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Operational Cost of Cabin Altitude Restriction (CAR)

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**Final Report
for August 2016 to January 2020**

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14. ABSTRACT

Conventional wisdom holds that cabin altitude restriction (CAR) ups risk for turbulence/physical stress on aircraft, prolongs flight times, and increases fuel consumption. As a result, systematic organizational resistance to CAR prescribing can be encountered. The Theater Validating Flight Surgeon (TVFS) often employs CAR to mitigate anticipated drops in tissue oxygen delivery; recent studies demonstrate salutary clinical effect with appropriate CAR prescribing. This study aimed to ascertain the operational impact of CAR on Flight Duration and Fuel Cost. Operational flight data, from January 2005 through December 2015, were obtained from the 618th Air & Space Operations Center Tanker Airlift Control Center Data Division and matched to data from the Transportation Command Regulating & Command & Control Evacuation System. In this way, the operational flight data (e.g., flight duration, fuel cost) could be separated into CAR and Non-CAR missions. 8,191 missions were identified. Inaccurate/incomplete data were purged. The result: Flight Duration dataset (n = 5,561) and Fuel Cost dataset (n = 2,601). Flight Duration analyses revealed a universal drop with CAR, ranging 1.8 to 18.6 minutes. Fuel Cost analyses yielded mixed results: CAR more expensive and operationally significant (defined as $5,000) in Balad Air Base (AB), Iraq to Ramstein AB, Germany (C-17) route by ~$5,500; CAR more expensive, but operationally not significant for C-17 and KC-135 in Bagram AB, Afghanistan to Ramstein AB, Germany route; CAR less expensive in Ramstein AB, Germany to Andrews Air Force Base, Maryland (C-17) route. In sum, these findings do not endorse the conventional wisdom, especially when weighed against both clinical dollar and human savings. In fact, the CAR prescription did not up Flight Duration nor did it seriously increase Fuel Cost. Consequently, this study strongly argues against any embargo, or push back, relative to appropriate TVFS prescribing of the CAR.

15. SUBJECT TERMS

Aeromedical evacuation, AE, cabin altitude restriction, CAR, theater validating flight surgeon, TVFS, flight duration, flight time, fuel cost, cost

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1.0 EXECUTIVE SUMMARY

Over the past two decades United States military medicine has made great strides in casualty care. In fact, lethality is at its lowest ever. There are a number of reasons for this success --- care is farther forward, care is at a higher quality, advanced technological support is ever-present, Critical Care Air Transport Teams (CCATTs) extend Intensive Care Unit (ICU) care onto aircraft, and Aeromedical Evacuation (AE) has agility not seen in yesteryear.

Each patient brought aboard an AE aircraft is cleared, or validated, for flight by the Theater Validating Flight Surgeon (TVFS). At altitude, there are a number of physiologic stressors that can add insult to an already ill/injured patient. It is the TVFS' job to minimize such inflight vulnerability. This is realized with patient prescriptions, including supplemental oxygen and assignment of CCATTs, and aircraft prescriptions, such as long, slow landings and, the focus of this study, cabin altitude restriction (CAR).

The CAR is often prescribed to maximize tissue oxygen delivery. Tissue oxygen delivery is key to the health and well-being of any patient. However, when flying, cabin altitude is generally around 8,000 feet. This means that a patient is exposed to hypoxia and hypobaria, both of which conspire to reduce tissue oxygen delivery not only to healthy tissues, but also, more importantly, to compromised tissues. An added physiologic insult to already compromised tissues predisposes the patient to added morbidity and, potentially, mortality. Recent studies have shown CAR may well abrogate that added morbidity. In fact, CAR appears to reduce the number of postflight procedures and complications, not to mention days in the ICU and days on the ventilator. In short, CAR appears to have a serious and positive impact on the clinical mission.

On the other hand, conventional wisdom holds CAR has a serious and negative impact on the operational mission. With CAR imposition, the engineered, most efficient cruising altitude often must be lowered. Accompanying this drop in cruising altitude is an upped risk for turbulence and physical stress on the aircraft, along with longer flight times and increased fuel consumption. As a result, systematic organizational resistance to CAR prescribing can be and has been encountered.

There are only two prior studies examining the operational impact of CAR and both were rather limited. Their findings suggest conventional wisdom may be overstated. Consequently, this study was performed.

Operational Line of the Air Force flight data was obtained from the 618th Air and Space Operations Center Tanker Airlift Control Center Data Division (618 TACC) for the period January 2005 through December 2015. The AE missions extracted were then matched to data from the Transportation Command Regulating and Command and Control Evacuation System (TRAC^{2}ES). In this way, the operational flight data (e.g., flight duration, fuel cost) could be separated into CAR and Non-CAR missions. A total of 8,191 missions were identified.

Unfortunately, the flight data was not pristine; thus, incomplete, inaccurate, missing, and estimated data were purged. The result was a Flight Duration dataset (n = 5,561) and a Fuel Cost dataset (n = 2,601).

Flight Duration analyses revealed that CAR was universally associated with reduced flight times, ranging from ~1.8 to ~18.6 minutes. None were operationally significant (defined as 30 minutes) and all contradicted the conventional wisdom, doing nothing to advocate against the CAR.

Fuel Cost analyses yielded mixed results. CAR flights were more expensive and operationally significant (defined as $5,000) in the Balad Air Base (AB), Iraq to Ramstein AB, Germany C-17 route by ~$5,500. CAR flights were more expensive, but operationally not significant for both the C-17 and KC-135 in the Bagram AB, Afghanistan to Ramstein AB, Germany route. And, CAR flights were less expensive in the Ramstein AB, Germany to Andrews Air Force Base (AFB), Maryland route by ~$2,800. These findings offer no ready support for the conventional wisdom bringing into question its sagacity and, when weighed against both the clinical dollar savings and clinical human savings, certainly do not offer an argument against the CAR.

In conclusion, this study's Flight Duration and Fuel Cost analyses do not unambiguously endorse the conventional wisdom. In fact, the CAR prescription was not associated with increased Flight Duration nor did its Fuel Cost consistently reach operational significance. Consequently, there should be no embargo, or push back, from appropriate prescribing of the CAR.

2.0 INTRODUCTION

Cabin altitude for the standard military flight ranges between 8,000 and 10,000 feet. (**Borden Institute, 2004**) Unfortunately, flying at these altitudes exposes aircrew as well as passengers to a number of physiological stressors --- acceleration/deceleration, excess noise, thermal instability (hypothermia/hyperthermia), lowered humidity, vibration, hypoxia, and hypobaria. These stressors can affect aircrew performance and mission safety. (**McFarland, 1958**) They can also affect passengers, more specifically casualties, or patients. Theater Validating Flight Surgeons (TVFS) often prescribe a cabin altitude restriction (CAR) to offset these effects. Conventional wisdom holds that a CAR adds serious cost to a mission --- reduced cruising altitude, increased risk for turbulence, more physical stress upon the aircraft, added fuel consumption, and longer flight time. Because a CAR appears to diminish patient morbidity when prescribed within the tissue oxygen delivery (DO_2) paradigm (**Henry, 1973; Butler, 2016; Fouts, 2017; Butler, 2018; Butler, 2019a; Butler, 2019b**), it is imperative to determine the operational cost of imposing a CAR. This study sought to examine this operational cost and specifically focused on CAR's impact on flight duration and fuel cost.

3.0 BACKGROUND

Aeromedical Evacuation (AE) is the main means of moving patients from one level of care to the next, always bringing them to a higher echelon of care. (**Hurd, 2006**) However, AE is not without risks. Patients endure any number of inflight stressors including gravitational forces, low humidity and temperatures, serious noise, increased vibration, not to mention reduced barometric pressure and oxygen levels. (**Schneider, 1921**) Of most import is cabin altitude which foists both hypoxia (reduced oxygen availability) and hypobaria (interstitial fluid shifting aka edema) upon patients. These two physiological phenomena, conjoined with vibration, present to tissues less oxygen which must travel over greater diffusion distances. A number of inciting mechanisms come to mind --- injury and its effects (**Hunt, 1988; Barillo, 2003; Richalet, 1995; Constanzo, 2010**), vibration (**Lundborg, 1987; Mittermayr, 2003**), hypoxia (**Henry, 1973; Schacke, 2007; Earnest, 2013; Johannigman, 2015)**, altitude (**Hackett, 2011; Luks, 2015**), accelerated Starling effects (**Shuster, 1996a; Shuster, 1996b; Mittermayr, 2003; Butler, 2016; Butler, 2019a**), inflammatory upregulation (**Goodman, 2011; Skovira, 2016**), bubble evolution/bubble infusion with concomitant growth (**Richalet, 1995; Roach, 1995; Butler, 2016**) as well as ischemia-reperfusion injury (**Carden, 2000**) --- though the precise mechanism remains unclear. That said, the physiological consequence seems clear, a potential drop in DO_2, while the clinical consequence seems just as clear, a potential rise in patient morbidity. (**Butler, 2016; Fouts, 2017; Butler, 2018; Butler, 2019a; Butler, 2019b**)

To counter this physiology and reduce patient vulnerability, the TVFS often prescribes supplemental oxygen, transfusions, and/or a CAR. Traditionally, a CAR has been prescribed to mitigate the effects of altitude on trapped gas, decompression sickness/air gas embolism, and severe pulmonary disease. (**Borden Institute, 2004**) However, in late 2006/early 2007, the notion of boosting DO_2 entered the AE arena. (**Pollan, 2006; Butler, 2007**) At that time CAR prescribing rose. Subsequent research suggested that the CAR prescription had a salutary impact on patient morbidity, particularly in lowering the number of both postflight procedures and postflight complications. (**Butler, 2016; Fouts, 2017; Butler, 2018; Butler, 2019a; Butler, 2019b**)

Normally, military aircraft fly at a cabin altitude of 8,000 to 10,000 feet. (**Borden Institute, 2004**) When restricted for a patient, the cabin altitude is set below 8,000 feet. The most commonly prescribed altitude restrictions are 5,000 feet, 6,000 feet, and 4,000 feet, in order of frequency. (**Butler, 2017**) Unfortunately, a CAR prescription may mean that the aircraft's most efficient cruising altitude (i.e., operating altitude designed to be most cost-effective) cannot be flown. Because of the engineered cabin-altitude/cruising-altitude relationship, a CAR imposition almost always demands a reduced cruising altitude. As a result, conventional wisdom suggests serious operational impact --- longer flight durations, increased fuel consumption, raised likelihood of inflight refueling, higher cost of flight, greater turbulence exposure, and more physical stress on the aircraft. Consequently, there has often been a systematic organizational resistance to CAR prescribing.

These facts prompted one of the authors (LWS), in 2007, to request from Headquarters Air Mobility Command (AMC) Test and Evaluation Squadron a mission impact assessment of the CAR. With a C-17 mission from Balad AB (Iraq) to Ramstein AB (Germany), they detected no mission impact for a flight flown with the cabin at sea level, 5,000 feet, or 10,000 feet. At the same time, with a C-17 mission from Bagram AB (Afghanistan) to Ramstein AB (Germany), they detected no mission impact for a flight flown with the cabin at 5,000 feet or 10,000 feet, but, with a flight flown at sea level, they detected minimal impact, that being “requires air refuel or fuel stop (due to lower cruise altitude).” (**Fouts, 2017**) See **Appendix 9.1** for further details.

Later, Fouts et al, using a matched case-control methodology, demonstrated no statistically significant difference in either flight duration or fuel cost when comparing CAR versus Non-CAR flights, whether the flight was intratheater or intertheater and no matter what the aircraft type. That said, however, *post hoc* testing suggested these analyses underpowered to detect a significant difference. (**Fouts, 2017**) See **Appendix 9.2** for further details.

Consequently, this study was devised to attempt a more definitive examination of the operational cost associated with the imposition of a CAR.

4.0 METHODS

4.1 Institutional Review

Since this research did not involve human subjects, thus not meeting the regulatory definition of human subject research, the Air Force Research Laboratory Institutional Review Board determined it to be not-human-subject research (FWR20160146N) and not within its purview. The research was conducted at the U.S. Air Force School of Aerospace Medicine at Wright-Patterson Air Force Base in Dayton, Ohio.

This study analyzed retrospective operational data consisting of both flight duration and fuel cost for AE missions with and without a CAR, specifically looking at mission class, mission route, and the C-17 and KC-135 airframes. No patient (aka human subject) data was collected.

4.2 Methodology

As noted earlier, conventional wisdom suggests CAR has a significant operational cost. The overarching study question was relatively simple: Is the conventional wisdom correct? Consequently, the study examined:

1. The difference in Flight Duration between CAR and Non-CAR flights.
2. The difference in Fuel Cost between CAR and Non-CAR flights.

Embedded within this effort and the operational data were several assumptions.

1. All flights involved AE. As a result, extra weight from coexistent cargo should be randomly distributed between CAR and Non-CAR flights, not affecting either Flight Duration or Fuel Cost in a systematic fashion.
2. An operationally significant difference in Flight Duration was defined as at least 30 minutes.

   a. Maximum Flight Duty Period (FDP) for tanker air crew is 16 hours. In an operationally rigorous environ, an extra 30 minutes flying could potentially have an adverse effect on FDP as well as mandated crew rest. (**USAF Instruction, p. 13**)

3. An operationally significant difference in Fuel Cost was defined as at least $5,000.
   a. Mandated Fuel Reserve (FR) must provide 45 minutes of flying time. In an operationally rigorous environ, though unlikely, $5,000 in extra fuel consumed could potentially have an adverse effect on FR. (**USAF Instruction, p. 36**)
   b. Operational cost of an aircraft is not exclusive of fuel. Taking around a third of the combined average estimated hourly operating cost of the C-17 and KC-135, though arbitrary, seemed a reasonable estimate of operational significance.
4. Flight Duration was derived from takeoff time and landing time, rounded to the nearest 0.1 hour. Flights listed as lasting several days were assumed to be recording errors and not considered.
5. Fuel Cost was derived from takeoff and landing fuel levels. These levels were recorded in pounds. The common jet fuel pound to gallon conversion of 6.7 gallons per pound and the October 2016 price of $2.97 per gallon were assumed.
6. Although departing and arriving airfields were known, the actual flight route was not recorded. Thus, a Great Circle route with its accompanying standard mileage was assumed. (Great Circle Mapper; https://www.greatcirclemapper.net; accessed 25 June 2019)

7. Sample size calculations employed a Power = 0.80 and alpha = 0.05. As no prior studies offered up estimates for the difference between means (Delta) or standard deviation (SD), the following assumptions were made.
    a. Flight Duration (t-test):
        i. Delta = 0.5 hours; SD = 0.5 hours.
        ii. A sample size of at least 17 flights per group was required.
        iii. In cases of unequal group sizes where one group had less than 17 flights, *post hoc* testing was performed to determine if there was appropriate power.
    b. Fuel Cost (t-test):
        i. Delta = $5,000; SD = $4,000.
        ii. A sample size of at least 12 flights per group was required.
        iii. In cases of unequal group sizes where one group had less than 12 flights, *post hoc* testing was performed to determine if there was appropriate power.

Retrospective operational flight data from January 2005 through December 2015 was obtained from the 618th Air and Space Operations Center Tanker Airlift Control Center Data Division (618 TACC). Included in the dataset were mission ID, year, aircraft, mission class, departing ICAO (International Civil Aviation Organization) and airfield name, arriving ICAO and airfield name, date and time of takeoff, date and time of landing, best takeoff fuel, best landing fuel, departing theater, and arriving theater. Derived from this data were flight duration, mission route, mission miles, fuel consumed, and fuel cost. A total of 8,191 AE missions were identified.

Using mission ID, these flight data were merged with mission cabin altitude data as found in the TRANSCOM Regulating and Command and Control Evacuation System (TRAC^{2}ES). In this way, CAR missions could be separated from Non-CAR missions. The resultant final variables pertinent to this study were CAR (yes, no), CAR altitude, aircraft, mission class, mission route, flight duration, and fuel cost. No patient data was recorded.

