Coast Guard Aviation & the Assignment Problem: An Auction Model to Allocate the Future 'All-Jayhawk' Fleet

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Abstract

As the US Coast Guard (CG) prepares to transition from a mixed rotary wing fleet of MH-65 Dolphins and MH-60 Jayhawks to an 'All-Jayhawk' fleet, an opportunity is presented to seek an optimized set of aircraft assignments, prior to making capital facilities investments. Through more optimized assignments, the CG can achieve better mission value at cost. The objective of this thesis is to build a model to aid the CG in making rotary wing aircraft basing and satellite unit organizational decisions as it transitions to an 'All Jayhawk' fleet of 127 aircraft, by building a model that can tradeoff between geographic coverage and cost. The decision to assign Jayhawks to different aviation locations will be assessed under the auspices of the 'Assignment Problem,' the combinatorial optimization problem of assigning two sets of elements to each other, while seeking optimization for greater metrics. Optimization will be sought with an auction technique, one solution to the Assignment Problem.

This thesis will begin with a historical review of the CG's rotary wing fleet and aviation facilities since the CG first created an aviation program in 1916. This review will showcase trends and possible correlation between increasing rotary wing aircraft ranges, reductions in full-service Air Stations, and growth in satellite aviation facilities used to forward deploy aircraft. This thesis will then break down these different Aviation Support Constructs by Architectural Decisions and model them with Design Structure Matrices to better understand differences and cost drivers. The Architectural Decisions will be used to build a model that estimates the total cost of the Jayhawk fleet's global assignment to any mix of 39 locations under four Support Constructs. Ten years of CG mission data and aircraft capability range rings will be overlaid in GIS software, to visualize and quantify where CG missions are required, and which air stations are most valuable. Six Assignment Problem Auctions will then be conducted with differing objective criteria to seek a best identifiable set of global assignments for the Jayhawk fleet, with metrics including mission coverage percent and the Net Present Value cost of the assignment set over the fleet's lifespan.

This analysis and the six auctions will show the relationship between geographic mission coverage and costs and will suggest a Pareto front to showcase a short list of sets of global Jayhawk assignments for consideration by the CG. Auction B will be performed with the objective criteria to seek the lowest cost set of fleet assignments while still achieving the threshold mission coverage rate. Auction B's result will be proposed as the best-identifiable result, achieving the baseline mission coverage percent with only 14 aviation locations, 25 fewer than the status quo, and 36% less expensive than the CG's notional plan. Following demonstration of this technique, it will be proposed for use by the CG, to be adapted with refined objective criteria, to seek an optimal set of global assignments for the future All-Jayhawk fleet.

Thesis Supervisor: Bruce Cameron
Title: Director, System Architecture Group

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Semper Paratus

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List of Acronyms

AFB – Air Force Base

AIRFAC – Air Facility

AIRSTA – Air Station

AIRSUPFAC – Air Support Facility

ALC – Aviation Logistics Center

ANG – Air National Guard

ATC – Aviation Training Center

AVDET – Aviation Detachment

ATTC – Aviation Technical Training Center

BAS – Basic Allowance for Subsistence

BAH – Basic Allowance for Housing

CAD - Computer Aided Design

CG – Coast Guard

CGBI – Coast Guard Business Intelligence

COLA – Cost of Living Adjustment

CONOPS – Concept of Operations

CONUS – Contiguous United States

D-Level – Depot Level (Maintenance)

DOD – Department of Defense

DHS – Department of Homeland Security

DSM – Design Structure Matrix

FVL-MS – Future Vertical Lift – Maritime Strike

FW – Fixed Wing

FOB – Forward Operating Base

FOL – Forward Operating Location

GIS – Geographic Information System

GPS – Global Positioning System

GSA – General Services Administration

HITRON – Helicopter Tactical Interdiction Squadron

MRR – Medium Range Recovery

MSBM – Mission Support Business Model

NAS – Naval Air Station

NCRAD – National Capital Region Air Defense

NPV – Net Present Value

NM – Nautical Mile

OCONUS – Outside the Contiguous United States

OPBAT – Operations Bahamas, Turks, and Caicos

O-Level – Unit (Organizational) Level (Maintenance)

PAL – Personnel Allowance List

RW – Rotary Wing

RWAI – Rotary Wing Air Intercept

SF – Square Foot

SRR – Short Range Recovery

SILC – Shore Infrastructure Logistics Center

SME – Subject Matter Expert

TANB – Trailerable Aids to Navigation Boat

TDY – Temporary Duty

US – United States

USAF – United States Air Force

USC – United States Code

USCG – United States Coast Guard

USN – United States Navy

Chapter 1: Introduction

Objective

The objective of this thesis is to build a model to aid the US Coast Guard in making rotary wing aircraft basing, and satellite unit organizational decisions as it transitions its currently mixed- fleet to an 'All Jayhawk' fleet of 127 MH-60 Jayhawk aircraft, by building a model that can tradeoff between geographic coverage and cost.

The United States Coast Guard (USCG) current operates a mixed fleet of vertical lift, rotary wing (RW) aircraft, including 45 MH-60 'Jayhawk' and 98 MH-65 'Dolphin' helicopters to perform and support its missions across the United States (US) and around the world. These helicopters are based out of 39 Air Stations, logistics facilities, and forward operating satellite locations in the US, and often deployed aboard cutters (naval ships) and to these satellite locations to extend their reach. To house and support these RW aircraft, and multiple Fixed Wing (FW) aircraft, the CG owns, leases, or permits a non-standardized portfolio of 57 hangars around the United States.

The Dolphin fleet averages 35 years and 17,000 airframe hours in age, rapidly approaching its initially planned service life of 20,000 hours (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 505). The CG will soon complete a Service Life Extension Project (SLEP) to maintain the Dolphin fleet and extend the aircraft's expected lifespans to 30,000 hours (estimated 13 year life extension to 2035) (Werner, 2018) (Acquisition Directorate, 2023). However, with Airbus, the Dolphin's manufacturer, ceasing aircraft and parts production in 2018, the future viability of the CG MH-65 Dolphin fleet is increasingly challenged (Hooper, 2022). Therefore, with new parts and airframes still available for the capable MH-60 Jayhawk aircraft, the CG has made the decision to grow the MH-60 fleet and to transition to an 'All Jayhawk' fleet of 127 by the mid 2030's.

The USCG requires 100% hangaring of all of its RW aircraft to protect them from weather, to help maintain their material condition, and to support post-storm responsiveness (USCG, 2014, pp. Civil Eng Manual, Ch 12). The Jayhawk aircraft is 64' 10" long from nose to tail, 68% larger than the Dolphin aircraft. Therefore, due to many legacy hangars being designed for Dolphins, it is likely that new construction will be required at multiple locations to hangar and maintain these new Jayhawks. Furthermore, with staffing and facilities square footage building support standards different for the two aircraft, new staffing assignments and additional construction will likely be required. Capabilities of the Jayhawk aircraft also differ from the Dolphin, with the Jayhawk capable of a responding to missions more than twice as far from their home base than the Dolphins.

The transition from a mixed fleet of 143 helicopters to 127 Jayhawks will not be a one for one transition. The Jayhawk assignment decisions are not made yet, and different locations create differing regional mission capabilities and present varying costs. Furthermore, it is not yet determined if the satellite locations used to forward deploy Dolphin aircraft will be desired in the future. The objective of this thesis is therefore to build a model to aid the USCG in making RW aircraft basing and Support Construct decisions as it transitions its currently mixed fleet to an 'All Jayhawk' fleet of 127 MH-60 Jayhawks.

Motivation

My motivation for this thesis is to assist the USCG in attaining the best value at cost, in the 'All-Jayhawk' Fleet's aviation asset and mission performance, by supporting decision for basing assignments & infrastructure investments. This motivation has three parts.

First, with new infrastructure likely required, the USCG is on the cusp of a $1B+ investment to convert or upgrade various facilities to support the planned 'All-Jayhawk' fleet. Recognizing the rare opportunity this is to make a major investment into the CG's aviation infrastructure while strategically redistributing the fleet, all involved CG offices, and stakeholders desire to help the new fleet to achieve maximum value at overall cost. If the USCG is about to spend $1B+ to construct new aviation hangars, it behooves the USCG to take a deliberate and global approach to determine optimal basing locations, and where to make infrastructure investments.

In my 20+ years with the CG I have witnessed numerous occasions where new aviation or naval assets were deployed to new locations, without adequate facilities, thereby degrading the asset's performance, readiness, or maintainability. For example, in the early 2000's, the Coast Guard built and deployed more than 100 new 45' Response Boat Medium (RBM's) to replace older 41' Utility Boats. Regrettably, many were deployed without advance upgrades to their docks' electrical utilities, thereby challenging their operational readiness. A comparable situation occurred in the 2010's when the Coast Guard fielded the modernized 26' Trailerable Aids to

Navigation Boat (TANB) to replace older 19' boats which maintained buoys and other navigational aids. The boathouses that stored and maintained them were designed decades ago for the smaller 19' boats, not systematically planned for replacement or expansion, therefore challenging the maintainability of the new TANBs. More recently in the late 2010's, the CG fielded new C-130 Hercules model 'J' aircraft on a one for one replacement for older C-130 aircraft. Uniquely within the CG, these new C-130 J aircraft require liquid oxygen for high altitude flights, and thus require new ground based O2 storage facilities. The CG incorporated new facilities planning into this aircraft acquisition program, and did initiate construction of liquid oxygen facilities, but fielded them late in multiple locations, after the delivery of the new aircraft, therefore challenging the operability of the new fleet. All parties involved in today's transition from a mixed RW fleet to the planned 'All Jayhawk' fleet including field units, headquarters offices, and logistics units desire to avoid these challenges. Fortunately for the Jayhawk fleet transition, funding is already notionally budgeted to support new hangar construction and modifications, as well as staffing & other logistics changes. But this situation presents a new challenge different from these previous examples. With the transition not being a one for one replacement, the aircraft assignments represent a new challenge to deliver carefully targeted upgrades to CG Air Stations & other aviation facilities nationwide.

This research is motivated by a second aspect, a future planning component. With the new Jayhawks being procured with a lifespan of 20,000 or 12,000 airframe hours for new or Navy-used airframes respectively, this 'new' fleet is projected to operate thru the early 2050's (Acquisition Directorate Aviation Programs) (Eberly, Interview with CG-8-PAE, 2023). As a comparison, the average current age of CG owned hangars is 47 years old, with the oldest operational hangar being 88 years old (US Coast Guard, MAXIMO/Shore Asset Management (SAM), 2023). So, it is conceivable that new hangars planned for the new Jayhawk fleet will last into the 2070's and beyond, and therefore potentially supporting the Jayhawk's replacement fleet. This motivates a desire to seek opportunities to co-optimize the construction of these new hangars to support both the new Jayhawk fleet and its undetermined future replacement fleet, to save future construction funds through value-engineering now.

Finally, this thesis is motivated by the desire to exercise the auction algorithm solution to the Assignment Problem, for a real-world challenge of how to decide how to assign emergency response elements to geographically dispersed locations with overlapping range rings. A well-studied combinatorial optimization problem, the Assignment Problem represents the decision challenge to assign one set of elements, to another set of elements, for an overall objective. In this take on the Assignment Problem, the challenge is to assign aircraft to regional bases of different types and locations, for the overall objective of seeking an optimal trade-off between costs and mission performance. An asymmetric set of assignments, this use of the Assignment Problem allows more than one aircraft to be assigned to any one CG aviation location.

Research Questions

This research aims to analyze where to optimally deploy and hangar the US Coast Guard's upcoming 'All-Jayhawk' fleet as it replaces the current mixed MH-65 and MH-60 fleet. This research and its model are aimed to help the CG answer the following sub-questions.

Sub Questions include:

1) Which assignment set of aircraft to legacy facility locations represents the best distribution from which to allocate aircraft. Are there less expensive legacy locations which can provide the same or similar levels of capability as current RW aircraft locations with higher costs?
2) Are there any facility locations which could be closed with minimal effect on mission performance or capabilities, with the disestablishment objective being cost savings?
3) Are there new facility locations which could be established which might significantly improve mission capabilities or reduce costs?
4) Of the current and organically developed models for satellite or forward operating aircraft deployments, including Forward Operating Bases, Forward Operating Locations and Air Facilities, do any achieve superior value at cost? Should any satellite locations be upgraded to full-service Air Stations? Should any full-service Air Stations locations be downgraded to satellite locations, and if so, to which Support Construct?
5) This research will also exercise this model and auction technique for a similar objective to support the future replacement of the MH-60 Jayhawk in the mid 2050's. This research will consider specifically, the Sikorsky-Boeing Defiant X helicopter, a hypothetical replacement for the Jayhawk aircraft, which is larger, and boasts a more capable speed, range, and cargo capacity. Under this hypothetical, are there investment

decisions that could be co-optimized for both the near future 'All-Jayhawk' fleet, and a potential future Defiant X fleet?

Research Approach and Methods

This thesis will approach these questions with multiple methods including the following:

1) Mission Definition & Understanding: The primary missions of CG aviation forces will be defined and reviewed. This begins with the USCG's two-hour planning standard for search and rescue entities and assets.
2) Historical Review: A review will be conducted of the history of the CG's portfolio of aviation locations and RW aircraft. This review will seek out trends in how the portfolio of aircraft and facilities have evolved over the decades, and how they have changed in recent years. The history of how locations were created, changed, or divested will be reviewed for any lessons learned.
3) Design Structure Matrix (DSM) Methods: The various Support Constructs the CG uses to support aircraft in the field, including Air Stations and three types of satellite units will be broken down by Architectural Decisions to better understand their differences and cost drivers. DSM models will then be created and assessed for how these various aviation entities operate. This will include creating 'Process DSM's' for four distinct types of CG aviation Support Constructs including full-service Air Stations and multiple types of satellite entities like Forward Operating Locations. These Process DSM matrices will break down aviation entities to better understand which sub-assets, staffing or entities are interconnected or have dependencies, and which assets must be collocated, and which may be dispersed.
4) Geo-Spatial Analysis via Geographic Information System (GIS) software: An analysis of historic mission data will be performed to help identify better locations to distribute the fleet. The ability of the 'All-Jayhawk' fleet to respond to missions within their radius rings will be used as a one primary metric for comparing various aircraft assignment Concepts.
5) Cost estimation of various fleet assignments for the 'All Jayhawk' fleet: This will include creation of a cost estimating tool to promptly estimate the total cost of lifecycle ownership of the 'All-Jayhawk' Fleet based on the available data and estimated costs.

The total lifetime NPV from now until the fleet's retirement will be used as a second metric for comparing various aviation assignments and models. Due to many standards being ill-defined, some of these cost estimates will interpolate costs and standards based on empirical evidence.

6) Ideations and Auctions of various new Aviation Assignment Concepts: This will first include suggestions for new Concepts for global assignment of the Jayhawk fleet to understand the relative costs and merits of different locations. This will also include multiple auction techniques to objectively determine more optimal sets of aviation assignments. The origin for this auctioning technique is based upon methods proposed to solve the 'Assignment Problem.'
7) Analysis of the relationship between fleet assignment costs and mission coverage percents: This will include graphically presenting and comparing the relative costs & mission coverage percents of various fleet assignments. Through this graphical presentation, a Pareto Front will be proposed to help seek a more optimal future fleet assignment.

Thesis Hypothesis

The author hypothesizes the following:

1) There is an All-Jayhawk fleet assignment list that is superior to the notional plan under current consideration by the CG, based on the metrics of mission capability and costs. This model will also objectively prioritize force laydown locations for regions where current facilities create overlapping response rings. Specific regions of interest include the Pacific Northwest, The Great Lakes, and the Gulf Coast.
2) The Coast Guard can achieve similar service levels to high-cost regions at better value (better capability at less cost) with Jayhawk helicopters, by reassigning response aircraft to more distant locations. Specific high-cost areas of interest include San Francisco, CA and Miami, FL.
3) The USCG can achieve greater value in some regions by disestablishing legacy locations and establishing completely new facilities in new, more strategic locations. Specific areas of interest include a review of locations around the Great Lakes and the Marianas Islands.

4) Of the multiple current models used to forward deploy RW aircraft to satellite locations, the Forward Operating Base Support Construct will be found to be superior to other models currently being used. These other Support Constructs include Forward Operating Locations & AIRFACs.

Thesis Overview and Organization

This thesis is organized into the following Chapters.

Chapter 2

Chapter 2 sets the stage for this thesis by first presenting an overview of the US Coast Guard and its missions, and how its aviation program is structured. It will provide a general description for all CG aircraft including detailed information on current helicopters. It will also explain how RW aircraft are dispatched for missions in different manners from different types of units. Chapter 2 further describes the trajectory for the CG's RW fleet, while showcasing current assignments as well as a notional list of assignments under consideration for the future All Jayhawk fleet.

Chapter 3

Chapter 3 takes a step back to provide a historical perspective on the CG aviation program. Specifically, the history of all aviation locations is reviewed to seek our trends in where they are and where they came from. The history of the CG's RW aircraft is also reviewed to explain the evolution of CG RW aircraft capabilities and how the fleet is currently bifurcated with two RW airframes. Through this historical lens, certain helpful trends are revealed which may support future decision making.

Chapter 4

Chapter 4 showcases multiple techniques other researchers have used to solve the Assignment Problem or to help allocate emergency service assets for greater value or metrics. This chapter delves into multiple techniques, explaining why they are or are not applicable to the Coast Guard's problem at hand, finally arriving upon Dimitri Bertsekas' auction technique. His auction algorithm is found to be applicable as it allowed the author to seek optimization of two metrics while also allowing for perturbation between auctions, that being the changes in value propositions as various aviation locations are eliminated during the auctions.

