REDUCING AIRLIFT INEFFICIENCY THROUGH AIRCRAFT SELECTION MODELING [1]

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ABSTRACT

When selecting military airlift assets to be used for a given inter-theater movement requirement, current mobility airlift planning typically defaults to the larger, more capable strategic fleet. We identify potential efficiency improvements by holistically considering all feasible airlift assets, regardless of their current classification as tactical or strategic. We propose a method that quickly enumerates all logical airframe combinations to perform a specific airlift operation, given user-defined constraints. Analyzing one month of historic data for four strategic city pairs, our proposed model suggests a significant possible fuel savings over actual consumption.

INTRODUCTION

Military airlift planners are responsible for the daily tasking and tracking of nearly 900 mobility sorties world-wide. Using a hub-and-spoke model, planners generally conceptualize airlift requirements and assets as either strategic or tactical. Tactical aircraft (usually C-130 variants) are smaller and are used primarily for intra-theater airlift within a defined Area of Operation (AOR), while strategic aircraft (C-5B/M, C-17A) have larger payload capacities and extended ranges making them useful for inter-theater transportation between different AORs or Geographic Combatant Commands (GCCs). Similarly, Air Force Doctrine describes air mobility operations as either "inter-theater or intra-theater in nature" [1].

The USAF's hub-and-spoke system, similar to the one employed in the civilian aviation industry, allows maximum opportunity for aggregation at major aerial port hubs and promotes increases in efficiency versus a simple point-to-point delivery method [2]. It also seemingly enhances the need to segregate the Air Force's mobility aircraft into strategic airlift for long-haul distances and tactical airlift for the short-haul distances, or "spoke" routes. The tactical/strategic model has remained unchanged since the advent of air mobility following World War II, but while the planning model remained somewhat static, improvements in aircraft technology have increased the flexibility, speed, and range of the modern airlifters in the Air Force's fleet. This presents an opportunity to challenge the current model by taking a holistic approach to aircraft selection, given a set of validated requirements. Regardless of a route's or requirement's designation as strategic or tactical, all assets within the current airlift fleet should be analyzed in an effort to minimize fuel

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consumption and cost, while still meeting the warfighter's requirement.

A recent analysis performed by the 317th Airlift Group compared the C-130J-30 and the C-17A, finding that while the C-17A is obviously superior in both payload and range, when time is not a critical factor the C-130J-30 can accomplish the same mission with less fuel and at a lower operating cost. While the C-130J-30 is limited in its range and payload (it has significantly fewer pallet positions and cannot carry oversized cargo), it consumes only about a quarter of the fuel per flight hour of a C-17A, while the cost to operate the aircraft is approximately 70 percent lower per flight hour. The 317th Airlift Group's analysis, simulating a 72-pallet move, demonstrated that for two strategic channel routes that, despite taking longer and adding stops to refuel, the C-130J-30s moved more cargo at a lower cost than their C-17A counterparts. The study also cited the additional benefit of possibly reducing delivery timeframes in some circumstances by sending full C-130J-30s in-lieu-of waiting to aggregate cargo on the larger C-17As [3]. By using smaller aircraft and essentially tailoring capacity to demand, higher load factors and greater efficiency should be achieved.

METHODOLOGY

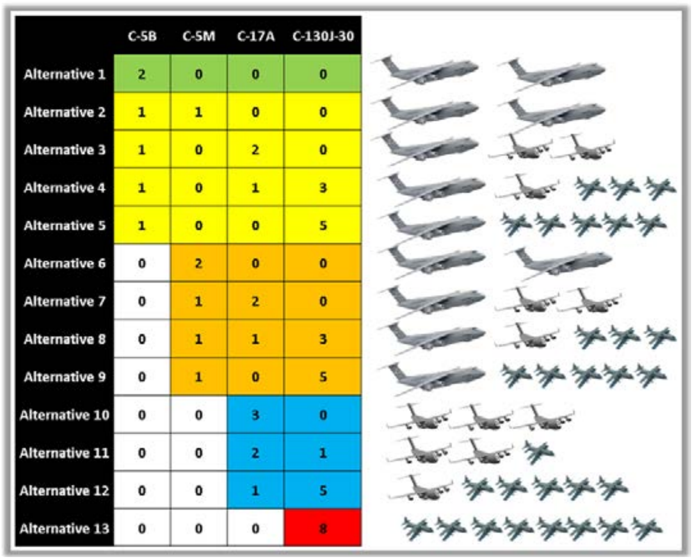
We developed the Aircraft Selection Model (ASM) as a tool to enumerate the entire decision space so that an objective aircraft selection choice can be made. While the ASM can be modified to model different objective functions, our model minimizes a scenario's fuel consumption. To create the ASM, a simple multi-step heuristic was applied to satisfy variations of two common complex problems. The first step requires the complete enumeration of the set of aircraft alternatives for a given set of requirements, while the second step attempts to efficiently allocate the specified payload to each aircraft in each alternative. After the model enumerates alternatives and loads the required cargo, step 3 computes metrics for each alternative based on aircraft type, routing, and payload and each alternative is ranked based on minimum fuel consumption. Finally, in order to make the model more user-friendly, ASM was coded into Hypertext markup Language (HTML) format using JavaScript.