In order to normalize CAR to Non-CAR missions as closely as possible, a sequential matching was performed. Five aircraft (C-5, C-17, C-130, KC-10, and KC-135) were recorded in the dataset; however, only two flew CAR missions --- the C-17 and the KC-135. Similarly, there were eleven Mission Classes flying AE (**see Table 1**); however, only four flew CAR missions --- Airevac, Channel, Contingency, and SAAM (Special Assignment Airlift Mission).

Table 1. Mission Class Description

Aeromedical Evacuation Missions (2005-2015)	
Mission Class	**Description**
Airevac	aeromedical evacuation
Channel	scheduled service missions between specified locations
Contingency	mission in direct support of an event
Deploy	mission in direct support of a deployment
Dualrole	dual role missions where both air refueling and airlift are provided
Exercise	training missions conducted during a sponsored exercise
Guardlift	mission supporting the Air National Guard
Refuel	air refueling mission
Special Assignment Airlift Mission	funded airlift that cannot be supported by channel missions due to unusual nature, sensitivity, or urgency
Support	mission supporting an operation
Training	see Exercise

Note: Derived from AFI 11-2AEV3, 15 August 2014 and AMCI 11-206, 8 May 2008 [https://doctrine.af.mil/download.jsp?filename=3-17-D40-Appendix-1-MSN-Types.pdf; accessed 25 June 2019]

Lastly, out of 319 Mission Routes recorded, only five had more than a few reported CAR flights. See **Table 2** for details. Missions without valid data were then excluded. Valid Flight Duration data being that where takeoff and landing times were recorded and valid Fuel Cost data being that where preflight and postflight fuel weights were recorded. This was done first with Flight Duration then with Fuel Cost.

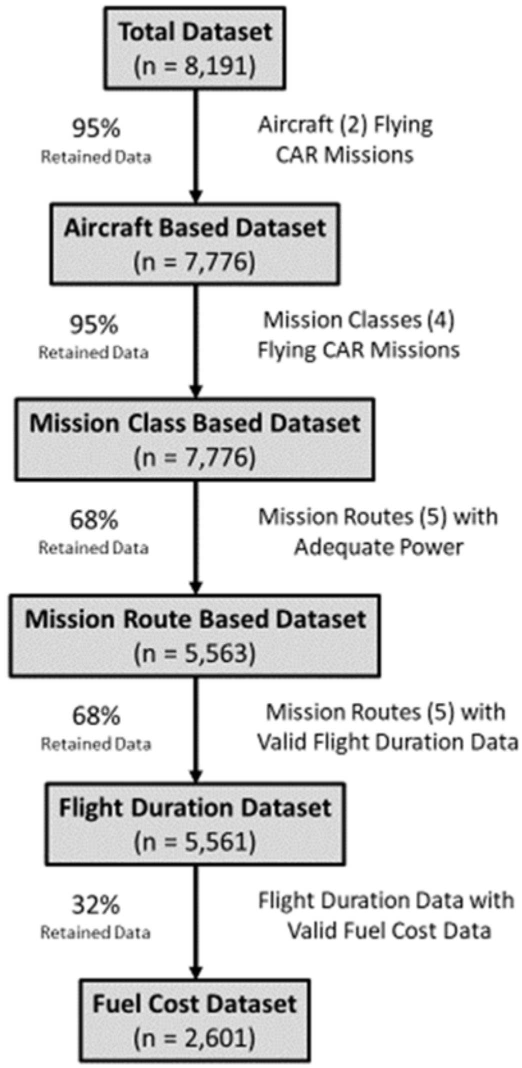
Table 2. Mission Routes with Requisite Sample Sizes

Aeromedical Evacuation Missions (2005-2015)		
Mission Routes*	**CAR**	**Non-CAR**
OAIX to ETAR	163	1,848
ORBD to ETAR	187	1,378
ETAR to KADW	88	1,353
OKAS to ETAR	14	347
OAKN to ETAR	12	173

Note: *Power estimates suggested a requisite of 17 missions for Flight Duration and 12 missions for Fuel Cost. Of the 35 Mission Routes with at least 1 CAR mission, only 5 routes had more than 5 reported CAR missions.
Note: OAIX to ETAR (Bagram AB, Afghanistan to Ramstein AB, Germany); ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany); ETAR to KADW (Ramstein AB, Germany to Andrews AFB, Maryland, USA); OKAS to ETAR (Ali al Saleem AB, Kuwait to Ramstein AB, Germany); OAKN to ETAR (Kandahar AB, Afghanistan to Ramstein AB, Germany).

The overall result was two datasets --- Flight Duration (n = 5,661; with 32% data loss from the original dataset) and Fuel Cost (n = 2,601; with 68% data loss from the original dataset). See **Figure 1**.

Figure 1. Decision Tree for Final Flight Duration and Fuel Cost Dataset Determinations



Flight Duration and Fuel Cost were then examined employing data visualization techniques including box plots, density curves, and dot plots. Categorical variables were described with number (percent) while continuous variables were expressed with mean, standard deviation (SD). Hypothesis testing applied Welch's two sample t-test (the better t-test when unequal sample sizes/variances exist). (**Pereira-Maxwell, 2018**) In using the t-test, analyses assumed normality or an appeal to the Central Limit Theorem. Effect size, when appropriate, was calculated with the Hedge's *g* methodology (the better effect size method when unequal sample sizes exist). (**Nakagawa, 2007**) In addition, linear modeling was exercised. With Flight

Duration, only the OAIX to ETAR route was modeled, as it was the sole route having a predictor variable beyond CAR, specifically the variable "KC-135 aircraft." On the other hand, with Fuel Cost, linear models employing both CAR and Flight Duration as predictor variables were considered for all five Mission Routes; however, two routes were underpowered for the modeling.

Throughout the study, data were cleaned, merged, and analyzed with the statistical package R (R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/).

5.0 RESULTS

5.1 Descriptive Analyses

There were 8,191 AE missions. Of these, 507 were CAR missions and 7,684 were Non-CAR missions. There were twelve different CAR altitudes prescribed; the most prevalent, in order, were 5,000 feet (53%), 6,000 feet (33%), and 4,000 feet (6%). See **Appendix 9.3** for details. Five aircraft were recorded as flying AE missions --- C-17 (n = 6,987), KC-135 (n = 804), C-130 (n = 390), C-5 (n = 7), and KC-10 (n = 3). Only the C-17 and KC-135 flew CAR missions. Similarly, there were eleven Mission Classes flying AE missions (see **Table 1**) --- Airevac (n = 1,305), Channel (n = 5,514), Contingency (n = 363), Deployment (n = 1), Dualrole (n = 6), Exercise (n = 1), Guardlift (n= 31), Refuel (n = 2), SAAM (n = 865), Support (n = 82), and Training (n = 21). Only the Airevac, Channel, Contingency, and SAAM mission classes flew CAR missions. At the same time, there were 319 Mission Routes with only 35 reporting any CAR missions, and just 5 having more than 5 reported CAR missions (see **Table 2**). Invoking these restrictions and accepting only valid data produced two interlocking study datasets --- the Flight Duration dataset (n = 5,561) and the Fuel Cost dataset (n = 2,601). See **Figure 1** and **Table 3** for details.

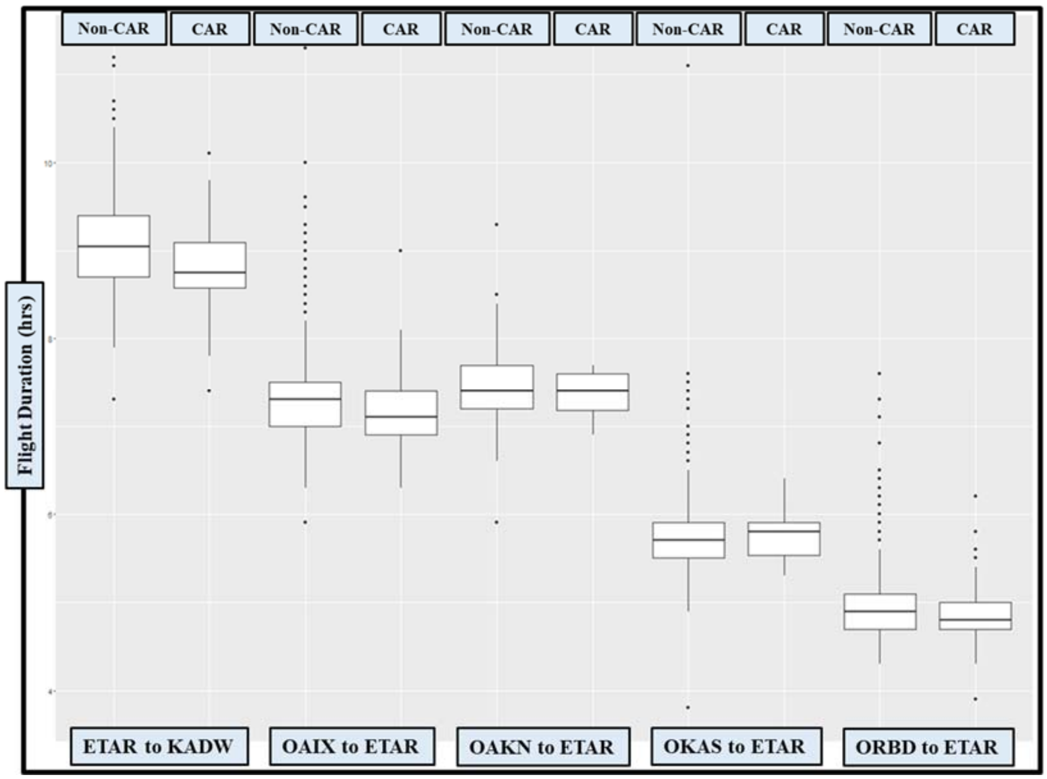
Table 3. Descriptive Analysis of AE Missions

Aeromedical Evacuation Missions (2005-2015)				
Variable	**C-17**		**KC-135**	
	CAR	**Non-CAR**	**CAR**	**Non-CAR**
Mission Class Dataset				
Mission Class, N (%)	**(n = 449)**	**(n = 6,528)**	**(n = 58)**	**(n = 741)**
Airevac	67 (15)	981 (15)		68 (9)
Channel	317 (70)	4,494 (69)	58 (100)	636 (85)
Contingency	12 (3)	296 (4)		30 (4)
Special Assignment Aircraft Mission	53 (12)	757 (12)		7 (1)
Flight Duration Dataset				
Mission Routes, N (%)	**(n = 408)**	**(n = 4,480)**	**(n = 56)**	**(n = 617)**
OAIX to ETAR	107 (26)	1,242 (27)	56 (100)	606 (98)
ORBD to ETAR	187 (46)	1,378 (31)		
ETAR to KADW	88 (22)	1,345 (30)		6 (1)
OKAS to ETAR	14 (3)	345 (8)		2 (<1)
OAKN to ETAR	12 (3)	170 (4)		3 (<1)
Fuel Cost Dataset				
Mission Routes, N (%)	**(n = 101)**	**(n = 2,163)**	**(n = 17)**	**(n = 320)**
OAIX to ETAR	57 (56)	907 (42)	17 (100)	320 (100)
ORBD to ETAR	11 (11)	309 (14)		
ETAR to KADW	18 (18)	750 (35)		
OKAS to ETAR	6 (6)	107 (5)		
OAKN to ETAR	9 (9)	90 (4)		

Note: Fuel Cost Dataset is derived from the Flight Duration Dataset and consists of actual preflight and postflight fuel entries.
Note: OAIX to ETAR (Bagram AB, Afghanistan to Ramstein AB, Germany); ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany); ETAR to KADW (Ramstein AB, Germany to Andrews AFB, Maryland, USA); OKAS to ETAR (Ali al Saleem AB, Kuwait to Ramstein AB, Germany); OAKN to ETAR (Kandahar AB, Afghanistan to Ramstein AB, Germany).

Flight Duration data were then graphically described employing a density curve and box plot. The box plot depicted three levels of Flight Duration within the five mission routes --- around 9 hours being ETAR to KADW, around 7 hours being OAIX to ETAR and OAKN to ETAR, and around 5 hours being OKAS to ETAR and ORBD to ETAR. See **Figure 2**.

Figure 2. Box Plot of Flight Duration for All Valid CAR versus Non-CAR Missions



These observations when combined with the mission route Great Circle mileage (see **Table 4**) confirmed the intuitive notion: the longer the mission route, the longer the flight duration.

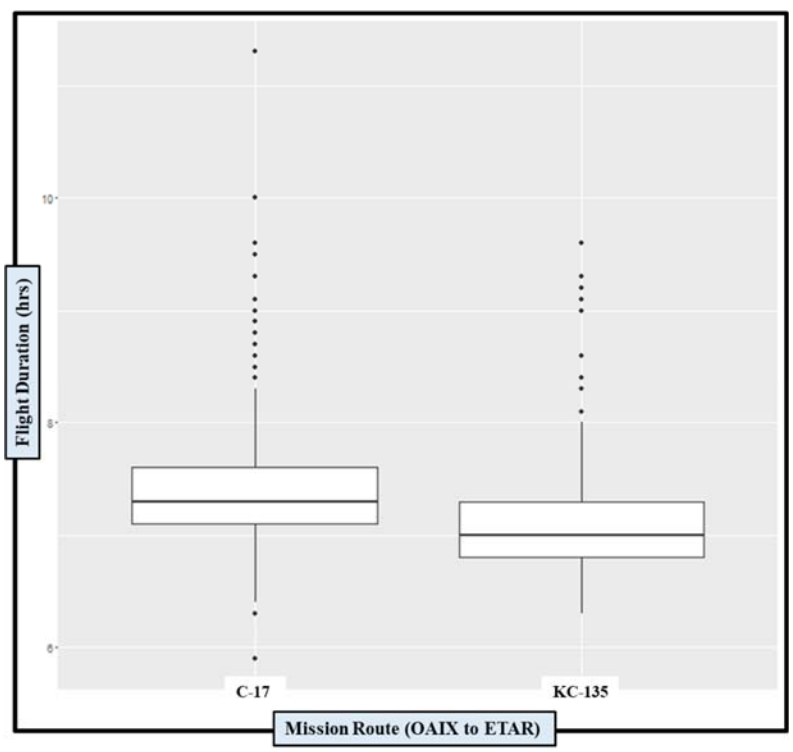
Table 4. Great Circle Mileage for Mission Route Flights

Aeromedical Evacuation Missions (2005-2015)		
Mission Routes	**Airfields**	**Great Circle Miles***
ETAR to KADW	Ramstein AB, Germany to Andrews AFB, Maryland	3,507
OAIX to ETAR	Bagram AB, Afghanistan to Ramstein AB, Germany	2,796
OAKN to ETAR	Kandahar AB, Afghanistan to Ramstein AB, Germany	2,793
OKAS to ETAR	Ali Al Saleem AB, Kuwait to Ramstein AB, Germany	2,175
ORBD to ETAR	Balad AB, Iraq to Ramstein AB, Germany	1,869

Note: *Employed Great Circle Mapper [https://www.greatcirclemapper.net; accessed 25 June 2019]
Note: OAIX to ETAR (Bagram AB, Afghanistan to Ramstein AB, Germany); ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany); ETAR to KADW (Ramstein AB, Germany to Andrews AFB, Maryland, USA); OKAS to ETAR (Ali al Saleem AB, Kuwait to Ramstein AB, Germany); OAKN to ETAR (Kandahar AB, Afghanistan to Ramstein AB, Germany).