Chapter 5

Chapter 5 assesses the various Aviation Support Constructs used to field RW aircraft including full-service Air Stations, and forward deployed facilities such as Forward Operating Locations (FOLs), Forward Operating Bases (FOB, and Air Facilities (AIRFACs). Chapter 5 breaks these constructs down by Architectural Decisions, and models them with Design Structure Matrices to visualize their processes. Through these modeling tools, various strengths and weaknesses, and cost drivers can be discussed.

Chapter 6

Chapter 6 discusses how a model was built that can assess tradeoffs between fleet coverage and cost. Estimated costs include capital facility and aircraft costs, as well as fuel, personnel, and logistics expenses, which vary by Support Construct. Fleet geographic coverage is visualized and modeled in GIS software in combination with 10 years of CG mission data. Through this GIS model, the fleet's mission coverage can be assessed. To provide a baseline target, the mission coverage of the current two-airframe fleet is assessed at 87.08%. As a thought experiment, Chapter 6 conducts a thought experiment to apply this same modern data set to GIS for the CG's past mixed fleet of HH-52A Seaguard and HH-3F Pelican helicopters and to explore how its capabilities compare to today's fleet. Chapter 6 also lists assumptions made while making and exploring the model created in this thesis.

Chapter 7

Chapter 7 exercises the model in two manners. First, the author suggests 30 'Concepts', or sets of global assignments for the future All-Jayhawk fleet. The lifecycle costs of these Concepts will be estimated, and their utilities determined via GIS assessment of Jayhawk range rings around selected locations. Secondly, and more objectively, five Assignment Problem Auctions will be held with varying objective criteria to objectively determine better global fleet assignment Concepts. Finally, these Concepts' utilities will be plotted against their costs, and a Pareto Front will be suggested to define several good Concepts for consideration.

Chapter 8

Chapter 8 performs a thought experiment on modeling the future of the CG's aviation facilities portfolio. A sixth and final Assignment Problem Auction is conducted the Sikorsky-Boeing Defiant X aircraft, one potential candidate to replace the Jayhawk aircraft in the early 2050's. This Auction reveals possible synergies between required facilities investments to support the All-Jayhawk fleet and facilities investments for a future fleet.

Chapter 9

Chapter 9 presents research conclusions and summarizes the answers to the five research questions. Chapter 9 goes on to make recommendations to the US Coast Guard for actions and future study to improve upon this model or to apply this model to other organizations.

Chapter 2: US Coast Guard Mission & Aviation Background

Brief Description and Missions of the U.S. Coast Guard

With roots dating to 1790 when the United States Revenue Cutter Service was formed, the modern US Coast Guard was established in 1915 by Congress, created as both a military service and a law enforcement agency (Congress, 14 USC §102 Primary Duties, 1949). Multiple federal agencies merged over the service's 230+ year history including the Lighthouse Service, the US Life-Saving Service, the Bureau of Navigation, and the US Steamboat Inspection Service. Since 1915, the USCG has also moved within the US Government, transferring from the Treasury Department to the Department of Transportation in 1976, and then to the Department of Homeland Security in 2002. Today, the USCG is tasked by the Homeland Security Act of 2002, and responsible for the following eleven statutory missions (US Coast Guard, Missions of the US Coast Guard, 2002):

1) Ports, Waterways & Coastal Security
2) Drug Interdiction
3) Aids to Navigation (ATON; including maintaining the nation's lighthouses, buoys & Vessel Tracking Systems)
4) Search & Rescue (SAR)
5) Living Marine Resources
6) Marine Safety
7) Defense Readiness (National Security & Military Preparedness)
8) Migrant Interdiction
9) Maritime Environmental Protection
10) Polar, Ice & Alaska Operations (including the International Ice Patrol)
11) Law Enforcement

Varied in nature, these eleven statutory missions contain the common thread of a sea-going service operating and around US waters, in protection of mariners operating on the seas, in defense of threats delivered by sea, and in protection of the seas themselves (Coast Guard Publication 3.0: Operations, Feb 2012, p. 5). The USCG operates Cutters (ships), small boats, rotary wing and fixed wing aircraft, deployable specialized forces, and shore-based forces out of dozens of locations along US Coastlines in performance of these missions. Key to these forces is that they are designed to be "durable platforms,…flexible enough for many different types of missions" depending on the situation of the day in the location assigned (Coast Guard Publication 1: USCG: America's Maritime Guardian, May 2009, p. 58). Operational forces, including aviation units, are hierarchically assigned, first to major Area Commands (Pacific & Atlantic Areas), and subordinately, to nine numbered regional Districts, (see Figure 1).

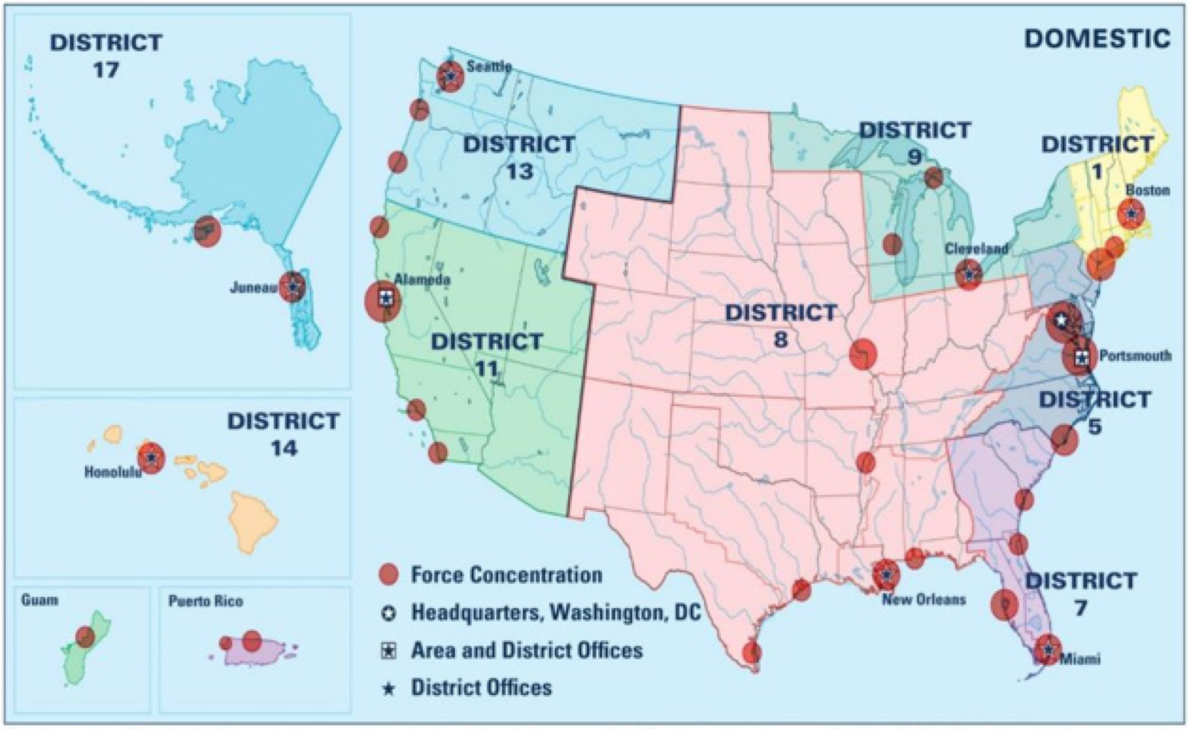

Figure 1: The US Coast Guard's Domestic Organization

Source: (US Coast Guard, Missions of the US Coast Guard, 2002)

US Coast Guard Aviation Assets, Program & Current Assignments

The USCG operates a mixed fleet of different RW and FW airframes to perform and support performance of CG missions across the US and around the word (Acquisition Directorate Aviation Programs). While this thesis will focus on RW assets, a brief overall summary is helpful. The CG's FW fleet consists of 22 HC-130J 'Super Hercules' long range and heavy air transport and patrol aircraft, 18 HC-144 'Ocean Sentry' & 14 C-27J 'Spartan' medium range transport and patrol aircraft, and two C-37B long range Command and Control Aircraft. These aircraft are based out of 39 operational, training, and logistics facilities in the US, and often deploy aboard cutters, and to forward operating locations to extend their reach. Summaries of these aircraft and their capabilities are shown in Tables 1 and 2.

Table 1: CG RW Aircraft Summary and Capabilities

Sources: (Acquisition Directorate Aviation Programs) (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022)

	MH65 Dolphin	**MH-60 Jayhawk**
Current CG Fleet Size	98	45
Manufacturer	Airbus Helicopters	Lockheed Martin/Sikorsky
Maintenance parts readily available?	No	Yes, including new hulls
CG Cutter Landing Compatibility?	All CG Cutters with Flight Decks	OPCs and NSCs (larger new Cutters ≥ 360’)
Average Age	35 years / 17,000 hours	30 years / 16,000 hours
Average Service Life Remaining (Hours)	3,000 hours	4,000 hours
Cruise Speed	148 knots	140 knots
90 min Mission Radius Ring	90 NM	210 NM
Extreme Dimensions (L x W x H) (Length of hull excluding rotors & width including rotors)	38’ x 39’2” x 13’2”	64’10” x 53’8” x 17’
Flight Range	350NM / 3 hours	700NM / 6.5 Hours
Primary Mission	Short Range Recovery	Medium Range Recovery

Figure 2: The Airbus MH-65 Dolphin

Source: (Defense Visual Information Distribution Service)

Figure 3: The Sikorsky MH-60 Jayhawk

Source: (Defense Visual Information Distribution Service)

Table 2: CG FW Aircraft Summary and Capabilities

Sources (Acquisition Directorate Aviation Programs) (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022)

	HC-130J Hercules	**C-27J Spartan**	**HC-144 Ocean Sentry**	**C-37B**
Current CG Fleet Size/ Program of Record	22	14	18	2
Manufacturer	Lockheed Martin	Alenia Aermacchi	Airbus Group	Gulfstream
Cruise Speed	320 knots	290 knots	215 Knots	300 Knots
Extreme Dimensions (L x W x H)	97'9" x 132'7" x 38'11"	74'6" x 94'2" x 31'8"	70'2" x 84'8" x 26'10"	96'5" x 93'6" x 25'11"
Flight Range (NM)	4,900 NM / 20+ Hours	2,675 NM / 12 Hours	2100 NM / 10.5 Hours	5,000 NM
Primary Missions	Long Range Surveillance	Medium Range Surveillance	Medium Range Surveillance	Long Range Command and Control (12 pax)

The CG supports these aircraft with five organizational elements: 1) training; 2) acquisitions, 3) policy, 4) logistics and engineering, and 5) operations (US Coast Guard Organization). The CG trains its enlisted aviation workforce at the Aviation Technical Training Center (ATTC) in Elizabeth City, NC. The CG trains its officer aviation workforce from the

Aviation Training Center (ATC) in Mobile, AL, partnering closely with the US Navy's nearby flight training school in Pensacola, FL. In addition to its primary training mission, ATC also contains a smaller operations department, capable of responding to missions nearby Mobile, AL (Eberly, Interview with CG-8-PAE, 2023). Acquisitions of new aircraft and major upgrades to legacy aircraft are directed out of the CG-91 Aviation Acquisitions Office at CG Headquarters in Washington, DC. Aviation policy, including oversight of doctrine, requirements and training is lead out of the CG-711 *Office of Aviation Forces,* also at CG Headquarters. CG aviation logistics and engineering are directed from the CG-41 Aeronautical Engineering Office at Headquarters in Washington, DC, with a subordinate unit, the Aviation Logistics Center (ALC) tasked with performance of Depot Level Maintenance for all CG aircraft, also based out of Elizabeth City, NC. Key to the CG's Aviation maintenance program is its bifurcated maintenance strategy, with Depot-Level Maintenance executed out of ALC, and Organizational-Level Maintenance executed out of field level aviation units (Deputy Commandant for Mission Support, 2015, p. 55). Depot-Level Maintenance tasks are generally maintenance efforts requiring high degrees of capacity or capability, for example, aircraft overhauls or repainting entire airframes. In comparison, Organizational-Level Maintenance tasks are those tasks within the capability of field units, for example, oil changes and propellor replacements.

Finally, aviation operations are dispersed across the Coast Guard, based out of 23 regional 'Air Stations'. Organized similarly with respect to engineering, command and control, and logistics, aircraft assignments are iteratively made based on the unique needs of various regions, operational, engineering and manpower efficiencies, the physical capabilities of the Air Stations and their facilities, and the geographical location of legacy units. Additionally, seven of these 23 Air Stations maintain and operate ten non-standard forward deployed facilities, often on a seasonal or temporary basis to further their operational capabilities. Standardized in maintenance and operational procedures, these 23 Air Stations are situated along the coastlines, ready to deploy FW or RW aircraft in support of training or mission assignments (Dolbow, 2013, p. 54). Duties of these 'normal' Air Stations include training, maintaining & providing crews to operate aircraft, execution of assigned missions, human resources administration, public affairs, maintenance of its buildings and facilities, and Organizational-Level Maintenance of their assigned aircraft. In addition to operating aircraft for regional missions, multiple specific Air Stations maintain additional RW aircraft, deploying them cyclically aboard major law enforcement Cutters deployed at sea. These currently include Air Stations Kodiak, Honolulu, North Bend, San Francisco, New Orleans, Miami, Borinquen and Atlantic City. Figure 4 depicts the CG's current force laydown of RW aircraft. Note that Figure 4 does not depict Air Stations Sacramento, CA and Washington, DC which only host FW aircraft.

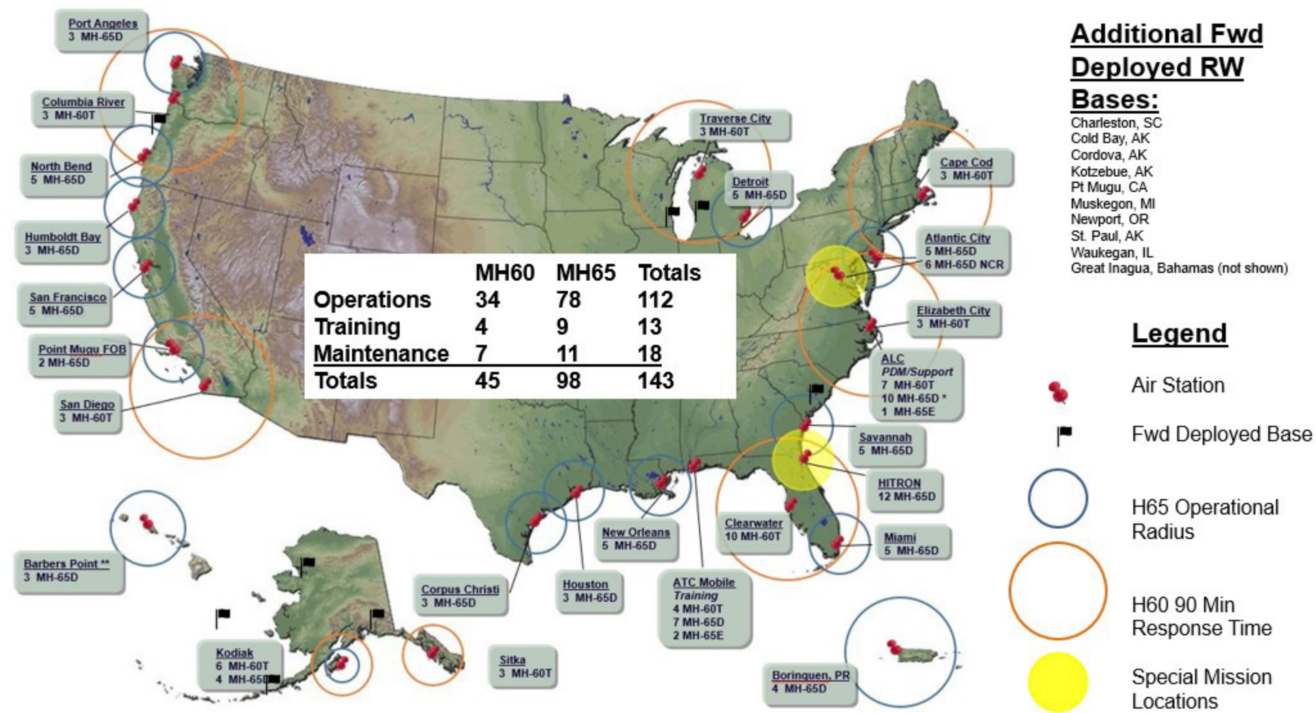

Figure 4: Current USCG Rotary Wing Fleet Laydown

Source: Adapted from a graphic provided by: (CG-711, 2022); (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 54)

There are three unique aviation units. Commissioned in 1998, the Helicopter Interdiction Tactical Squadron (HITRON) is located out of a leased hangar at Cecil Airport in Jacksonville, FL and maintains twelve MH-65 Dolphin Helicopters and crews (Thisesen, 2022). These Dolphins and crews are trained and prepared with specialized aerial use of force and drug interdiction capabilities for deployable use from patrolling cutters in the Atlantic, the Caribbean, and the Gulf of Mexico. Commissioned in 1952, Air Station Washington, DC, operates two C-37B Gulfstream passenger jets to provide transportation to senior CG and DHS personnel. Air Station Washington operates out of leased hangar space in Ronald Reagan Washington National Airport. And thirdly, the National Capital Region Air Defense Unit (NCRAD) operates MH-65 Dolphin helicopters, providing national capital air defense through its Rotary Wing Aerial Intercept (RWAI) mission, further described below.

