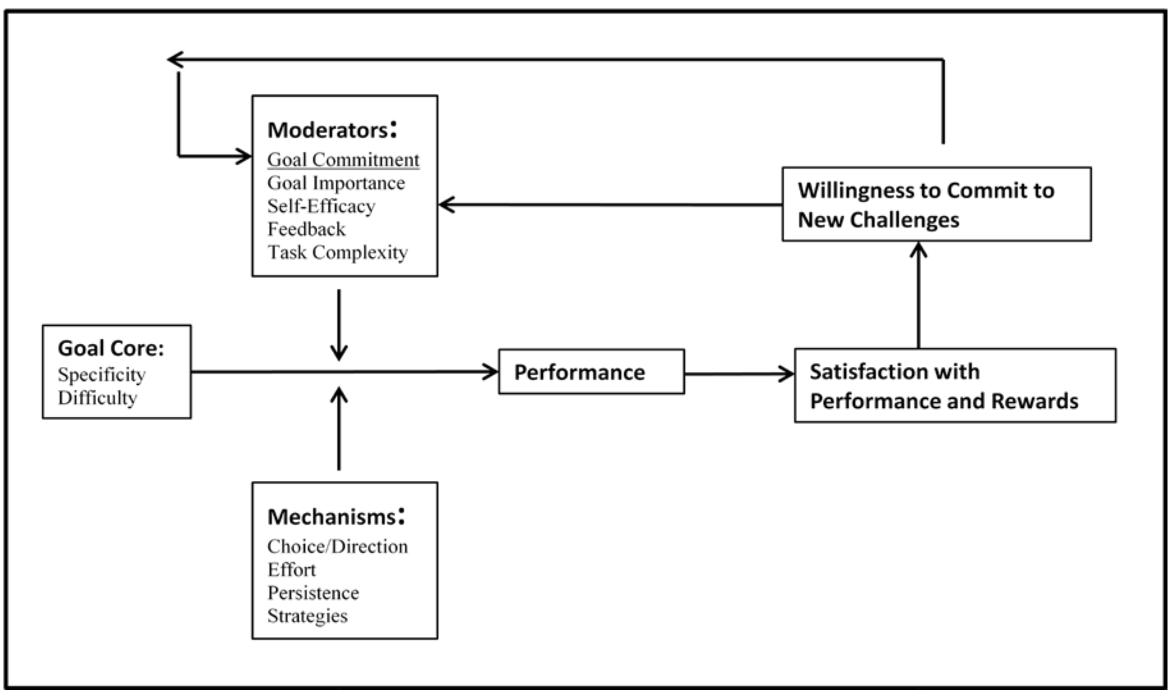


Figure 1: Components of GST

Two broad attributes exist within GST: content and intensity. Content includes the attributes of specificity and difficulty while intensity is primarily concerned with goal commitment. Beginning with specificity, Locke describes it as being attained "through quantification (increase sales by 10%) or enumeration (here is a list of tasks to be accomplished). Thus it reduces *variance* in performance, providing the individual can control performance" (1996:118). Goal specificity alone does not lead to better results. Variations in difficulty exist regardless of specificity. A goal can be specific and easily reached which does not fit with the tenet of GST that requires goal difficulty as a performance facilitator. Specificity provides clarity to the individual tasked which, in turn, reduces variability and uncertainty (Locke et al., 1989). Higher performance levels cannot be achieved absent specificity, but specificity alone does not increase performance.

To illustrate an example range of goal specificity, consider the following four goals from a division manager of sales (Locke et al., 1989:272):

1. Improve division profits
2. Increase division profits
3. Increase profits by 10% or more
4. Increase profits by exactly 15%

The desired result when dealing with specificity is to get as close to option four as possible. The literature cautions against option three as it is essentially setting a low goal and then asking for a vague "do your best" goal which is counter to GST. It is more optimal to be precise in setting a difficult goal and allowing the individual or team to self-set a higher goal.

The next specific content-related attribute involves goal difficulty which relates individuals or teams with a particular task or goal. Ability and experience are key individual factors as they make the level of goal difficulty different for each person. "The higher the absolute level of the goal the more difficult it is for a person to achieve it" (Latham and Locke, 1991:214). Figure 2 demonstrates the results of 12 studies that examined the relationship between goal difficulty and task performance. The x-axis shows the probability of reaching a goal ranging from 0.10 to 1. The x-axis is the performance output rated from -6 to 6. The results show a positive relationship between the set difficulty of a goal and the output of that goal.

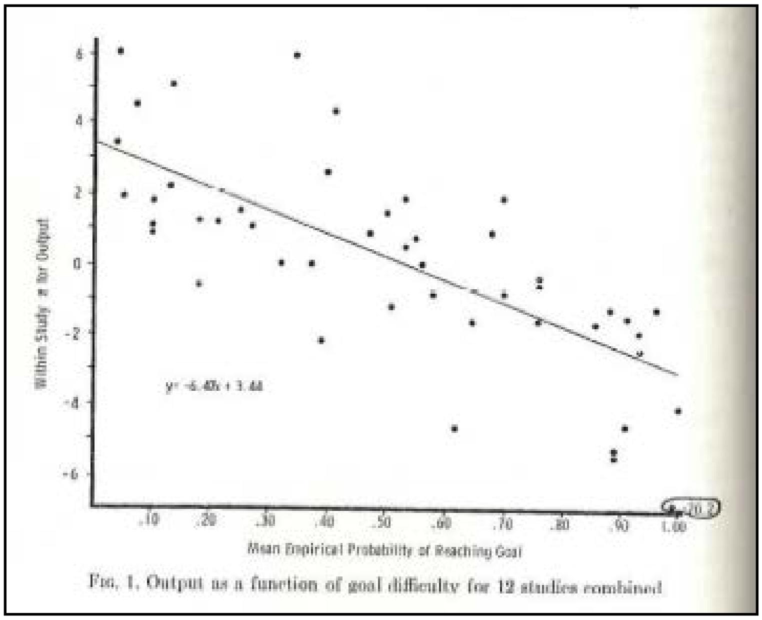


Figure 2: Goal Difficulty and Task Performance (Locke, 1968:162)

As with specificity, Latham and Locke (1991:213-214) provide a simple example of setting goal difficulty:

1. Easy: Try to get 5
2. Moderate: Try to get 10
3. Difficult: Try to get 15
4. Impossible: Try to get 50

Dependent on the skills and abilities of a test group, the goal difficulty should be set to push the group to the highest level of performance while simultaneously keeping the goal attainable. One way that difficulty is often set is though percentiles. For instance, the easy goal may contain the 0-25th percentiles while the difficult goal may only contain the 90th percentile. The challenge of the researchers is to determine what percentiles the different scores fall into and make sure the goal contains the appropriate level of specificity and difficulty.

The second broad attribute of intensity is described under the auspices of goal commitment. Latham and Locke describe goal commitment as:

> The degree to which the individual is attached to the goal, considers it significant or important, is determined to reach it, and keeps it in the face of setbacks and obstacles. It must be stressed, however, that the feeling of commitment does not automatically lead one to act in accordance with it (1991:217).

Goal commitment is unique within GST because it acts as both a moderator and a direct causal factor. If high commitment is evident, a moderating effect is found because of the strong association between goals and commitment (positive slope). If commitment is low, causality is found because performance essentially flatlines (straight-line slope) regardless of goal level (Latham and Locke, 1991:217-218).

One contenscious area regarding goal commitment has to do with assigned and participative goals. Depending on the study, contradictory findings exist as to whether participative goal-setting leads to higher performance. To remedy this discrepancy, a joint study was performed by the two groups of researchers. The method of goal delivery explained the contradictory findings. Latham delivered goals in a supportive manner coupled with rationale while Erez was far more brief and direct in goal-setting which caused the participative setting to contrast heavily with the assigned method. Additionally, the researchers differed in "goal difficulty, setting personal goals before treatments were introduced, self-efficacy inducing instructions, and instructions to reject disliked goals" (Latham et al., 1988:753). Once all factors were accounted for, little difference was found in participative and assigned goals. This illustrates the importance of delivery regardless of which method is selected. If the experiment is centered on assigned goals, a supportive, explanatory environment is important to garner optimal results.

The beliefs that goals are important (attractiveness) and possible (expectancy) are determinants of goal commitment. Factors associated with attractiveness include authoritative influence, peer influence, publicness, incentives and rewards, internal rewards, punishment, and valence. The major factor associated with the belief that a goal is possible is self-efficacy.

Beginning with attractiveness, the researcher will examine authoritative influence, peer influence, and publicness. The follow-on experiment will be absent rewards, punishment, and tangible incentives (monetary, time off, etc.) so they will not be considered in this literature review. First, authoritative influence has a relationship with goal commitment. According to Locke and Latham (1990:135-136), goals are most effective when:

1. The authority figure is seen as legitimate
2. Goal assignment conveys (positive) self-efficacy information
3. Goal assignment fosters a sense of achievement
4. The assigned goals imply opportunities for self-improvement
5. The assigned goals challenge people to prove themselves
6. The authority figure
    a. Is physically present
    b. Is supportive
    c. Is trustworthy
    d. Provides a convincing rationale for the goal
    e. Exerts reasonable pressure
    f. Is knowledgeable and likable

The AF structure provides a good platform to foster these leadership attributes. The command/subordinate chain-of-command structure enables an environment where these conditions can be met, thus, enhancing goal commitment. If the goals are properly assigned and "sold" to the AC's in the follow-on research, the authority component of goal attractiveness will be effectively met. Leadership and researcher communication and involvement are also imperative for success.

Next, peer influence will be considered, particularly as it relates to competition. In one of the experimental treatments, the goals and progress will be made public to foster competition. Numerous studies have shown that competition can increase performance. As mentioned in Chapter I, the logging crew example illustrates the impact of competition. "Competition was a crucial factor in bringing about goal acceptance and commitment in this study" (Latham and Locke, 1979:72-73).

Finally, a goal being made public impacts the level of commitment. In an experiment that studied college student performance with extra credit, Hollenbeck et al. (1989:22) found that "goal publicness was an important factor that enhanced the degree of goal commitment". This aspect of goal commitment is relatively easy to attain. Individuals can make their own goals public or management can make the goals public and facilitate commitment.

In addition to goal attractiveness, expectancy (belief that a goal is possible) is important to goal commitment. Self-efficacy is a commonly used term in relation to expectancy and "refers to one's beliefs about how well one can perform a task." Self-efficacy is not only centered on effort and the belief that increased effort leads to higher performance. Rather it is engrained in "the individual's *overall* or total judgment of performance capability" (Locke and Latham, 1990:115). This includes effort, planning ability, previous success or failure, stress management, problem solving, and coping mechanisms. An individual uses some or all of these factors to establish a level of self-efficacy for a particular goal or task which, in turn, impacts how a person performs against an established goal.

Now that the moderators of GST have been described, four mechanisms in which performance and goals are connected is discussed. The first method involves the focus of effort with predetermined goal activities, which causes unwarranted activities to be ignored and important tasks to receive the majority of attention. The second mechanism increases effort and energy. With a goal set, individuals will try harder and exert more energy toward the desired task. Third, persistence is found in the relationship of performance and goals; difficult, specific goals are met with increased determination. Finally, action is attained by people through possession of previous knowledge or the development of knowledge (Locke and Latham, 2002:706-707).

Feedback

The additional consideration of feedback will be instrumental in the follow-on experiment. In discussing importance of feedback to goal-setting, Locke and Latham (1990:173) state that "neither is very effective in the absence of the other." The importance of feedback cannot be overstated and is an instrumental piece in the fulfillment of effective goals. While the follow-on research will examine feedback extensively, the researcher will provide an overview of what feedback is as well as its mediating and moderating attributes.

First, Air Force members have a basic framework for performance feedback. In Air Force Instruction 36-2406 "Officer and Enlisted Evaluation Systems", feedback is defined as "a private, formal communication a rater uses to tell a ratee what is expected regarding duty performance and how well the ratee is meeting those expectations" (AFPC/DPSID, 2013:71). Describing the importance of the relationship of goals and feedback, Locke and Latham state:

> For goals to be effective, people need summary feedback that reveals progress in relation to their goals. If they do not know how they are doing, it is difficult or impossible for them to adjust the level or direction of their effort or to adjust their performance strategies to match what the goal requires (2002, p. 708).

Although the Air Force definition deals primarily with private feedback, in some instances varying the types of feedback proved effective.

Feedback is unique in GST because goals act as a mediator of feedback and feedback acts as a moderator of goals. To understand the mediating effect, the cognitive underpinnings must first be explored. Locke and Latham (1990:174) discuss knowledge of results (KR), cognitive appraisals, and value appraisals to better understand goals as a mediator. KR, although often used synonymously with feedback, is slightly different. KR is taking the feedback provided and translating the feedback into a deeper understanding. A person can receive feedback that doesn't have concrete meaning and, thus, does not influence behavior. The process for achieving KR is to perform an internal cognitive appraisal which attempts to provide greater meaning to the results and what they mean to the individual. Value appraisals occur at the same time and place a good, neutral, or bad identifier on the results. Taken together, these three terms provide a mechanism in which the feedback has meaning and value. If the result of these processes is a lack of understanding, the feedback is not properly constructed, and thus, not having the desired impact. As a mediating relationship, feedback influences goals in varying ways. Feedback could cause goals to increase, decrease, or remain the same.