Flight duration differences based on aircraft type were then examined. As all the mission routes save OAIX to ETAR flew only the C-17, OAIX to ETAR was isolated for study. See **Figure 3**. Here, the C-17 appeared to exhibit a slightly longer flight time than the KC-135, most likely reflecting its slower cruising speed (518 mph versus 530 mph, respectively). (**U.S. Air Force, 2019**)

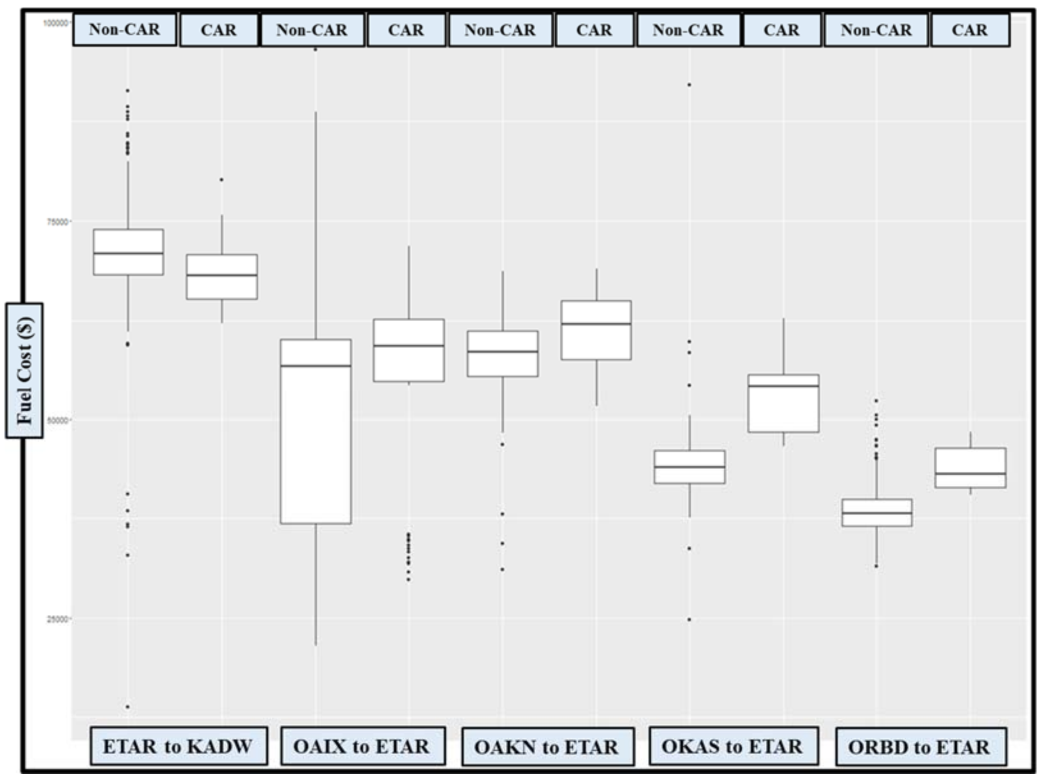
Figure 3. Flight Duration Between Aircraft within the OAIX to ETAR Mission Route



Taking a closer look at the graphics (**Figure 2**), it was difficult to discern any systematic differences in Flight Duration between the CAR and Non-CAR flights as bracketed into the five mission routes.

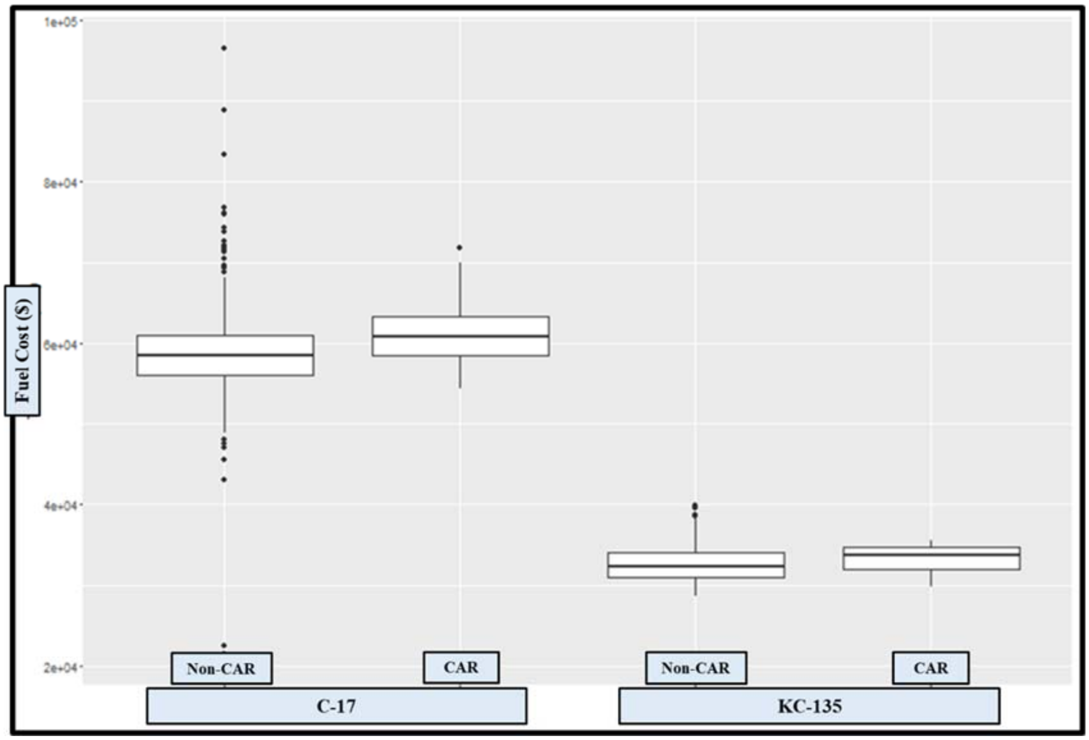
Turning to the Fuel Cost, a density curve and box plot were again created. The box plot suggested that Fuel Cost dropped as Mission Route Great Circle mileage dropped. However, the OAIX to ETAR route box plot configuration differed from that of the other routes. See **Figure 4**.

Figure 4. Box Plot of Fuel Cost for All Valid CAR versus Non-CAR Missions



As this was the only route sporting two AE aircraft, the C-17 and the KC-135, it was singled out for a more detailed look. Indeed, there was a conspicuous difference in fuel cost between aircraft. See **Figure 5**.

Figure 5. Fuel Cost Between Aircraft within the OAIX to ETAR Mission Route



This most likely reflected the speedier cruising speed of the KC-135 (530 mph versus 518 mph) and its cheaper hourly operating cost. See **Table 5** for details.

Table 5. Estimated Hourly Cost for Operating Aircraft Employed in AE

Aeromedical Evacuation Missions (2005-2015)	
Aircraft	**Cost ($/hour)****
C-17*	16,310
KC-135*	14,847
C-130J*	14,845
C-130E/H*	9,226
KC-10	18,883
C-5	35,737
C-21	1,777

Note: *These are the most commonly employed aircraft in AE. **These estimates of hourly operating cost include fuel cost and were provided by Transportation Command representatives during the Advanced Clinical Concepts in Aeromedical Evacuation course (September 2019).

Taking a closer look at the graphics (**Figure 4 and Figure 5**), it appeared that CAR flights might well be systematically more expensive than Non-CAR flights, the one exception being the ETAR to KADW route.

In sum, the descriptive graphics suggested no obvious systematic difference in flight duration when looking at either CAR versus Non-CAR flights or C-17 versus KC-135 aircraft. Indeed, flight duration appeared to be most related to mission route mileage, the longer the mission route the longer the flight duration. Likewise, fuel cost appeared to be related to mission route mileage; however, in contradistinction, fuel cost also appeared to be related to both CAR imposition and the operating cost of the aircraft.

5.2 Comparative Analyses

Contrary to conventional wisdom, CAR was associated with a shorter flight duration across all five mission routes. In addition, CAR was associated with a shorter flight duration with both aircraft. See **Table 6** for details. Focusing on the C-17, CAR was associated with a drop in flight duration from ~1.8 to ~18.6 minutes (0.05% to 3.4%). With the KC-135, CAR was associated with a drop of ~4.8 minutes (1.1%). Although the difference in flight duration was statistically significant for ORBD to ETAR/ETAR to KADW/OAIX to ETAR (C-17), those differences (~7.2 minutes, ~18.6 minutes, and ~11.4 minutes, respectively) were not operationally significant (defined as 30 minutes). In sum, there was no evidence to suggest the CAR prescription had a significant operational impact on flight duration.

Table 6. Summary: Mission Route Flight Duration Analyses (t-Tests)

Aeromedical Evacuation Missions (2005 - 2015)								
CAR versus Non-CAR Comparison of Flight Duration (hours)								
Aircraft	**Mission Route**	**CAR, M (SD)**	**Non-CAR, M (SD)**	**95% CI**	**t-statistic (DF)**	**p-value**	**Difference in Means**	**Effect Size**
C-17	ORBD to ETAR	4.83 (0.29)	4.95 (0.32)	0.08, 0.17	5.40 (252)	<0.0001	-0.12	0.38
	ETAR to KADW	8.77 (0.47)	9.08 (0.50)	0.21, 0.42	6.15 (100)	<0.0001	-0.31	0.62
	OKAS to ETAR	5.74 (0.33)	5.77 (0.50)	-0.17, 0.22	0.27 (15)	0.79	-0.03	*
	OAKN to ETAR	7.36 (0.28)	7.46 (0.42)	-0.08, 0.29	1.22 (15)	0.24	-0.10	*
	OAIX to ETAR	7.20 (0.37)	7.39 (0.42)	0.12, 0.26	5.65 (137)	< 0.0001	-0.19	0.51
KC-135	OAIX to ETAR	7.01 (0.46)	7.09 (0.41)	-0.05, 0.21	1.24 (63)	0.22	-0.08	*

Note: *Since there was no statistical difference detected, effect size calculations were not performed.
Note: OAIX to ETAR (Bagram AB, Afghanistan to Ramstein AB, Germany); ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany); ETAR to KADW (Ramstein AB, Germany to Andrews AFB, Maryland, USA); OKAS to ETAR (Ali al Saleem AB, Kuwait to Ramstein AB, Germany); OAKN to ETAR (Kandahar AB, Afghanistan to Ramstein AB, Germany).

When it came to fuel cost, C-17 CAR flights were significantly more expensive in two mission routes, ORBD to ETAR by ~$5,510 and OAIX to ETAR by ~$2,496 (~14.3% and ~4.2%, respectively). Similarly, the OAIX to ETAR KC-135 CAR flights were more expensive by ~$572 (~1.8%); however, the difference proved not significant. In contrast, the ETAR to KADW mission route found CAR to be significantly less costly by ~$2,779 (~3.9%). Independent of statistical significance, only the ORBD to ETAR mission route demonstrated an operationally significant (defined as $5,000) fuel cost difference.

Notably, these relationships remained unchanged even after using linear models to help account for differences in flight duration. With ORBD to ETAR (C-17), CAR added ~$5,226 to fuel cost ($p < 0.0001$); with OAIX to ETAR (C-17), CAR added ~$2,741 ($p < 0.0001$); with OAIX to ETAR (KC-135), CAR added $598 ($p = 0.26$); and with ETAR to KADW (C-17), CAR subtracted ~$1,893 from fuel cost. Once again, the ORBD to ETAR route had the sole operationally relevant fuel cost differential. Not unexpected, the various models suggest that every hour of flight adds to the fuel cost, ranging from ~$414 to ~$5,285. In sum, there appears to be little evidence that a CAR prescription has a significant operational impact on fuel cost.

The one mission route reaching operational relevance, ORBD to ETAR, did so by only a few hundred dollars. See **Table 7** for details.

Table 7. Summary: Mission Route Fuel Cost Analyses (t-Tests & Linear Modeling)

Aeromedical Evacuation Missions (2005 - 2015)									
CAR versus Non-CAR Comparison of Fuel Cost (dollars[$])									
Aircraft	**Mission Route**	**CAR, M (SD)**	**Non-CAR, M (SD)**	**95% CI**	**t-statistic (DF)**	**p-value**	**Difference in Means**	**Effect Size**
C-17	ORBD to ETAR	44,022 (3,013)	38,512 (325)	-7,554; -3,465	-5.94 (11)	0.0001	5510	8.85
	ETAR to KADW	68,677 (4,740)	71,456 (4,720)	402; 5,155	2.46 (18)	0.02	-2779	0.59
	OKAS to ETAR	53,364 (6,116)	44,822 (5,893)	**Underpowered for formal analyses**			8,542	
	OAKN to ETAR	61,552 (5,213)	58,418 (4,810)				3,134	
	OAIX to ETAR	61,084 (3,691)	58,588 (6,770)	-3,521; -1,471	-4.86 (68)	< 0.0001	2496	0.39
KC-135	OAIX to ETAR	33,189 (1,648)	32,617 (2,157)	-1,446; 301	-1.37 (19)	0.19	572	*

ORBD to ETAR

C-17 --- Linear Model of Fuel Cost
(Non-CAR was used as reference state)

***** Fuel Cost = y + 5,226 (CAR) + 2,592 (Flight Time) *****

Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	5,226	972	3,314; 7,138	5.38	< 0.0001
Flight Time	2,592	606	1,400; 3,784	4.73	< 0.0001

F-statistic = 25.3 (DF = 2, 317), p < 0.0001

ETAR to KADW

C-17 --- Linear Model of Fuel Cost
(Non-CAR was used as reference state)

***** Fuel Cost = y - 1,893 (CAR) + 5,285 (Flight Time) *****

Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	-1,893	931	-3,590; 290	-2.03	0.042
Flight Time	5,285	280	4,666; 5,792	18.91	< 0.0001

F-statistic = 183.20 (DF = 2, 764), p < 0.0001

OKAS to ETAR

Underpowered for formal analyses

OAKN to ETAR

Underpowered for formal analyses

OAIX to ETAR

C-17 --- Linear Model of Fuel Cost
(Non-CAR was used as reference state)

***** Fuel Cost = y + 2741 (CAR) + 1,869 (Flight Time) *****

Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	2,741	637	1,491; 3,991	4.3	< 0.0001
Flight Time	1,869	363	1,156; 2,592	5.15	< 0.0001

F-statistic = 20.96 (DF = 2, 963), p < 0.0001

KC-135 --- Linear Model of Fuel Cost
(Non-CAR was used as reference state)

***** Fuel Cost = y + 598 (CAR) + 414 (flight Time) *****

Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	598	531	-447; 1,642	1.13	0.26
Flight Time	414	299	-174; 1,001	1.39	0.17

F-statistic = 1.54 (DF = 2, 334), p = 0.22

Note: *Since there was no statistical difference detected, effect size calculations were not performed.
Note: OAIX to ETAR (Bagram AB, Afghanistan to Ramstein AB, Germany); ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany); ETAR to KADW (Ramstein AB, Germany to Andrews AFB, Maryland, USA); OKAS to ETAR (Ali al Saleem AB, Kuwait to Ramstein AB, Germany); OAKN to ETAR (Kandahar AB, Afghanistan to Ramstein AB, Germany).

Unfortunately, two mission routes, OKAS to ETAR and OAKN to ETAR, were underpowered for formal comparative analyses. As a result, descriptive statistics were reported.

For the details of each mission route analysis, see **Appendices 9.4 – 9.8**.

6.0 DISCUSSION

6.1 Discussion

When a CAR is prescribed for an AE mission by the TVFS, it generally mandates a less efficient lower cruising altitude. Conventional wisdom holds that this has a price --- increased risk for turbulence, increased physical stress on the aircraft, increased flight time, and increased fuel consumption. The result, a seriously negative operational impact on mission and, historically, a systematic organizational resistance to CAR.

In contrast, CAR appears to have a seriously positive clinical impact on seriously ill/injured patients. When prescribed using the tissue oxygen delivery paradigm, it appears to drop the number of patients needing postflight procedures, the overall number of postflight procedures, the number of patients suffering postflight complications, and the overall number of postflight complications. (**Butler, 2016**; **Fouts, 2017**; **Butler, 2018**; **Butler, 2019a**; **Butler 2019b**) In addition, CAR may well moderate ventilator, intensive care unit, and length of stay days. (**Butler, 2018**; **Butler, 2019a**) In short, CAR is associated with reduced postflight patient morbidity. Hence, CAR is frequently prescribed.