Concept of Operations for U.S. Coast Guard RW Assets

CG RW aircraft are utilized in 3 ways. First, and the most common manner is following routine distress or other mission request calls received by regional Command Centers (Dolbow, 2013, p. 7). Regional Command Centers receive these mission calls via phone call or VHF radio channel 16. Command Centers then assess the situation, decide whether to respond, and determine the most appropriate respond method. If appropriate, the Command Center assigns the mission to either afloat Cutters, to regional Small Boat Stations, or Air Stations. This decision is based on criteria including the mission location, the number of people or victims involved, the mission's nature, and the weather (Aponte, 2023). If assigned to an Air Station, the mission is then assigned to a 'ready aircraft' with a crew on 'B-0' (Bravo-Zero) status, meaning that the air crew is ready to respond to the mission assignment within zero minutes. This requires one aircraft fully fueled and operational, as well as an air crew who sleeps overnight at or near the facility. Air Stations which control satellite aviation locations may choose to assign missions to an air crew forward deployed at that subordinate unit, depending on the mission's location.

A second way RW aircraft are deployed is from afloat cutters (Dolbow, 2013, p. 53). The CG routinely deploys RW aircraft aboard flight-deck equipped cutters to enhance the ship's capabilities. In this manner, the cutter then tasks the aircraft for mission assignments based on the ship's general mission assignment or following commands from superior District or Area Commands (Pacific or Atlantic Area Commands).

A third way RW aircraft are used is for the RWAI mission, a new mission since 2006 (NORAD and USNORTHCOM Public Affairs, 2007). Currently operating as a satellite entity from Air Station Atlantic City, NJ, the NCRAD unit operates six rotating MH-65 Dolphin aircraft and crews in performance of their RWAI mission in defense of the Washington, DC capital region. These aircraft, and their Atlantic City based air crews stand ready to respond to aviation incursions into the Washington, DC Air Defense Identification Zone (ADIZ). The unit operates the aircraft out of two different locations: 1) Ronald Reagan Airport in Washington, DC; and 2) Mission Support Facility (MSF) Hangar 14 at Joint Base Andrews, MD (Eberly, Interview with CG-8-PAE, 2023). These teams deploy on rotating two-week deployments from Atlantic City to

Washington, DC. To maximize readiness and improve work-life balance for the air crews, an initiative is underway to permanently relocate the aircraft and their support crew from Atlantic City, NJ to newly leased hangar space at Joint Base Andrews, MD where they will continue to forward deploy to Ronald Reagan National Airport. This will establish the unit as an independent field unit, operating all organizational maintenance and administrative functions out of Joint Base Andrews while rotating duty helicopters to the Reagan airport location, closer to the capital region, and more ready to respond to capital incursions.

Status and Trajectory of the Coast Guard's Rotary Wing Fleet

As explained above in Chapter 1, the CG's Dolphin fleet averages 35 years and 17,000 airframe hours in age, approaching its initially planned service life of 20,000 hours. With recent fleet maintenance, the fleet is expected to last until 2035, but this is uncertain due to the Dolphin's manufacturer discontinuing parts production. Therefore, with new parts and airframes still available for the capable MH-60 Jayhawk aircraft, the CG has made the decision to grow the MH-60 fleet and to transition to an 'All Jayhawk' fleet of 127 by the mid 2030's.

The USCG requires 100% hangaring of all of its RW aircraft to protect them from weather, to help maintain their material condition, and to immediately perform post-storm response missions (USCG, 2014, pp. Civil Eng Manual, Page 12-6). Therefore, with most CG hangars designed for the 26% smaller Dolphins, it is likely that new construction will be required at multiple locations to hangar these new Jayhawks. Furthermore, with staffing and facilities square footage building support standards different for the two aircraft, staffing assignments or reassignments & additional construction will likely be required. The capabilities of the Jayhawk aircraft also differ from the Dolphin, with the Jayhawk boasting better range, speed, and cargo capacity.

The transition from a mixed fleet of 143 helicopters to 127 Jayhawks will not be a one for one transition. The Jayhawk assignment decisions are not made yet, and different locations create differing regional mission capabilities and present varying costs. Furthermore, it is not yet determined if the satellite locations used to forward deploy Dolphin aircraft will be maintained into the future. The CG is however, considering a notional plan to deploy the future 'All Jayhawk' Fleet (See Figure 5) (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 18).

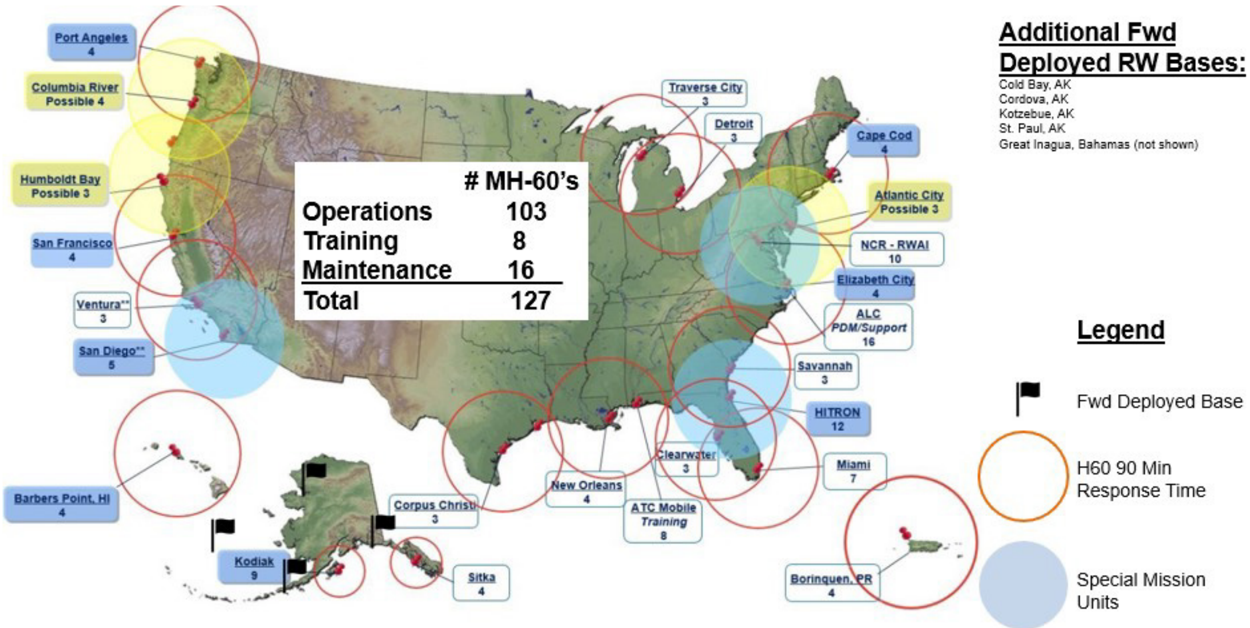

Figure 5: The Notionally Proposed All-Jayhawk Fleet Laydown

Source: Adapted from a graphic provided by: *(CG-711, 2022)* & *(Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 54)*

While the full approach that generated this pre-decisional and notional plan was not reviewed, certain steps and criteria for the decision-making process were gleaned through SME interviews. As a first step, CG-711, the CG's Office of Aviation Forces performed a force requirements analysis yielding a pre-decisional desired fleet size of 127 Jayhawk aircraft. Next, the CG's Civil Engineering Tactical Operations Product Line conducted a hangar space analysis of each of the CG's 48 hangars at 32 facilities to determine how many larger Jayhawk helicopters could fit inside the hangar decks. This space assessment used computer aided design (CAD) software to virtually fit Jayhawk helicopters into legacy hangars, while ensuring standard DoD safety clearances around all sides of the aircraft would be maintained (See Table 3 and Figure 6). The results of this space assessment are summarized in Tables 4 and 5, with examples of hangars fitting or not fitting Jayhawk helicopters shown in Figures 7 and 8.

The CG then made the first notional Jayhawk assignments to hangars that could sufficiently host Jayhawks with the de-facto criteria of leveraging legacy locations already able to support Jayhawks (Rathbun, 2023) (Smolowitz, 2023). Interviews with the CG's office of Aviation Forces (CG-711) indicated that a primary reason for the preference for legacy locations was because of the urgency associated with the limited remaining Dolphin lifecycles and the challenge of obtaining sufficient capital construction funding. There is also a preference against downgrading any full-service ‘Air Station’ Facility to a satellite unit or conversely upgrading a satellite unit. Additionally, there is a reluctance against establishing new facilities or disestablishing any legacy facilities. Finally, assignment locations are being planned and considered on a unit-by-unit basis, rather than from a nation-wide perspective. It is important to note that this planning, internal to the CG, is still underway, and no decisions have yet been made for any future new Jayhawk assignments.

Table 3: DoD Minimum Aircraft Maintenance Bay Clearances

(Navy Type II hangars clearances highlighted for CG Jayhawk applicability)
Source: (US Dept of Defense, Aircraft Maintenance Hangars, UFC 4-211-01, 2021, p. Pg 26)

SEE CLEARANCES A THROUGH H ON FIGURES 2-1 THROUGH 2-4			AIR FORCE AND ARMY		NAVY - NOTE 10				NOTES:
			WINGSPAN < 100' 30.48M	WINGSPAN > 100' 30.48M	HANGAR TYPE I	HANGAR TYPE II	HANGAR TYPE III	HANGAR TYPE IV	
FIGURE 2-1 AND 2-2	A	AIRCRACT TO NEAREST FIXED OBSTRUCTION ALONG BACK WALL	10'-0" 3.05M	15'-0" 4.57M	10'-0" 3.05M	10'-0" 3.05M	20'-0" 6.01M	15'-0" 4.57M	1, 2, 3
	B	AIRCRAFT TO INSIDE FACE OF HANGAR DOOR	10'-0" 3.05M	10'-0" 3.05M	7'-6" 2.29M	10'-0" 3.05M	15'-0" 4.57M	15'-0" 4.57M	1, 2, 4
	C	AIRCRAFT TO NEAREST FIXED OBSTRUCTION ALONG SIDE WALL	10'-0" 3.05M	15'-0" 4.57M	7'-6" 2.29M	10'-0" 3.05M	20'-0" 6.01M	15'-0" 4.57M	1, 2, 3
	D	AIRCRAFT TO ADJACENT AIRCRAFT	10'-0" 3.05M	15'-0" 4.57M	7'-6" 2.29M	10'-0" 3.05M	20'-0" 6.01M	15'-0" 4.57M	1, 2, 5
	E	AIRCRAFT TO HANGAR DOOR JAMB	10'-0" 3.05M	10'-0" 3.05M	6'-0" 1.83M	8'-6" 2.59M	18'-6" 5.64M	13'-6" 4.12M	1, 2, 6
FIGURES 2-3 AND 2-4	F	AIRCRAFT TO NEAREST FIXED OR MOBILE OVERHEAD OBSTRUCTION	10'-0" 3.05M	10'-0" 3.05M	5'-0" 1.52M	5'-0" 1.52M	5'-0" 1.52M	5'-0" 1.52M	1, 7, 8
	G	AIRCRAFT TO UNDERSIDE OF DOOR HEAD	7'-0" 2.13M	7'-0" 2.13M	5'-0" 1.52M	5'-0" 1.52M	5'-0" 1.52M	5'-0" 1.52M	1, 7, 8
	H	HOOK HEIGHT (SADDLE OF HOOK)	Army: Per Std Design Air Force: Per FRD		Refer to Table 7-1				1, 7, 9

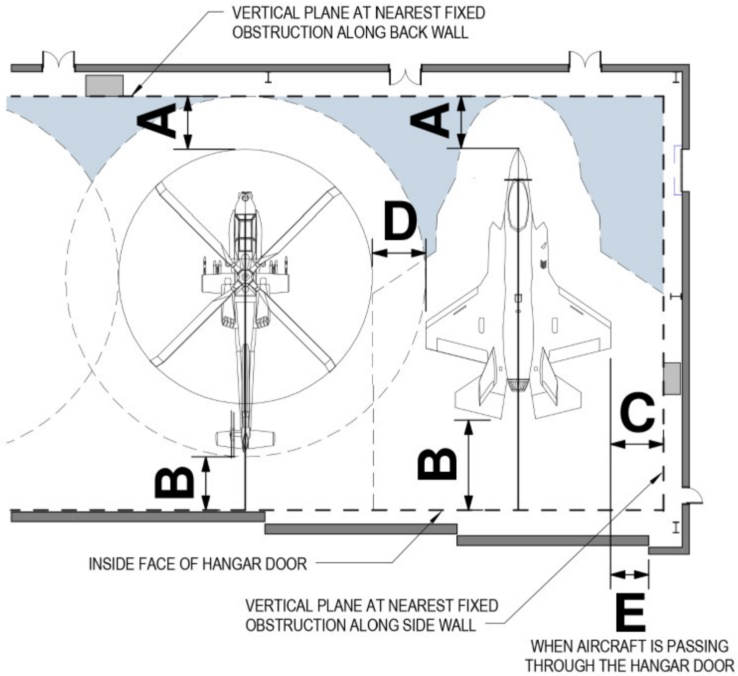

Figure 6: DoD: Minimum Aircraft Maintenance Bay Clearances

(See Table 3 for Dimensions A thru E)
Source: (US Dept of Defense, Aircraft Maintenance Hangars, UFC 4-211-01, 2021, p. Pg 28)

Table 4: RW Assignments & Hangar Space Assessments, Permanent Assignments Only

Color coding: Green–Sufficient Hangar deck space is available for notional assignment; Red-Insufficient space per notional assignment; Yellow–Facility notionally planned for closure; Orange-N/A
Source: Adapted and expanded upon from data provided in (Henderson, McClain, Converse, & Henkelman, 2022)

		Current RW Assignments		Notional All-60 Fleet Assignments		
Aviation Location	**# Hangars**	**MH65**	**MH60**	**MH60**	**# MH-60 Fit in Hangar per CG Stds?**	**Comments**
Air Sta Barbers Point, HI	2	3	0	4	4	New 2nd Hangar designed for 4x C-130's
Air Sta Kodiak, AK	2	4	6	9	9	Hangar is intended fully for FW Aircraft
Air Sta Sitka, AK	1	0	3	4	4	
Air Sta Port Angeles, WA	1	3	0	4	2	
Air Sta Columbia River, OR	1	0	3	4	3	
Air Sta North Bend, OR	1	5	0	0	2	Notionally considered for closure
Air Sta Humboldt Bay, CA	1	3	0	3	2	
Air Sta San Francisco, CA	1	5	0	4	2	
Air FOB Point Mugu, CA	1	2	0	0	1	Planned for closure once Ventura is operational
Air Sta Ventura, CA	1	0	0	3	3	Designed for 4x Dolphins
Air Sta Sacramento, CA	1	0	0	0	n/a	Location currently fully utilized for FW Aircraft
Air Sta San Diego, CA	2	0	3	5	4	
Air Sta Corpus Christi, TX	1	3	0	3	3	
Air Sta Houston, TX	1	3	0	0	2	Notionally considered for closure
Air Sta New Orleans, LA	1	5	0	4	2	
ATC (Mobile, AL)	2	9	4	8	8	
Air Sta Clearwater, FL	2	0	10	3	3	
Air Sta Miami, FL	2	5	0	7	7	
HITRON (Jacksonville, FL)	1	12	0	12	n/a	HITRON unit recap under separate planning
Air Sta Savannah, GA	1	5	0	3	0	
Air Sta Elizabeth City, NC	2	0	3	4	3	
ALC (Elizabeth City, NC)	7	11	7	16	n/a	16 Jayhawks used for rotating fleet maintenance
NCRAD (JT Base Andrews, MD)	1	3	0	7	7	
NCRAD +Air Sta Washington, DC	2	3	0	3	3	
Air Sta Atlantic City, NJ	1	5	0	3	3	5 Dolphins excludes Helos rotating to NCRAD
Air Sta Cape Cod, MA	2	0	3	4	4	
Air Sta Detroit, MI	2	5	0	3	1	
Air Sta Traverse City, MI	1	0	3	3	3	
Air Sta Borinquen, PR	1	4	0	4	4	
Totals	**45**	**98**	**45**	**127**	**89**	

Table 5: RW Assignments & Hangar Space Assessment, Satellite Locations Only

Color coding: Green–Sufficient Hangar deck space is available for notional assignment; Red-Insufficient space per notional assignment; Yellow–Facility notionally planned for closure; Orange-N/A
* Facilities only opened seasonally or on an ad-hoc basis
Source: Adapted and expanded upon from (Henderson, McClain, Converse, & Henkelman, 2022)

		Current RW Deployments		Notional All-60 Fleet Deployments		
Aviation Location	# Hangars	MH65	MH60	MH60	# MH-60 Fit in Hangar per CG Stds?	Comments
Air FOL Kotzebue, AK*	1	0	2	2	2	Permitted from the AK Natn'l Guard
Air FOL St Paul, AK*	1	0	1	1	1	Hangar space leased from private owned
Air FOL Cold Bay, AK*	2	0	2	2	2	
AIRFAC Cordova, AK*	1	0	1	1	1	
AIRFOL Newport, OR	1	1	0	0	0	Notionally considered for closure
AIRFOL Charleston, SC	1	1	0	0	0	Notionally considered for closure
AIRFOL Waukegan, IL*	1	1	0	0	1	Notionally considered for closure
AIRFOL Muskegon, MI*	1	1	0	0	0	Notionally considered for closure
Air FOL OPBAT, Bahamas	1	0	2	2	2	
Totals	**10**	**4**	**8**	**8**	**9**	