The moderating effect is found in feedback because it strengthens the relationship between goals and performance. In an analysis of feedback/goal studies, Locke and Latham (1990:192-193) found that "Seventeen out of 18 studies found the combination of goals and feedback to be better than goals alone, and 21 out of 22 studies…found it better than feedback alone." Through a variety of experimental designs, these studies show the impact of feedback on performance and goals. The author's best described this relationship as:

> "Feedback tells people what is; goals tell them what is desirable. Feedback involves information; goals involve evaluation. Goals inform individuals as to what type or level of performance is to be attained so that they can direct and evaluate their actions and efforts accordingly. Feedback allows them to set reasonable goals and to track their performance in relation to their goals, so that

> adjustments in effort, direction, and even strategy can be made as needed" (Locke and Latham, 1990:197).

Benefits and Pitfalls

Core tenets, moderators, mechanisms, and feedback provide a solid foundation for what encompasses GST and how to best account for the aspects of effective goals. Another area that should be considered is potential pitfalls in relation to GST. Latham and Locke highlight ten areas of consideration in their article titled "Enhancing the Benefits and Overcoming the Pitfalls of Goal Setting." Each pitfall should be examined to determine if it is applicable in the follow-on research. Table 1 provides a summary description of the ten pitfalls. With the exception of pitfall number six (monetary incentives), each will be discussed in the context of the follow-on experiment.

Table 2: Ten GST Pitfalls (Latham and Locke, 2006:334-337)

	Pitfalls
1	Lack of knowledge or skill to attain goal
2	Performance goal can have a detrimental impact on group performance if there is a conflict among members
3	Goal is a threat rather than a challenge
4	Goals may have an adverse effect on risk taking, if failure to attain a specific high goal is punished
5	Goal attainment. Past successes increase goals without reevaluating overall strategy
6	Monetary incentives
7	A leader tying identity to the goal
8	Nongoal performance dimensions get ignored
9	Goals increase stress
10	Employees who reach or exceed challenging goals may be assigned future goals that are impossible to attain

Pitfall one discusses the possibility that goal recipients may not have the requisite skill to attain the goal. If this is the case, the authors stress the importance of using a learning goal over a performance goal. Regarding fuel efficiency, a performance goal may be to attain a certain percentage or klbs of fuel savings while a learning goal may be to master efficient flying in all aspects of being a pilot (not just having a fuel savings focus but to become a better overall pilot).

The problem with learning goals is that they can potentially conflict with goal specificity if they are written too vague. Careful consideration of the target group will provide a clear picture of what type of goal is appropriate.

Pitfall two focuses on group dynamics and the potential for conflict among members. The authors state “when two or more people believe that their goals are competitively rather than cooperatively related, they are likely to be tempted to pursue their own goals single-mindedly” (Latham and Locke, 2006:334). Withholding information is a serious concern if the goal is viewed as purely competitive. This seems contrary to the logging example in which competition was lauded as a facilitator to performance. The key is to foster competition while simultaneously promoting collaboration. One way this is accomplished is to make sure the goals do not provide an incentive to withhold collaboration. As an example, if AC’s were promoted based on relative standing with fuel efficiency, they would not want to help their competition.

Pitfalls three and four are interrelated and have to do with personal threats and punishment. If a person views a goal as a threat, performance goes down. The same result is seen if a person is punished for not attaining a goal. Framing the goal in a positive way and avoiding punishment are essential to increase performance and keep individuals from downgrading specific, difficult goals to easier goals.

Pitfall five discusses goal attainment and long-term reliance on successful strategies, even if those strategies need to be evolved. This is not an issue in the short-term follow-on research but must be considered in the future if any policy changes occur due to the efficiency research.

Pitfall seven occurs when an organization’s identity is tied to a goal, causing overreach and over commitment. This occurs when a leader or group of leaders will do anything to attain a goal, regardless of the second and tertiary effects. In the flying community, this is dangerous as efficient flying is not the number one priority. Safety of flight and mission requirements should take precedence over saving fuel.

Pitfall eight focuses on nongoal dimensions and warns against ignoring them. The risk is that an individual could miss other important factors (outside of the goal) that could lead to increased performance or be important to the situation. It is important for individuals and groups not to lose focus on the bigger picture of goal attainment.

Pitfall nine states that stress must be considered when setting goals. When setting goal difficulty, stress implications should be factored into the decision. A goal should be difficult enough to maximize performance while not so difficult that it creates undue stress. Dealing specifically with fuel efficiency, AC's are under a significant amount of stress with the nature of their jobs and with all of the requirements of the AF.

The final pitfall is what the military would call "goal creep". If an individual or group attains a goal, the goal is then raised higher. If that goal is attained, it is raised again. At some point in time, the goal goes from difficult to impossible; this should be avoided. This pitfall is closely related to pitfalls five (goal attainment) and nine (stress). While a single goal will be set for the follow-on experiment, the danger lies in leadership not reevaluating goals and the potential for success at intermittent, appropriate points in time.

III. Methodology

Introduction

The purpose of this chapter is to provide methodological details of this thesis topic. Two areas are covered including the analyzed data and the method of analysis for the data. In the first section, the raw fuel tracker data provided from AMC/A3F (Fuel Efficiency Office) is described. The second section details the methods employed to compare metrics as well as the methods used to determine a fuel efficiency goal for AC's.

Data to be Analyzed

The field data are found in a continuously updated fuel tracker report (Microsoft Excel®) that is submitted upon sortie completion to AMC/A3F. The majority of the data collected in the fuel tracker are from a fuel tracker worksheet entered by the aircraft commander. A C-17 worksheet example is found in Appendix A. The data is obtained from AMC/A3F. While 51 fields are present in the Excel® tracker data, $M1_{Cargo\ Adjusted}$ uses 8 fields while $M2_{Regression}$ uses 5 fields, highlighted in Table 2 and Table 3. It is important to note that $M2_{Regression}$ "cargo actual" includes 1/2 of all onloaded and offloaded in-air fuel received as well as the weight of the actual cargo load. The name column shows the fields as seen in the excel report. The description provides clarity to the abbreviated fields and acronyms.

Table 3: $M1_{Cargo\ Adjusted}$ Excel Fields

Field	Name	Description
1	D_ICAO	Departure Location
2	A_ICAO	Arrival Location
3	CARGO PLN	Planned Cargo in Thousands of Pounds
4	CARGO ACT	Actual Cargo in Thousands of Pounds
5	RAMP FUEL PLN	Planned Fuel in Thousands of Pounds
6	RAMP FUEL ACT	Actual Fuel in Thousands of Pounds
7	LAND FUEL PLN	Planned Landing Fuel in Thousands of Pounds
8	LAND FUEL ACT	Actual Landing Fuel in Thousands of Pounds

Table 4: $M2_{Regression}$ Excel Fields

Field	Name	Description
1	CARGO ACT	Actual Cargo in Thousands of Pounds
2	FLY_TIME_ACT	Hours of Actual Flight
3	RAMP FUEL PLN	Planned Fuel in Thousands of Pounds
4	RAMP FUEL ACT	Actual Fuel in Thousands of Pounds
5	LAND FUEL PLN	Planned Landing Fuel in Thousands of Pounds

Method of Analysis

Various analyses are performed in order to assess the metrics and create an efficiency goal. First, $M1_{Cargo\ Adjusted}$ formulation is described as well as the factors that take the formulated metric and allow it to be used as an efficiency score for AC's. Second, $M2_{Regression}$ is reviewed on the basis of regression analysis. Third, $M1_{Cargo\ Adjusted}$ and $M2_{Regression}$ will be compared using the criteria in "the Metric Handbook" (Nowak, 1992) and scoring those criteria with two separate decision-based matrices found in "The Quality Toolbox" (Tague, 2005). Once the optimal metric is chosen, GST criteria are applied to the metric to comprise an effective efficiency goal. Finally, VBA code is utilized to provide feedback to AC's via Excel® in the follow on research.

First, the development process that more accurately accounts for cargo payload in $M1_{\text{Cargo Adjusted}}$ is described. Accounting for cargo is vital because if payload is not factored into the fuel efficiency scoring metric, AC's could purposely try to carry less cargo to attain a better efficiency score. Lack of cargo accountability makes current data less accurate from a metric perspective. $M1_{\text{Cargo Adjusted}}$ formulations take payload out as a factor in AC efficiency score evaluation.

It is important to understand the methodology that derives $M1_{\text{Cargo Adjusted}}$ into a useable format before analyzing its efficacy in Chapter IV. $M1_{\text{Cargo Adjusted}}$ consists of four major components illustrated in Equation 2:

$$\alpha = y_{act} - y_{pl} - \delta \tag{2}$$

Where:

α = Fuel Efficiency Goal Metric (AC Efficiency Score)

y_{act} = Fuel Consumed Actual:
= Actual Ramp Fuel – Actual Landing Fuel

y_{pl} = Fuel Consumed Planned
= Planned Ramp Fuel – Planned Landing Fuel

δ = Change in Fuel Consumed due to Actual Payload

As seen in Table 3, the actual ramp/actual landing and planned ramp/planned landing fuel are provided in the tracker data. Next, the change in fuel consumed due to actual payload is computed. Work from Reiman (2014) aids in the formulation of this component of the metric, shown in Appendix B (equations 22 & 23). Reiman's research uses regression analysis to determine aircraft fuel consumption given distance and payload. In Excel®, thirty-two additional fields are attached to the end of the Figure 4 fuel tracker fields in order to facilitate the additional formulas that incorporate the efficiency metric.

Next, $M2_{Regression}$ assumptions are tested based on the AMC/A3F regression coefficients to check for validity. Fuel tracker data paired down to C-17 SAAM missions from active duty wings are used to test the regression performance (Sep 11-Aug14). Regression assumptions of normality, constant variance, and independence will be tested for validity.

Finally, a comparison of metrics is performed in relation to Active Duty Wings to determine how the metrics perform with actual data. Several statistical comparisons are performed to judge the overall performance of the metrics in comparison to each other. Descriptive statistics are evaluated including standard deviation, variance, and range. Mean efficiency scores in relation to geographic location as well as time-series are evaluated to look for differences between the metrics.

Third, GST criteria of content (difficulty/specificity) and intensity (commitment) are coupled with the chosen metric to establish an efficiency goal. Previous GST literature provides examples and case studies to aid in the establishment of an effective goal. Once the quantitative goal is set, considerations of feedback and GST pitfalls are also be considered.

Finally, once the selected metric is calculated for the AC's, a VBA code will be required in the follow-on research to filter the vast amounts of data into simplified reports capable of being sent out to the AC's being evaluated.

IV. Results

In this chapter, the evaluation results from $M1_{Cargo\ Adjusted}$ and $M2_{Regression}$ are described. First, outliers are addressed. Second, the replicated regression analysis of $M2_{Regression}$ is performed. Third, the Metric Handbook model is discussed in relation to $M1_{Cargo\ Adjusted}$ and $M2_{Regression}$. Finally, the researcher will compare the metrics and their performance.

Outliers

To facilitate this research as well as the follow-on research, outliers are considered. After reviewing a fuel tracker data set from September 2013 to August 2014, it is determined that sorties outside of +- 3 standard deviations are largely the result of improperly input fuel tracker fields or the result of other mitigating circumstances that disproportionately impact the fuel efficiency score. For instance, an AC may have written a note that the flight was diverted but did not properly code the flight as diverted. Another example of an outlier is if a flight received in-air refueling making it an extremely efficient flight. Based on this review, histograms are generated for each metric, as shown in Figure 3 and Figure 4. Overall 151 data points are removed from the total of n=5727 to get a total reduction of 2.7% of the data points.