These two opposing forces must be balanced. As the evidence mounts for CAR's clinical benefit, there is essentially no evidence for CAR's operational detriment. Previous studies, an operational assessment by the Line of the Air Force (**Appendix 9.1**) and a matched case control study (**Appendix 9.2**), suggest the negative operational impact of CAR might well be overstated. (**Fouts, 2017**)

Since these studies had considerable limitations, this study, designed to be a more authoritative look at the operational cost of CAR, was conducted. Indeed, its results strongly suggest CAR does not have a significantly negative operational impact. In fact, AE flights prescribed a CAR demonstrated a consistent drop in Flight Duration (ranging from around 2-19 minutes) while, at the same time, a not so consistent rise in Fuel Cost (ranging from around -$2,800 to +$5,500). Only the ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany) mission route saw an operationally significant rise in fuel cost, and that by only a few hundred dollars. Of note, significant operational impact for Flight Duration was defined as 30 minutes (~5-10% of a 5-10 hour flight) and for Fuel Cost it was defined as $5,000 (~3-7% of the cost for operating a C-17 or KC-135 for a 5-10 hour flight). Both definitions were AFI-based, educated best guesses.

It seems clear the CAR prescription does not necessarily mean a longer flight. In fact, across the two aircraft and the five mission routes eligible for this study, CAR flights, if anything, were somewhat shorter than Non-CAR flights. Indeed, the flight time differential was statistically significant half the time, while operationally significant none of the time. Clinically, CAR and its concomitant drop in flight time, arguably, are doubly good all the time. First, the CAR itself means a lower altitude for patients, reducing inflight hypoxia and hypobaria while, simultaneously, enhancing tissue oxygen delivery. (**Butler, 2019a**; **Butler, 2019b**) Second, shorter flight times mean less exposure to all of the flight stressors, including both hypoxia and hypobaria. Consequently, reduced patient morbidity would be expected and studies have confirmed that expectation. (**Butler, 2016**; **Fouts, 2017**; **Butler, 2018**; **Butler, 2019a**; **Butler, 2019b**)

Although finding CAR associated with a shorter flight times seems counterintuitive, several explanations come to mind. The most common AE mission class is Channel (~69%) and the most common AE mission class flown with a CAR is Channel (~74%). Channel flights are routinely scheduled and dedicated almost exclusively for AE. As a result, the flights are generally not loaded with cargo, meaning there is less overall weight to transport, making possible swifter flights. Also, the air crew (aka pilots) know they are flying very sick casualties (aka "brothers in arms") and they are well aware of the detrimental physiologic impact of flight stressors. Indeed, they may well seek out the shortest possible route flying at the greatest possible speeds.

Equally counterintuitive is the fact that fuel cost was not seriously upped with the CAR prescription. With the two aircraft and three mission routes available for formal analyses, even linear modeling confirmed CAR's modest impact on fuel cost, ranging from -$1,893 to +$5,226. Excepting the one mission route (ETAR to KADW), CAR proved more expensive; this was also true with the two underpowered mission routes. Even so, only one route (ORBD to ETAR) was operationally significant. Interestingly, that route was the shortest at 1,869 Great Circle miles (see **Table 4**), flown almost exclusively by the C-17 (cruising speed ~518 mph). (**U.S. Air Force, 2019**) Perhaps, the shorter the route the less it can be manipulated by the air crew (aka pilots). In fact, this route proved to have less variation when looking at both CAR and Non-CAR flight times (i.e., standard deviation) than any of the other routes (See **Table 6**). On the other hand, the mission route where CAR appeared to reduce fuel cost (ETAR to KADW) was 3,507 Great Circle miles (see **Table 4**). It, being the longest route, may have accorded greater flexibility of action for the air crew (aka pilots). In fact, this route proved to have the greatest variation in CAR and Non-CAR flight times (See **Table 6**).

All told, CAR had very little operational impact on fuel cost. With the OAIX to ETAR mission route, fuel cost was higher for both the C-17 and KC-135, but was operationally not significant. With the ETAR to KADW, fuel cost was less than flying without a CAR. With ORBD to ETAR, the excess fuel cost was operationally significant at ~$5,500.

Pricing this out, assume that CAR produces an average excess fuel cost of $5,500 across all platforms across all mission routes. Clinical studies suggest CAR moderates both the number of postflight procedures and postflight complications and the number of patients suffering postflight procedures and complications. A conservative estimate might be one less procedure and one less complication. (**Butler, 2016**; **Fouts, 2017**; **Butler, 2018**; **Butler, 2019b**) In addition, CAR is associated with fewer ICU and ventilator days, with one day each perhaps a conservative estimate. (**Butler, 2018**) An extra day in the ICU may cost ~$3,500. (**Hunter, 2014**) An extra day on the ventilator may cost ~$1,500. (**Dasta, 2005**) Moreover, one postoperative complication appears to increase the risk for reoperation, added hospital days, and death. If the extra one complication (e.g., without a CAR) comes in the face of other existing complications the relative risk rises even more. (**Tevis, 2013**) Lastly, the one additional procedure (e.g., without a CAR) may well range from as little as ~$4,600 for an operating room wound debridement to ~$32,000 for a hip replacement. (**Woo, 2013**; **LendingPoint, 2019**; **CostHelper, 2019**) Even these rough estimates suggest the monetary savings from a CAR exceed the potential added cost of it, not to mention the more important human savings by way of reduced patient morbidity and possibly mortality.

In summary, this study provides no evidence that the CAR prescription extends flight duration. Furthermore, although it appears that the CAR prescription trends to higher fuel costs, those fuel costs do not offer up serious operational impact, particularly in the face of CAR's salutary clinical impact.

6.2 Limitations

This retrospective study looking at the operational cost of the CAR prescription had one glaring limitation --- data accuracy. Prior to August 2009, recording of actual takeoff and landing times as well as takeoff and landing fuel weights were uncommon. Often the entries were incomplete, inaccurate, estimated or even missing. Following August 2009, the data, still not perfect, was much more complete. Unfortunately, the very robust initial dataset of 8,191 AE missions, when trimmed of invalid data, became two smaller datasets --- the Flight Duration dataset with a 32% data loss and the Fuel Cost dataset with a 68% data loss. See **Figure 1**. The Flight Duration dataset fully met sample size requirements; however, the Fuel Cost dataset did not. In fact, the OKAS to ETAR/OAKN to ETAR mission routes were underpowered for any quantitative fuel cost analyses. In addition, flight duration and fuel cost analyses for individual CAR altitudes were not possible as sample size requirements could not be met. See **Appendices 9.3 and 9.9** for details. In addition, the flights were not matched by patient acuity (e.g., patient precedence, CCATT assignment) or other operational factors (e.g., flight route priorities, diplomatic clearances, weather, accompanying cargo). And, lastly, the operationally significant definitions for Flight Duration (30 minutes) and Fuel Cost $5,000), though AFI-based, were both no more than educated best guesses.

7.0 CONCLUSION

Conventional wisdom holds that a CAR prescription will seriously increase flight duration and up fuel cost, even to the point of significant operational mission impact. This study failed to confirm that notion. In fact, CAR appeared to drop flight duration, ranging from ~1.8 to ~18.6 minutes. Although half of the flight duration CAR versus Non-CAR differentials proved statistically significant, none proved operationally significant (defined as a 30 minute difference).

In addition, CAR trended toward a higher fuel cost with one route, ORBD to ETAR, proving to be both statistically and operationally significant (defined as $5,000) with a CAR versus Non-CAR differential of $5,500. With OAIX to ETAR, CAR posted a higher fuel cost for both the C-17 (by $2,496) and the KC-135 (by $572), though neither reached operational significance. Even with the underpowered OKAS to ETAR and OAKN to ETAR routes, CAR appeared to be more expensive. Contrary to expectation, CAR was more economical with the ETAR to KADW mission route (by $2,779), statistically but not operationally significant. All told, CAR appeared to have, at best, only a modest impact on fuel cost.

Taking the $5,500 as a CAR-imposed generalized boost in fuel cost and bumping it up against the clinical cost of no CAR suggests CAR may well be cost-effective. Indeed, prior studies hold that CAR moderates the number of postflight procedures and complications. The cost savings in dollars from averting extra procedures/complications most likely easily match up against the extra fuel dollars. But, it is the cost savings in human terms, that is reduced patient morbidity and possibly even mortality, that favors a relatively unfettered application of the CAR prescription. Thus, the TVFS should prescribe a CAR without serious concern for operational cost.

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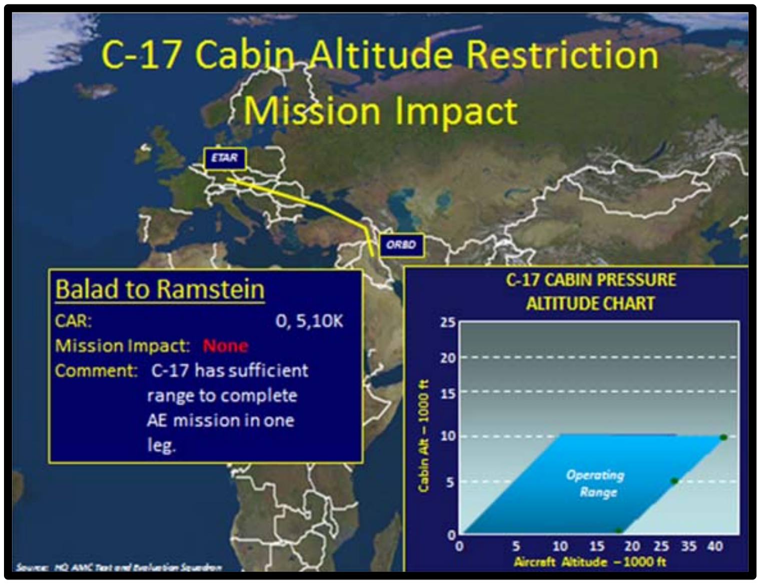
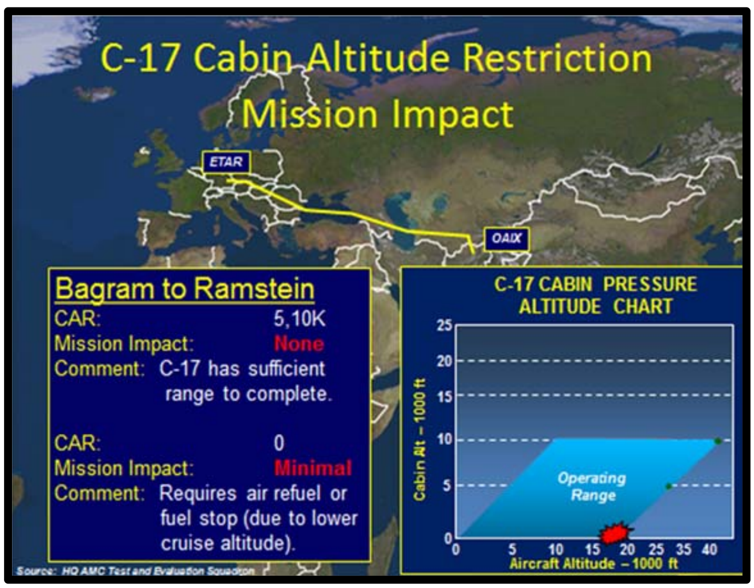
9.0 APPENDICES

9.1 Operational Impact of CAR on C-17 Missions as Determined by Headquarters AMC Test & Evaluation Squadron, 2007 (Fouts, 2017)

In 2007, responding to systematic organizational resistance, one of the authors (LWS) approached Headquarters Air Mobility Command Test and Evaluation Squadron for a mission impact assessment of the CAR prescription. No mission impact was detected for a C-17 flying the ORBD to ETAR mission route and, short of a sea level cabin altitude, no mission impact was detected for a C-17 flying the OAIX to ETAR mission route. See **Figure A1**.

Figure A1. Mission Impact of the CAR Prescription





9.2 Cost Comparisons for CAR & Non-CAR Missions (Fouts, 2017)

In a case-control study matching 50 CAR patients with 50 Non-CAR patients, postflight outcomes were examined. In addition, an operational cost comparison between CAR and Non-CAR flights was performed. (**Fouts, 2017**) No statistical difference was detected whether looking at Flight Duration (aka Flying Time) or Fuel Cost (aka Mission Cost/Hour). This was true overall (**Tables A1** and **A2**), by aircraft (C-17, C-130, and KC-135; **Tables A3**, **A4**, and **A5,** respectively), or by mission type (intratheater and intertheater; **Tables A6** and **A7**, respectively). Unfortunately, *post hoc* testing proved these analyses underpowered to detect a significant difference.

Table A1. Cost Comparison for CAR & Non-CAR Missions Using All Data*

Factor	CAR (*n*=29) M (*SD*)	Non-CAR (*n*=26) M (*SD*)	*p*-value	Power (%)
Flying Hours	4.78 (2.94)	5.15 (2.79)	0.638	---
Flight Miles	1753.55 (1182.36)	1922.73 (1137.03)	0.592	---
Fuel Consumption (gal)	11267.66 (8812.39)	11795.65 (8088.02)	0.819	6
Flight Miles/Gallon	0.215 (0.089)	0.209 (0.076)	0.813	---
Mission Cost/Hour	$5495.11 ($2797.19)	$6064.08 ($2955.34)	0.480	11

Note: **All Data* refers to all entries including actual values, estimated values, and modeled values, essentially whatever was recorded in the database. Tables B2 through Table B7 employ actual value data.

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Table A2. Cost Comparison of CAR & Non-CAR Missions

Factor	CAR (*n*=13) M (*SD*)	Non-CAR (*n*=17) M (*SD*)	*p*-value	Power (%)
Flying Hours	5.8 (2.47)	5.8 (2.65)	0.97	---
Flight Miles	2151 (1036.18)	2203 (1066.77)	0.90	---
Fuel Consumption (gal)	13,122 (7504.20)	13,924 (7900.60)	0.79	6
Flight Miles/Gallon	0.19 (0.06)	0.20 (0.07)	0.89	---
Mission Cost/Hour	$6521.75 ($2816.48)	$6846.54 ($2855.72)	0.77	6

Table A3. Cost Comparison of C-17 CAR & Non-CAR Missions

Factor	CAR (*n*=8) M (*SD*)	Non-CAR (*n*=10) M (*SD*)	*p*-value	Power (%)
Flying Hours	6.3 (2.01)	7.4 (0.33)	0.21	---
Flight Miles	2363 (847.41)	2795 (1.50)	0.22	---
Fuel Consumption (gal)	16,767 (6457.38)	19,858 (1233.62)	0.25	27
Flight Miles/Gallon	0.16 (0.04)	0.14 (0.01)	0.39	---
Mission Cost/Hour	$8041.80 ($2534.51)	$8745.11 ($2111.30)	0.56	10

Table A4. Cost Comparison of C-130 CAR & Non-CAR Missions

Factor	CAR (*n*=2) M (*SD*)	Non-CAR (*n*=4) M (*SD*)	*p*-value	Power (%)
Flying Hours	1.4 (0.28)	1.1 (0.14)	0.42	---
Flight Miles	335 (65.97)	280 (19.57)	0.56	---
Fuel Consumption (gal)	1269 (373.13)	933 (146.81)	0.53	23
Flight Miles/Gallon	0.27 (0.03)	0.31 (0.04)	0.43	---
Mission Cost/Hour	$3053.83 ($22.10)	$3416.62 ($634.01)	0.39	21

Table A5. Cost Comparison of KC-135 CAR & Non-CAR Missions Using

Factor	CAR (*n*=3) M (*SD*)	Non-CAR (*n*=3) M (*SD*)	*p*-value	Power (%)
Flying Hours	7.3 (0.22)	6.9 (0.14)	0.15	---
Flight Miles	2796 (0.00)	2796 (0.00)	1.00	---
Fuel Consumption (gal)	11,303 (579.90)	11,463 (375.22)	0.76	7
Flight Miles/Gallon	0.25 (0.01)	0.24 (0.01)	0.74	---
Mission Cost/Hour	$4780.23 ($179.25)	$5091.21 ($188.24)	0.17	55

Table A6. Cost Comparison of Intratheater CAR & Non-CAR Missions

Factor	CAR (*n*=3) M (*SD*)	Non-CAR (*n*=4) M (*SD*)	*p*-value	Power (%)
Flying Hours	1.4 (0.23)	1.1 (0.14)	0.14	---
Flight Miles	313 (62.19)	280 (19.57)	0.54	---
Fuel Consumption (gal)	1194 (322.42)	933 (146.81)	0.37	26
Flight Miles/Gallon	0.27 (0.02)	0.31 (0.04)	0.23	---
Mission Cost/Hour	$2995.62 ($84.27)	$3416.62 ($634.01)	0.34	26

Table A7. Cost Comparison of Intertheater CAR & Non-CAR Missions*

Factor	CAR (*n*=10) M (*SD*)	Non-CAR (*n*=13) M (*SD*)	*p*-value	Power (%)
Flying Hours	7.1 (0.73)	7.3 (0.36)	0.50	---
Flight Miles	2702 (277.83)	2795 (1.46)	0.34	---
Fuel Consumption (gal)	16,700 (4206.04)	17,921 (3703.41)	0.50	11
Flight Miles/Gallon	0.17 (0.05)	0.17 (0.04)	0.71	---
Mission Cost/Hour	$7579.60 ($2336.90)	$7901.90 ($2409.79)	0.76	6

*Missions arriving in Germany.