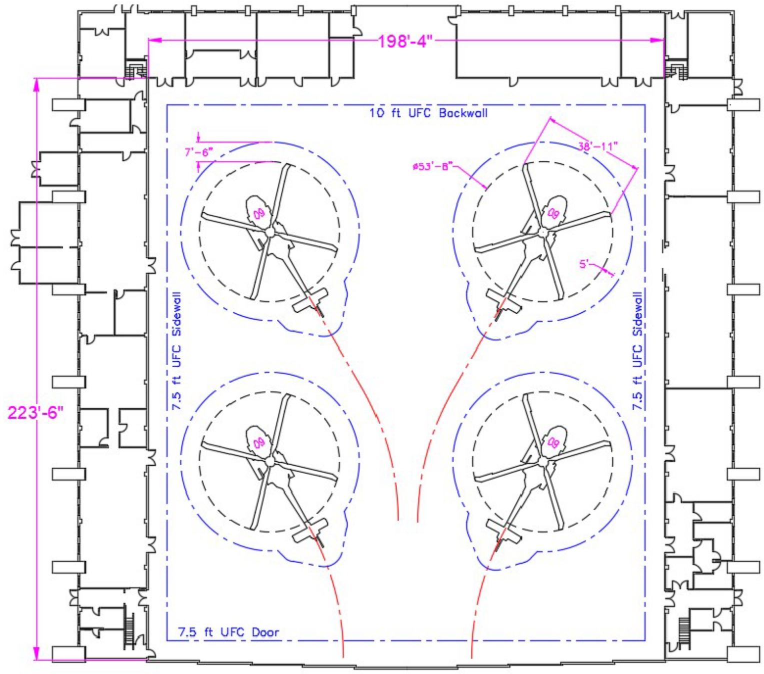

Figure 7: Air Station Borinquen Hangar Building Plan View

(Notionally Assigned Four Jayhawks; Fit is Satisfactory)
Source: (Henderson, McClain, Converse, & Henkelman, 2022, p. 22)

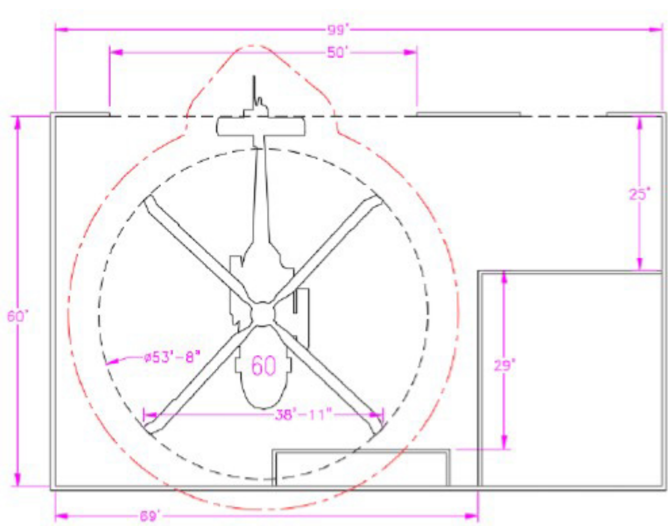

Figure 8: Air Facility Muskegon, MI Building Plan View

(Insufficient Hangar Space for Jayhawk Helicopters)
Source: (Henderson, McClain, Converse, & Henkelman, 2022, p. 18)

There are multiple challenges hindering this planning. Chief among them is a lack of a target cost, a target service level, and required areas of service. Without these targets or cost estimates, it is difficult to compare various plans. The CG also lacks staffing and facilities space planning criteria for Jayhawk helicopters. Routinely established for modern assets before field deployment, staffing and building criteria for Jayhawks were not established in the early 1990's when initially fielded. An Infrastructure Requirements Catalog is currently being developed for the Jayhawk aircraft, to specify space requirements for required for units with varying numbers of assigned aircraft, but it will not be ready for some time (Smolowitz, 2023). Once completed, this will enable the CG to perform a more detailed gap analysis of each aviation location to better understand the full capital costs associated with requirements to build out new building space. Further review of the current notional planning effort reveals that it has not considered establishing any new aviation locations and is not considering downgrading any location from an Air Station to a satellite facility, or vice versa. The model built in this thesis aims to support CG decisions by incorporating these options and criteria.

Chapter 3: A Historic Review of Coast Guard Aviation

It is often stated that USCG aviation history dates to 1903 when the Wright Brothers first achieved heavier than air flight. In fact, CG crewmen from the Kill Devil Hill, NC Life Boat Station supported the Wright Brothers in their achievements at Kitty Hawk, NC by transporting the Wright Flyer to and from launch sites, and assisting with photography on that historic day (CGAviationHistory.org, n.d., p. 1). To provide an understanding of the Coast Guard's Aviation program including its assets and facilities, a brief history of Coast Guard Aviation, focusing on facilities and RW aircraft is provided.

The Coast Guard aviation program's earnest beginning occurred in 1916 when it sent the first trainee, LT Elmer Stone, to Naval Flight School. The impetus for this included myriad nascent Concepts for how aircraft could aid and support legacy Coast Guard missions, including ideas for converting surfboats with flight capabilities, enhancing visual search capabilities with elevation, and aerial deployment of rescue equipment (Pearcy A. , 1991, p. 2). While the First World War saw the Coast Guard temporarily assigned to the US Navy and minimal growth in Coast Guard controlled or directed aviation programs, it springboarded the exposure of the Coast Guard to the naval aviation progress already made by the US Navy, including progress in navigation, communications, combat & general aviation operations. 1916 included another aviation milestone, with the US Congress approving the Naval Deficiency Act, which authorized, but did not fully fund, the acquisition and construction of ten new Air Stations along coastal waters to support Coast Guard missions (Pearcy A. , 1989, p. 1). The end of World War 1 further spurred the growth of Coast Guard aviation as the US Navy divested the former Naval Air Station at Morehead City, NC to the Coast Guard, along with a loan of six surplus Curtis HS-2 flying boats. This event provided a key opportunity for the Coast Guard to experiment with and evaluated the merits of operating aircraft in support of its missions. CG Air Station Morehead City, NC was closed in 1922 due to budget constraints. A second CG Air Station was established at Ten Pound Island, MA in 1925, with seaplane loaned from the Navy in 1925, but it was similarly closed in 1926 due to lack of funding.

The rum running years of the 1920's and 30's provided the first permanent, purposeful, and physical support to the CG aviation program. As a direct result of the successes proven at Moorhead City and Ten Pound Island, and in support of the CG's new 'rum running' responsibility to enforce prohibition law, congress appropriated $152,000 in 1926 for five aircraft to operate out of the existing small boat station in Gloucester, MA as well as Naval Air Station Cape May, NJ (Pearcy A. , 1989, p. 3). Growth continued for the same missions in 1933 with the lease of property and the first Coast Guard hangar build on Dinner Key, near Miami, FL.

Following success at these locations, the US Treasury Department directed the consolidation of all aircraft and aviation mission sets from the US Customs Service into the US Coast Guard to focus law enforcement efforts on countering smuggling of aliens and liquor (Pearcy A. , 1991, p. "USCG Aircraft" 12). This mission growth led the Coast Guard to establish new 'Air Patrol Detachments' in Buffalo, NY; San Antonio, TX; and San Diego, CA. While the term Air Patrol Detachment model hasn't survived to the present day, the property and facilities at Cape May, NJ and San Diego, CA have (Pearcy A. , 1989, p. 93 & 108). Naval Air Station Cape May was transferred to the US Coast Guard in 1946 for use as an Air Station until 1998, and for use at the Coast Guard's primary enlisted recruit training location from 1948 to present day. Air Station San Diego represents the first continuously and permanently located aviation facility, still operating at the same location today. World War 2, and the Coast Guard's second temporary assignment to the Navy provided additional strong support to the Coast Guard's capabilities, facilities, and assets with Congress authorizing and funding aviation programming to support legacy missions as well as growing missions in support of national defense. By 1941 the Coast Guard had established permanent operations of nine Air Stations at Biloxi, MS; Brooklyn, NY; Elizabeth City, NC; Miami, FL; Port Angeles, WA; St Petersburg, FL; Salem, MA; San Diego, CA; and San Francisco, CA in addition to one Air Patrol Detachments at Traverse City, MI (Pearcy A. , 1989, p. 85).

History of Coast Guard Air Stations

While a full history of each Coast Guard aviation location is not relevant, a synopsis of how each was acquired or established yields helpful information. Tables 6 and 7 list a brief history of all past and present USCG Aviation facilities and locations.

Table 6: CG Aviation Facilities (West Coast, Pacific & European Locations)

Aviation Location	State/ Country	Year Established	Property/Facilities Origin	Year Closed?	Comments
Barbers Point	HI	1949	Originally formed as an AirDet on USMC Base Kaneohe Bay	-	Relocated for expansion reasons & evolved to an Air Station in 1965
Guam	GU	1947	Established as an AIRSTA on Naval Base Guam	1972	Closed in 1972 due to the new CNMI assuming non-SAR duties & there being limited SAR duties
Kotzebue	AK	2015	Established as a seasonal AIRFAC at a leased Army NG Hangar	-	
St Paul	AK	2010	Established as a seasonal AIRFAC with a leased Hangar & legacy LORAN Barracks	-	
Cold Bay	AK	2008	Established as an AIRFAC in 2008 to support seasonal missions in Bering Sea	-	2nd Jayhawk Hangar Built in 2016
Kodiak	AK	1941	Acquired legacy USN Air Station. CG assumed posession of entire Base in 1972	-	Originally formed as an Air Detachment & evolved to a full Air Station 1964
Cordova	AK	1980	Established as an AIRFAC in 1980 to support seasonal missions around Prince William Sound	-	
Sitka	AK	1944	Originally formed as an AirDet on Annette Island	-	Moved to Sitka to be closer to mission locations & evolved to a full Air
Port Angeles	WA	1935	Formed on legacy CG property adjacent to a lighthoue & small boat station	-	Formed in 1935 as the first CG Air Station on the Pacific Coast
Columbia River	OR	1964	Originally formed as an AIRSTA, Tenant on Naval Air Station Tonque Point	-	Moved to current location 1966 after hangar construction
Newport	OR	1994	Established as an AIRFAC to support AIRSTA North Bend operations	-	
North Bend	OR	1974	Established as an AIRSTA at Southwest Oregon Regional Airport	-	
Humboldt Bay	CA	1977	Formed as an AIRSTA at Eureka Airport	-	AIRSTA San Francisco supported missions in Northern CA prior to 1977
San Francisco	CA	1941	Established as an AIRSTA at Mills Field	-	
Los Angeles	CA	1962	Formed as a full AIRSTA onboard LAX Airport with support from LA Chamber of	2016	USCG property lease expired & CG forced to relocate in 2016
Point Mugu/Ventura	CA	2016	Formed as an AIRDET in 2016 onboard USN Air Station Ventura	-	Intended to become a full AIRSTA in 2023 when new Hangar is completed
Sacramento	CA	1978	Formed as an AIRSTA & tenant at McClellan USAF Base	-	Established as an outgrowth of AIRSTA San Francisco due to growing missions & lack of space
San Diego	CA	1934	Established at Lindbergh Field, with property gifted from the City of San Diego	-	Originally formed as an Air-Sea Rescue Squadron to support USN flight
Naples	Italy	1958	Established in 1958 at US Naval Air Facility Naples to support LORAN logistics in	1972	Closed as the LORAN system consolidated to fewer LORAN C sites
Sangley Point	Philippines	1946	Established in 1946 at US Naval Air Station Sangley Point to support LORAN logistics in SE Asia	1972	Closed as the LORAN system consolidated to fewer LORAN C sites

Sources: (Pearcy A. , 1989, pp. 77-116); (Pearcy A. , 1991, pp. 12-15); (Bryan Construction); (CGAviationHistory.org, n.d.); (Dolbow, 2013, p. 53); (Edhat.com, 2021); (Moseley & Thiesen, 2021); (NORAD and USNORTHCOM Public Affairs, 2007); (Thisesen, 2022); (US Coast Guard Historian, n.d.); (Workman, 2012, p. 127)

Table 7: CG Aviation Facilities (Gulf & East Coast, Great Lakes & Caribbean Locations)

Aviation Location	State/ Country	Year Establishe	Property/Facilities Origin	Year Closed?	Comments
Corpus Christi	TX	1950	Originally formed as an AIRDET 1950 at USN Air Station Corpus Christi	-	Evolved to current Air Station in 1980 & moved in 2010's to enable expansion
El Paso	TX	1935	Established as an AIRDET at Army Fort Sam Houston to support border customs mission	1939	Moved to Army Fort Bliss (El Paso), TX in 1936. Closed in 1939 for budget reasons
Houston	TX	1963	Originally formed as an AIRSTA and tenant at Ellington AF Base	-	Moved in 1987 to north end of the Air Force airfield on newly CG purchase property
New Orleans	LA	1955	Originally formed as an AIRSTA and tenant at USN Air Station New Orleans	-	Moved with the USN to Callender Field in 1957. New CG Hangar built in 1968
Biloxi	MS	1935	Established at Biloxi Municipal Airport	1966	Closed in 1966, with missions consolidating to Mobile, AL
Mobile	AL	1966	Property Acquired from a former USAF Reserve Base	-	Formed as a Training Center in 1966.
Clearwater	FL	1934	Originally formed at Whited Airport (St Petersburg, FL)	-	Moved to St Petersburg in 1976 to enable expansion
Miami	FL	1932	Originally formed as an AIRSTA at Dinner Key on Biscayne Bay	-	Moved to Opa Locka Airport in 1965 to enable expansion
HITRON	FL	1998	Established at a leased hangar at Cecil Field, to provide Airborne Use of Force capabilities	-	
Savannah	GA	1963	Commissioned as an AIRSTA as a tenant of Hunter Army Air Force Base	-	Expanded in 1965 to support enlisted aviation training until training moved to E-City in 1978.
Charleston	SC	1937	Commissioned as an AIRSTA in 1937.	1941	Decomissioned due to mission consolidation to E City in 1941
Charleston	SC	1990	Established as an AIRFAC in 1990 to support AIRSTA Savannah	-	
Morehead City	NC	1920	Legacy USN Air Station transferred to USCG post WW1	1922	Disestablished due to lack of maintenance funding
Elizabeth City	NC	1940	Established as the CG's east coast's aviation overhaul location.	-	Major expansions funded by USN during WW2. Expanded with school facilities in 1978
Norfolk/St. Augustine	VA/FL	1987	Formed by the Drug Abuse Act, as an Air Warning Squadron, operating out of USNAS Norfolk	1991	Relocated to St. Augustine, FL 1989. Closed in 1991 after an accident with four deaths.
NCRAD	DC	2006	Established in a partial lease of an FAA hangar & also a lease at Joint Base	-	CG assumed Washington, DC Air Intercept Mission in 2006 from USCBP
Washington	VA	1952	Established as AIRDET Washigton in 1952 at Washington National Airport	-	Primary mission is to provide transportation for USCG & DHS VIPs. Redesignated an AIRSTA 1964
Cape May	NJ	1926	Legacy USN Air Station transferred to USCG post WW2 (full Air Station in 1946)	1998	Closed in 1998 with mission consolidation to Atlantic City, NJ
Atlantic City	NJ	1998	Established as an AIRSTA at Atlantic City Airport	-	Established to consolidate operations from Cape May, NJ, and Brooklyn, NY
Brooklyn	NY	1938	Established as an AIRSTA with property deeded from NYC at Floyd Benned Field	1998	Closed in 1998 with mission consolidation to Atlantic City, NJ
Buffalo	NY	1935	Established as an AIRDET to support border customs mission	1940	Closed in 1940
Quonset Point	RI	1950	Established as an AIRDET under the supervision of AIRSTA Salem	1970	Closed in 1970 with mission consolidation to Cape Cod, MA
Salem/Gloucester	MA	1925	Established on Ten Pound Island, moved to Gloucester in 1932, then Salem in 1935	1970	Closed in 1970 with mission consolidation to Cape Cod, MA
Cape Cod	MA	1970	Acquired property at legacy USAF Otis AF Base 1970	-	Now one of the few remaining major tenats at Joint Base Cape Cod
Detroit	MI	1966	Established as an AirDET as a tenant at Selfridge USAF Base	-	Evolved to an Air Station 1966
Traverse City	MI	1938	Established as a seasonal AirDET at Traverse City Airport	-	Expanded to a full AIRSTA & acquired a legacy USN Hangar in 1946
Waukegan	IL	2000	Established as a seasonal AirDET under supervision of AIRSTA Traverse City	-	
Chicago	IL	1969	Established as an Air Station and a tenant at US NAS Glenview, IL.	1995	Closed in 1995 with mission consolidation to Traverse City, MI
Muskegon	MI	2006	Established as a seasonal AirDET under supervision of AIRSTA Detroit	-	
OPBAT/Great Inagua	Bahamas	1982	Established in partnership with the Bahamas, & the UK to support the war on drugs	-	Hangar built in 1990 & rebuilt in 2013 following major storm damage
Borinquen	PR	1970	CG Acquired and moved to the legacy Ramey USAF Base in 1976	-	Orinally located at San Juan in 1970

Sources: (Pearcy A. , 1989, pp. 77-116); (Pearcy A. , 1991, pp. 12-15); (Bryan Construction); (CGAviationHistory.org, n.d.); (Dolbow, 2013, p. 53); (Edhat.com, 2021); (Moseley & Thiesen, 2021); (NORAD and USNORTHCOM Public Affairs, 2007); (Thisesen, 2022); (US Coast Guard Historian, n.d.); (Workman, 2012, p. 127)

History of Coast Guard Rotary Wing Aircraft

Since 1942, the USCG has played a key role in developing and evolving the use of helicopters, specifically for use as a search and rescue platform. In April 1942, after observing flight tests of the Sikorsky model XR-4, Commander Burton, the Commanding Officer of Air Station Brooklyn, NY, wrote in a report that:

"The helicopter in its present stage of development has many of the advantages of the blimp and few of the disadvantages. It hovers and maneuvers with more facility in rough air than the blimp. It can land and take off in less space. … It does not need a large hangar. There is sufficient range in this particular model to make its use entirely practical for harbor patrol and other Coast Guard duties." (Pearcy A. , 1991, p. 46)

The Coast Guard acquired its first helicopters, three Sikorsky HNS-1 aircraft in 1943, and designated Air Station Brooklyn as a helicopter training base. Experiments and training followed with simulated shipboard landings on a 40' by 60' moving platform, developments in anti-submarine warfare, open sea navigation, and partnerships with the US and Royal UK Navies. Notable due to its achievements, Coast Guard Air Station Brooklyn was designated and assigned to train all Allied helicopter pilots during the beginning years of World War 2 (Pearcy A. , 1991, p. 50).