Aircraft Enumeration: Step 1

A simple, logic-based heuristic was developed and coded as a looping algorithm. Starting with the largest aircraft type available and working down to the smallest, by either finding the ratio of the cargo requirement's total Pallet Position Equivalents (PPE) divided by aircraft PPE capacity or total cargo weight divided by aircraft weight capacity (whichever is greater) and applying a round-up function, the smallest amount of aircraft of a specific type necessary to accommodate the cargo requirement is determined. The aircraft weight capacity was determined by using the maximum payload weight for the given city-pair route that resulted in optimal cargo throughput. A loop is then used to iteratively reduce the number of aircraft within this specific type by one until zero is reached for this aircraft type. During each iteration, another embedded loop calculates the smallest number of necessary aircraft of the next type being analyzed by considering the remaining cargo, and again using the maximum of the PPE or weight ratios and a round-up function. Each of those loops include subordinate loops with the same function for the next aircraft type in the alternative until the function enumerates the maximum C-130Js necessary for the requirement. Repeating this process iteratively results in the enumeration of all viable combinations of type and quantity. Figure 1 is a sample representation of this process.

Cargo Loading: Step 2

An iterative cargo loading algorithm ensures an equitable and viable distribution of cargo items. This step is also crucial since the weight of the payload affects the speed, fuel consumption, and number of stops necessary to complete the mission. Given *N* cargo items and *M* aircraft, the cargo items are sorted by weight (heaviest to lightest) and each cargo item is tested against each aircraft in each alternative. The cargo items are loaded one by one onto all of the aircraft (checking for dimensionally outsized cargo, which cannot be loaded on C-130J-30s) and each aircraft's remaining available capacity is compared (both in terms of volume and



	C-5B	C-5M	C-17A	C-130J-30
Alternative 1	2	0	0	0
Alternative 2	1	1	0	0
Alternative 3	1	0	2	0
Alternative 4	1	0	1	3
Alternative 5	1	0	0	5
Alternative 6	0	2	0	0
Alternative 7	0	1	2	0
Alternative 8	0	1	1	3
Alternative 9	0	1	0	5
Alternative 10	0	0	3	0
Alternative 11	0	0	2	1
Alternative 12	0	0	1	5
Alternative 13	0	0	0	8

Figure 1. Representative Aircraft Enumeration Output

weight) after the item is loaded. Since this must be applied to heterogeneous sets of aircraft, a percentage-based metric we call a "J-Rate" was adopted which calculates the used capacity of each aircraft, defined as the maximum of the consumed PPE or weight capacity. After loading, the aircraft in the alternative with the greatest remaining capacity available is selected and the cargo item is removed from the other aircraft in the alternative. This process is then repeated for all *N* cargo items until all items are assigned to the *M* specific aircraft types and respective quantities. A visual representation of two iterations of this process is shown in Figures 2-4.

Application of Optimal Routing/Sortie Metrics: Step 3

The model benefits from previous modeling work by Reiman [4] on routing algorithms and metrics. We use the nodal reduction technique in his prior research to quickly ascertain the optimal routing for each aircraft in an alternative based on that aircraft type's range constraints. Fuel consumption data is calculated by including his fuel regression equations for each aircraft type. These equations were validated by the Air Force Research Laboratory and are currently used in their operational energy research [5].