9.3 CAR Altitudes Levied for Mission Routes

The CAR is essentially a prescription unique to the purview of the TVFS. (**Hurd, 2006**) Unfortunately, little has been published discussing the actual level of CAR imposed. In the sole report dedicated to the TVFS practice, CAR level prescribing frequency, though unstated, was 5,000 feet (49%), 6,000 feet (42%), and 4,000 feet (7%). (**Butler, 2017**)

In the present study, the most common C-17 CAR altitudes were 5,000 feet (52%), 6,000 feet (33%), and 4,000 feet (7%) while the most common KC-135 CAR altitudes were 5,000 feet (59%) and 6,000 feet (34%). Taken as a whole, the overall CAR altitude profile was, in order of frequency, 5,000 feet (53%), 6,000 feet (33%), and 4,000 feet (6%). See **Table A8** for details.

Table A8. Altitude of CAR Prescriptions by Aircraft

Aeromedical Evacuation Missions (2005 - 2015)					
		C-17	KC-135	Totals	Percent
Altitude (ft)	0	9		9	2
	1,500	2		2	< 1
	2,000	3		3	< 1
	2,500	1		1	< 1
	3,000	15	2	17	3
	3,500	1		1	< 1
	4,000	31	1	32	* 6 *
	4,500	1		1	< 1
	5,000	235	34	269	* 53 *
	5,500	2		2	< 1
	6,000	146	20	166	* 33 *
	7,000	3	1	4	1
Totals		449	58	507	
Percent		89	11		

Note: *x* denotes the three most common altitudes levied with a CAR prescription.

Breaking out CAR levels by Mission Class, the most common CAR altitudes with Channel missions were 5,000 feet (51%), 6,000 feet (37%), and 4,000 feet (5%) while the most common CAR altitudes for Airevac missions were 5,000 feet (49%) and 6,000 feet (38%). The most common CAR altitude with both the Contingency and SAAM missions was 5,000 feet (58% and 70%, respectively). Taken as a whole, the CAR altitude profile for Mission Class was, in order of frequency, 5,000 feet, 6,000 feet, and 4,000 feet. See **Table A9** for details.

The Channel Mission appeared to be the only mission class that could potentially meet the sample size requirements for both Flight Duration and Fuel Cost.

Table A9. Altitude of CAR Prescriptions by Mission Class

Aeromedical Evacuation Missions (2005 - 2015)							
		Airevac	Channel	Contingency	SAAM	Totals	Percent
Altitude (ft)	0		9			**9**	**2**
	1,500		2			**2**	**< 1**
	2,000		3			**3**	**< 1**
	2,500		1			**1**	**< 1**
	3,000	5	6	1	5	**17**	**3**
	3,500			1		**1**	**< 1**
	4,000	7	20		5	**32**	*** 6 ***
	4,500	1				**1**	**< 1**
	5,000	33	192	7	37	**269**	*** 53 ***
	5,500		2			**2**	**< 1**
	6,000	20	139	2	5	**166**	*** 33 ***
	7,000	1	1	1	1	**4**	**1**
Totals		**67**	**375**	**12**	**53**	**507**	
Percent		**13**	**74**	**2**	**10**		

Note: *x* denotes the three most common altitudes levied with a CAR prescription. SAAM (Special Assignment Airlift Mission).

Looking at CAR levels by Mission Route, the most common CAR altitudes with the ORBD to ETAR mission route were 5,000 feet (43%), 6,000 feet (44%), and 4,000 feet (7%) while the most common CAR altitudes for OAIX to ETAR and ETAR to KADW were 5,000 feet (70% and 49%, respectively) and 6,000 feet (24% and 39%, respectively). With both the OKAS to ETAR and OAKN to ETAR mission routes, the most common CAR altitude was 5,000 feet (43% and 50%, respectively). Taken as a whole, the CAR altitude profile for Mission Route was, in order of frequency, 5,000 feet, 6,000 feet, and 4,000 feet. See **Table A10** (upper portion) for details.

The OAIX to ETAR route appeared to be the only mission route that could potentially meet the sample size requirements for both Flight Duration and Fuel Cost. Since the Channel mission and the OAIX to ETAR route offered the potential for comparing Flight Duration and Fuel Cost by CAR level, the OAIX to ETAR Channel mission was explored. Only the CAR level of 5,000 feet appeared to meet the sample size requirements. Consequently, there was really no opportunity for CAR level comparisons for either Flight Duration or Fuel Cost. See **Table A10** (lower portion) for details.

In sum, it can be confidently stated that 5,000 feet was the more commonly prescribed CAR followed by 6,000 feet, then 4,000 feet. As seen in Section 5.2 (Results, Comparative Analyses), there appeared to be no serious operational impact from CAR on either Flight Duration or Fuel Cost; however, the data did not permit a more detailed analysis to determine whether specific CAR altitudes mirrored this finding. For added discussion regarding individual CAR altitude analyses, see **Appendix 9.9**.

Table A10. Altitude of CAR Prescriptions by Mission Route

Aeromedical Evacuation Missions (2005 - 2015)												
	OAIX to ETAR		ETAR to KADW		ORBD to ETAR		OKAS to ETAR		OAKN to ETAR		Totals	Percent
Altitude (ft)	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost		
0			3	3	4	4	1	1			8	2
1,500			1	1			1	1			2	< 1
2,000									1	1	1	< 1
2,500							1	1			1	< 1
3,000	1/1*	1/1*	1	1	3	3	1	1	2	2	9	2
3,500					1	1					1	< 1
4,000	3/1*	1/1*	5		14	1			1	1	24	* 5 *
4,500									1	1	1	< 1
5,000	81/33*	51/15*	43	12	81	2	6	2	6	4	250	* 54 *
5,500			1		1						2	< 1
6,000	19/20*	3/0*	34	1	83		4		1		161	* 35 *
7,000	3/1*	1/0*									4	1
Totals	163	74	88	18	187	11	14	6	12	9	464	

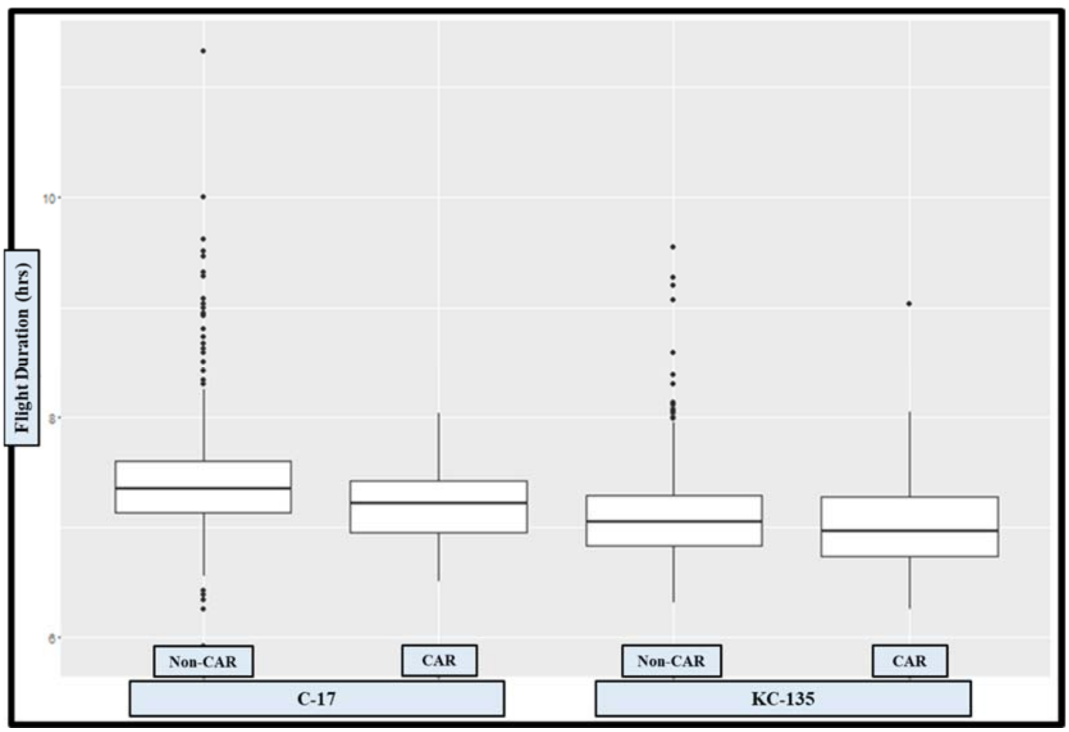
Aeromedical Evacuation Missions (2005 - 2015)												
Channel Missions												
	OAIX to ETAR		ETAR to KADW		ORBD to ETAR		OKAS to ETAR		OAKN to ETAR		Totals	Percent
Altitude (ft)	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost	Flight Duration	Fuel Cost		
0			3	3	4	4	1	1			8	2
1,500			1	1			1	1			2	1
2,000									1	1	1	< 1
2,500							1	1			1	< 1
3,000	1/1*	1/1*	1	1							3	1
3,500											1	< 1
4,000	0/1*	1/1*	5		12	1					18	* 5 *
4,500												0
5,000	36/33*	27/15*	41	10	73	2	4	1	1	1	199	* 53 *
5,500			1		1						2	1
6,000	3/20*	1/0*	33	1	77		3				136	* 37 *
7,000	0/1*										1	< 1
Totals	96	47	85	16	167	7	10	4	2	2	372	

Note: *x* denotes the three most common altitudes levied with a CAR prescription. x/y* denotes the number of missions by aircraft (x = C-17 and y = KC-135). The Channel mission class is a one of the four Mission Classes that contained CAR missions (see Section 4.2 for details).

9.4 Flight Duration & Fuel Cost Comparison for CAR & Non-CAR, Mission Route OAIX to ETAR

The OAIX to ETAR mission route (Bagram AB, Afghanistan to Ramstein AB, Germany) was the sole route with adequate observations for both the C-17 and the KC-135. With Flight Duration, box plots and ANOVA analysis suggested that Mission Class did not play a role. As a result, the four mission classes were collapsed into a single grouping. Subsequent box plots depicted little difference in flight duration whether it be CAR versus Non-CAR or C-17 versus KC-135. See **Figure A2**.

Figure A2. OAIX to ETAR Flight Duration, CAR versus Non-CAR for C-17 and KC-135



On average, the C-17 CAR/Non-CAR differential was only around 11 minutes, CAR being the shorter flight (by ~3%). This proved to be a statistically significant difference, though not an operationally significant difference. Similarly, the KC-135 CAR/Non-CAR differential was only around 5 minutes, again CAR being the shorter flight (by ~1%). This proved to be neither a statistically nor operationally significant difference. Linear modeling suggested that a

CAR prescription subtracted almost 10 minutes flight time. Interestingly, substituting a KC-135 for a C-17 dropped just over 17 minutes of flight time. See **Table A11** for details.

Table A11. Flight Duration Analyses for Mission Route OAIX to ETAR

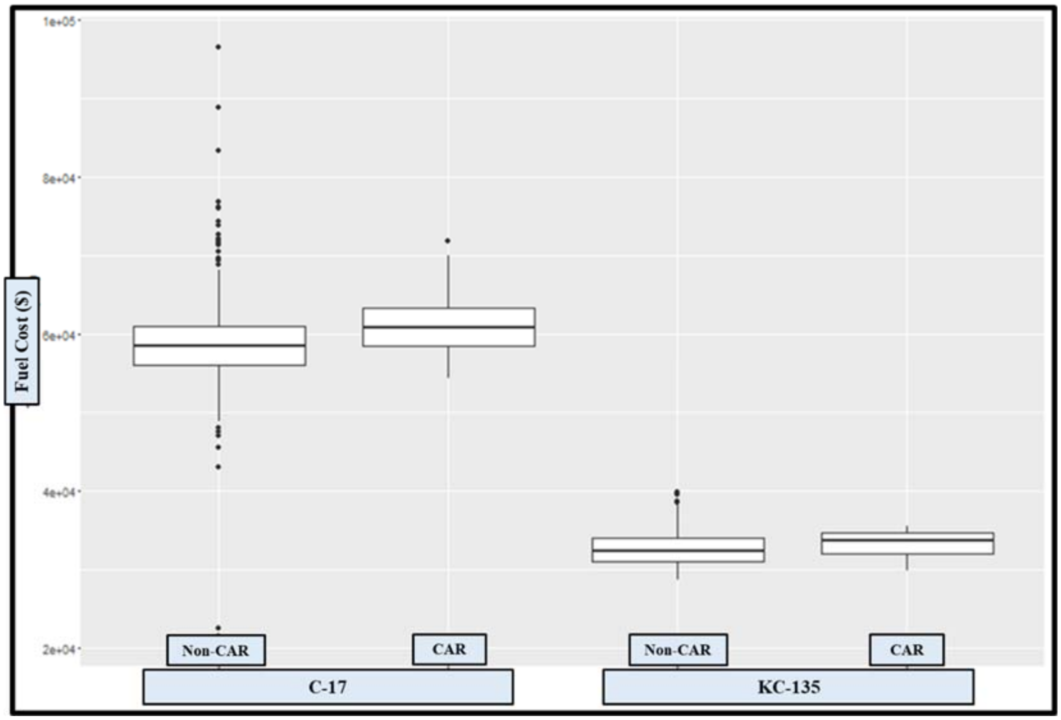
Aeromedical Evacuation Missions (2005 - 2015)					
OAIX to ETAR					
*** Flight Duration ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 107	n = 1,242	95% CI	t-statistic (DF)	p-value
C-17	7.20 (0.37)	7.39 (0.42)	0.12; 0.26	5.65 (137)	< 0.0001
	n = 56	n = 606			
KC-135	7.01 (0.46)	7.09 (.041)	-0.05; 0.21	1.24 (63)	0.22

Linear Model of Flight Duration (Non-CAR and C-17 were used as reference states)					
*** Flight Duration = y - 0.16 (CAR) - 0.29 (KC-135) ***					
Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	-0.16	0.03	-0.23; -0.10	-5.09	< 0.0001
KC-135	-0.29	0.02	-0.33; -0.26	-15.7	< 0.0001
F-statistic = 136.80 (DF = 2, 1997), p < 0.0001					

In sum, there was no evidence that the CAR prescription, as applied to the OAIX to ETAR mission route, offered up any significant operational impact on Flight Duration.