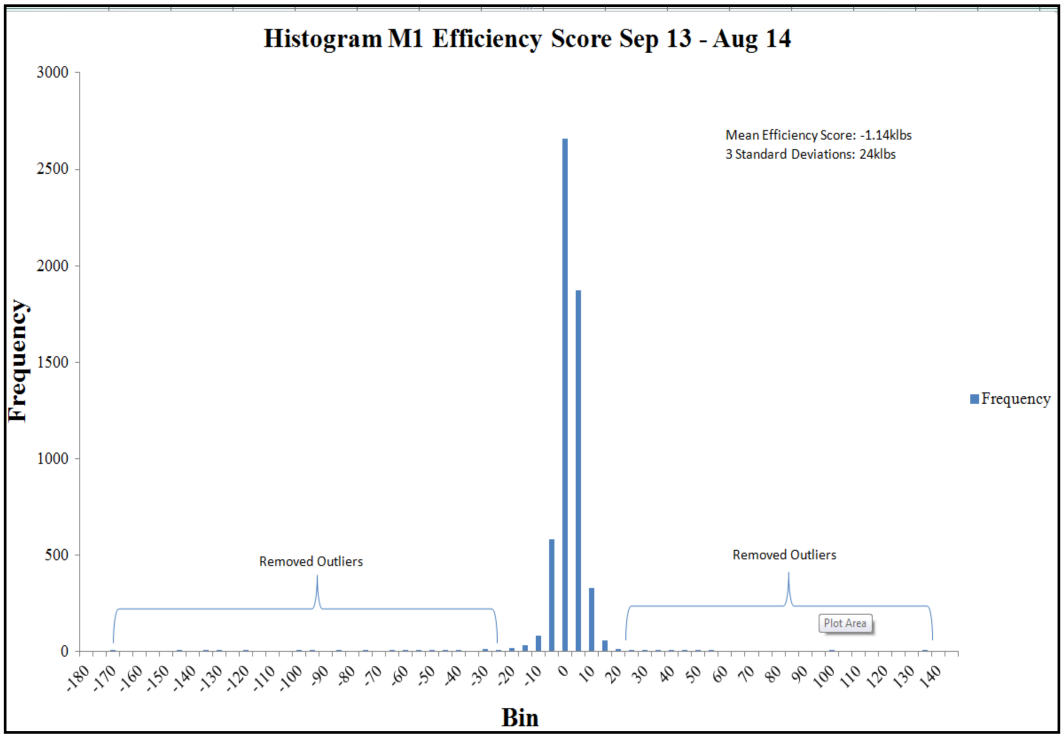


Figure 3: M1$_{\text{Cargo Adjusted}}$ Histogram Sep 13 to Aug 14

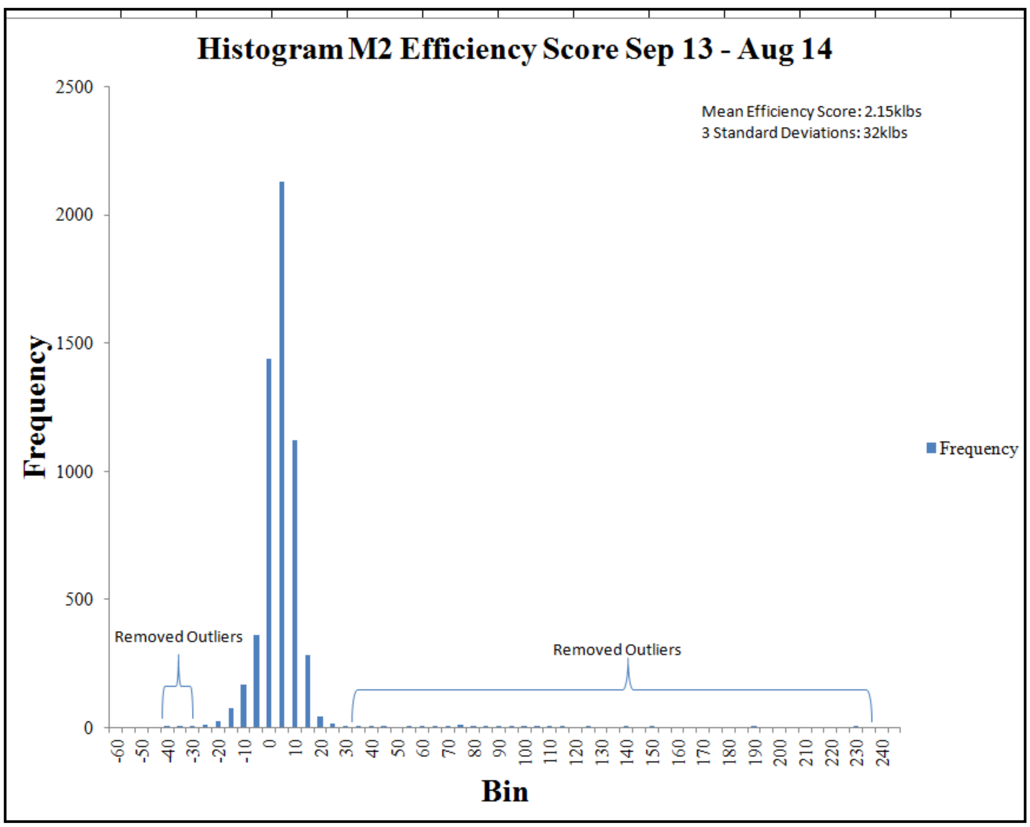


Figure 4: M2$_{\text{Regression}}$ Histogram Sep 13 to Aug 14

Due to time constraints, it was determined that rather than investigate every outlier, an across-the-board approach based on standard deviations would appropriately mine and provide validity to the data.

Regression

The original $M2_{Regression}$ regression, performed by AMC/A3F, utilized C-17 sorties for FY10 (1Oct10-30Sep11). This data was not available so the researcher instead used data for FY11 (1 Oct 11-30Sep12) to determine if the regression analysis proved viable to determine fuel efficiency. The original work from AMC did not specify if the data was paired down in any way such as location, outliers, etc. so the assumption is made that the analysis was performed on all Wings including Guard and Reserve and that no outliers were removed from the data set prior to the regression analysis.

The replicated regression analysis was performed in JMP® statistical software. The initial results showed a similar R-Square to the AMC results of .97. To further validate the results, multicollinearity and regression assumptions needed to be addressed including constant variance, normality, and independence to ensure the entire model is valid.

First, a multicollinearity check is performed by examining a multivariate plot in JMP® and the variance inflation factors (VIF) within the output. Several trends are found in the plot suggesting some multicollinearity (see Appendix F). Squared and interaction terms are expected to show a trend as are any terms associated with the y variable (actual fuel consumed). An issue of multicollinearity would occur if actual fly time and actual cargo showed a trend but they do not. VIF scores provide a further check for multicollinearity as they “descrive how much multicollinearity (correlation between predictors) exists in a regression analysis (Minitab, 2015).

A VIF score above five causes concern while a VIF score above 10 strongly suggests multicollinearity. Figure 7 shows the JMP® output and corresponding VIF scores.

Response Actual Fuel Consumed

Summary of Fit

RSquare	0.987902
RSquare Adj	0.987891
Root Mean Square Error	5.954382
Mean of Response	72.50552
Observations (or Sum Wgts)	5575

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	16122610	3224522	90947.76
Error	5569	197447	35	**Prob > F**
C. Total	5574	16320057		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	4012	168714.52	42.0525	2.2788
Pure Error	1557	28732.49	18.4537	**Prob > F**
Total Error	5569	197447.01		<.0001*
				Max RSq
				0.9982

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	2.8143192	0.212053	13.27	<.0001*	.
Cargo(Cargo Act+(.5*Offload/Onload) klbs	0.0275158	0.008145	3.38	0.0007*	10.286082
Cargo Act^2	-0.000369	9.07e-5	-4.07	<.0001*	9.5341464
Fly Time Act	14.479448	0.102467	141.31	<.0001*	15.48852
Fly Time Act^2	0.1260845	0.009843	12.81	<.0001*	14.809766
Cargo*Fly Time	0.0381797	0.000955	39.98	<.0001*	6.0076535

Figure 5: Summary Statistics Output $M2_{Regression}$ Replication

Next, the assumption of constant variance is essential to validate the regression. A check of the predicted and residual values will show if there are any variance problems. As seen in Figure 10, the data exhibits some curvature, violating the constant variance assumption.

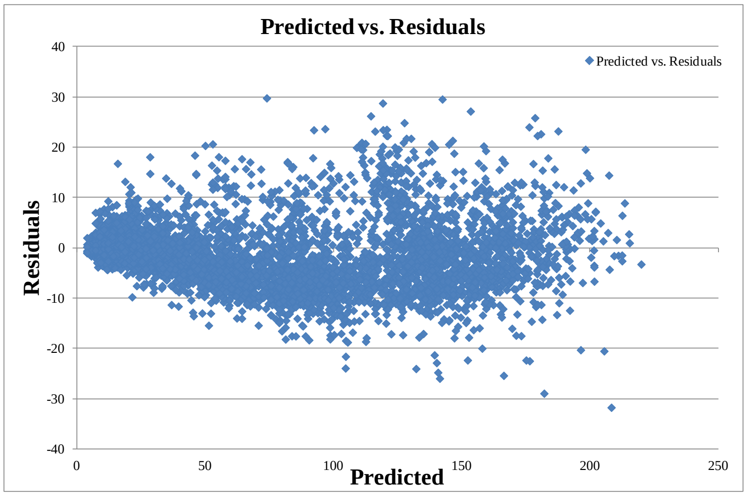


Figure 6: Predicted/Residual Constant Variance Check M2$_{Regression}$ Replication

The next assumption of normality can be checked in JMP® using a normal quantile plot. If the regression exhibits normality, the data would show a linear trend. If there is any curvature in the graph, normality is violated. As seen in Figure 11, the normality assumption is violated as the normal quantile plot shows definitive curvature in the trendline.

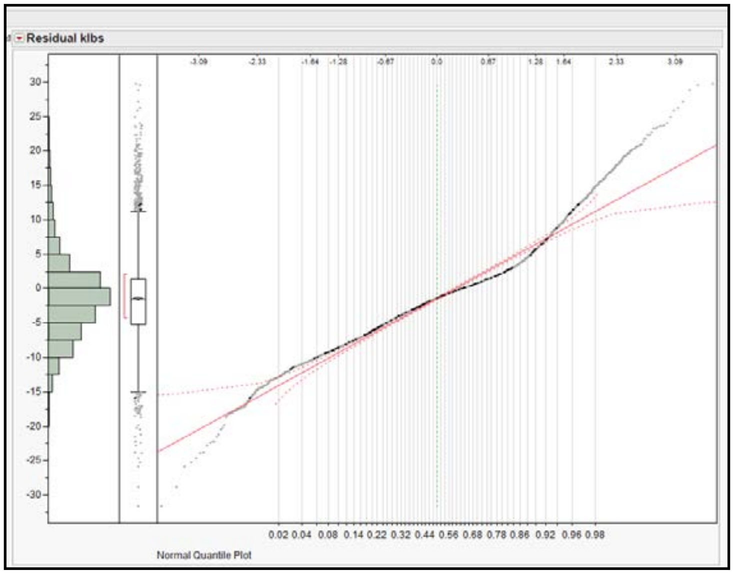


Figure 7: M2$_{Regression}$ Replication Normality Test

The final assumption that needs to be addressed is independence. A time series vs. residual scatterplot performs this check. Figure 12 is a one-week snapshot of the data; the entire data set is too complex to look for trends in a scatterplot. The figure shows that the data appears to pass the test for independence as it does not show specific trends.

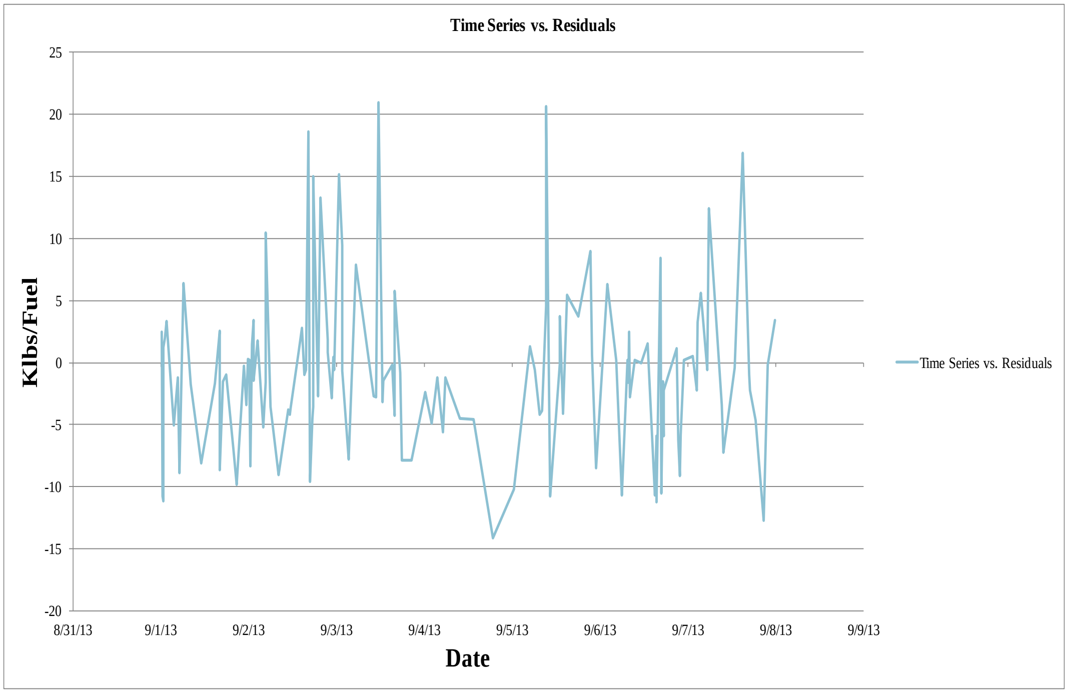


Figure 8: Independence Check $M2_{Regression}$ Replication

To further examine this finding, a Durbin Watson test was performed. JMP® statistical software calculated a d-statistic of 1.839. Based on an alpha of 0.05, critical values of $d_{L,alpha}$ =1.72 and $d_{U,alpha}$=1.82, and a 4-d value of 2.17, autocorrelation does exist within the data. Therefore, the test for independence fails.

Metric Handbook

With the statistical analysis of $M2_{Regression}$ completed, an analysis of "The Metric Handbook" model (Nowak, 1992:2-1) in relation to each metric will provide an overall picture on how the metrics perform. For the purposes of this section, A1-A6 will signify attribute 1-

attribute 6 in the model. It is important to note that this analysis is being performed through the lens of using this metric to influence AC behavior in future motivational experiments.

$M1_{Cargo\ Adjusted}$:

A1: It is accepted as meaningful to the AC's?

Undecided, $M1_{Cargo\ Adjusted}$ accounts for factors outside of the AC's' control. Payload is accounted for through comprehensive calculations. Other ACFP factors included in $M1_{Cargo\ Adjusted}$ are tail fuel degrade, air traffic control hold down, thunderstorms and turbulence fuels, planned air refueling, planned flight route, planned altitude, forecasted temperatures and winds

A2: Is It Unambiguously defined?

Yes, the metric entails the difference between planned fuel consumed adjusted for actual payload and actual fuel consumed.

A3: It tells how well organizational goals and objectives are being met through processes and tasks?

Yes, once efficiency goals are set, AC's will have a clear measure to meet the set goal. If AC's are not meeting organizational goals, it will be clearly evident in the $M1_{Cargo\ Adjusted}$ calculations and graphical trends.