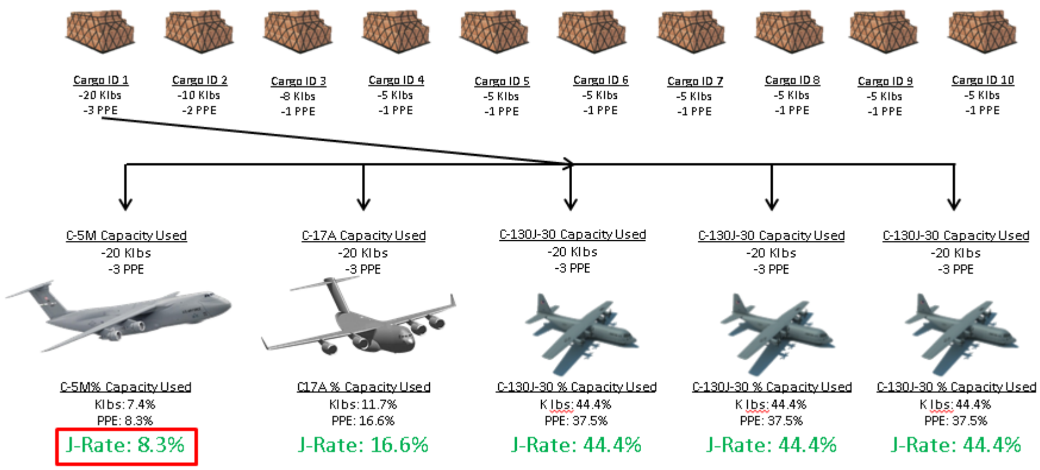


Figure 2: Iteration 1.

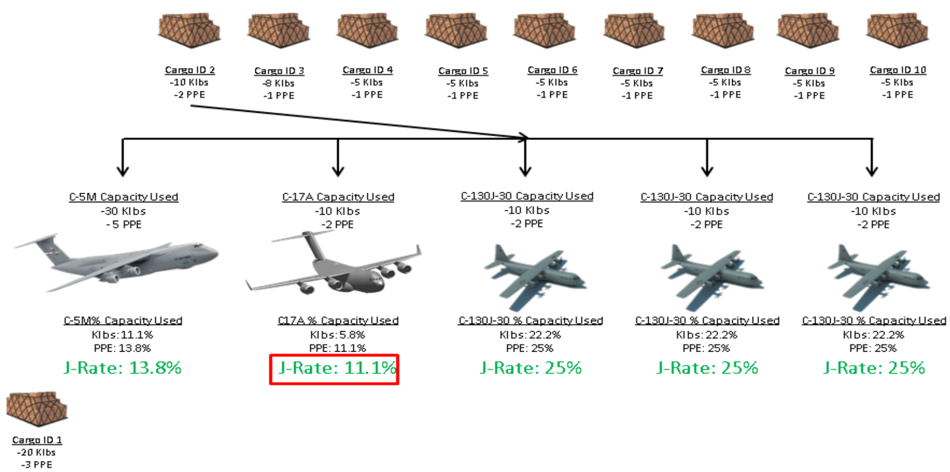


Figure 3: Iteration 2.

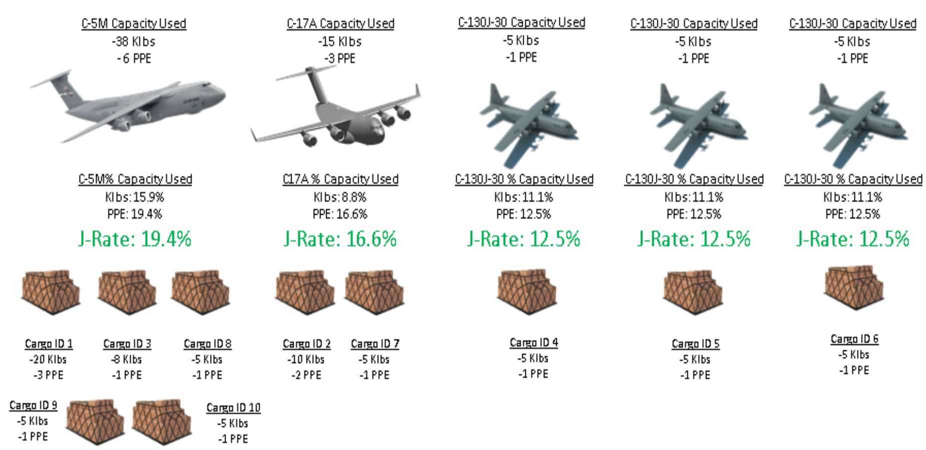


Figure 4: Iteration 6 (all cargo loaded).

EXAMPLE SCENARIO

We note that our model assumes aircraft are available as needed, which in reality is a significant constraint to air mobility planners. The scope of our analysis focused on one month of cargo movement data (July 2012) for four high-traffic, inter-theater city pairs:

- Dover AFB, DE (KDOV) to Ramstein Air Base, Germany (ETAR)
- Dover AFB, DE (KDOV) to Rota Naval Station, Spain (LERT)
- Travis AFB, CA (KSUU) to Hickam Air Field, HI (PHIK)
- Travis AFB, CA (KSUU) to Joint Base Elmendorf, AK (PAED)

We chose July 2012 because of the relatively large amount of cargo moving from stateside to overseas that month, which allows the ASM to come up with unique alternative solutions. Available data suggests that cargo movement is highly seasonal and tends to peak in the summer months.