When it came to Fuel Cost, box plots and ANOVA analysis suggested no role for Mission Class, making collapse of classes into one group reasonable. However, subsequent box plots depicted a serious difference in Fuel Cost between the aircraft while, at the same time, a not-so-serious difference with the CAR prescription; the C-17 and CAR being more expensive. See **Figure A3**.

Figure A3. OAIX to ETAR Fuel Cost, CAR versus Non-CAR for C-17 and KC-135



On average, the C-17 CAR/Non-CAR differential was just under $2,500, CAR being more expensive (by ~4%). This proved to be a statistically significant difference, though not an operationally significant difference. Similarly, the KC-135 CAR/Non-CAR differential was almost $600, again, CAR being more expensive (by ~2%). Linear modeling was then performed. It was limited to Channel mission class observations, as the KC-135 data was most solid there. The model indicated that the CAR prescription added $2,741 to the C-17 mission and $598 to the KC-135 mission. Interestingly, in the model, 1 hour of flight time added $1,869 to the C-17 mission and $414 to the KC-135 mission. See **Table A12** for details.

Table A12. Fuel Cost Analyses for Mission Route OAIX to ETAR

Aeromedical Evacuation Missions (2005 - 2015)					
OAIX to ETAR					
*** Fuel Cost ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 57	n = 909	95% CI	t-statistic (DF)	p-value
C-17	61,084 (3,691)	58,588 (6,770)	-3,521; -1,471	-4.86 (68)	< 0.0001
	n = 17	n = 316			
KC-135	33,189 (1,648)	32,617 (2,157)	-1,446; 301	-1.37 (19)	0.19

C-17 --- Linear Model of Fuel Cost (Non-CAR was used as reference state)					
*** Fuel Cost = y + 2741 (CAR) + 1,869 (Flight Time) ***					
Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	2,741	637	1,491; 3,991	4.3	< 0.0001
Flight Time	1,869	363	1,156; 2,592	5.15	< 0.0001
F-statistic = 20.96 (DF = 2, 963), p < 0.0001					

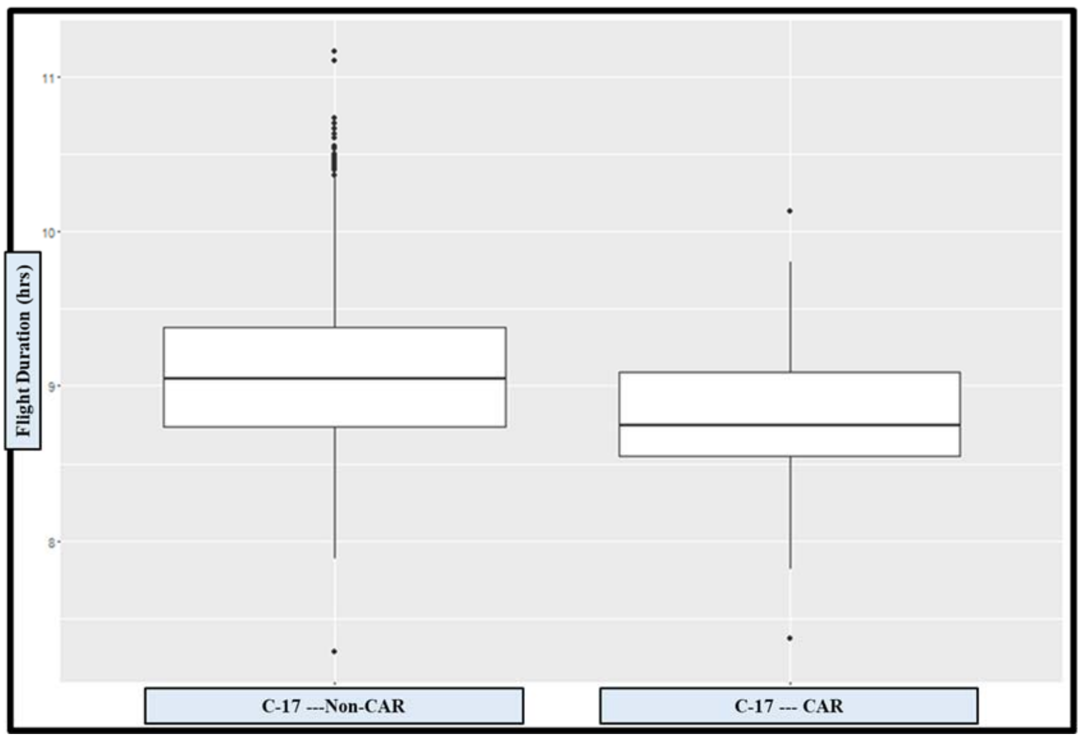
KC-135 --- Linear Model of Fuel Cost (Non-CAR was used as reference state)					
*** Fuel Cost = y + 598 (CAR) + 414 (flight Time) ***					
Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	598	531	-447; 1,642	1.13	0.26
Flight Time	414	299	-174; 1,001	1.39	0.17
F-statistic = 1.54 (DF = 2, 334), p = 0.22					

In sum, the CAR prescription upped Fuel Cost with both C-17 and KC-135 missions flying the OAIX to ETAR; however, the added expense was operationally not significant.

9.5 Flight Duration & Fuel Cost Comparison for CAR & Non-CAR, Mission Route ETAR to KADW

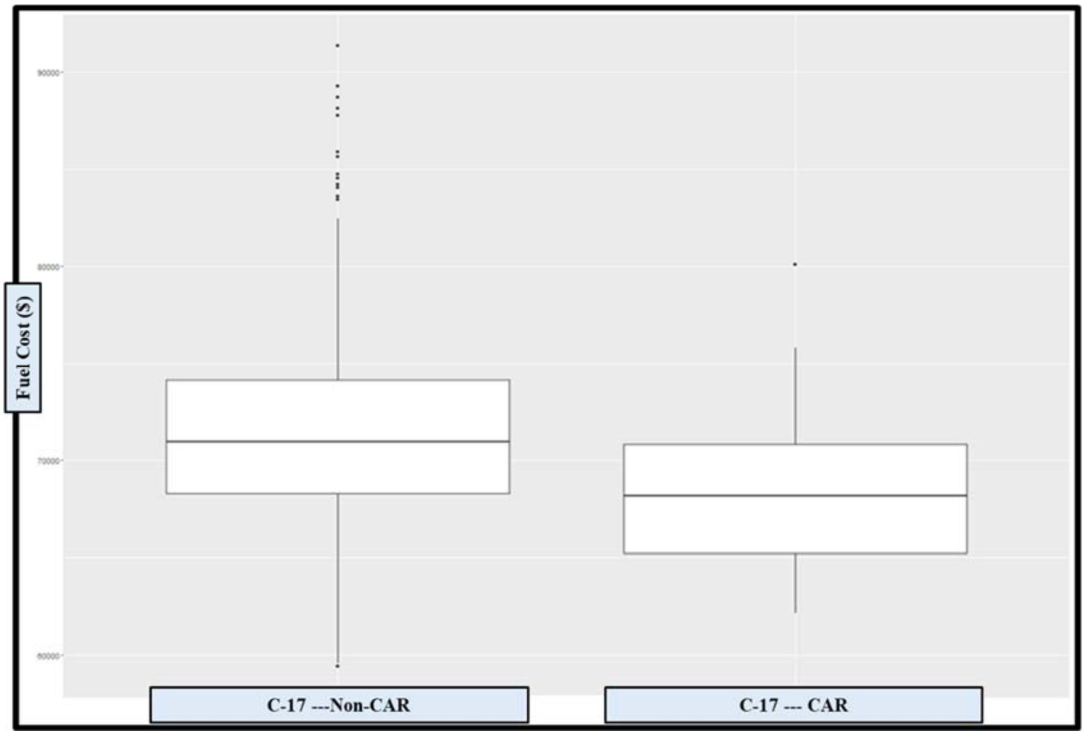
The ETAR to KADW mission route (Ramstein AB, Germany to Andrews AFB, Maryland) observations were limited to C-17 flights and the Channel mission class. There were very few KC-135 flights (none were CAR) and the vast majority of C-17 flights were Channel missions. The result was a tightly homogenous dataset. With Flight Duration, box plots depicted little difference between CAR and Non-CAR flights, though CAR flights appeared to take less time. See **Figure A4**.

Figure A4. ETAR to KADW Flight Duration, CAR versus Non-CAR for C-17



Similarly, Fuel Cost box plots depicted little difference between CAR and Non-CAR flights, though CAR flights appeared less expensive. See **Figure A5**.

Figure A5. ETAR to KADW Fuel Cost, CAR versus Non-CAR for C-17



On average, the Flight Duration CAR/Non-CAR differential was only around 19 minutes, CAR being the shorter flight (by ~3%). This proved to be a statistically significant difference, though not an operationally significant difference. At the same time, the Fuel Cost CAR/Non-CAR differential was just over $2,500, CAR being less expensive (by ~4%). This also proved to be statistically significant and operationally not significant. These relationships were maintained in the linear model. Here, the CAR prescription subtracted $1,893 from fuel cost. Interestingly, 1 hour of flight time added $5,285. See **Table A13** for details.

Table A13. Flight Duration and Fuel Cost Analyses for Mission Route ETAR to KADW

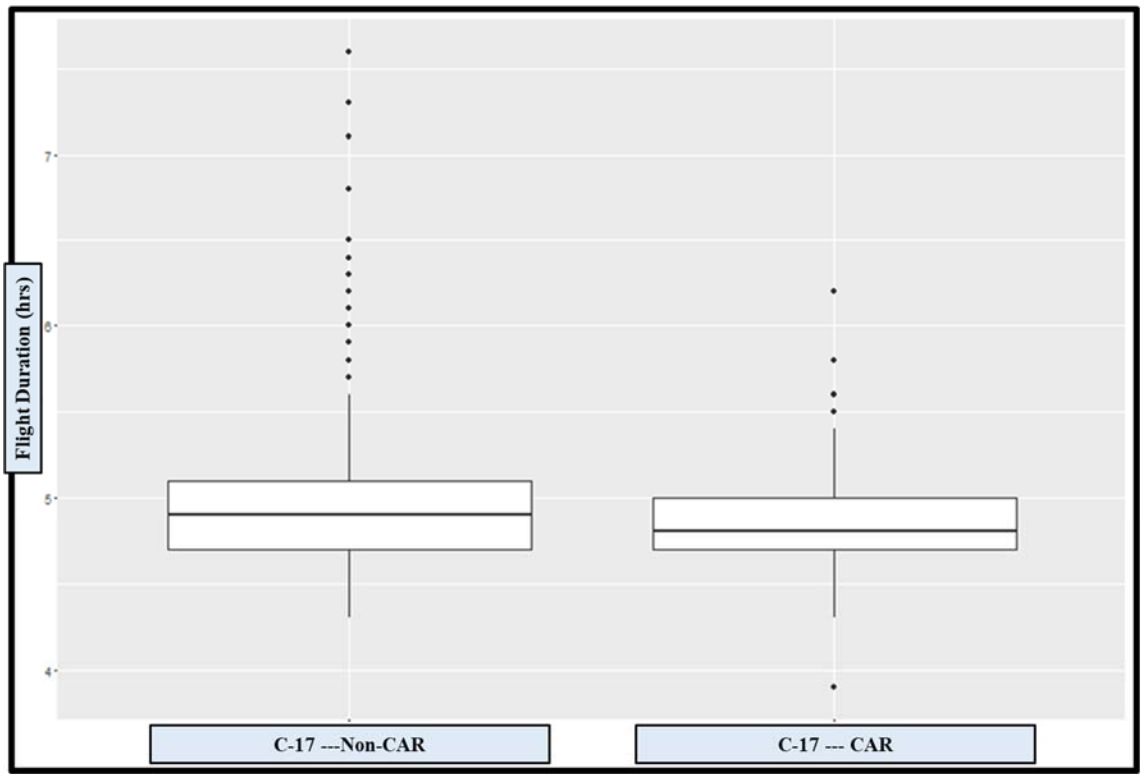
Aeromedical Evacuation Missions (2005 - 2015)					
ETAR to KADW					
*** Flight Duration ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 85	n = 1,278	95% CI	t-statistic (DF)	p-value
C-17	8.77 (0.47)	9.08 (0.50)	0.21; 0.42	6.15 (100)	< 0.0001
*** Fuel Cost ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 18	n = 749	95% CI	t-statistic (DF)	p-value
C-17	68,677 (4,740)	71,456 (4,720)	402; 5,155	2.46 (18)	0.024
Linear Model of Fuel Cost (Non-CAR was used as reference state)					
*** Fuel Cost = y - 1,893 (CAR) + 5,285 (Flight Time) ***					
Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	-1,893	931	-3,590; 290	-2.03	0.042
Flight Time	5,285	280	4,666; 5,792	18.91	< 0.0001
F-statistic = 183.20 (DF = 2, 764), p < 0.0001					

In sum, the CAR prescription shortened Flight Duration and dropped Fuel Cost for C-17s flying the ETAR to KADW Channel mission, making CAR impact operationally not relevant.

9.6 Flight Duration & Fuel Cost Comparison for CAR & Non-CAR, Mission Route ORBD to ETAR

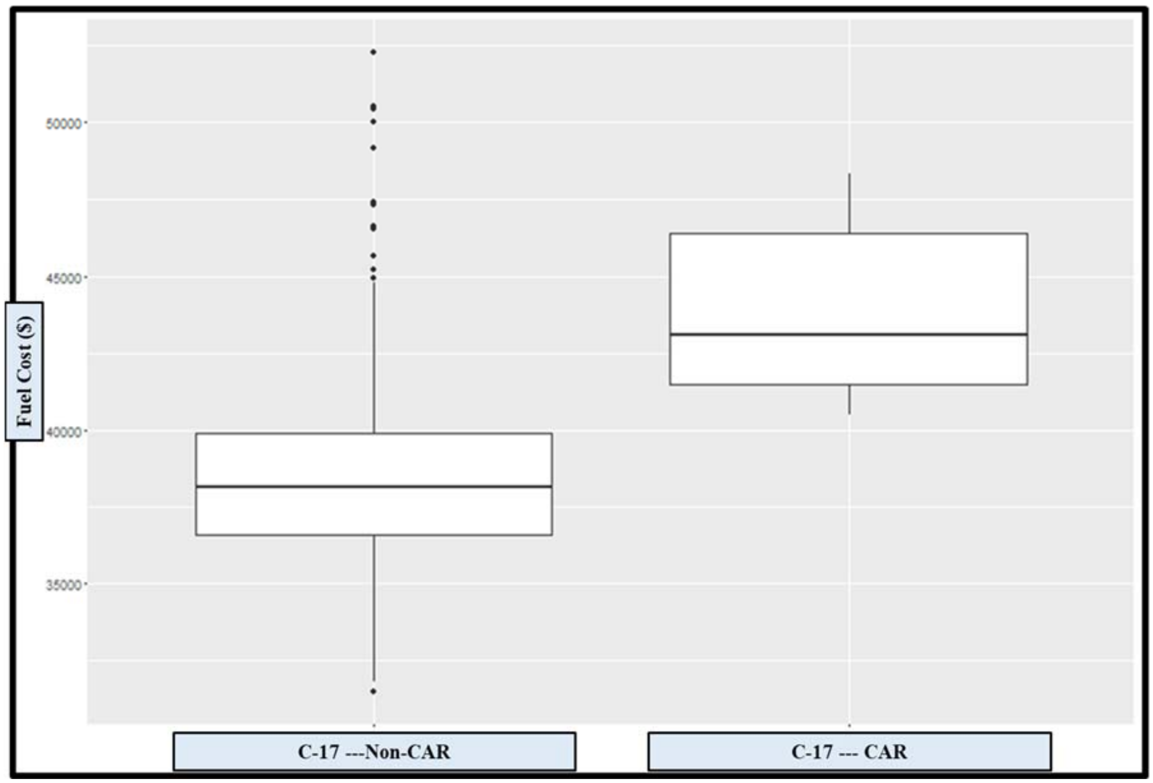
The ORBD to ETAR mission route (Balad AB, Iraq to Ramstein AB, Germany) was limited to C-17 aircraft, as there were no KC-135 missions. With Flight Duration, box plots and ANOVA analysis suggested that Mission Class did not play a role. As a result, the four mission classes were collapsed into a single grouping. Subsequent box plots depicted little difference between CAR and Non-CAR flights. See **Figure A6**.