A4: It is simple, understandable, logical, and repeatable?

Undecided, once the calculations are embedded into excel spreadsheets or VBA code, it is easy to follow and utilize. The formulas are lengthy and prone to mistakes if attention to detail is not prevalent. Embedding the calculations into VBA or other coding program could reduce a lot of errors and simplify M1. M1 is derived from ACFP which is well understood planning software for the flying community.

A5: Its data is timely and economical to collect.

Yes, simple spreadsheet calculations coupled with fuel tracker data can be performed if the formulas are already coded.

A6: It drives the appropriate action.

Undecided, a subsequent discussion is provided at the end of this analysis.

$M2_{Regression}$:

A1: Is it accepted as meaningful to the AC's?

Undecided, $M2_{Regression}$ fails to take into account ACFP planning factors such as tail degrade, winds, temperature, planned air refueling, planned routing, planned altitude, turbulence, thunderstorms, icing, and air traffic control. The simplistic approach of using time and cargo to predict fuel burn might not have adequate buy-in from the flying community.

A2: Is It Unambiguously defined?

Yes, $M2_{Regression}$ has a clear definition and understandable construct. The variables used are clear and known to AC's. From a definition perspective, the metric is understandable.

A3: It tells how well organizational goals and objectives are being met through processes and tasks it shows a trend.

No, it contrasts performance to a 2011 baseline based on time of flight and gross weight. There are many other planning factors outside of the AC's control that are assessed through ACFP that are not considered by the regression.

A4: It is simple, understandable, logical, and repeatable?

Undecided, $M2_{Regression}$ meets these criteria if the user has an understanding of regression analysis and its application. AC's have an understanding of the fuel tracker and how it works but if they cannot make the transition from tracker input to regression output, simplicity and ease of use will be degraded.

A5: Its data is timely and economical to collect.

Yes, AC's are already required to input fuel tracker data and a system is in place for AMC to collect this data. Any statistical software package or Microsoft Excel® can quickly transform the fuel tracker data into a usable form of $M2_{Regression}$. It is simple and user-friendly to perform regression analysis with a basic understanding of the steps and process surrounding the technique.

A6: It drives the appropriate action.

Undecided, a subsequent discussion is provided at the end of this analysis.

Attribute 6 is the most important aspect of each of the metrics. The ability of each metric to drive action and behavior will have the largest impact in fuel efficient flying. For this reason, flight factors both inside and outside of an AC's control will be addressed in relation to each metric. An examination of the impact of temperature, winds, routing, speed, and altitude will provide a distinct comparison between the metrics and the behavior they induce.

ACFP uses forecasted temperature which influences $M1_{\text{Cargo Adjusted}}$. This allows AC's a moderate amount of control to fly an alternate route that may have lower average temperatures, increasing fuel efficiency. Conversely, $M2_{\text{Regression}}$ does not account for temperature which minimizes AC control. For example, an AC flying out of northern (cold weather) city-pairs will have a higher efficiency than an AC flying in southern (warm weather) city-pairs. Under $M2_{\text{Regression}}$, an AC could look for the more favorable temperatures, similar to $M1_{\text{Cargo Adjusted}}$, but it will still be very disproportionately negative in warmer climates.

Next, forecasted winds are included in ACFP. Under $M1_{\text{Cargo Adjusted}}$, AC's may find significant improvement based on finding lower headwinds than the planned route is recommending. $M2_{\text{Regression}}$ does not account for winds in the regression; instead, the metric factors flight time which negatively impacts the AC in the case of high, inefficient, headwinds. The AC benefits heavily from favorable headwinds due to decreasing flight time (regression variable) but is more heavily penalized from going into the headwinds. Under M2, the benefit from finding a lower headwind on improved fuel consumption is offset by the decreased flight time's reduction of the planned fuel consumed. $M2_{\text{Regression}}$ will favor crews going east and penalize crews going west due to winds.

Routing considerations also favor $M1_{\text{Cargo Adjusted}}$ because the AC may ask for a more favorable direct route based on experience. $M2_{\text{Regression}}$ does not contain routing factors as a regression variable so an AC may choose whatever route can be accomplished in the shortest amount of time rather than the most fuel efficient route. Getting a direct route with $M2_{\text{Regression}}$ will reduce the actual fuel consumed, but will also reduce the planned fuel consumed by decreasing the time component of the regression.

Planned altitude is also included in ACFP which could benefit AC's under $M1_{\text{Cargo Adjusted}}$. A higher altitude is often more efficient so the AC may choose a higher altitude to fly at to gain fuel efficiency. A step climb is another option for an AC in which an AC climbs to maximum altitude based on weight and then gradually climbs as weight is lost due to fuel burn. $M2_{\text{Regression}}$ does not factor in altitude so step climb tactic would not necessarily benefit them. Climbing to a higher altitude will often decrease the time enroute by achieving a greater true airspeed. The decrease in time will decrease the planned fuel consumed often negating the fuel efficiency benefit from the higher altitude.

Overall, there is a sharp contrast between $M1_{\text{Cargo Adjusted}}$ and $M2_{\text{Regression}}$ in relation to whether the metrics drive the appropriate behavior. $M1_{\text{Cargo Adjusted}}$ incentivizes efficient flying behaviors by including planning factors such as temperature, winds, routes, and altitude. Essentially, the factors that are outside of an AC's control that are due to the uniqueness of the sortie are removed for $M1_{\text{Cargo Adjusted}}$ but not for $M2_{\text{Regression}}$. This allots AC's the opportunity to utilize their knowledge, skills, and abilities (KSA's) to try and garner efficiency above and beyond ACFP recommendations without circumventing efficient maneuvers to "play to a metric." $M1_{\text{Cargo Adjusted}}$ efficiency is not dependent on payload. It also increases if actual ramp fuel is reduced (lighter aircraft) or actual landing fuel is increased (fuel conservation).

In order to quantify A1-A6, two decision matrices were taken from "The Quality Toolbox" written by Nancy Tague (2005). Weighted (Table 2) and rank-order matrices (Table 3) will provide a score to each metric based on the six criteria found in "The Metric Handbook." Based on the scores of 22 and 15 (Method 1) compared to 33 and 30 (Method 2), $M1_{\text{Cargo Adjusted}}$ is shown to be the more optimal choice when quantitatively analyzed in regards to the metric criteria.

Table 5: Weighted Matrix (Fuel Efficiency Metrics)

	Method 1 (Weighted) Decision Matrix: Fuel Efficiency Metric					
Criteria → Problems ↓	Meaningful/ Unambiguously Defined 3	Organizational Goals Being Met 2	Simple, Understandable, Logical, Repeatable 2	Economical Collection/Time ly 1	Drives Appropriate Action 3	**Total s**
Metric 1	Medium 3X2=6	High 2X3=6	Medium 2X2=4	High 1X3=3	High 3X3=9	**28**
Metric 2	Low 3X1=3	Low 2X1=2	Medium 2X2=4	High 1X3=3	Low 3X1=3	**15**

Table 6: Rank Order Matrix (Fuel Efficiency Metrics)

	Method 2 (Rank Order) Decision Matrix: Fuel Efficiency Metric					
Criteria → Problems ↓	Meaningful/ Unambiguously Defined 3	Organizational Goals Being Met 2	Simple, Understandable, Logical, Repeatable 2	Economical Collection/Time ly 1	Drives Appropriate Action 3	**Total s**
Metric 1	2X3=6	3X2=6	1X2=2	4X1=4	5X3=15	**33**
Metric 2	3X3=9	1X2=2	4X2=8	5X1=5	2X3=6	**30**

Metric Comparison

The next analysis regarding the metrics will compare the performance of the metrics using actual fuel tracker data from 2011-2014. First, the summary statistics will be examined to demonstrate the differences in variability as well as the range of data. Second, the metrics will be compared at the Wing level to determine if Wings perform differently from each other. Third, questions of tail impact and location will be examined from an individual AC perspective to see if aircraft or location causes differences in AC fuel efficiency. Finally, an examination of AC performance based on percentiles will allow an overview of how efficiency scores from the most and least efficient AC's compare. This will be vital in setting the final efficiency goal.

An initial Excel® summary statistics examination of the metrics showed significant differences in variance and mean values. Shown in Table 4, $M2_{Regression}$ exhibits a higher variance and mean than $M1_{Cargo\ Adjusted}$. $M1_{Cargo\ Adjusted}$ scores are more efficient on average at 0.84 klbs while M2 suggests more inefficient flying with a mean score of over 1.4klbs.

Table 7: Summary Statistics M1 and M2 Sep13 - Aug14 (SAAM missions, Outliers Removed)

M1		M2	
Mean	-0.84	Mean	1.42
Standard Error	0.06	Standard Error	0.08
Median	-0.66	Median	1.44
Standard Deviation	4.44	Standard Deviation	6.16
Sample Variance	19.72	Sample Variance	37.97
Range	48.65	Range	61.48
Minimum	-25.99	Minimum	-29.79
Maximum	22.66	Maximum	31.69
Sum	-4671.87	Sum	7912.34
Count	5576.00	Count	5576.00
Confidence Level(95.0%)	0.12	Confidence Level(95.0%)	0.16

The next analysis will focus on the differences in metric performance in relation to Wings and individual AC's. Several areas will be examined including the mean efficiency scores between installations, time-series mean efficiency scores, and how individual AC's compare from a percentile perspective. Taken together, these analyses will provide better insight into metric performance and potential problems in the metrics from a trend perspective.

Beginning with an examination of the C-17, active duty Wings in relation to $M1_{Cargo\ Adjusted}$ and $M2_{Regression}$, the researcher will show whether any significant differences (or similarities) exist among the Wings. Figure 13 identifies the mean efficiency score (SAAM missions) for each Wing over a 12 month period (Sep13-Aug14). M2 showed significantly higher averages while all mean $M1_{Cargo\ Adjusted}$ values were +- 1.35Klb. Hold-down fuel could contribute to some of the results; according to a fuel policy letter from November 2014 (Gillson), the two most efficient $M1_{Cargo\ Adjusted}$ scores (Dover, McGuire) both receive 4,500 lbs of hold-down fuel due to busy ATC conditions. The added fuel could be contributing to the increased efficiency by allotting the AC's more fuel than they burn, beating the planned landing fuel and increasing efficiency. Charleston could also be very efficient due to this factor; sorties leaving Charleston often transit Dover or McGuire and are subject to the hold-down fuel addition. $M2_{Regression}$ performs in a similar fashion with Dover, McGuire, and Charleston being the most efficient. Appendix F contains the policy letter details.

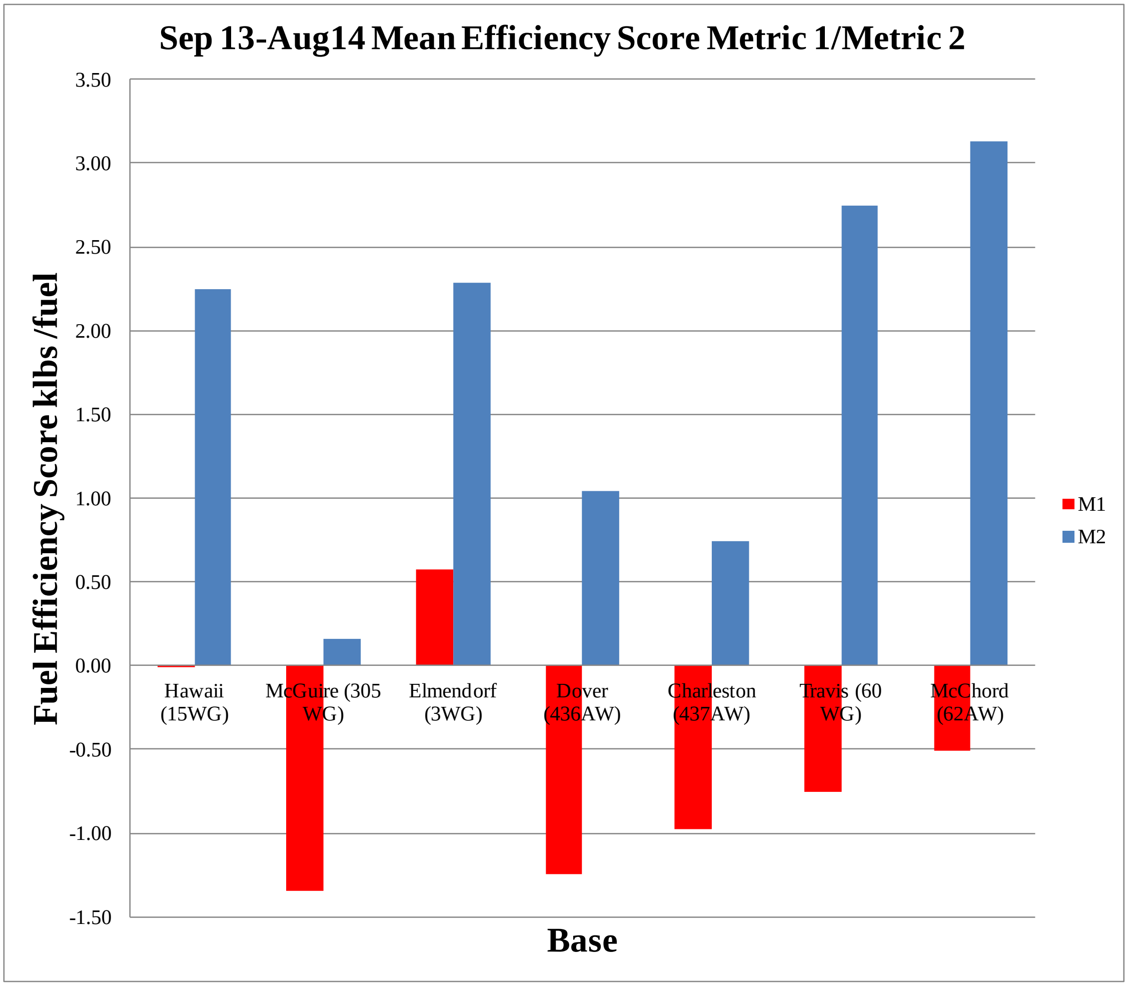


Figure 9: $M1_{\text{Cargo Adjusted}}$ & $M2_{\text{Regression}}$ Mean Efficiency Scores

The most efficient (McGuire) and least efficient (Elmendorf) Wings based on the mean value over a 12 month period amounted to a range of (-1.35, 0.57) for $M1_{\text{Cargo Adjusted}}$. The most efficient for M2 is McGuire and the least efficient is McChord with a range of (0.16, 3.13). To more accurately determine if these ranges are statistically significant, a comparison of means was performed in Excel®. Table 5 output statistics show statistically significant p-values based on a 0.05 alpha value. The p-values show that the mean values are statistically different. This is important because different mean values may make it difficult for a single goal to be set for all Wings.