The Coast Guard's use of helicopters evolved rapidly during and after World War 2. This included developing new aviation techniques including water landing abilities with inflatable doughnut floatation on the Sikorsky HO3S-1 and aerial rescue-hoist capabilities (CGAviationHistory.org, n.d.). Ideally suited to perform many Coast Guard missions including search and rescue, maritime law enforcement and defense operations, the Coast Guard's fleet and size and performance grew with the acquisition of numerous difference RW aircraft including newer Sikorsky HO2S, multiple different Bell HTL's, the Sikorsky H05S-1G, and the Sikorsky HUS-1G 'Seahorse'. A full listing and brief description of the Coast Guard's RW fleet history is shown in Table 8 below.

Table 8: Historic Coast Guard Rotary Wing Aircraft: 1943-Present

Helicopter	Year First Acquired	Year Retired	Total Range (NM)	Cruising Speed (knots)	Lift/Hoist Capability?	Total Quantity Acquired	90 min range (NM) (mission radius)	Comments
Sikorsky HNS-1 'Hoverfly'	1943	1949	56	52	yes	10	78	
Sikorsky HOS-1	1944	1947	213	78	yes	2	117	
Sikorsky HO2S-1/HO3S	1946	1954	239	74	yes	10	111	
Bell HTL 1/4/5/7	1947	1968	184	61	no	6	92	
Piasecki HRP-1 'Flying Banana'	1948	1952	122	64	yes	3	96	
Kaman K-225 'MixMaster'	1950	1955	126	52	no	1	78	
Sikorsky HO4S 'Horse'	1951	1960	313	79	yes	4	119	
Sikorsky HO5S-1G	1952	1959	165	78	yes	8	117	
Bell HUL-1G	1955	1967	174	87	yes	2	131	
Sikorsky HUS-1G 'Seahorse'	1959	1965	215	84	yes	6	126	
Sikorsky HH-52A 'Seaguard'	1963	1989	412	85	yes	99	128	Aquired specifically for 'SRR' Missions
Sikorsky HH-3F 'Pelican'	1968	1994	650	130	yes	54	195	Acquired specifically for 'MRR' Missions
Aerospatiale HH-65D 'Dolphin'	1985	2038	350	148	yes	102	90	Formal SRR Replacement for the HH-52A Fleet
Sikorsky HH-60 'Jayhawk'	1990	2050	700	140	yes	45	210	Formal MRR Replacement for the HH-3F Fleet

(Excludes aircraft briefly leased in the 1990's for HITRON)

Table 8 Sources: (Pearcy A. , 1991, pp. 104-314); (CGAviationHistory.org, n.d.); (Sparfell, 2021); (US Coast Guard Historian, n.d.)

The acquisitions of the Sikorsky HH-52A 'Seaguard' and HH-3F 'Pelican' represented a paradigm shift in the Coast Guard aviation program (See Figures 9 and 10). These two aircraft fleets were acquired purposefully for bifurcated mission sets: Short Range Recovery (SRR) and Medium Range Recovery (MRR) (Pearcy A. , 1991, pp. 56, 297 & 304). Not only assigned based on this geographical distinction, the smaller Seaguard was additionally capable of, and assigned for routine deployment aboard Coast Guard Cutters.

Figure 9: The Sikorsky HH-52A Seaguard

Source: (CGAviationHistory.org, n.d.)

Figure 10: The Sikorsky HH-3F Pelican

Source: (CGAviationHistory.org, n.d.)

These SRR and MRR classifications continued into the next acquisitions cycle. The Aerospatiale HH-65 Dolphin was first acquired in 1984 as a modernized replacement for the Seaguard and its SRR mission set (Pearcy A. , 1991, pp. USCG Aircraft 56-62). Faster and lighter than its predecessor, but not amphibious capable, the Dolphin was a rarity for the Coast Guard, not having been previously certified, proven and selected for use by the US Navy or Air Force. Notably due to this challenge, the Coast Guard Commandant at the time, Admiral Paul Yost said "I will never again buy a helicopter or an airplane that was not a DoD-supported piece of equipment" (Pearcy A. , 1991, p. 62). The Dolphin is the mainstay of the Coast Guard's RW fleet, "operating from air stations ashore and from flight deck equipped cutters to fulfill search and rescue, law enforcement and tactical transportation mission requirements" (Dolbow, 2013, p. 58). Finally, the medium range Pelican was replaced beginning in 1990 with the Sikorsky HH-60 Jayhawk, a variant of the US Navy and Army's recently acquired SH-60 Seahawk and UH-60 Blackhawk. The Jayhawk is the "Coast Guard's 'workhorse', able to perform rescues in the harshest of weather and sea states…and provide shore-based aviation surveillance capability and transportation" (Dolbow, 2013, p. 57). Today, the Coast Guard operates 102 Dolphins and 45 Jayhawks in performance of, and in support of all Coast Guard mission sets.

Historic Conclusions

While a historic review of the Coast Guard's aviation program cannot predict the future, it does suggest certain trends. First, it is shown that a 53% majority of the Coast Guard's aviation locations have been established either onboard or from DoD facilities. This may be because of the relative ease of acquiring permitted or leased space onboard DoD military facilities, in comparison with leasing, buying or otherwise acquiring property elsewhere. Next, a plurality of the 15 facilities that have been closed, were purposefully closed for reasons to consolidate missions for asset or budget savings. These include the disestablishment of Air Stations Biloxi, LA; Charleston, SC; Cape May, NJ; and Brooklyn, NY; as well as Air Detachments Quonset Point, RI and Gloucester, MA, all deliberately disestablished to consolidate forces at ATC Mobile, AL; and Air Stations Savannah, Atlantic City, and Cape Cod, respectively (Pearcy A. , 1989, pp. 87-116). In conjunction with the Coast Guard's overall history of air station locations, this showcases the Coast Guard's ability to respond to budget, population, and mission fluctuations. Furthermore, simple counts of full-service Air Stations, and remote facilities reveal trends in the force laydown of Aviation facilities (See Figure 5).

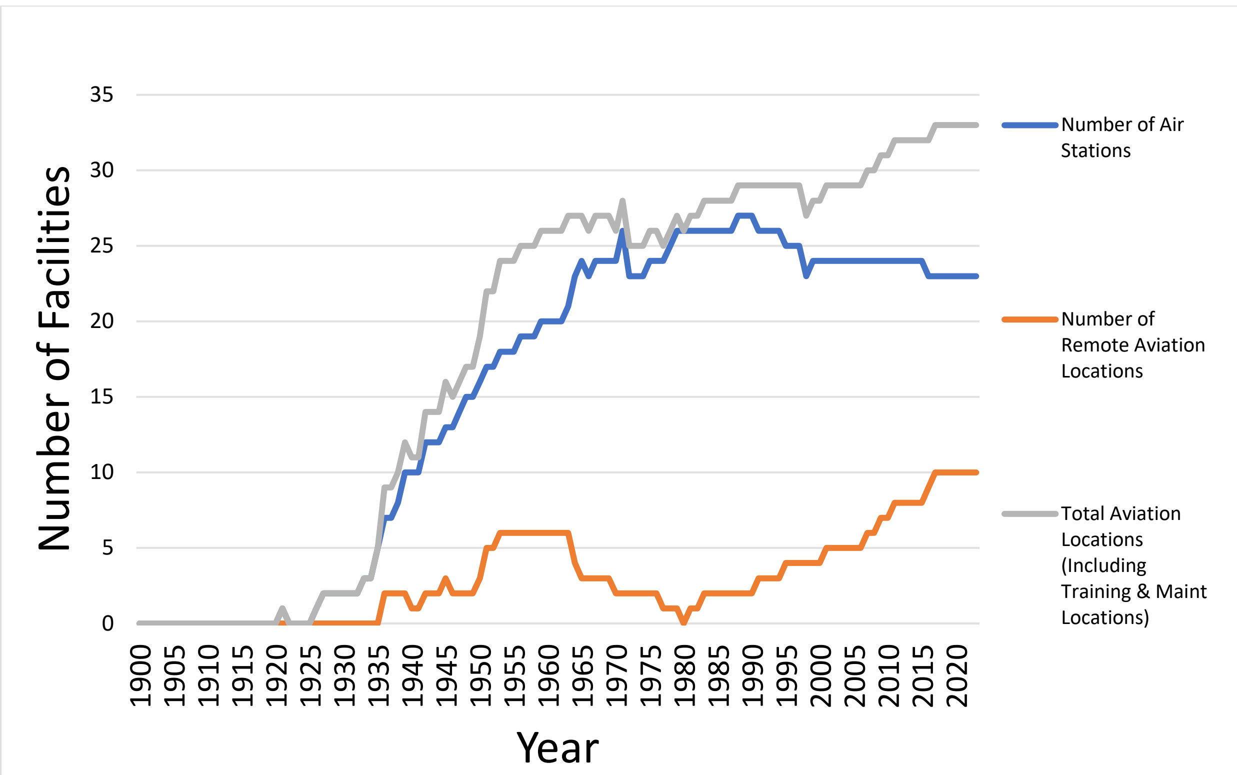

Figure 11: Number of CG Aviation Facilities (1900-2023)

Sources: (Pearcy A. , 1991, pp. 104-314); (CGAviationHistory.org, n.d.); (Sparfell, 2021); (US Coast Guard Historian, n.d.)

Figure 11 shows the change in number of Air Stations and remote aviation locations over the years (‘remote locations’ include Air Detachments, Forward Operating Locations, Forward Operating Bases, Air Facilities, and Aviation Support Facilities). The number of full-service, and independent Air Stations peaked in 1988 following the establishment of the Air Warning Squadron in Norfolk in 1988, and then was slowly reduced with the closure of five locations. While only five data points, each is notable. First, The Air Warning Squadron in Norfolk, VA, moved to St Augustine, FL in 1989, was closed in November 1991, possibly as an indirect result of a recent plane crash in August 1990 resulting in the deaths of four crewmen (US Coast Guard Historian, n.d.). Air Station Chicago was downgraded to a seasonal Air Facility in 1995, with its operational control shifted to the nearby full-service Air Station Traverse City, MI (CGAviationHistory.org, n.d.). Air Stations Cape May, and Brooklyn were closed in 1998 as part of an “aviation streamlining initiative to realign unit locations with the capabilities of … modern aircraft” (US Coast Guard Historian, n.d.). Finally, Air Station Los Angeles was closed in 2016 due to the expiration of its property lease at LA Airport, resulting in the subsequent opening of AIR FOB Point Mugu, CA, at Naval Air Station Point Mugu, only 50 miles away (Rathbun, 2023). Meanwhile, it is also shown that the count of total remote locations has increased from zero to ten since 1980 when Air Facility Cordova, AK was established, to the present day. Since then, 10 remote, subordinate, and often temporary locations have been established in Illinois, Michigan, South Carolina Alaska, Oregon, California, and the Bahamas. Figure 12 presents the same data as Figure 11 but is overlaid with the Average Range of the Coast Guard’s RW aircraft fleet. Notably, the data for the Average 90 min RW Aircraft Response Range is weighted for the quantity of each aircraft fleet, and also incorporates the overlap years between when one aircraft is purchased and the previous retired. Figure 12 also includes polynomial trendlines for the quantities of Air Stations and remote locations, projected them out to the year 2045.

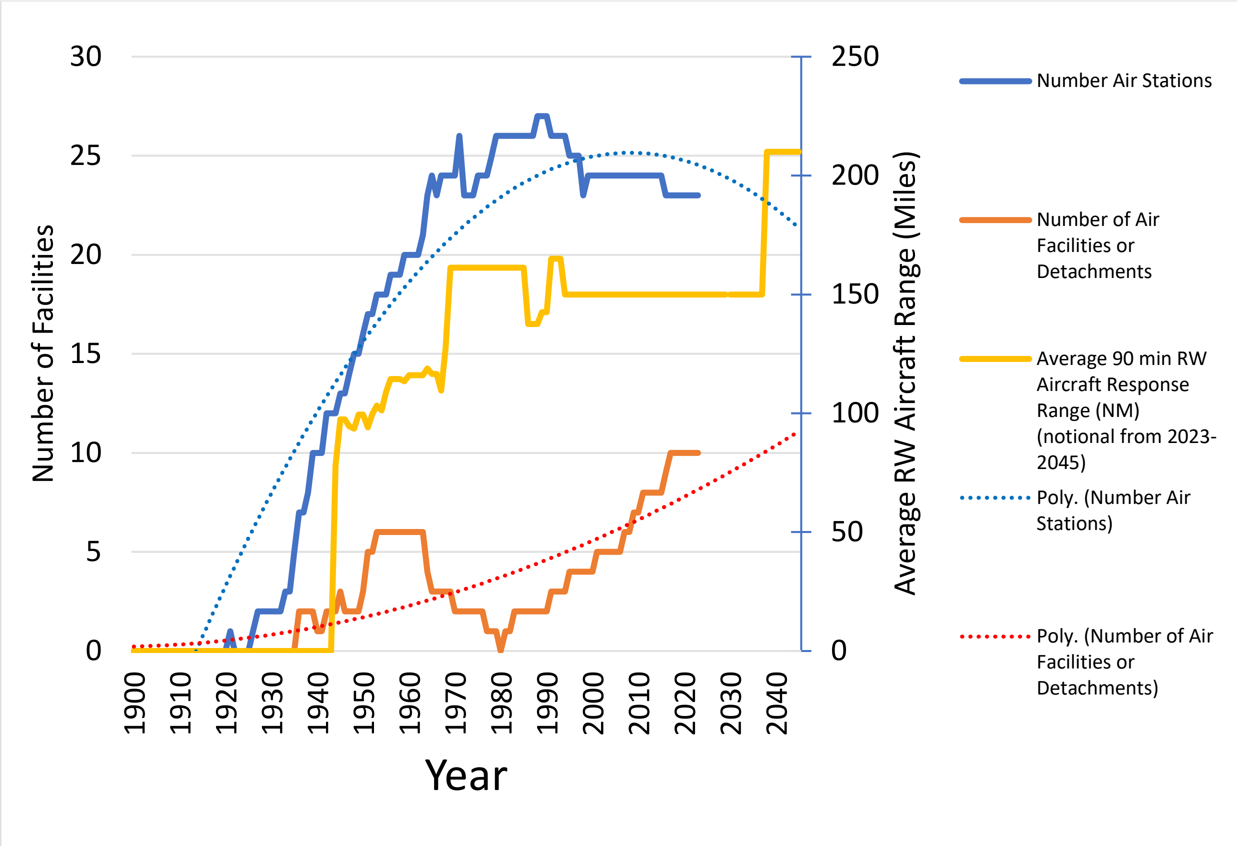

Figure 12: CG Aviation Facilities overlaid with Average RW Aircraft Response Range

(Average RW fleet response ranges notionally projected from 2023-2045, per plans for the All-Jayhawk Fleet)

Sources: (Pearcy A. , 1991, pp. 104-314); (CGAviationHistory.org, n.d.); (Sparfell, 2021); (US Coast Guard Historian, n.d.)

Through this overlay, Figure 12 reveals possible correlation between the evolution of the Coast Guard's RW aviation assets and its basing laydown. As the average range of the Coast Guard's RW aircraft fleet has increased over the years, the number of full-service Air Stations peaked and then decreased, and the number of remote, subordinate facilities grew rapidly. While this doesn't prove correlation or causality, due to the few data points, this demonstrates that the CG has the capacity and decision-making ability to open or close Air Stations as politics, missions, aircraft capabilities or budgets evolve.

Chapter 4: The Assignment Problem: A Literature Review

Of central interest for this thesis is the Assignment Problem. The Assignment Problem is a combinatorial optimization problem, representing the bipartite decision to assign one set of elements, to another set of elements, for an overall system profit, cost, or value, with different element-to-element links incurring different costs, based on the nature of the link. Often the two sets of elements are referred to as 'sinks' and 'sources.' In some problems, the number of elements on both sides of the problem are equal, and the problem is described as 'balanced,' or 'symmetrical' (Bertsekas & Castanon, A Forward/Reverse Auction Algorithm for Asymmetric Assignment Problems, 1992) In this take on the Assignment Problem, the challenge is to assign aircraft to regional bases of different locations and Support Constructs, for the overall objective of seeking an optimal trade-off between costs and mission performance. For this problem, the number of aircraft available (U, 147) and the number of considered locations (V, 39) are not the same, therefore the problem is 'unbalanced,' or 'asymmetrical.' The challenge lies in the large number of possible combinations, and the binary system of 'U' and 'V' elements creating a trade-space of 2^{U*V} possible architectures (Crawley, Cameron, & Selva, 2016, p. 374). With 39 locations considered, and with options of up to two aircraft at each satellite location or up to 3 at each Air Station (7 possible assignments, including no assignment), this represents a total possibility of 2^{39*7}, or $1.52x10^{82}$ solutions, impossible to estimate and understand manually. Therefore, this research turns to various solutions to the assignment problem.