Figure A6. ORBD to ETAR Flight Duration, CAR versus Non-CAR for C-17



On the other hand, box plots of Fuel Cost suggested a serious difference between CAR and Non-CAR flights. See **Figure A7**. However, dot plots indicated an ambiguous Mission Class influence. That coupled with the lack of observations in the Airevac and Contingency mission classes precluded an ANOVA analysis. Consequently, Channel and SAAM mission classes were considered together and collapsed into one grouping.

Figure A7. ORBD to ETAR Fuel Cost, CAR versus Non-CAR for C-17



On average, Flight Duration CAR/Non-CAR differential was only around 7 minutes, CAR being the briefer flight (by ~2%). This proved statistically significant, though not operationally significant. In contrast, Fuel Cost CAR/Non-CAR differential was just over $5,500, CAR being more expensive (by ~14%). This proved to be be both statistically and operationally significant. This relationship was maintained in the linear model. Here, the CAR prescription added an operationally significant $5,226 to Fuel Cost. Interestingly, 1 hour of flight time added $2,592. See **Table A14** for details.

Table A14. Flight Duration and Fuel Cost Analyses for Mission Route ORBD to ETAR

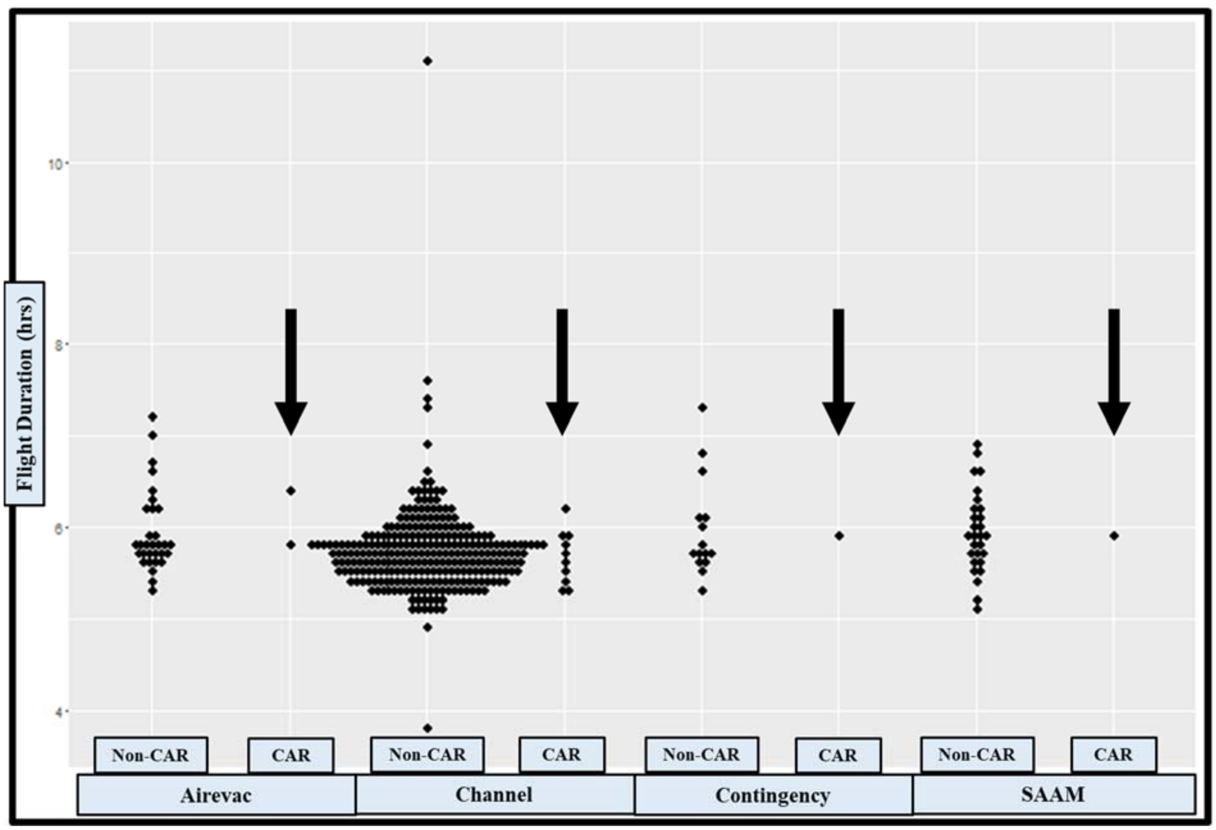
Aeromedical Evacuation Missions (2005 - 2015)					
ORBD to ETAR					
*** Flight Duration ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 187	n = 1,378	95% CI	t-statistic (DF)	p-value
C-17	4.83 (0.29)	4.95 (0.32)	0.08; 0.17	5.40 (252)	< 0.0001
*** Fuel Cost ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 11	n = 309	95% CI	t-statistic (DF)	p-value
C-17	44,022 (3,032)	38,512 (325)	-7,554; -3,465	-5.94 (11)	< 0.0001
Linear Model of Fuel Cost (Non-CAR was used as reference state)					
*** Fuel Cost = y + 5,226 (CAR) + 2,592 (Flight Time) ***					
Variable	Coefficient	Standard Error	95% CI	t-statistic	p-value
CAR	5,226	972	3,314; 7,138	5.38	< 0.0001
Flight Time	2,592	606	1,400; 3,784	4.73	< 0.0001
F-statistic = 25.3 (DF = 2, 317), p < 0.0001					

In sum, the CAR prescription dropped Flight Duration across mission classes for C-17s flying the ORBD to ETAR mission route, making it operationally not significant. In addition, the CAR prescription upped Fuel Cost across the Channel and SAAM missions for C-17s flying the ORBD to ETAR mission route. The added expense, though operationally significant, was so by only a few hundred dollars.

9.7 Flight Duration & Fuel Cost Comparison for CAR & Non-CAR, Mission Route OKAS to ETAR

The OKAS to ETAR mission route (Ali Al Saleem AB, Kuwait to Ramstein AB, Germany) was limited to C-17 aircraft, as there were only two KC-135 missions (none were CAR). With Flight Duration, box plots, dot plots, and ANOVA analysis suggested that Mission Class played a role. Of the four mission classes, only Channel missions appeared to have adequate observations. Subsequent dot plots depicted little difference between CAR and Non-CAR flights. See **Figure A8**.

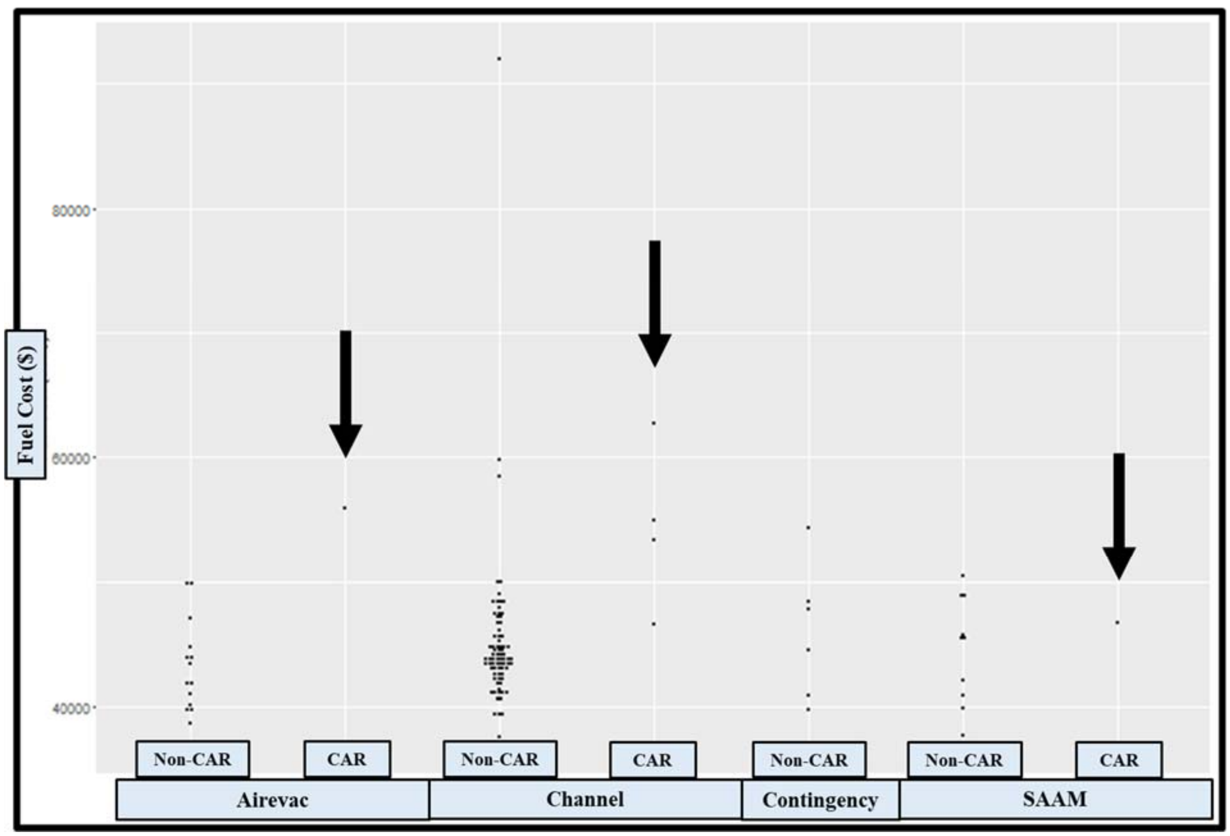
Figure A8. OKAS to ETAR Flight Duration, CAR versus Non-CAR for C-17



Note: Arrows (→) point out the number of CAR flights within each mission class, emphasizing too few observations in all but the Channel mission class.

In contrast, with Fuel Cost, dot plots made it clear that there were very few CAR flights. In fact, collapsing all four mission classes produced only 6 CAR observations. *Post hoc* testing revealed inadequate power for quantitative analysis, confirming *a priori* sample size calculations. See **Figure A9**.

Figure A9. OKAS to ETAR Fuel Cost, CAR versus Non-CAR for C-17



Note: Arrows (→) point out the number of CAR flights within each mission class, emphasizing too few observations in all four mission classes.

On average, Flight Duration CAR/Non-CAR differential was only around 2 minutes, CAR being the shorter flight (by < 1%). This proved both statistically and operationally not significant. Despite the limited number of observations, *post hoc* analyses confirmed adequate power. Comparative analyses for differences in Fuel Cost were not performed due to small sample size and failed *post hoc* power analyses. Being less influenced by potential outliers, Median and Median Absolute Deviation (MAD) were also reported as measures of central tendency and deviance. (**Leys, 2013**) The observed difference in mean ($8,542), while not formally tested, would potentially represent an operationally significant difference. See **Table A15** for details.

Table A15. Flight Duration and Fuel Cost Analyses for Mission Route OKAS to ETAR

Aeromedical Evacuation Missions (2005 - 2015)					
OKAS to ETAR					
*** Flight Duration ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 14	n = 345	95% CI	t-statistic (DF)	p-value
C-17	5.74 (0.33)	5.77 (0.50)	-0.17; 0.22	0.27 (15)	0.79
*** Fuel Cost ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 6	n = 107	95% CI	t-statistic (DF)	p-value
C-17	Underpowered for formal analyses				
Qualitative Evaluation of Fuel Cost					
Statistic	CAR	Non-CAR	Cost Difference		
Mean	53,364	44,822	8,542		
SD	6,116	5,893			
Median	54,169	43,885			
MAD (normal scaled)	6,769	2,957			

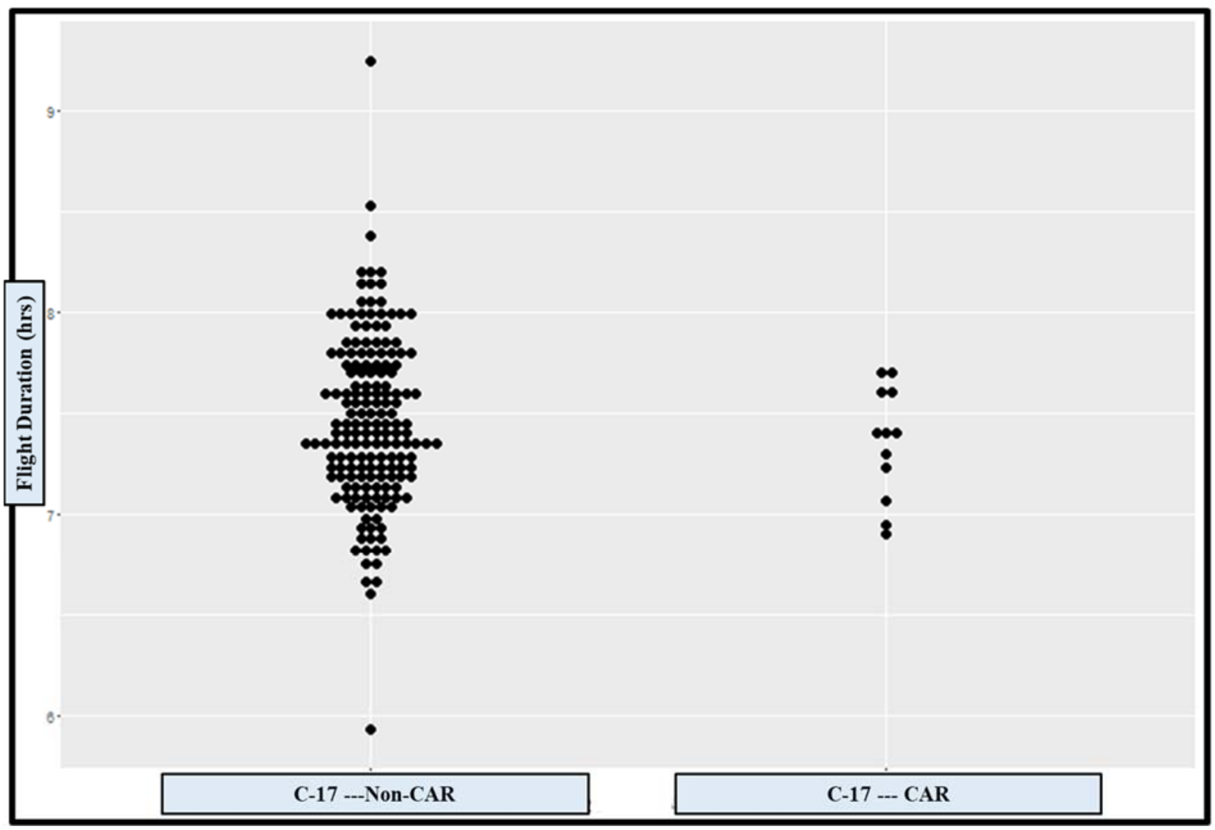
Note: SD (standard deviation); MAD (median absolute deviation).

In sum, the CAR prescription dropped the Flight Duration for C-17s flying Channel missions along the OKAS to ETAR mission route, making it operationally not significant. Unfortunately, Fuel Cost determination could not be executed because the dataset was underpowered for analysis.