Table 8: M1/M2 Most/Least Efficient Bases Mean Comparison

M1: Most/Least Efficient Wing Comparison			M2: Most/Least Efficient Wing Comparison		
z-Test: Two Sample for Means			z-Test: Two Sample for Means		
	Variable 1	*Variable 2*		*Variable 1*	*Variable 2*
Mean	-1.35	0.57	Mean	0.16	3.13
Known Variance	20.61	15.77	Known Variance	32.73	45.67
Observations	644.00	266.00	Observations	644.00	970.00
Hypothesized Mean Difference	0.00		Hypothesized Mean Difference	0.00	
z	-6.35		z	-9.49	
P(Z<=z) one-tail	0.00		P(Z<=z) one-tail	0.00	
z Critical one-tail	1.64		z Critical one-tail	1.64	
P(Z<=z) two-tail	0.00		P(Z<=z) two-tail	0.00	
z Critical two-tail	1.96		z Critical two-tail	1.96	

The next analysis examines $M1_{Cargo\ Adjusted}$ and $M2_{Regression}$ performance over a 12 month time-series from Sep 13 to Aug 14. Originally, the data set contained 3 years worth of data. Large fluctuations occurred in the data from 2011 to 2014 (see 3 year chart output in Appendix D) suggesting outside factors skewed the efficiency trends. While the exact cause of the changes are difficult to pinpoint, Mr. Joe Jackson, the Flight Manager from the 618 AOC/XOCM, points to Flight Crew Information File (FCIF) changes as a potential reason for fluctuations. These changes include descent fuel calculation alterations, additional fuel authorizations, and modifications to the fuel tracker itself.

This highlights the importance of examining external factors when looking at fuel efficiency metrics. Policy changes can significantly impact metrics, trends, and how overall performance is viewed. Appendix E contains FCIF changes that may have influenced metric performance.

The data becomes more consistent when the last 12 months of data is viewed together rather than the entire three years. Figure 14 suggests much greater fuel savings from $M1_{Cargo\ Adjusted}$ while $M2_{Regression}$ is significantly less. Appendix D contains the three year data set with outliers removed.

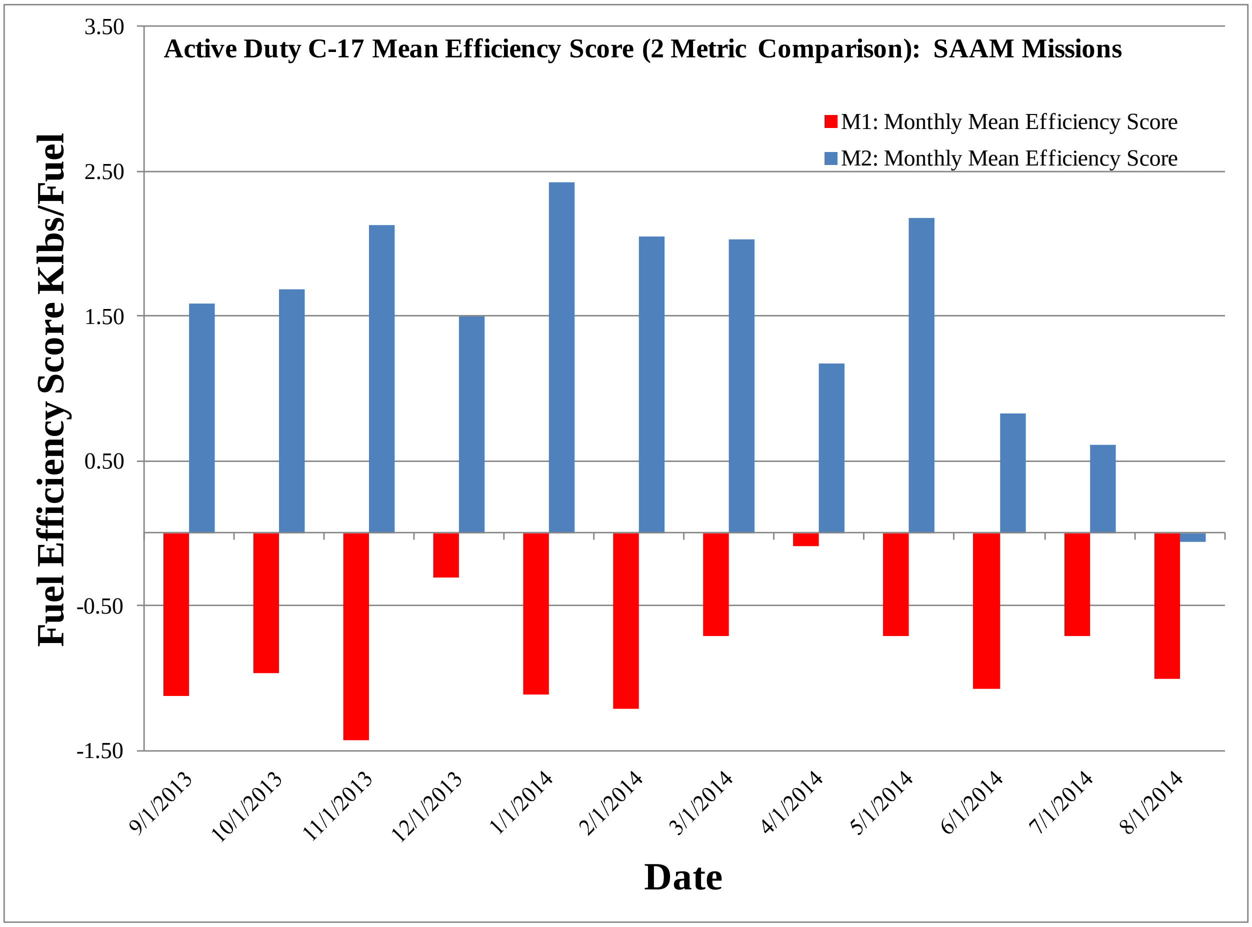


Figure 10: Time Series Metric Comparison

Finally, individual AC performance will be examined. A statistical means comparison was performed on individual AC's that flew multiple tail numbers at the same location to see if differences existed in aircraft performance. 10 AC's were found that flew more than 10 sorties on two different aircraft. The means comparison proved to be inconclusive with approximately half of the AC's having statistically similar means while the other half had statistically different means, seen in Table 6. A location analysis (same AC at different locations) was unable to be performed due to sample size constraints.

Table 9: Aircraft Tail Analysis

Same AC, Same Squadron, 2 Different Tails Mean Comparison p-values			
Pilot #	**M1**	**M2**	**# Sorties/Tail**
1	0.69	0.43	11/10
2	0.57	0.94	10/11
3	0.21	0.17	12/10
4	0.20	0.14	16/14
5	0.58	0.01	22/13
6	0.02	0.0015	11/21
7	0.03	0.28	10/10
8	0.02	0.00	10/24
9	0.0013	0.000062	10/24
10	0.21	0.33	23/12

The final analysis will focus on percentile rankings and fuel efficiency. This analysis will provide significant information that will aid in setting an appropriate goal for AF AC's. $M2_{Regression}$ will not be analyzed in this section because this information is primarily aimed at the follow-on research and percentile calculations can be applied to any metric.

Initially, all sorties were evaluated without regards to specific AC's. AF percentiles were calculated for SAAM missions with outliers removed from Sep 13- Aug 14. The results in Table 7 show the breakdown of all AF fuel efficiency percentiles over a total of 5576 sorties.

Table 10: AF Percentiles SAAM Mission Klbs/fuel

AF Percentiles	
0	-25.99
0.1	-5.78
0.2	-3.73
0.3	-2.54
0.4	-1.61
0.5	-0.66
0.6	0.008
0.7	0.9
0.8	2.15
0.9	4.12
1	22.66

Next, percentiles were calculated for each Wing. This was done so that the Wings could be compared to each other and against overall AF performance. The most interesting finding is that the bottom 50th percentile of sorties was very consistent across all Wings. The top 50th percentile differed in that the Wings varied more. The top 10% of all sorties varied by -3.44klbs between the most and least efficient Wings. Additionally, the Wings differed from each other and from the AF. For instance, the top 10% of flights from the 305th Wing at McGuire had a score of -7.18klbs (Table 8) while the AF percentile was -5.78klbs (Table 7).

Table 11: $M1_{Cargo\ Adjusted}$ Klbs Percentiles All Wings

M1 Klbs/Fuel Percentiles/Wing (SAAM, No Outliers)										
Percentiles	15WG	305WG	3 WG	436 WG	437 WG	60 WG	62WG	Min	Max	Difference
10th	-3.96	-7.18	-3.74	-6.95	-5.85	-4.36	-4.86	-7.18	-3.74	-3.44
20th	-2.58	-4.68	-1.71	-4.67	-3.84	-3.26	-3.28	-4.68	-1.71	-2.97
30th	-1.57	-3.31	-0.76	-3.17	-2.70	-2.13	-2.18	-3.31	-0.76	-2.55
40th	-0.85	-2.22	-0.01	-2.01	-1.88	-1.49	-1.17	-2.22	-0.01	-2.22
50th	-0.23	-0.90	0.60	-0.90	-0.95	-0.62	-0.43	-0.95	0.60	-1.55
60th	0.33	0.00	1.57	0.00	-0.05	0.01	0.19	-0.05	1.57	-1.61
70th	1.27	0.59	2.17	0.81	0.71	0.73	1.17	0.59	2.17	-1.58
80th	2.54	1.57	3.20	2.18	2.02	1.78	2.23	1.57	3.20	-1.63
90th	4.54	3.53	4.90	4.01	3.99	3.63	4.25	3.53	4.90	-1.37

A better pairing of percentile scores and efficiency goals may be attained from looking at individual AC's and how they perform. The data provided 24 AC's that performed over 30 sorties at a single location. The percentiles were calculated for all flights involving these AC's and can be seen on the right side of Table 9. Next, the mean scores were calculated for each AC and placed into one of the aforementioned percentiles. Utilizing these mean scores and percentiles may provide better insight into a potential efficiency goal because these are the AC's with the most flights in relation to their mission. If a percentile score is picked from the overall AF population, the pilot may only have a few sorties and thus, the set goal could be misleading. Rather, averaging experienced AC sorties and using that score as a benchmark provides a more realistic and attainable number for all AC's to achieve.

Table 12: Percentile Scores AC's with >30 Sorties

AC's with >30 Sorties Mean Fuel Efficiency Score				
AC #	Mean	AC Mean Percentile	Percentiles (All SAAM Sorties)	
1	-4.21	0.2	0	-23.46
2	-3.04	0.3	0.1	-6.86
3	-2.55	0.4	0.2	-4.10
4	-2.31	0.4	0.3	-2.70
5	-2.27	0.4	0.4	-1.84
6	-1.58	0.5	0.5	-0.70
7	-1.45	0.5	0.6	0.00
8	-1.43	0.5	0.7	0.92
9	-1.19	0.5	0.8	2.23
10	-1.11	0.5	0.9	4.52
11	-1.06	0.5	1	19.34
12	-0.90	0.5		
13	-0.87	0.5		
14	-0.82	0.5		
15	-0.67	0.6		
16	-0.65	0.6		
17	-0.42	0.6		
18	-0.36	0.6		
19	-0.32	0.6		
20	-0.12	0.6		
21	0.01	0.7		
22	0.15	0.7		
23	0.68	0.7		
24	0.87	0.7		

V. Discussion

With the results of this research in place, this chapter will transition to a discussion of the investigative questions described in Chapter I as well as potential future research topics. Specifically, the researcher will discuss the adequacy of $M1_{Cargo\ Adjusted}$ and $M2_{Regression}$ as fuel efficiency metrics, how the metrics perform from a Wing and individual perspective, which metric should be utilized in future AF operations, and what the specific efficiency goal should be for AF leaders to set.

Investigative Questions

1. *From a metric criteria perspective, is $M1_{Cargo\ Adjusted}$ or $M2_{Regression}$ a more adequate measure of fuel efficiency for AC's?*

$M1_{Cargo\ Adjusted}$ is the selected metric based on factors outlined in "The Metric Handbook". The analysis of metric criteria using the decision matrices demonstrated a difference in how the metrics would be accepted, and instituted, within an organization. In particular, the underlying formulations of $M1_{Cargo\ Adjusted}$ (taking into account planning factors) clearly define and provide meaning to the metric. An understanding of the relationship between ACFP and metric formulation will be more intuitive to AC's.