The Assignment Problem is one of three important minimum cost-flow problems, the other two being the Shortest Path or Traveling Salesman Problem, and the Maximum Flow Problem (Orlin & Lee, QuickMatch: A Very Fast Algorith for the Assignment Problem, 1993, p. 2). The Traveling Salesman Problem poses the problem of a salesman tasked to travel to several cities of varied location; his problem is to find the shortest cumulative route possible to visit each city. The Maximum Flow Problem is analogous, representing the problem of a transportation or shipping network tasked to ship cargo from one location to another via multiple shipping links (i.e., railways or highways), each with different capacities, while seeking the optimal total cost or value. Together, the objective of all three are similar, that being to determine good or optimal solutions for how to assign cargo, destinations, or a set of elements to conduits, travelers, or other elements, based on objective metrics like time, flow, or profit.

Study of the Assignment Problem dates to the 1920's including studies of various matching problems by Philip Hall, a mathematician and professor with the University of Cambridge, England (Alfaro, Perez, Valencia, & Vargas, 2021). Mathematically, the linear program for the problem can be stated as the following:

$$\begin{aligned}
\text{maximize} \quad & \sum_{(i,j)\in\mathcal{L}} a_{ij}x_{ij} \\
\text{subject to} \quad & \sum_{\{j \mid (i,j)\in\mathcal{L}\}} x_{ij} \leq 1, \quad \forall i \in \mathcal{U}, \\
& \sum_{\{i \mid (i,j)\in\mathcal{L}\}} x_{ij} \leq 1, \quad \forall j \in \mathcal{V}, \\
& x_{ij} \geq 0, \quad \forall (i,j) \in \mathcal{L}.
\end{aligned}$$

Equation 1: The Assignment Problem

Source: (Bertsekas, A Distributed Algorithm for the Assignment Problem, 1979)

In this equation, U and V represent two finite sets of elements (sources and sinks respectively), and $\mathcal{L}$ represents a set of links between elements with elements i and j. For this equation, each different link (i, j) has a weight of a_{ij}, which may, depending on the problem, represent profit, value, or cost of the link. This research reviewed several solutions to the Assignment Problem including the Enumeration Method, the Hungarian Method, and the Bertsekas Auction Algorithm, along with two different methods specifically focused on emergency services.

The Enumeration Method

Simple, but somewhat naïve, this method requires the solver to calculate the profit, cost, or value of all possible combinations of links between source elements and sink elements for the problem at hand. Then, the set of assignments creating the optimal profit, cost or value is selected. This method works with small numbers of assignments, but it exponentially escapes the realm of the practical, depending on the computing power or time available. For example, a problem with 2 sources and 3 sinks would create 64 possible assignment sets to calculate ($2^{U*V} = 2^{2*3}$). But if increased to a problem with 3 sources and 3 sinks, the number of possible assignment sets increases to 512. For this thesis' problem of assigning Jayhawks to 39 possible locations with up to 7 types of assignments, calculating 1.52×10^{82} architectures is seen as nearly impossible. Even with the modern computing power of normal desktop software, they are quickly surpassed by this problem. Microsoft Excel for example, with a maximum of 1,048,576 rows would be unable to solve an assignment problem with 4 sources and 6 sinks (2^{4*6} = 16,777,216 assignment sets), or a problem with 3 sources and 7 sinks (2^{3*7} = 2,097,152 assignment sets).

The Hungarian Method

The first algorithm proven to solve the Assignment Problem was the Hungarian Method, pioneered by Harold Kuhn in the 1950's. Also known as the Kuhn-Munkres algorithm, this method involves first creating a U x V matrix of the profit, cost, or value of every individual possible link of each source to each sink (Kuhn, 1955). This method works with unbalanced and balanced assignment problems and methodically eliminates individual links from the matrix via a deterministic, and intuitive algorithm. Solvable in polynomial time, this method eliminates links one by one through its process until only one set of assignment links remain.

1) The following example 4 x 4 matrix is given, representing an assignment problem with four sources, and four sinks, seeking the lowest total cost:

8	7	9	9
5	2	7	8
6	1	4	9
6	3	2	6

2) The minimum number from each row is subtracted from each row.

1	0	2	2	(-7)
3	0	5	6	(-2)
5	0	3	8	(-1)
4	1	0	4	(-2)

3) The minimum number from each column is subtracted from each column.

0	0	2	0
2	0	5	4
4	0	3	6
3	1	0	2
(-1)	(-0)	(-0)	(-2)

4) Cover all zeros with a minimum number of lines.

~~0~~	~~0~~	~~2~~	~~0~~
2	0	5	4
4	0	3	6
~~3~~	~~1~~	~~0~~	~~2~~

5) The number of lines is three, less than the size of the NxN matrix, therefore, the process continues. The smallest uncovered number is 2. Subtract '2' from all uncovered numbers and add it to any number covered twice.

0	2	2	0
0	0	3	2
2	0	1	4
3	3	0	2

6) Cover all zeros again with the minimum number of lines possible.

~~0~~	~~2~~	~~2~~	~~0~~
~~0~~	~~0~~	~~3~~	~~2~~
~~2~~	~~0~~	~~1~~	~~4~~
~~3~~	~~3~~	~~0~~	~~2~~

There are four lines required to cover all zeros. Because four is equal or greater than the size of the NxN matrix, the optimal assignment is found with the zeros.

0	2	2	0
0	0	3	2
2	0	1	4
3	3	0	2

7) Four zeros are selected, allowing for only one selected zero per column and per row. These correspond to the optimal assignments per the original matrix.

8	7	9	9
5	2	7	8
6	1	4	9
6	3	2	6

8) Therefore, the optimal assignment for this NxN matrix is found, and the cumulative total cost is 9+5+1+2 = 17. This represents the optimal (lowest) cumulative assignment cost for the example NxN matrix.

With it being a proven technique, and with the Coast Guard's required matrix only being a 39 x 17 matrix with 663 total values to be computed, it presents an intriguing possibility for use in this thesis. However, the positioning of CG aviation locations presents a different challenge. With adjacent aviation locations presenting overlapping range rings (see Figures 4 and 5), the unique value created by aircraft assignments to individual locations is unknown without knowledge of the total fleet assignment. For example, when considering the value of aviation locations around the great lakes, range rings around Muskegon, MI, Traverse City, MI, Waukegan, IL, and Detroit, MI are created. With the range rings created from each of the four locations overlapping each other, the absolute value of any of the cumulative four is not known until the final cumulative assignment list is known. This challenge led the author to seek out a more iterative solution to the Assignment Problem which allowed the author to reconsider the value of each location repetitively.

Chaiken and Larson's Approach with Queuing Theory

Jan Chaiken and Richard Larson take a different approach on the problem, by not assigning or measuring the amount of mission coverage, but instead, modeling the problem of emergency services response with queuing theory (Chaiken & Larson, 1971). They establish key metrics including the average amount of time police, fire or ambulance services take to dispatch a unit, the average time that unit takes to arrive on scene, and the probability of any emergency call being placed into a queue. With the Coast Guard often referred to as the police and fire departments on the water, this presents an interesting possibility, which is opposed from this thesis' primary metrics of NPV cost and total mission coverage. This technique was not chosen for two reasons. First, this technique was not chosen due to there already being a 2-hour maximum mission response time promulgated by CG policy. Described in greater detail in Chapter 6, the USCG Addendum to the National Search and Rescue Supplement establishes this response timeline under an umbrella policy of the federal government (US Coast Guard, US CG Addendum to the US NSS, 2022). Secondly, when interviewing SMEs, many stated that there are normally diminishing returns on seeking response timelines less than 2 hours, as the Coast Guard already helps mariners in distress by maintaining vessel safety through its commercial vessel inspection program and with safety requirements for life rafts and other survival equipment. Therefore, this Queuing method approach was not selected.

Koselar and Walker's Dynamic Relocation Approach

Koselar and Walker proposed a similar method to Chaiken and Larson, which was implemented for Fire Departments in NYC (Kolesar & Walker, 1973). This two-step method first assigns assets (i.e., fire trucks) to fire departments based on standard units of coverage with the ideas being that areas are 'covered' if a unit can respond within a threshold unit of time. The number of assets were also assigned to fire departments based on their assigned area of coverage, with the areas varying per department in alignment with their localized speed of travel. His second step was to monitor the location of all equipment and the status of all emergencies, and to dynamically reposition assets around the city to balance mission capabilities around the clock according to a prescribed algorithm. While repositioning fire department assets with this idea has been performed for decades, this technique arose in NYC due to numerous fire departments becoming frequently fully deployed, simultaneously. While the idea to monitor and continuously redeploy CG RW aircraft is enticing, this method was not selected for two reasons. First, fire trucks driving in a city and RW aircraft flying away from land have a major difference, that being the need to land when empty on fuel. With Jayhawk's having a maximum endurance of 6.5 hours (round trip) and with aircraft crews having additional maximum flight time and mission requirements, the ability of the CG to dynamically reposition aircraft around the clock is wholly different. Jayhawks cannot be repositioned over the water for more than a few hours. Secondly, the CG's aviation program is different from the NYC Fire Department in that its aviation locations rarely experience simultaneous missions with no available aircraft. Therefore, this technique was not selected for this thesis.

The Assignment Problem's Auction Algorithm

Proposed in 1979 by Dimitri Bertsekas and updated over the years, his auction algorithm is proposed to equate economic equilibrium to the Assignment Problem (Bertsekas, The Auction Algorith for Assignment and other Network Flow Problems, 1989, pp. 2-15). Bertsekas proposes that "an equilibrium assignment offers maximum total benefit, and thus solves the assignment problem" by maximizing the value and happiness of all persons in an iterative fashion. Therefore, a complete assignment set is at equilibrium when all persons are happy. While Bertsekas acknowledges that this technique presents a solution that is not always optimal for assignment problems that seek optimization of two competing metrics, he has found it highly efficient for assignment problems of all types including balanced and unbalanced problems as well as large scale problems. It is also adaptable for other transportation problems like the Traveling Salesman Problem, and the Maximum Flow Problem. His solution takes place in rounds until the auctioneer, or all persons are considered happy, and proceeds as follows (Bertsekas, A Distributed Algorithm for the Assignment Problem, 1979, pp. 2-10):

1) In round one, one "optimum source is assigned to the sink offering maximum profit margin relative to the price." Thus, the most valuable source is auctioned, prioritized, and linked to a sink.
2) In step 2, the sinks reduce their desired profit margin from that achieved in step one, until another source is auctioned, prioritized, and linked to a sink. At each step, the sinks must broadcast the price they offer to the auctioneer and their neighboring sinks.
3) This process is repeated, with new prices until the assignment process assigns all sources or sinks to capacity, or the auction reaches a termination such as a target profit or other metric.

This process was found to be suitable for the Coast Guard's challenge to assign Jayhawk helicopters (sources) to locations (sinks) for maximum mission coverage at cost. The auction is well suited to this challenge as it allows the sinks to change their value proposition at each step in the auction, as CG aviation location values change if an adjacent location with an overlapping range ring is prioritized. Simply put, as an example, the value proposition (CG mission coverage at cost) of a potential Air Station Port Angeles, WA would change depending on if the adjacent Newport, OR; Colombia River, OR; or Northbend, OR locations were active or not, each of which have overlapping range rings with that around Port Angeles, WA. This method was selected for use in this thesis and is demonstrated in Chapters 7 and 8.

Chapter 5: Modeling Aviation Support Constructs

Satellite Support Construct Overview

Briefly described above, the multiple constructs used by the CG to support RW aircraft at satellite locations are worthy of review and analysis. Evolving over the years, the different locations have been organically, colloquially, and somewhat formally named Forward Operating Locations, Forward Operating Bases, Air Facilities, Aviation Detachments (AVDETs), and Aviation Support Facilities (AVSUPFACs). The names are not consistently applied. For example, as personnel are assigned to military units in the CG, they are assigned to formal Personnel Allowance Lists (PALs) (US Coast Guard, Coast Guard Business Intelligence (CGBI), 2023). On these PALs, the satellite units in Muskegon, MI; Charleson, SC; and Newport, OR are labelled as AIRFACs, the satellite facility in Cordova, AK is labelled an AVSUPFAC, and the facility at Point Mugu, CA is labelled an FOB. In contrast, in the CG's database of buildings and real property, 'IBM Maximo-SAMS,' the Waukegan, Muskegon and Charleston facilities are titled AIRFACs, Newport, OR and Cordova are labelled AVSUPFACs, Pt Mugu is labelled an Air Station, and Cold Bay and St. Paul are simply labelled Airfields. Meanwhile, the facilities in Kotzebue, AK, and Great Inagua, Bahamas are simply named 'Koztebue National Guard Facility' and 'OPBAT Site' (OPBAT - Operations Bahamas, Turks, and Caicos).

For comparison, the DoD utilizes and defines similar terms in the *DoD Dictionary of Military and Associated Terms as* following (Department of Defense, 2017, pp. 50, 88):

Forward Operating Base (FOB): "An airfield used to support tactical operations without establishing full support facilities."

Cooperative Security Location (CSL): "A facility located outside the United States and US territories with little or no permanent US presence, maintained with periodic service, contractor, or host-nation support. Cooperative security locations provide contingency access, logistic support, and rotational use by operating forces and are a focal point for security cooperation activities."

Forward Operating Site (FOS): "A scalable location outside the United States and US territories intended for rotational use by operating forces. Such expandable 'warm facilities' may be maintained with a limited US military support presence and possibly prepositioned equipment. Forward operating sites support rotational rather than permanently stationed forces and are a focus for bilateral and regional training."

Not cleanly fitting these DoD definitions, and with no clear CG definition, and for the purposes of this thesis to establish consistency, <u>the author provides the following naming convention:</u>

Air Forward Operating Location (FOL): A CG owned or leased aviation facility with *no personnel or aircraft permanently assigned, and with aircraft and personnel rotated in and out* from a full-service 'parent' Air Station to perform or support CG missions. FOLs may be operated 365 days per year, or on a seasonal basis.

Example Current Locations: Kotzebue, AK; St. Paul, AK, Cold Bay, AK; Newport, OR; Charleston, SC; Waukegan, IL; Muskegon, MI; and OPBAT, Bahamas.

Air Forward Operating Base (FOB): A CG owned or leased aviation facility with *permanent air and facility operations crews assigned and with aircraft rotated in and out* to perform or support CG missions.

Example Current Location: Pt Mugu, CA

Air Facility (AIRFAC): A CG owned or leased aviation facility with *only facility operations crews permanently assigned and with aircraft and aircrews rotated in and out* to perform or support CG missions. AIRFACs may be operated 365 days per year, or on a seasonal basis.

Example Current Location: Cordova, AK

Note that each of these models is assigned under a full-service 'parent' Air Station, from which O-Level Maintenance of the aircraft is performed and where administrative functions are supported. While FOBs are operated around the year, AIRFACs and FOL's can be operated seasonally for various reasons including fishing or recreation seasons.

Modeling these Support Constructs: Architectural Decisions

One way to model the various Aviation Support Constructs the CG uses to field RW aircraft for mission execution is by looking at the Architectural Decisions inherently built in. Architectural Decisions are the most integral design decisions, usually made early in product process design that substantially differentiate different designs from each other, and "materially impact technical parameters or important metrics" (Crawley, Cameron, & Selva, 2016, p. 197). For example, the number of driven wheels on a car or whether an aircraft has a tail strongly influences the final design and substantially differentiates it from alternative designs. Architectural Decisions "determine the performance envelope," "encode key tradeoffs" in the product or process, and strongly influence costs. The differences in these forward deployment models were reviewed & the following distinct architectural decisions were found:

1) Hangaring location of the aircraft when ready and awaiting mission assignment: Alternatives include hangaring the aircraft at the main base (Air Station), at a forward deployed CG facility, aboard a CG cutter afloat, or at a rented or leased hangar at a commercial airport. Cost ramifications of this decision include the costs to construct or rent hangar space, costs to transport crews and supplies back and forth to the satellite location every cycle, as well as the cost to transport the aircraft itself to and from the satellite location for required maintenance. Another significant cost is the cost of fuel for use during missions, which varies based on the proximity of the hangaring location to the missions' locations themselves.
2) Permanently assigned housing location for Air Crews and their families: Options include assigning them to live at the parent Air Station location or the satellite facility location. The impact of this decision is the cost of the crew members' housing allowance, which represents roughly 1/3 of their total take-home pay and is dependent upon their specifically assigned location. These personnel will either receive a housing stipend and live on the economy, or the regional military base receives their stipend, and they live in military owned family housing.
3) Permanently assigned housing location for the personnel who will maintain and operate the satellite facility: Similar cost ramifications as above, but additionally including the possible costs to transport the members back and forth to the satellite unit location.
4) The Quantity of Aircraft deployed to the satellite facility: The number of aircraft assigned correlates to the service level provided to the region. See the below Chapter 6 section on Operational Availability for a full description.
5) As a final and distinct Architectural Decision, the CG as a whole, has the opportunity to make a global list of aircraft assignments to various units around the country.

This list of Architectural Decisions was tabulated and is shown in Table 9.