9.8 Flight Duration & Fuel Cost Comparison for CAR & Non-CAR, Mission Route OAKN to ETAR

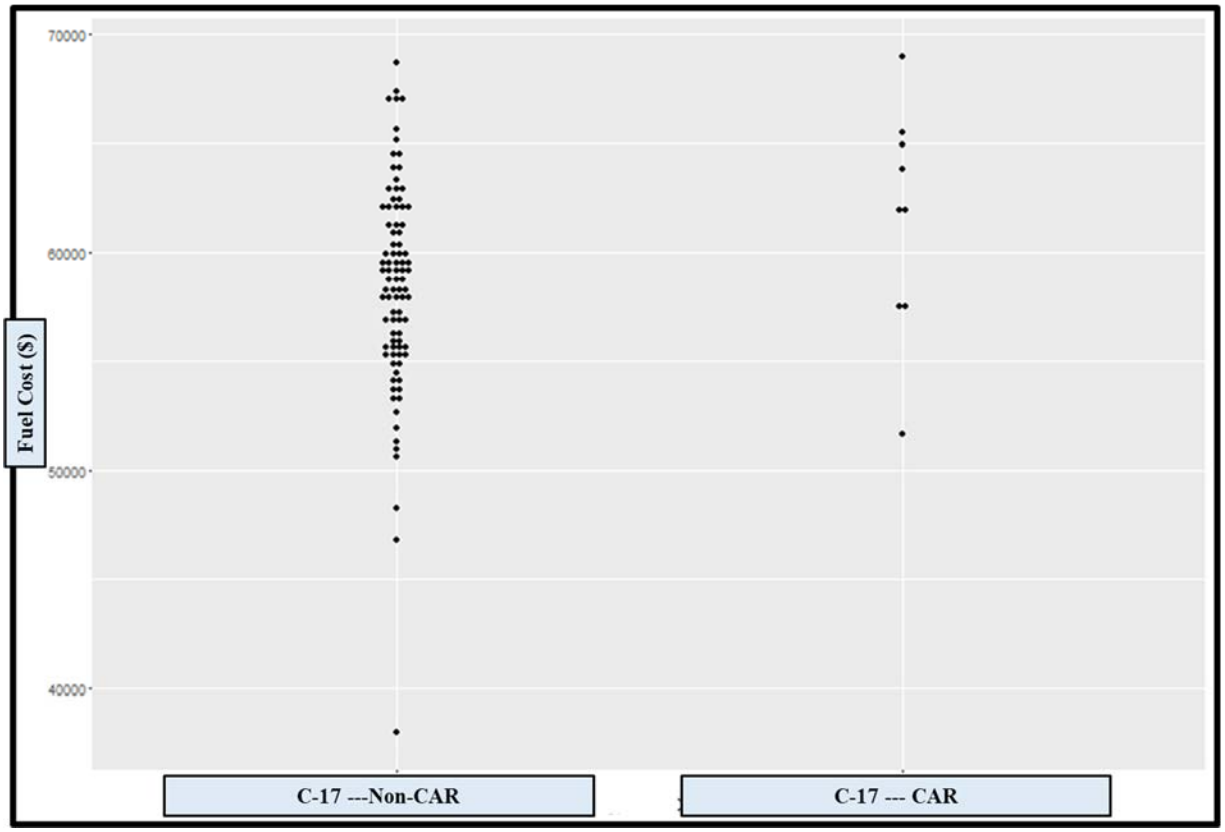
The OAKN to ETAR mission route (Kandahar AB, Afghanistan to Ramstein AB, Germany) was limited to C-17 aircraft, as there were only three KC-135 missions (none with CAR). With Flight Duration, box plots, dot plots, and ANOVA analysis suggested that Mission Class did not play a role. As a result, the four mission classes were collapsed into a single grouping, thus preserving sample size requirements. Subsequent dot plots depicted little difference between CAR and Non-CAR flights. See **Figure A10**.

Figure A10. OAKN to ETAR Flight Duration, CAR versus Non-CAR for C-17



Similarly, dot plots of Fuel Cost depicted little difference between CAR and Non-CAR flights. The dot plots and ANOVA analysis suggested that Mission Class did not play a role, making collapse of classes into one group reasonable. Even so, there were only nine CAR flights. *Post hoc* testing revealed inadequate power for quantitative analysis, confirming *a priori* sample size calculations. See **Figure A11**.

Figure A11. OAKN to ETAR Fuel Cost, CAR versus Non-CAR for C-17



On average, Flight Duration CAR/Non-CAR differential was only around 6 minutes, CAR being the shorter flight (by ~1%). This proved both statistically and operationally not significant. Comparative analyses for differences in Fuel Cost were not performed due to small sample size and failed *post hoc* power analyses. Being less influenced by potential outliers, Median and Median Absolute Deviation (MAD) were also reported as measures of central tendency and deviance. (**Leys, 2013**) The observed difference in mean ($3,134), while not formally tested, would potentially represent an operationally not significant difference. See **Table A16** for details.

Table A16. Flight Duration and Fuel Cost Analyses for Mission Route OAKN to ETAR

Aeromedical Evacuation Missions (2005 - 2015)					
OAKN to ETAR					
*** Flight Duration ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 12	n = 170	95% CI	t-statistic (DF)	p-value
C-17	7.36 (0.28)	7.46 (0.42)	-0.08; 0.29	1.22 (15)	0.24
*** Fuel Cost ***					
	CAR, M (SD)	Non-CAR, M (SD)			
Aircraft	n = 9	n = 90	95% CI	t-statistic (DF)	p-value
C-17	Underpowered for formal analyses				
Qualitative Evaluation of Fuel Cost					
Statistic	CAR, M (SD)	Non-CAR, M (SD)	Cost Difference		
Mean	61,552	58,418	3,134		
SD	5,213	4,810			
Median	62,059	58,735			
MAD (normal scaled)	5,126	4,535			

In sum, the CAR prescription dropped the Flight Duration across all mission classes for C-17s flying the OKAS to ETAR mission route, making it operationally not significant. Unfortunately, Fuel Cost determination could not be executed because the dataset was underpowered for analysis.

9.9 Limitations --- Data Loss

Loss of data proved to be a serious limitation in this study. This was due to incomplete, inaccurate, missing, or estimated data entry. Valid Flight Duration data required takeoff and landing times; valid Fuel Cost data required takeoff and landing fuel weights. Going from the full dataset (n = 8,191) to the validated Flight Duration dataset (n = 5,561) saw a data loss of 32%. At the same time, the validated Fuel Cost dataset (n = 2,601) saw an overall data loss of 68%, not to mention a 53% data loss from the Flight Duration dataset. See **Figure 1**.

Notably, the data loss between CAR and Non-CAR observations was not consistent across mission routes (chi square = 24.86, $p < 0.0001$). The three mission routes with the most data --- ETAR to KADW/ORBD to ETAR/OAIX to ETAR --- consistently had a larger loss of data with CAR missions (chi square = 3.47, $p = 0.33$). In contrast, the two mission routes with the least data --- OKAS to ETAR/OAKN to ETAR --- consistently had a larger loss of data with Non-CAR missions (chi square = 12.96, $p = 0.16$). See **Table A17** for details.

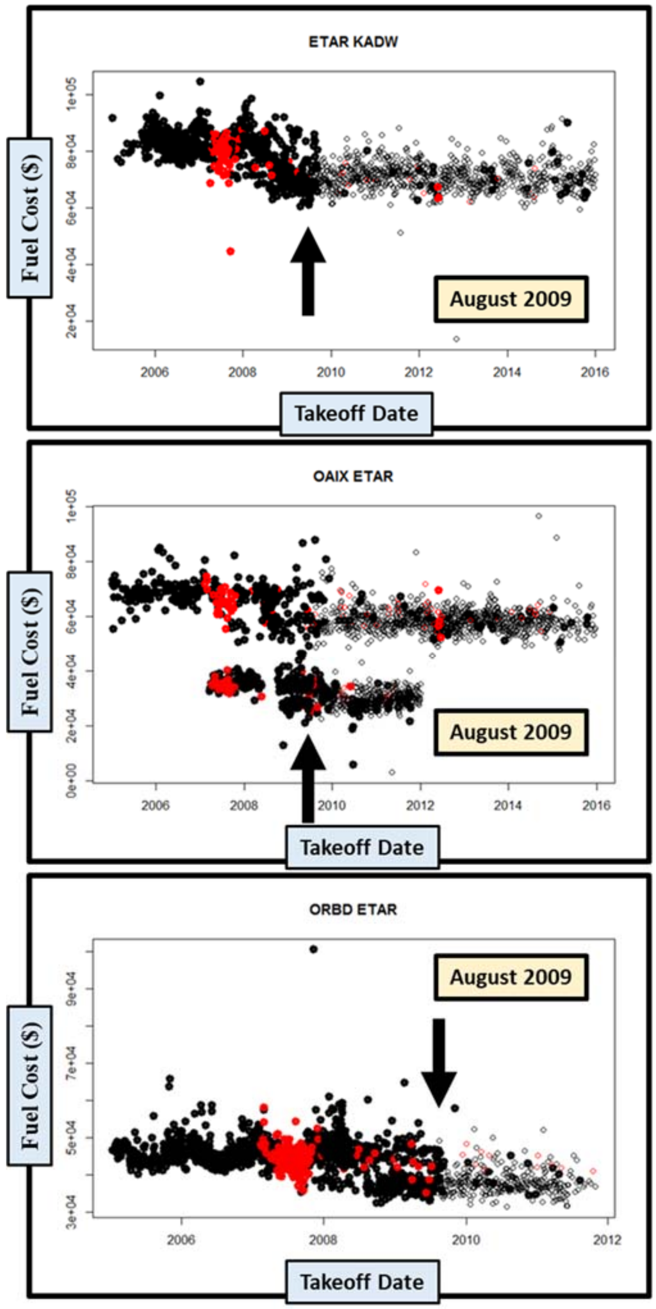
Table A17. Percent Data Loss by Aircraft and Mission Route and CAR Status

Aeromedical Evacuation Missions (2005 - 2015)													
	C-17										KC-135		Totals
	ETAR to KADW		ORBD to ETAR		OKAS to ETAR		OAKN to ETAR		OAIX to ETAR				
	CAR	Non-CAR	CAR	Non-CAR	CAR	Non-CAR	CAR	Non-CAR	CAR	Non-CAR	CAR	Non-CAR	
Flight Duration	88	1,345	187	1,378	14	345	12	170	107	1,242	56	606	**5,550**
Fuel Cost	18	750	11	309	6	107	9	90	57	907	17	320	**2,601**
Data Loss (%)	80	44	94	78	57	70	25	47	47	27	70	47	**47**

Note: Percent Data Loss represents the loss of data going from the Flight Duration Dataset to Fuel Cost Dataset.
Note: OAIX to ETAR (Bagram AB, Afghanistan to Ramstein AB, Germany); ORBD to ETAR (Balad AB, Iraq to Ramstein AB, Germany); ETAR to KADW (Ramstein AB, Germany to Andrews AFB, Maryland, USA); OKAS to ETAR (Ali al Saleem AB, Kuwait to Ramstein AB, Germany); OAKN to ETAR (Kandahar AB, Afghanistan to Ramstein AB, Germany).

This inconsistency across mission routes may well be explained by two factors --- the critical lack of CAR observations with the OKAS to ETAR/OAKN to ETAR mission routes and the lack of regular reporting of actual takeoff and landing parameters prior to August 2009. In fact, with the OKAS to ETAR/OAKN to ETAR mission routes, half of the CAR observations (13 missions) took place before 2009; whereas, with the ETAR to KADW/ORBD to ETAR/OAIX to ETAR mission routes, 76% were seen before 2009 (333 missions). Arithmetically, this meant that there was a greater percent data loss with CAR missions in the ETAR to KADW/ORBD to ETAR/OAIX to ETAR mission routes than the OKAS to ETAR/OAKN to ETAR mission routes. See **Figure A12** (the focus being reporting of actual fuel weights).

Figure A12. Graphic Depiction of the Initial Recording of Actual Fuel Weights



Red = CAR
Black = Non-CAR
Filled = Missing Starting or Ending Fuel Weights
Empty = Starting and Ending Fuel Weights Recorded

Note: Arrows depict date when actual fuel weight recording seemingly became routine --- August 2009.

Lastly, it was hoped that Flight Duration and Fuel Cost could be examined with the most commonly prescribed CAR altitudes --- 5,000 feet, 6,000 feet, and 4,000 feet. With ETAR to KADW/ORBD to ETAR/OAIX to ETAR mission routes, the bulk of CAR observations occurred pre-2009 when actual takeoff and landing parameters were poorly recorded. As a result, sample size requirements for separate CAR altitude analyses could not be attained for Flight Duration, much less for Fuel Cost. See **Table A18** for details (the focus being actual fuel data *vis a vis* CAR altitudes).

Table A18. Fuel Data *before* & *after* August 2009 by CAR Altitude

Aeromedical Evacuation Missions (2005-2015)

ETAR to KADW

	CAR Altitude (ft)						
	0	1,500	3,000	4,000	5,000	5,500	6,000
All Observations	3	1	1	5	43	1	34
Observations *before*	0	0	0	5	29	1	33
Observations *after*	3	1	1	0	14	0	1
Actual Fuel Data	3	1	1	0	12	0	1

OAIX to ETAR (C-17/KC-135)

	CAR Altitude (ft)				
	3,000	4,000	5,000	6,000	7,000
All Observations	1/1	3/1	81/33	19/20	3/1
Observations *before*	0/0	2/0	26/16	15/20	2/1
Observations *after*	1/1	1/1	55/17	4/0	1/0
Actual Fuel Data	1/1	1/1	51/15	3/0	1/0

ORBD to ETAR

	CAR Altitude (ft)						
	0	3,000	3,500	4,000	5,000	5,500	6,000
All Observations	4	3	1	14	81	1	83
Observations *before*	0	0	0	13	79	1	83
Observations *after*	4	3	1	1	2	0	0
Actual Fuel Data	4	3	1	1	2	0	0

Note: With OAIX to ETAR, x/y denotes the number of missions by aircraft (x = C-17 and y = KC-135).

The OKAS to ETAR/OAKN to ETAR mission routes were even more problematic. The sample size requirement for a CAR versus Non-CAR assessment was barely achieved for Flight Duration and not reached at all for Fuel Cost. Consequently, there was no possibility for individual CAR altitude breakdowns.

In sum, poor reporting of Fight Duration and Fuel Cost data pre-2009 meant that many CAR missions could not be included in the final datasets. As a result, individual CAR altitudes did not meet the sample size requirements, making Flight Duration and Fuel Cost analyses not possible. For an added discussion regarding individual CAR altitude analyses, see **Appendix 9.3**.

10.0 LIST OF ABBREVIATIONS AND ACRONYMS

618 TACC	618th Air and Space Operations Center Tanker Airlift Control Center Data Division
AB	Air Base
AE	aeromedical evacuation
AFB	Air Force Base
AMC	Air Mobility Command
CAR	cabin altitude restriction
CASEVAC	casualty evacuation
CASF	contingency aeromedical staging facility
CCATT	Critical Care Air Transport Team
DO_2	tissue oxygen delivery
ETAR	Ramstein AB, Germany (ICAO airfield identifier)
FiO_2	fraction of inspired oxygen
Fx	fracture
GSW	gunshot wound
Hgb	hemoglobin
HQ	headquarters
ICAO	International Civil Aviation Organization
ICD-9	International Classification of Diseases, Ninth Revision
ICU	intensive care unit
ISS	Injury Severity Score
IV	intravenous
KADW	Andrews AFB (aka Joint Base Andrews), Maryland (ICAO airfield identifier)
LOC	loss of consciousness
LPM	liters per minute
M	mean
MAD	median absolute deviation
MEDEVAC	medical evacuation
NC	nasal cannula
O_2	oxygen
OAIX	Bagram AB, Afghanistan (ICAO airfield identifier)

OAKN	Kandahar AB (International Airport), Afghanistan (ICAO airfield identifier)
OKAS	Ali Al Saleem AB, Kuwait (ICAO airfield identifier)
ORBD	Balad AB (aka Joint Base Balad), Iraq (ICAO airfield identifier)
pt	patient
SD	standard deviation
SpO_2	peripheral oxygen saturation
PMQR	Patient Movement Quality Report
TBI	traumatic brain injury
TMDS	Theater Medical Data Store
$TRAC^2ES$	Transportation Command Regulating and Command and Control Evacuation System
TVFS	theater validating flight surgeon
VAP	ventilator-associated pneumonia