M2's is useful for baseline comparison but not AC fuel efficiency. The replacement of ACFP planning measurements with predicted regression formulations doesn't allot for full use of a system designed to account for external factors outside the bounds of the AC's control. These factors must be controlled to the maximum extent possible to convince AC's that they have a locus of control over the metric and what it aims to influence. If planning factors are not a consideration, AC's will likely question the purpose of the metric and why ACFP does not play a larger role in determining efficiency.

2. From a metric comparison perspective, how do Wings/Individual AC's perform?

The summary statistic revealed important differences between the metrics. With a higher standard deviation and variance in $M2_{Regression}$, the individual sortie scores were spread further out from the mean. This suggests much broader efficiency scores across the AF. $M1_{Cargo\ Adjusted}$ had a smaller standard deviation by approximately 1.7klbs per sortie (outliers removed) showing a lot less variability in how AC's performed from an efficiency perspective. This is very important when considering how to use GST tenets to quantify efficiency goals for all AC's. Under $M2_{Regression}$, the increased variability presents more of a challenge when determining the appropriate level for a goal to be set.

The comparison at the Wing level as well as the time-series showed a stark difference between the metrics. First, it showed that all Wings may not be able to have the same goal set for them. Although they are not drastically different, there are statistical differences. Dependent upon the approved Wings for the experiment, this difference should be evaluated before determining a final goal. Next, the time series illustrated that FCIF changes and any other factors that impact the manner in which AC's fly must be accounted for when determining an optimal metric and efficiency goals.

3. Which metric should be provided to AC's and for what purpose?

From a broader perspective, $M1_{Cargo\ Adjusted}$ leverages current ACFP system capability by utilizing planning factors that have already been established. The additions of payload and distance adjustments made in $M1_{Cargo\ Adjusted}$ calculations could eventually be incorporated into ACFP, negating the need for separate calculations. This would provide more validity to the system, strengthen AC commitment to the efficiency metric and goal, and more accurately account for fuel use and savings. To illustrate the savings associated with $M1_{Cargo\ Adjusted}$ fuel efficiency, a simple illustration of the adjusted metric over a three year period is relevant. Figure 15 shows a continual downward trend over a three year period. The costs associated with this trend are highlighted in Table 10 which shows a $19.1M cost swing from 2011 – 2014. It is important to understand that the 42083 sorties captured in this analysis only cover Channel, SAAM, and Contingency missions at Active Duty Wings for C-17's. The magnitude of applying a more robust metric across the fleet and at Reserve Wings has the potential to demonstrate significant cost savings by providing a more accurate efficiency calculation.

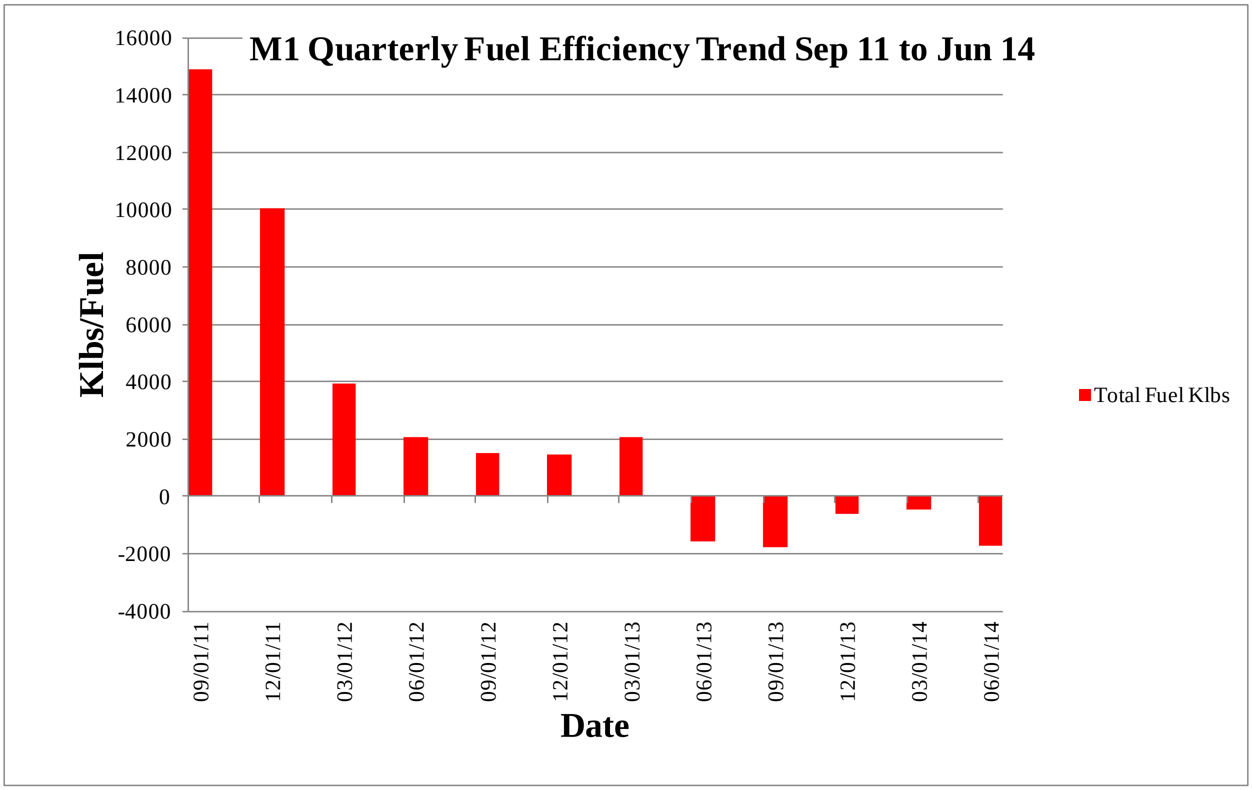


Figure 11: M1$_{\text{Cargo Adjusted}}$ Efficiency Trend Sep 11 - Sep 14

Table 13: $M1_{Cargo\ Adjusted}$ Cost Trend Sep 11 - Sep 14

12 Month Cost Comparison M1 (Channel/SAAM/Contingency)			
	1 Sep 11-31 Aug 12	1 Sep 12 - 31 Aug 13	1 Sep 13 - 31 Aug 14
Klbs	30,971	3,510	(4,530)
lbs	30,970,675	3,510,151	(4,530,229)
Gallons	4,622,489	523,903	(676,154)
$/Gallon	3.62	3.62	3.62
Total Cost	$ 16,733,409.23	$ 1,896,529.48	$ (2,447,676.05)

4. *Using GST, how can the chosen metric be presented as a goal for AC's? What specific efficiency goal can be set for AF AC's?*

As discussed in Chapter II, content (specificity, difficulty) and intensity (commitment) are the key components of GST that will increase the probability of higher performance and goal attainment. Commitment will be heavily reliant on the design and execution of the experiment. Specificity and difficulty can be instituted by pairing the metric and the percentile analysis. Using GST principles and examples (Latham and Locke 1991:213-214 and Locke et al., 1989:272), specificity and difficulty can be paired, illustrated in the following example:

1. Easy: Attain a mean score in the 70th percentile by achieving a 5 sortie moving average of 1klbs.
2. Moderate: Attain a mean score in the 60th percentile by achieving a 5 sortie moving average of 0klbs.
3. ***Difficult: Attain a mean score in the 30th percentile by achieving a 5 sortie moving average of -3klbs. This is an example of a possible goal for the experiment.***
4. Impossible: Attain a mean score in the 20th percentile by achieving a 5 sortie moving average of -4klbs.

Several implications exist within this goal. First, it gives the AC's a relative standing amongst their peers. Only one AC out of 24 scored in the 20th percentile. The impact of not targeting AC's in the highest percentiles is negligible compared to not giving the majority of AC's an attainable goal. He or she is already extremely efficient and may self set a higher goal. Next, by using a moving average of sorties in the experiment, anomalies can be mitigated. If an

AC experiences severe weather (and ACFP doesn't accurately account for it), the rolling average will reduce the impact and eventually fall out of the score. Finally, by attaching a specific klb figure to the goal, the metric becomes very important. The AC's must trust the measurement for the assigned klb figure to have any motivational impact. $M1_{Cargo\ Adjusted}$, if explained properly in the commitment attainment phase, will have this buy-in.

Future Research

More research is needed on the overall performance of the Fuel Tracker and ACFP. The underlying assumptions built into ACFP should be validated. For instance, what impact does ATC allowed hold-down fuel have on fuel efficiency? Is added fuel for extreme weather accurately allocated in fuel efficiency comparisons and calculations? Should a cargo adjustment be built into ACFP? How can the system be leveraged to capture important facets of fuel efficiency and use those facets to impact flying behavior?

Next, the culture of fuel efficiency in the Air Force should be evaluated. Proper metrics and goals can have a significant impact but the underlying culture of AC's, how they are trained, what is deemed important to them, leadership influence, peer influence, and other factors should be studied to determine their impact on fuel efficiency. This focus area coupled with metric and goal development could prove beneficial to the Air Force in the future of fuel efficiency studies.

As previously discussed, the selected metric and fuel goal set in this research should be utilized in a motivational study within Wings. The basic premise is that AC's will be given specific, difficult goals based on the metric. Two types of feedback will be distributed (public and private) to the AC's and their performance will be evaluated based on the types of feedback. This will test the tenets of GST, feedback, and metric development against actual performance and help determine if a behavioral approach to fuel efficiency is both warranted and cost effective. A basic model of this future research can be found in Appendix C.

Appendix A: C-17 Master Fuel Tracker Worksheet

C-17 Master Fuel Tracker Worksheet POC HQ AMC/A3F (Mar 2014)

Aircraft Commander: | **Wing:** | **Squadron:**

Mission #: | **Dept Date (Zulu):** | **ICAO From:** | **ICAO To:**

Ramp Fuel (Klbs)		Land Fuel (Klbs)		Duration (h.h)		Cargo + Pax (Klbs)		Takeoff CG		APU (h.h)		AR Onload (Klbs)	
Plan	Act	Plan	Act	Plan	Act	Plan	Act	Plan	Act	Pre	Post	Plan	Act

Did you tanker fuel? No | Yes for Cost Avoidance | Yes for Operational Requirement | Amount Tankered: (Klbs)____

Flight Plan Used: ☐ ACFP using MI Values ☐ ACFP Using "NA" MI Values ☐ PFPS ☐ None

Was MIF Used:
- ☐ Yes
- ☐ No, Flight times less than 1 hour
- ☐ No, Sortie did not operate above 10,000 ft
- ☐ No, Unable to use both MIF altitudes and airspeeds
- ☐ No, Due to slot time or airfield operating hours
- ☐ No, Due to crew duty day restrictions
- ☐ No, Mission computer inop/not available
- ☐ No, Tanker could not use MIF due to Coronet
- ☐ No

First half ERCC? Yes No | **Hvy Wt A/R Training?** Yes No | **Airdrop/Low Level Sortie:** Yes No

GPU Used Before Takeoff:
- ☐ No, GPU Not Functional
- ☐ No, Operational (Combat/Austere Ops)
- ☐ Yes
- ☐ No, A/C would not accept power
- ☐ No, Not Required
- ☐ No, Not at aircraft before engine start
- ☐ No, Weather precluded use

GPU Used At Destination:
- ☐ No, GPU Not Functional
- ☐ No, Operational (Combat/Austere Ops)
- ☐ Yes
- ☐ No, A/C would not accept power
- ☐ No, A/C Requires Tow to Parking
- ☐ No, Not at aircraft before engine start
- ☐ No, Weather precluded use
- ☐ No, Not Required

Ramp Fuel Deviation Reason: (Required if greater than 1,500 Lbs difference in plan vs. actual)
- ☐ N/A
- ☐ Additional Cargo/PAX
- ☐ AC Adjusted fuel (FM Agrees)
- ☐ AC Adjusted fuel (FM Disagrees) (Please Comment)
- ☐ Mission/Routing change
- ☐ Enroute WX
- ☐ Fuel Service Over-Fuel
- ☐ ERCC
- ☐ Tail Swap/Could not defuel
- ☐ Other (Please Comment)
- ☐ Tankered fuel (Ops/FM Directed)
- ☐ Burned less than Plan on previous leg

Landing Fuel Deviation Reason: (Required if greater than 3,000 Lbs difference in plan vs. actual)
- ☐ N/A
- ☐ Airfield Ops
- ☐ ATC (Hold Downs, Excessive Vectors, etc
- ☐ BASH
- ☐ Flew less than scheduled duration-TNG or MSN complete
- ☐ Air Abort: Tanker (Due to IFE, Tanker, MX or WX)
- ☐ Air Abort: Receiver (Due to IFE, Receiver MX, or WX)
- ☐ Mission Index Flying
- ☐ Cruise Wind/Temp Deviations
- ☐ Enroute WX Deviations
- ☐ Excessive Fuel Burn in Cruise
- ☐ Overflew Original Destination
- ☐ Extra Cargo Loaded
- ☐ Ramp Fuel Deviation
- ☐ Maintenance
- ☐ Receivers did not show
- ☐ Receivers took less fuel than planned
- ☐ Receivers took more fuel than planned
- ☐ Able to climb earlier than ACFP Forecast
- ☐ Other____________

Comments:

Aircraft Commander: | **Wing:** | **Squadron:**

Mission #: | **Dept Date (Zulu):** | **ICAO From:** | **ICAO To:**

Ramp Fuel (Klbs)		Land Fuel (Klbs)		Duration (h.h)		Cargo + Pax (Klbs)		Takeoff CG		APU (h.h)		AR Onload (Klbs)	
Plan	Act	Plan	Act	Plan	Act	Plan	Act	Plan	Act	Pre	Post	Plan	Act

Did you tanker fuel? No | Yes for Cost Avoidance | Yes for Operational Requirement | Amount Tankered: (Klbs)____

Flight Plan Used: ☐ ACFP using MI Values ☐ ACFP Using "NA" MI Values ☐ PFPS ☐ None

Was MIF Used:
- ☐ Yes
- ☐ No, Flight times less than 1 hour
- ☐ No, Sortie did not operate above 10,000 ft
- ☐ No, Unable to use both MIF altitudes and airspeeds
- ☐ No, Due to slot time or airfield operating hours
- ☐ No, Due to crew duty day restrictions
- ☐ No, Mission computer inop/not available
- ☐ No, Tanker could not use MIF due to Coronet
- ☐ No

First half ERCC? Yes No | **Hvy Wt A/R Training?** Yes No | **Airdrop/Low Level Sortie:** Yes No

GPU Used Before Takeoff:
- ☐ No, GPU Not Functional
- ☐ No, Operational (Combat/Austere Ops)
- ☐ Yes
- ☐ No, A/C would not accept power
- ☐ No, Not Required
- ☐ No, Not at aircraft before engine start
- ☐ No, Weather precluded use

GPU Used At Destination:
- ☐ No, GPU Not Functional
- ☐ No, Operational (Combat/Austere Ops)
- ☐ Yes
- ☐ No, A/C would not accept power
- ☐ No, A/C Requires Tow to Parking
- ☐ No, Not at aircraft before engine start
- ☐ No, Weather precluded use
- ☐ No, Not Required

Ramp Fuel Deviation Reason: (Required if greater than 1,500 Lbs difference in plan vs. actual)
- ☐ N/A
- ☐ Additional Cargo/PAX
- ☐ AC Adjusted fuel (FM Agrees)
- ☐ AC Adjusted fuel (FM Disagrees) (Please Comment)
- ☐ Mission/Routing change
- ☐ Enroute WX
- ☐ Fuel Service Over-Fuel
- ☐ ERCC
- ☐ Tail Swap/Could not defuel
- ☐ Other (Please Comment)
- ☐ Tankered fuel (Ops/FM Directed)
- ☐ Burned less than Plan on previous leg

Landing Fuel Deviation Reason: (Required if greater than 3,000 Lbs difference in plan vs. actual)
- ☐ N/A
- ☐ Airfield Ops
- ☐ ATC (Hold Downs, Excessive Vectors, etc
- ☐ BASH
- ☐ Flew less than scheduled duration-TNG or MSN complete
- ☐ Air Abort: Tanker (Due to IFE, Tanker, MX or WX)
- ☐ Air Abort: Receiver (Due to IFE, Receiver MX, or WX)
- ☐ Mission Index Flying
- ☐ Cruise Wind/Temp Deviations
- ☐ Enroute WX Deviations
- ☐ Excessive Fuel Burn in Cruise
- ☐ Overflew Original Destination
- ☐ Extra Cargo Loaded
- ☐ Ramp Fuel Deviation
- ☐ Maintenance
- ☐ Receivers did not show
- ☐ Receivers took less fuel than planned
- ☐ Receivers took more fuel than planned
- ☐ Able to climb earlier than ACFP Forecast
- ☐ Other____________

Comments:

Appendix B: Fuel Efficiency Background Metric (Reiman, 2014: 51-52)

$$\theta = \beta_0 + \beta_1\alpha + \beta_2\alpha^2 + \beta_3\omega + \beta_4\omega^2 + \beta_5\alpha\omega \tag{21}$$

Where:

θ = Specific Range in NMs per Klbs
α = Altitude in Thousands of Feet
ω = Aircraft Gross Weight in Klbs

Table 3: Specific range regression terms

	C-5	C-17	C-130
β_0	24.538	31.735	58.829
β_1	0.5511	0.9897	3.5292
β_2	0.0002	-0.0043	-0.0098
β_3	-0.0318	-0.0642	-0.2384
β_4	1.9E-05	5.8E-05	0.0010
β_5	-0.0005	-0.0011	-0.0155

Given the specific range regression equation, the distance flown in NMs for a given altitude and gross weight can be determined by integrating Equation 21 with respect to the change in fuel consumed over the interval from zero to the total fuel consumed as shown in Equation 22. After integrating and solving for cruise fuel, the resulting equation is as shown in Equation 23.

$$\delta = \int_0^{\omega_{ff}} (\beta_0 + \beta_1\alpha + \beta_2\alpha^2 + \beta_3\omega + \beta_4\omega^2 + \beta_5\alpha\omega)\, df \tag{22}$$

$$\omega_{ff} = -\frac{B}{3A} - \frac{1}{3A}\sqrt[3]{\frac{1}{2}\left[2B^3 - 9ABC + 27A^2D + \sqrt{(2B^3 - 9ABC + 27A^2D)^2 - 4(B^2 - 3AC)^3}\right]} - \frac{1}{3A}\sqrt[3]{\frac{1}{2}\left[2B^3 - 9ABC + 27A^2D - \sqrt{(2B^3 - 9ABC + 27A^2D)^2 - 4(B^2 - 3AC)^3}\right]} \tag{23}$$

Where (All weights in Klbs):

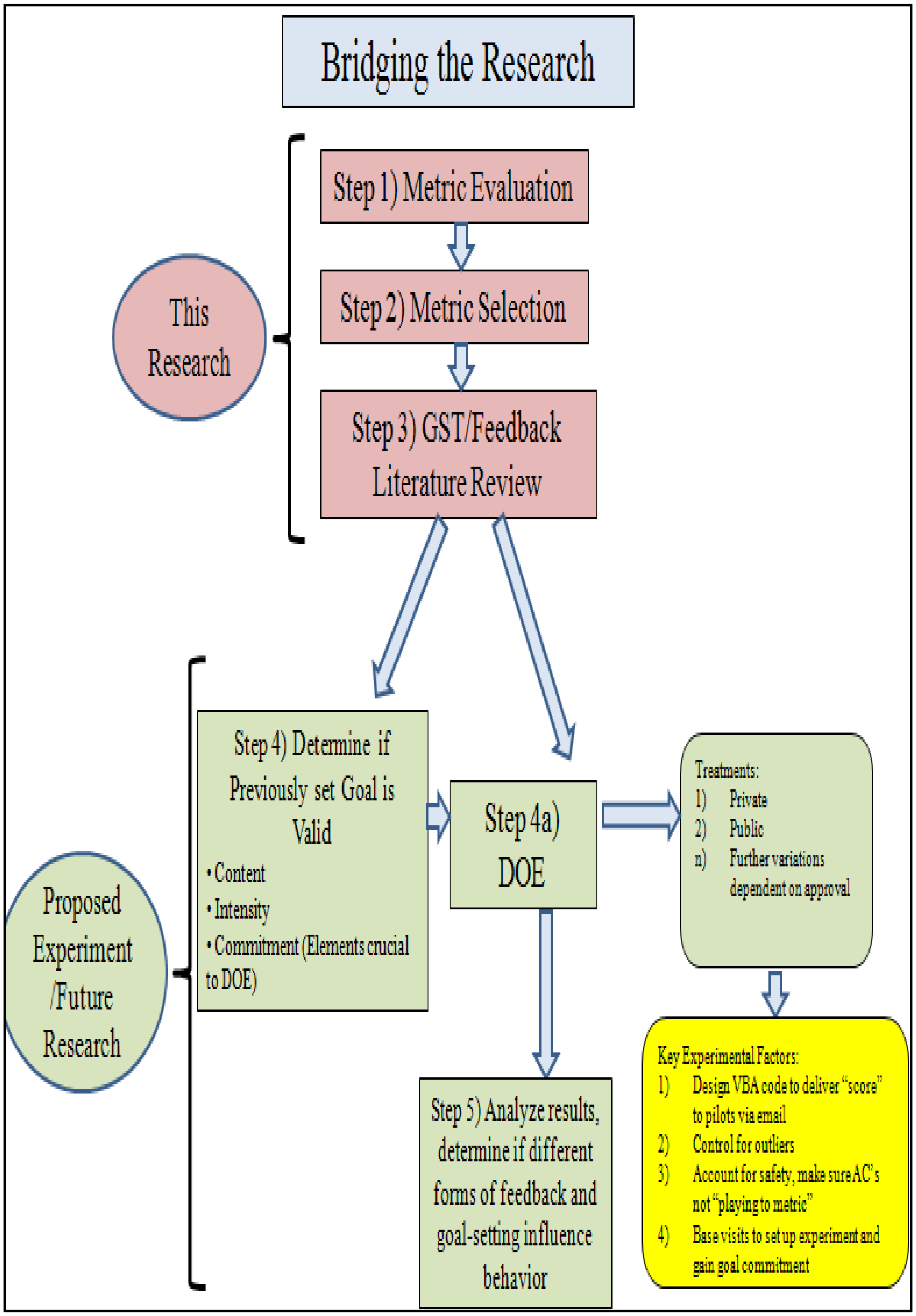
$A = \frac{\beta_4}{3}$

$B = \left(\frac{\beta_3}{2} + \beta_4(\omega_{op} + \omega_{frc} + \omega_{fah} + \omega_p) + \frac{\beta_5}{2}\alpha\right)$

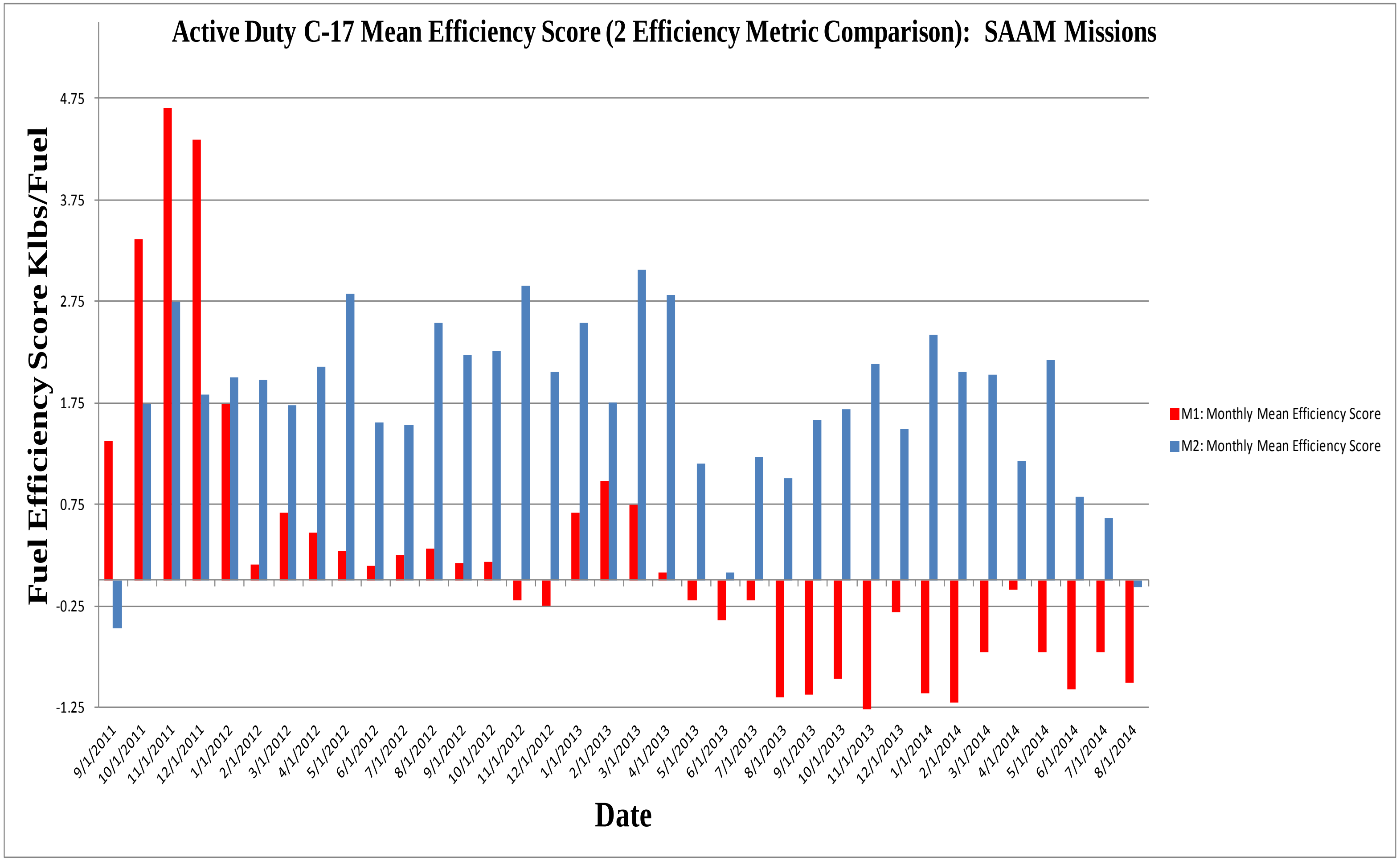
$C = \beta_0 + \beta_1\alpha + \beta_2\alpha^2 + \beta_3(\omega_{op} + \omega_{frc} + \omega_{fah} + \omega_p) + \beta_4(\omega_{op} + \omega_{frc} + \omega_{fah} + \omega_p)^2 + \beta_5\alpha(\omega_{op} + \omega_{frc} + \omega_{fah} + \omega_p)$