Table 9: Architectural Decisions for RW Aircraft Basing Ashore

Architectural Decision	Option 1	Option 2	Option 3	Option 4
Ready Aircraft Hangaring Location?	Regional Main Base	Forward Deployed at a CG Location	Deployed afloat aboard Cutters	Rental Hangars
Air Crews & Family Permanent Homes Location?	Regional Main Base	Forward Deployed at a CG Location	-	-
Satellite Facility Operations Crew & Family Home Location?	Regional Main Base	Permanently Assigned & Forward Deployed Crew	Not Required	-
Quantity Assigned Aircraft?	1	2	3	Etc…
Nationwide Aircraft Geographical Assignment?	Assignment List 1	Assignment List 2	Assignment List 3	Etc…

With this list of Architectural Decisions and their possible alternatives established, different decision combinations were reviewed, ideated, and considered. Table 10 displays the same list of decisions, along with six sets of decision combinations.

Table 10: Architectural Decision Combinations for RW Aircraft Basing Ashore

Architectural Decision	Option 1	Option 2	Option 3	Option 4
Ready Aircraft Hangaring Location?	Regional Main Base	Forward Deployed at a CG Location	Deployed afloat aboard Cutters	Rental Hangars
Air Crews & Family Permanent Homes Location?	Regional Main Base	Satellite Facility	-	-
Satellite Facility Operations Crew & Family Home Location?	Regional Main Base	Permanently Assigned & Forward Deployed Crew	Not Required	-
Quantity Assigned Aircraft?	1	2	3	Etc…
Nationwide Aircraft Geographical Assignment?	Assignment List 1	Assignment List 2	Assignment List 3	Etc…

- Architecture 1: Traditional, full-service Air Station
- Architecture 2: Air FOB *(currently only Pt Magu, CA)*
- Architecture 3: Air FAC *(currently only Cordova, AK)*
- Architecture 4: Air FOL
- Architecture 5: Shipboard Deployment
- Architecture 6: Ad Hoc Deployments

These six Architectures were then compared and contrasted, with the help of SME interviews, to better understand how they create different downstream costs and attributes (Glavan,

2023) (Kenshalo, 2023). For the purposes of the decision model built as part of this thesis, only Architectures 1 through 4 were specifically modeled, and only their attributes with specific cost ramifications were incorporated. Based on interviews, specific cost ramifications found for these models included the below items. It is noted that many of these costs are location dependent, sometimes higher or lower, depending on the location's cost of living or remoteness.

1) Capital Construction Requirements: All four models require significant capital construction, most notably, including hangar space to house assigned aircraft. Notably, the mere existence of FOLs, FOBs, and AIRFACs indicates significant additional capital construction, as each of those three require duplicate hangar space, to house aircraft at both the satellite location, as well as the parent location when traveling for maintenance. While FOLs require little more than hangar and tarmac construction, AIRFACs and FOBs require additional office and workspace for their permanently assigned facilities operations & maintenance crewmembers, and FOBs required additional workspace and shops for their permanently assigned aircrews. Full-service Air Stations require the most facilities, additionally including galleys, ready air crew berthing space, morale & recreation facilities, and warehouse space for parts storage.
2) Aircraft Fuel for Mission Transit: The requirement for fuel for mission usage is dependent on the proximity of the aircraft's assignment to the mission requirement. Traditionally, satellite units have been established to forward deploy aircraft, to be closer to where missions may be required, for example, closer to seasonal commercial fishing or summer recreational locations.
3) Aircraft Transit Fuel: FOLs, FOBs and AIRFACs incur additional costs over Air Stations including fuel costs to rotate aircraft to the parent Air Station and back for routine maintenance. These cycles are normally two-week cycles.
4) TDY Costs: Temporary Duty (TDY) costs are required for anyone traveling away from their permanently assigned home for any duration over 12 hours. FOLs and AIRFACs incur significant TDY costs to deploy aircrews to these satellite locations for two-week cycles. TDY costs include meal, lodging and incidental costs; these 'Per Diem' rates are prescribed by the US General Services Administration (GSA, 2013). As an alternative to Per Diem, some aviation locations maintain 'ready crew berthing' barracks buildings where duty crews sleep overnight. From a more subjective

angle, this cost could also be represented in the form of 'number of days away from home' per year, which may impact perceived the work-life balance of CG employees.

5) Permanent Housing Costs: Housing costs for USCG employees vary with the employee's permanently assigned location, as well as their rank and whether they have dependents or not (spouse or children). Housing costs are prescribed by the US Department of Defense (Defense Travel Management Office, Allowances, 2023).
6) C-130 Logistics Flights: CG C-130 cargo aircraft are used by FOLs and AIRFACs to routinely transport supplies, and personnel to and from their parent Air Station.

With these Architectural Decisions broken out for each Support Construct, their overall costs can then be estimated for different locations and numbers of assigned aircraft, as detailed in Chapter 6.

Modeling Aviation Support Constructs: DSM Diagrams

These various aviation Support Constructs were also modeled through Design Structure Matrices to understand how the elements within the different Aviation Support Constructs are interconnected and which elements are dependent on which. DSM matrices are a modeling technique "used to represent the elements comprising a system and their interactions" and are "well suited to applications in the development of complex, engineered systems" (Eppinger & Browning, 2012, p. 2). DSMs are N x N matrices that map the interactions between any set of N system elements, to deliver a compact and intuitively understood depiction of the system. DSM diagrams are also used to group or sequence systems in more streamlined ways. While there are four common types of DSM diagrams: Product, Organizational Architecture, Process and Multidomain DSMs, the process to produce a DSM is the same. DSMs are produced by first breaking down the system into its elements and aligning them along the left and top axes. Then interactions between different elements are noted by marking where the elements intersect in the matrix. The elements can then be re-ordered along the left and top matrix axes to seek efficiency in product, organizational or procedural adjacencies. Finally, interactions can be classified with different types of marks to categorize the interaction, and groups of interactions are boxed to prescribe which elements should be physically, organizationally, or procedurally grouped.

This research applied the Process DSM technique to the different aviation Support Constructs. One key aspect of these process DSMs is that these interactions are marked as interactions with the columns representing the inputs to the interaction, and the rows representing the outputs from the interactions. Process elements are broken into 'Sequential Activities' where one activity is directly dependent on its predecessor, 'Coupled Activities' where two activities each require input from each other, and 'Parallel Activities' which can be completed simultaneously (Eppinger & Browning, 2012, p. 134). DSM Diagrams of the process by which ready aircraft are prepared for duty, and then receive and complete mission assignments at Air Stations, FOLs, FOBs, and AIRFACS are shown in Figures 13 through 16. It is noted that these DSMs do not show all elements or processes which occur at these locations, excluding things like administrative processes. These DSMs focused on the major processes which make these four aviation Support Constructs different.

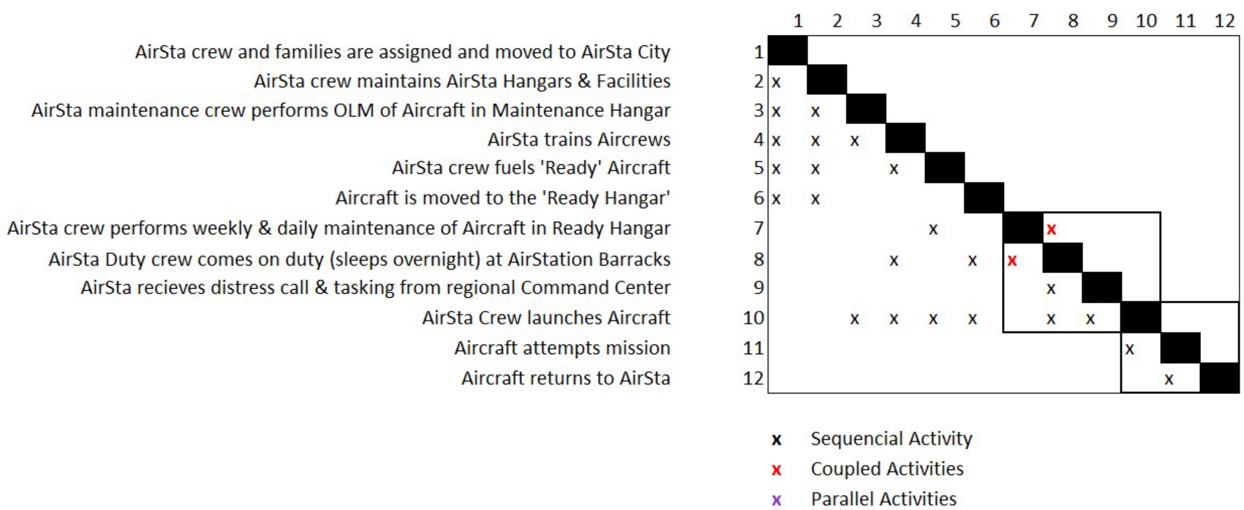

Figure 13: Air Station Mission Execution Process DSM

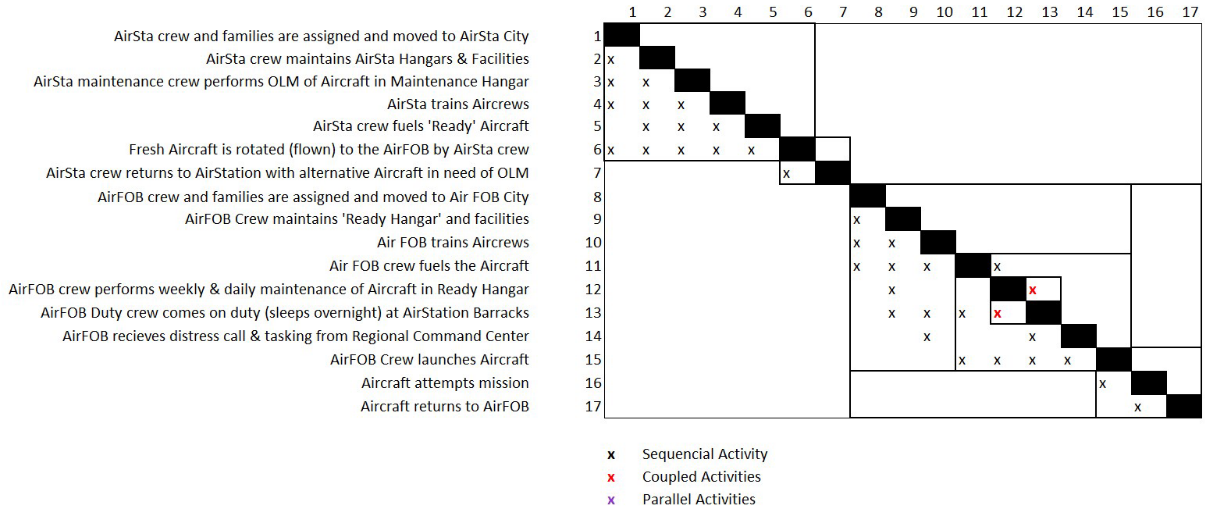

Figure 14: Air FOB Mission Execution Process DSM

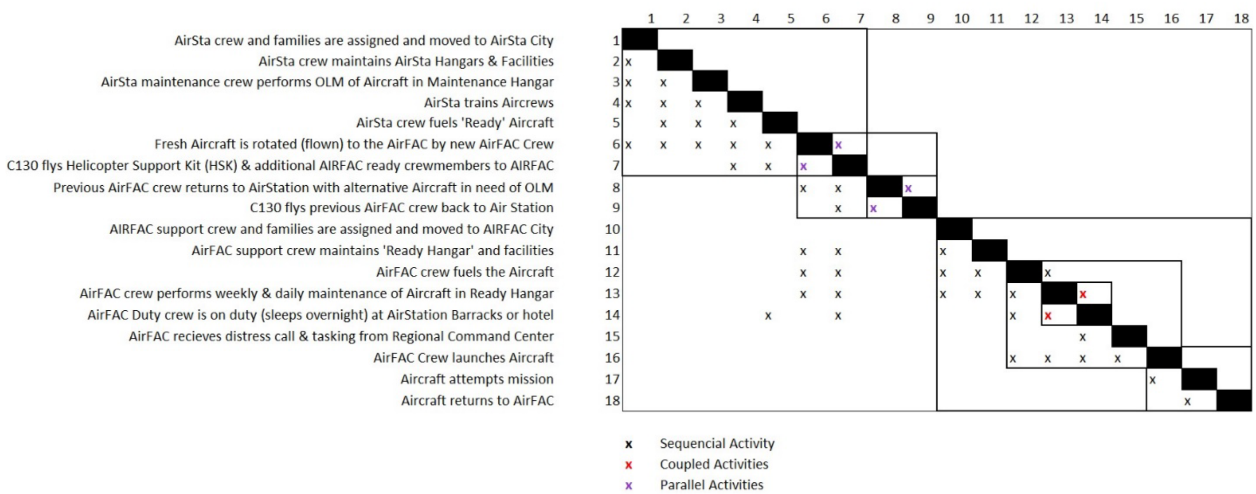

Figure 15: AIRFAC Mission Execution Process DSM

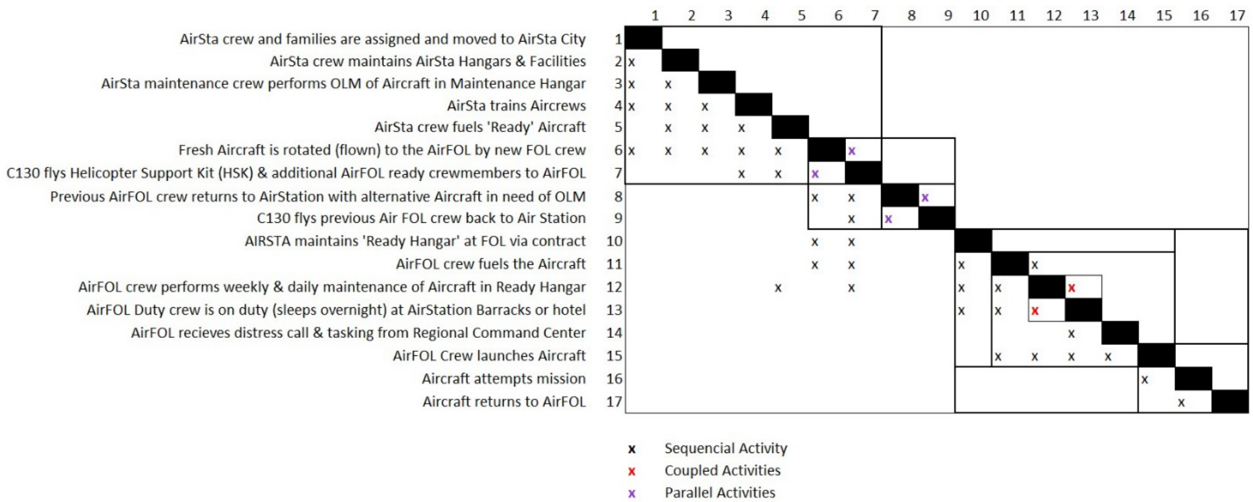

Figure 16: Air FOL Mission Execution Process DSM

Diagramming these four Aviation Support Constructs with process DSMs yields helpful perspectives. The traditional Air Station construct requires the fewest interactions and elements to complete missions, therefore having the least number of moving parts and likely experiencing the least complexity. The AIRFAC Support Construct requires the most process interactions to complete missions, therefore is likely the construct with the most complexity and procedural risk. Of the satellite Support Constructs, the FOB construct DSM was able to be cleanly grouped into the fewest boxes, indicating a process with high efficiency. Of the satellite constructs, the FOB construct also has the fewest number of interactions, therefore experiencing the least complexity of the satellite constructs. The Air Station construct had the fewest coupled or parallel activities, indicating a highly sequential overall process, more easily open to process discipline initiatives.

Chapter 6: Model Building

This model was built to seek optimization between two primary objective metrics: 1) the total estimated cost to allocate the global All Jayhawk Fleet and 2) mission coverage. The total cost estimate was calculated with a Net Present Value (NPV) calculation of the estimated capital and operational costs incurred by various assignments of the global Jayhawk fleet. The mission coverage percentage was assessed by comparing various Jayhawk Fleet assignment 'Concepts,' along with Jayhawk range rings, to historic mission locations from Fiscal year 2012-2021 to determine a fraction of historic missions within reach. With this model assembled, Chapters 7 and 8 then suggest numerous sets of fleet assignments to understand the value of various locations and perform multiple auctions to seek a best available fleet assignment. Figure 17 shows an overview of how this model was built. This chapter explains how each element of this model was derived, along with assumptions made in the process.

Automatic & Variable Cost Estimating

The first part of building this model was to assemble a cost estimating spreadsheet, able to quickly estimate capital and operating costs for aircraft assignments to various locations under different Support Constructs. The result of this spreadsheet is a tool where any number of Jayhawk aircraft can be assigned to any of 39 locations, with each location being designated as either an Air Station, FOL, AIRFAC, or FOB. The 39 locations were all current locations where the CG has an aviation presence, in addition to Guam and Cleveland, which were mentioned as areas of interest during SME interviews with CG Acquisitions & Aviation Forces Managers (Cole, 2023) (Jamros & Minopoli, 2023). The Architectural Decisions assessed in Chapter 5 served as the basis for estimating the difference in costs between Air Stations and the three satellite facility Support Constructs, with the default proposition that any Air Station could be downgraded to a satellite location, and vice versa. Estimated costs include capital construction costs, staffing salary and housing costs, aircraft capital costs, satellite facility logistics costs, mission fuel costs, TDY costs, and facilities maintenance costs. It is noted that there are many additional costs required to operate these facilities and aircraft; these particular costs were selected due to the data and cost drivers behind them being accessible and estimable, as well as the aspect that these costs vary by location and Aviation Support Construct.