Analyzing this month of airlift data showed several instances in which the ASM found ideal airlift choices that differ from the actual historical data, which resulted in significant fuel and operational cost savings. The 8 July 2012 Dover to Ramstein city-pair scenario illustrates the ASM potential. On that day, 20 individual cargo items accounting for 20.2 pallet position equivalents (PPE) and 112.5K lbs were moved between this city-pair by two C-17As.

Our model identified four viable aircraft mix alternatives which could conceivably fulfill this cargo lift requirement, representing a possible savings of either 148K lbs., 118K lbs., or 93.9K lbs. of fuel by respectively selecting three C-130J-30s, a single C-5M, or a C-17A and C-130J-30 for this particular cargo movement. Using the conversion rate of 6.7 lbs/gallon and the FY16 price of Defense Logistics Agency aviation fuel of $2.95, this represents a variable cost savings of about $65K, $52K, and $41K respectively. We also analyzed the effect of this modeling approach with respect to semi-variable costs by including two Air Force cost metrics; Air Force Total Ownership Cost (AFTOC) and logistics factor costs per flying hour (CPFH). By taking the total flight time for each aircraft type in the aircraft alternative and multiplying by their respective CPFH figures, we show that semi-variable flying hour costs could be reduced by about $113K, $72K, or $83K (using logistics CPFH figures) or $39K, $40K, or $37K (using AFTOC CPFH figures) respectively.

This method was repeated for each day and each city pair during our July month of analysis with the results shown in Figure 5. Total sorties would increase, but at less overall cost. As Figure 5 shows, significant fuel and operational cost savings can be achieved by using a holistic, fleet-based quantitative approach to select airlift aircraft. These results parallel a scheduling and delivery problem study conducted by Low, Chang, Li, and Huang [6] which shows that total costs (defined as fixed vehicle costs and variable routing costs), gradually decrease as the vehicle types employed are increased. By expanding delivery fleet diversity, planners are better able to tailor airlift capacity to a specific demand.

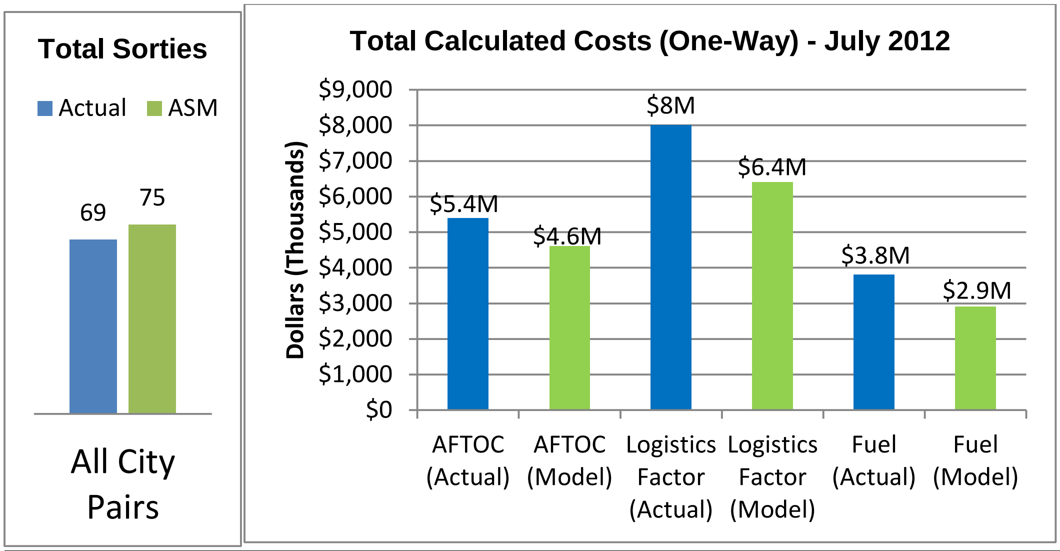


Figure 5. Actual vs ASM Cost Metric Comparison.

SUMMARY

The C-130J-30 aircraft improvements in speed, range, and cargo capacity give it a parity with larger mobility aircraft, and thus it should be examined as an inter-theater airlifter. We show that doing so will allow for a closer tailoring of capacity to demand, which can result in a reduction of fuel consumption, excess capacity, and costs. We should recognize that the current hub-and-spoke air mobility system's partition of missions as strategic or tactical in nature may be counterintuitive to the operation of an efficient airlift system. By using a more holistic, deliberate approach to the mobility aircraft selection process, planners can more closely tailor capability to demand, resulting in less excess capacity, waste, and a reduction in fuel consumption and operating costs.

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