D = $-\delta$
δ = Distance in NMs
α = Altitude in Thousands of Feet
ω = Aircraft Gross Weight
= $\omega_{op} + \omega_{frc} + \omega_{fah} + \omega_p + f$
ω_{op} = Operating Weight
ω_{frc} = Reserve/Contingency Fuel Weight
ω_{fah} = Alternate/Holding Fuel Weight
ω_p = Payload Weight
f = Fuel Consumed
ω_{ff} = Cruise Fuel Weight

Appendix C: Bridging the Research (Follow-On Experiment)



Appendix D: Mean Efficiency Scores Sep11-Aug14



Appendix E: FCIF Changes Jun 11 – Dec 14

FCIF#	Release Date	Subject
11-06-04	14-Jun-11	Pilot's Performance Advisory System (PPAS) Operational Procedures for C-17 Aircraft
11-06-06	17-Jun-11	Destination Weather Requirements
11-07-07	19-Jun-11	Equal Time Point and Depressurization/Decompression Fuel Procedures Update
11-09-06	22-Sep-11	Early Descent Fuel Calculation for KC-10s
11-10-11	24-Oct-11	Early Descent Fuel Calculation for all other MDSs
12-07-02	9-Jul-12	Cost Avoidance Tankering (MAFCAT) Program
12-08-10	28-Aug-12	Cargo Loading for Optimal Fuel Efficient Center of Gravity
13-02-11	22-Feb-13	Fuel Tracker
13-07-07	26-Jul-13	C-17A Tail Specific Fuel Bias Checklist
13-07-09	30-Jul-13	Waiver to OCONUS Alternate Requirements
14-01-03	10-Jan-14	Fuel Tracker
14-10-17	20-Oct-14	C-17 Authorized Identified Extra Fuel
14-12-02	3-Dec-14	Flight Planning Fuel Policy Letter

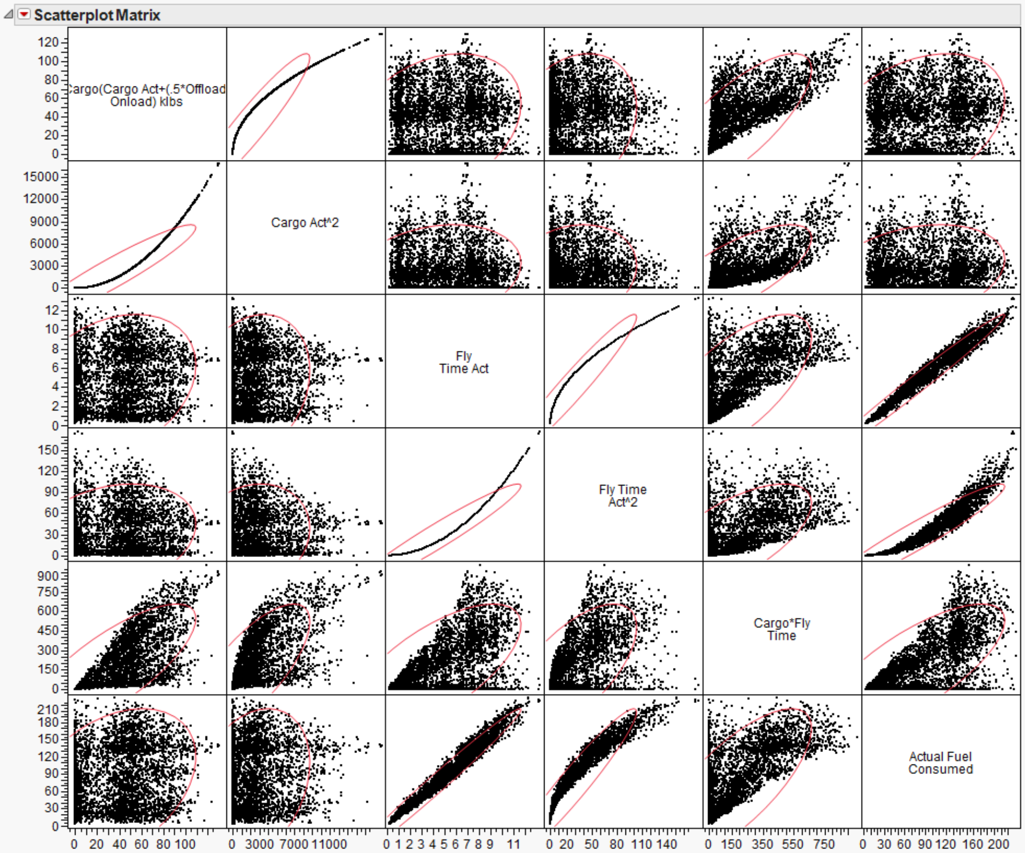
Appendix F: M2$_{Regression}$ Multivariate Plot

Multivariate

Correlations

	Cargo(Cargo Act+(.5*Offload/Onload) klbs	Cargo Act^2	Fly Time Act	Fly Time Act^2	Cargo*Fly Time	Actual Fuel Consumed
Cargo(Cargo Act+(.5*Offload/Onload) klbs	1.0000	0.9410	0.2955	0.2472	0.7756	0.3707
Cargo Act^2	0.9410	1.0000	0.2175	0.1703	0.7301	0.2926
Fly Time Act	0.2955	0.2175	1.0000	0.9641	0.6780	0.9884
Fly Time Act^2	0.2472	0.1703	0.9641	1.0000	0.6437	0.9567
Cargo*Fly Time	0.7756	0.7301	0.6780	0.6437	1.0000	0.7458
Actual Fuel Consumed	0.3707	0.2926	0.9884	0.9567	0.7458	1.0000

Scatterplot Matrix



Appendix G: Fuel Planning Policy letter Nov 14 (Gillson, 2014)

Flight Planning Fuel Policy Letter 14.2

Additional Fuel/Default Mission Index (MI):

Due to international airspace inconsistencies (erratic ATC clearances, ADS-B forced descents) and flight planning software constraints, planners are directed to add the following additional contingency fuels to the ACFP Flight Plan Request. MI values listed below are ACFP defaults:

Aircraft	Hold Down/Early Descent	Egypt O/F	Singapore O/F[1]	MI
C-130	N/A	2,500	N/A	N/A
C-17	4,500/4,500	8,000	4,000	31
C-5	6,000/6,000	12,000	6,500	41
KC-10	4,500/4,500	12,000	5,000	34
KC-135	3,000/3,000	8,000	4,000	R-24, T-19
C-21	200/200	N/A	N/A	N/A

[1] Do not include Singapore O/F fuel when WSAP is the departure or arrival ICAO.

Planners will use "Fuel D" for Hold Down fuel, and "Fuel I" for Early Descent Fuel and Overflight (O/F) Fuel. Planners will not bump cargo for additional O/F Fuel or apply O/F fuel additions to active CORONET legs. Do not add Hold Down/Early Descent fuel when sortie is planned under FL180.

Hold Down/Early Descent List:

KADW[1]	KDOV[1,2]	KMRB[1,2]	KSWF[1]
KPIT[3]	KCEF[1]	KWRI[1]	WSAP
RJTY	RJTA	OAKN	

[1] For C-21, only applies to arrivals from the west.
[2] For C-5, only applies to arrivals from the west.
[3] Only applies to flights transiting to/from the east to the northeast (KADW north through New York ARTCC airspace).

CORONET: Tankers may carry up to 1 hour extra holding fuel on active AR legs.

ACFP: All C-5s have a 4% degrade automatically added by default, UFN.

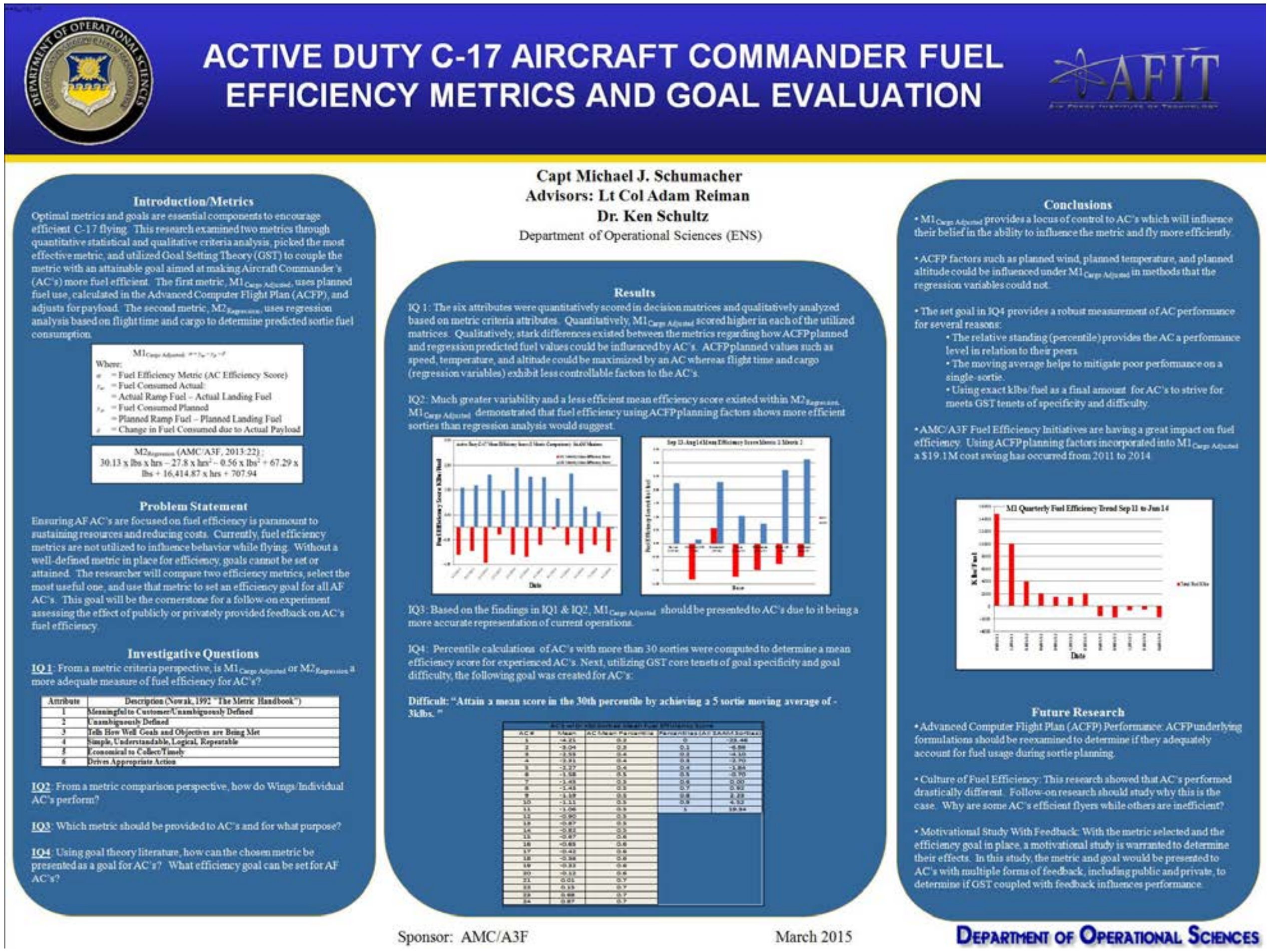
AOR/Combat Zone:

-Planners will tanker as much fuel as practical into Afghanistan and always tanker through Iraq. Otherwise, tanker fuel IAW MAFCAT Fuel Tankering Matrix located on 618 AOC (TACC) website.
--Planners will not bump cargo or passengers to tanker fuel if fuel is available.
--Operational requirements take precedence over fuel tankering policy.
--OASH: Calculate an SDP to depart OASH. If planning to tanker fuel over the value needed to get to the next refueling location, limit the TOGW to SDP weight minus 25K (do not reduce ACL in order to increase tankered fuel, this does not preclude going up to full SDP TOGW to get to the next ICAO).
-Planners will include a destination alternate when departing a location with limited fuel.
-Planners will plan an alternate for any mission into an AOR/Combat zone.
-OAIX Min Landing Fuel for C-17s & C-5s is 21K (3K extra).

NOTE: The Aircraft Commander (AC) is the final authority regarding aircraft fuel loads. Planners will comply with AC direction.

POC: HQ AMC/A3V, Mr. Andrew B. Gillson, DSN 779-3626 Latest Update: 17 November 2014

Appendix H: Storyboard



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14. ABSTRACT

As the largest consumer of fuel in the Department of Defense, the Air Force continually looks for new ways to advocate aircraft fuel efficiency. Optimal metrics and goals are essential components to encourage efficient flying. This research examined two metrics through quantitative statistical and qualitative criteria analysis, picked the most effective metric, and utilized Goal Setting Theory (GST) to couple the metric with an attainable goal aimed at making Aircraft Commander's (AC's) more fuel efficient. The first metric, $M1_{Cargo\ Adjusted}$, uses current sortie planning factors and adjusts these for payload. The second metric, $M2_{Regression}$, uses regression analysis based on flight time and cargo to determine predicted sortie fuel consumption. It was determined that $M1_{Cargo\ Adjusted}$ provided a more robust measure of efficiency that would provide AC's a locus of control over metric results. $M1_{Cargo\ Adjusted}$ was then paired with GST foundational principles of goal specificity, difficulty, and commitment and translated into an efficiency goal aimed at influencing AC behavior and optimizing long-term efficient fuel use.

15. SUBJECT TERMS

Goal-setting Theory, Metric, Fuel Efficiency, Aircraft Commander

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