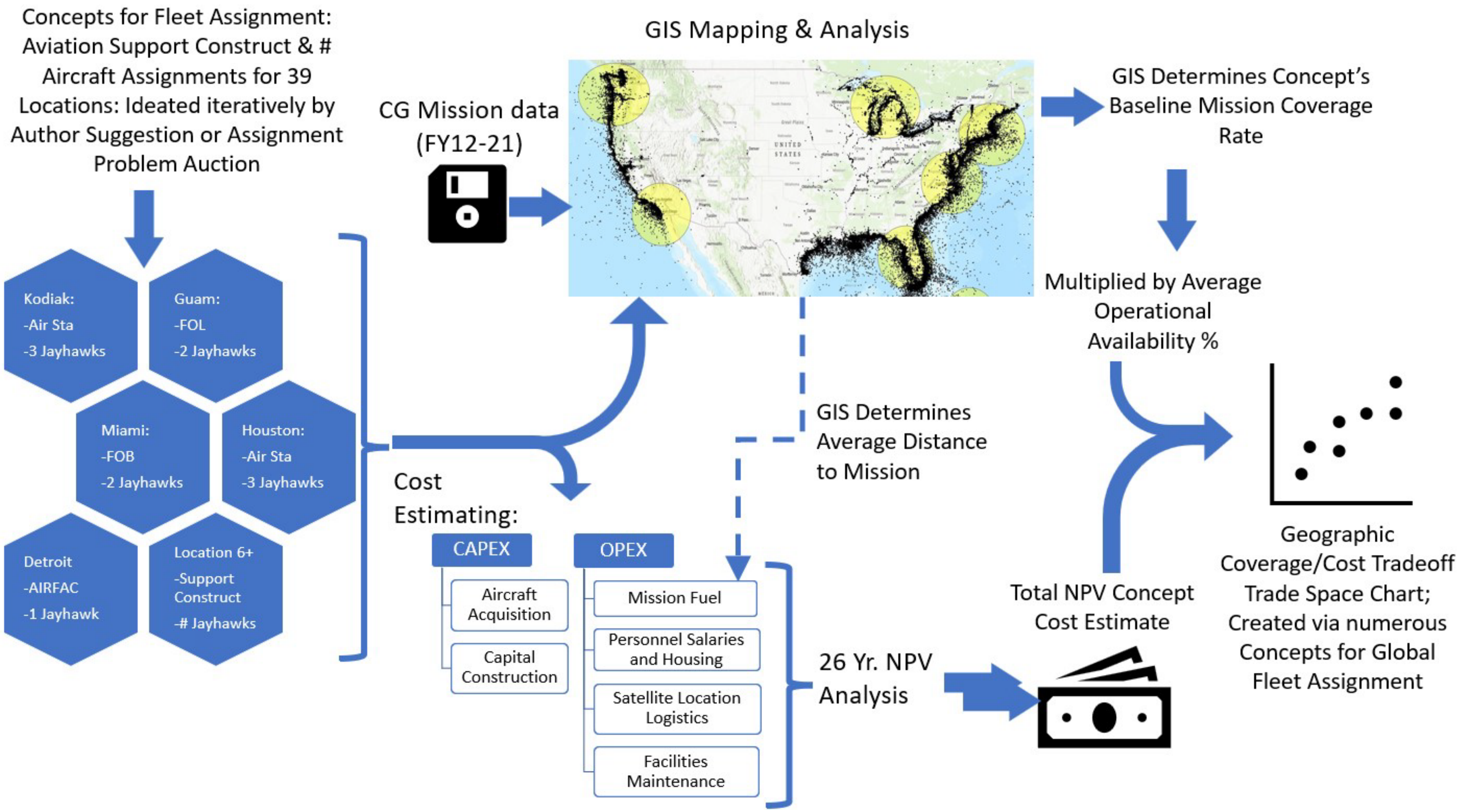

Figure 17: Geographic Coverage – Cost Tradeoff Model Creation

<u>Capital Construction Costs:</u> Capital construction costs were estimated by first determining parametric unit costs for capital construction and multiplying them by the required building construction sizes required to support different quantities of aircraft under different Support Constructs. Parametric unit costs for capital construction were calculated through the standard equation used by the US military to estimate major construction: "$A = $GUC x S x ACF x CE x TU x DC" (US Dept of Defense, Programming Cost Estimates for Military Construction, UFC 3-730-01, 2020). These variables are defined as following:

$A:	-Basic Adjusted Guidance Unit Cost
$GUC:	-Guidance Unit Cost; found in the US Army Corps of Engineer's Facilities Pricing Guide, for example, $734/SF for high bay maintenance hangars over 40' high, or $350/SF for an Administrative and Readiness Building (US Dept of Defense, DOD Facilities Pricing Guide, UFC 3-701-01, 2023)
S:	-Size Adjustment Factor; for example, 1.0 for high bay maintenance hangars 120,000SF.
ACF:	-Area Cost Factor, for example 0.87 for Mobile, AL, or 2.75 for Guam (US Army Corps of Engineers, DOD Area Cost Factors (ACF) PAX: Newsletter No. 3.2.1, Table 4-1; UFC 3-702-01, 2022).
CE:	-Cost Escalation Adjustment due to Inflation Factors. This was assumed to be 1.0, with the assumption being that all construction would occur immediately, now, per established prices.
TU:	-Technological Updating Adjustment Factor, 1.0 for hangars.
DC:	-Design Contingency Adjustment Factor, for example, 1.1 for pre-concept planning for medium complexity facilities.

For example, the Basic Adjusted Guidance Unit Cost ($A) for a 120,000 SF high bay maintenance hangar built in 2024 in Mobile, AL would be $702.43 per square foot.

Due to the lack of established CG square footage standards for aviation facilities, the requirements were empirically assessed from existing facilities nationwide. The existing facilities portfolio, including building types and sizes was retrieved from the CG's MAXIMO/SAM database and broken out by current number of aircraft assigned. To isolate for only Jayhawk requirements, only those units with only Jayhawks or used primarily by Jayhawks were assessed to determine requirements. These included Air Stations San Diego, CA (4 Jayhawks), Traverse City, MI (3), Sitka, AK (4), Clearwater (10) and Columbia River, OR (3), as well as AIRFAC Cordova, AK (1), and Air FOLs Kotzebue, AK (2), Cold Bay, AK (2) and Waukegan, IL (1). No current Jayhawk FOBs exist; therefore, the requirements were based off FOB Pt Mugu, CA which currently supports two Dolphins but can fit one Jayhawk in its hangar. Data from Tables 4 and 5 above, as well as the DoD's safety clearances required to house Jayhawks were then used to break these total requirements out into required hangar bay space to house aircraft, and additional required *other* building space (US Dept of Defense, Aircraft Maintenance Hangars, UFC 4-211-01, 2021). Measurements and estimates of required hangar space were broken out due to their significantly higher unit costs in comparison to other building types, as well as the fact that it is far more challenging to repurpose other building space for hangar purposes (Rathbun, 2023). All non-hangar building requirements, including warehouse, galley, administrative and other space requirements were grouped together for simplicity, and later estimated with average Guidance Unit Cost (GUC) for those building types. The existing facility sizes were then interpolated to estimate requirements for units with other aircraft quantities. Results of this empirical requirements estimation effort are shown in Table 11 below.

Table 11: Required Building Square Footage, for Various Assignments & Support Constructs

Support Construct:	# Assigned Jayhawks	Total Required SF	Total Hangar Bay SF Required	Total Other SF Required
Air Station	1	67,630	6,632	60,998
Air Station	2	77,271	13,265	64,006
Air Station	3	86,912	19,897	67,015
Air Station	4	96,553	26,530	70,023
Air Station	5	106,194	33,162	73,032
Air Station	6	115,834	39,794	76,040
Air Station	7	125,475	46,427	79,049
Air Station	8	135,116	53,059	82,057
Air Station	9	144,757	59,692	85,066
Air Station	10	154,398	66,324	88,074
Air FOL	1	10,338	6,632	3,705
Air FOL	2	21,145	13,265	7,880
AIRFAC	1	23,181	6,632	16,549
AIRFAC	2	33,988	13,265	20,723
Air FOB	1	24,402	6,632	17,769
Air FOB	2	35,209	13,265	21,944

With these interpolated requirements, unit construction costs and data on the existing facilities established; required capital construction costs were then estimated for units with different locations, Support Constructs & number of assigned aircraft. For example, Air Station Detroit currently hosts five Dolphins between two hangars, only one of which is large enough to host one Jayhawk. If assigned to host four Jayhawk helicopters, it is estimated to require 19,897

SF of hangar bay space, and 67,015 SF of *other* building space; cumulatively more than the total 74,926 SF of building space it currently maintains. Per this example, if assigned three Jayhawks, the required capital construction cost is estimated to cost $33,517,102. For comparison, if Air Station Detroit was converted to an FOB and assigned two Jayhawks, the required capital construction is estimated to cost, $10,944,943 to upgrade Detroit.

Aircraft Capital Costs: Jayhawk aircraft capital costs will be incurred by the CG as it grows its fleet to a desired fleet of 127 Jayhawks. Currently the CG is acquiring 'new' Jayhawk airframes in two ways, 1) buying used airframes from the US Navy for $18M or buying new airframes from Sikorsky for $35M each (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 496). Since the mix of where the CG will source the full fleet of airframes required is not yet determined, a simple average of $26.5M per aircraft frame was used. It is noted that there are many more costs associated with customizing these airframes to CG requirements.

Fuel Costs for Missions: Fuel costs for mission execution were calculated based on the above estimated fuel prices, in conjunction with the Jayhawk fuel economy of 0.75 NM/gallon, and the below GIS technique used to identify distances from mission requirements to aviation facility location.

Staffing Salary & Housing Costs: Estimating required staffing for these various aviation units and facilities was performed in a similar manner to estimating required construction, via empirical interpolation based on the status quo. Since there are no promulgated staffing standards for aviation units, the Personnel Allowance Lists (PALs) at each aviation unit were retrieved from the CG's personnel database, to include quantities of military and civilian employees at each rank (US Coast Guard, Coast Guard Business Intelligence (CGBI), 2023). The PALs at Jayhawk units were then compared to the number of Jayhawks assigned & interpolated at each civilian and military rank to determine required staffing levels for Jayhawk assignments. Interpolated and estimated required crew staffs, based on number of assigned Jayhawks are shown in Table 12. It is noted that Table 12 does not include personnel who would be designated to deploy to FOL and AIRFAC satellite units.

Table 12: Estimated Required Crew Sizes Based on Assigned Jayhawks

Support Construct:	# Assigned Jayhawks	Total Military Staff	Total Civilian Staff	Total Crew Size
Air Station	1	69	1	70
Air Station	2	80	1	81
Air Station	3	89	1	90
Air Station	4	102	2	104
Air Station	5	111	2	113
Air Station	6	125	7	132
Air Station	7	135	7	142
Air Station	8	145	8	153
Air Station	9	156	8	164
Air Station	10	165	8	173
Air FOL	1	0	0	0
Air FOL	2	0	0	0
AIRFAC	1	4	0	4
AIRFAC	2	6	0	6
Air FOB	1	16	0	16
Air FOB	2	21	0	21

Crew salaries were then estimated for military and civilian employees. Total compensation for military members includes Basic Pay, Basic Allowance for Housing (BAH), Basic Allowance for Subsistence (BAS), and possible Cost of Living Adjustment (COLA) for specific locations. Each of these allowances varies by rank, BAH and COLA also vary by dependent (children or spouses) status and assigned location, and COLA and Basic Pay also vary by employee time in service. It was assumed that 63% and 44% of officers and enlisted members have dependents (ICF, 2020). Average time in service was estimated based on average promotion and enlistment rates (CFR, 2020). Compensation levels for each employee rank and 39 locations were retrieved and combined to estimate the total compensation packages for staff of various ranks and dependent status at each location (Defense Travel Management Office, Overseas COLA Rate Lookup, 2023) (Defense Travel Management Office, Allowances, 2023) (FederalPay.org, Military Pay: Basic Pay Charts for 2023, 2023). It is noted that military personnel assigned to support FOLs or AIRFACs would be paid BAH, approximately 30% of their full compensation, based on the location of the 'parent' Air Station, not the location of the FOL or AIRFAC. Civilian employee compensation rates, which also vary by time in the current rank, were retrieved online, with it being assumed that the average civilian employee has 12 years in their current rank (FederalPay.org, How do Step Increases Work?, 2023) (Smith R. , 2021). As an example, if Air Station Barbers Point, HI were assigned four Jayhawks (and no other aircraft), it would require a total crew of 104 personnel costing $11,530,724 per year in labor costs. If it were converted to an FOB with two Jayhawks, it would require a permanent crew of 21 costing $2,751,335 per year.

Required staff sizes and costs were similarly estimated for satellite locations requiring rotating air crews. Estimated required staffing for FOLs and AIRFACs which require personnel to deploy from 'parent' Air Stations is shown in Table 13. These crews would permanently live at the 'parent' Air Station location, and biweekly deploy to and from the satellite FOL or AIRFAC location. These crew staffing costs were estimated with the same method as above.

Table 13: Estimated Required FOL and AIRFAC Deployment Crew Sizes

Aviation Support Construct	# Deploying Jayhawks	Required Deployment Crew (including support & air crews)
Air FOL	1	31
Air FOL	2	62
AIRFAC	1	22
AIRFAC	2	44

<u>Satellite Location Logistics Costs:</u> Satellite location logistics costs include three significant costs: 1) Temporary Duty (TDY) costs, 2) logistics fuel costs, and 3) C130 logistics flight costs. TDY costs are required by FOLs and AIRFACs for crews deploying to those locations for two-week cycles. TDY costs are prescribed by the GSA, and include meal, lodging and incidental costs. These 'Per Diem' rates are prescribed by the US General Services Administration (GSA, 2013). Logistics fuel costs were estimated by first finding the current cost of Jet-A fuel for each location under consideration and the distance to the next closest full-service Air Station for each global set of Jayhawk assignments under consideration (FlightAware.com, 2023). Then, the Jayhawks cruising speed fuel economy of 0.75 NM/gallon, and the normal 2-week deployment cycle were used to estimate annual fuel costs for these logistics trips to deliver fresh aircraft to FOLs, FOBs and AIRFACS (AeroCorner.com, n.d.). Finally, biweekly logistics transportation C130 flights were estimated with the CG's advertised reimbursement rate of $14,975/hour, C130J aircraft cruising speeds of 320 knots, and the distance to the nearest full-service Air Station (US Coast Guard, Reimbursable Standard Rates, CI7310.1Q, 2015).

Facilities Maintenance Costs: Facility maintenance costs at every location were simply estimated by multiplying their required total facility square footages by their DoD area cost factor, and a benchmarked national average costs of $5.59/SF per year and (FM Link, 2000).

NPV Analysis

The concept of the Net Present Value of money over time was incorporated into this model to combine capital costs with annual operating costs. The purpose is to bring all costs into a common time, to compare and combine their values (de Neufville & Scholtes, 2011, p. 199). For this task, it is assumed that the Jayhawk fleet will be operated until the end of the 2040's as explained in Chapter 1, thus, annual operating costs of various Jayhawk fleet assignments from the year after this Thesis is completed, 2024, through 2050 will be combined to form one NPV for those potential fleet lifecycles. With the fleet potentially operating from 2024-2050, this thesis will use a 26-year lifespan for this NPV analysis. Following the US Office of Personnel Management's 'Guidance for Benefit-Cost Analysis of Federal Programs' for a 26-year period, a Real Discount Rate of 2% will be used (Young, 2023). It is noted that this is the Federal government's 'Real' Discount Rate, not it's 'Nominal' Discount Rate. The difference lies with the Real rate accounting for the costs of borrowing money, while the Nominal rate accounting for that cost, as well as the impacts of inflation. As discussed in the assumptions, the impact of inflation is ignored in this thesis, equally impacting the analysis' capital and operating cost estimates.

Use of GIS and Range Rings

GIS software was used to visualize the mission capabilities of numerous sets of global assignments for the Jayhawk fleet. The Coast Guard provided a set of historical data including all search and rescue cases from Fiscal Year 2012 through Fiscal Year 2021, downloaded from the CG's MISLE (Marine Information for Safety and Lawn Enforcement) database (US Coast Guard, MISLE Response Sortie Data FY12-FY21, 2012-2021). These data included GPS coordinates of the locations of 167,180 search and rescue missions performed during this 10-year period and was assumed to be representative of all CG missions for any 10-year period. These data were uploaded into GIS software to visualize where CG missions are needed.

The mission capabilities of RW helicopters were estimated based on two criteria: mission response timelines and helicopter cruising speeds. CG mission response timeline expectations are set by the USCG Addendum to the National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual. This reference establishes a planning criterion for the CG to "state, site, base or stage search and rescue units…for no greater than a two-hour total response time" (US Coast Guard, US CG Addendum to the US NSS, 2022, p. 34). The Addendum further states that this planning should include 30 minutes of preparation time for response units. This leaves 90 minutes for aircraft to respond, one-way, to missions. At a cruising speed of 140 knots, Jayhawks can fly 210 NM, therefore a response radius of 210 NM was determined. Note that this is an assumption that all missions are responded to at aircraft cruising speeds. The MH-65 Dolphin's cruising speed is 148 knots, therefore, 90 minutes to and from the mission location could establish its response radius at 222NM. However, traveling both ways to a mission 222NM distant (222 NM x 2 = 444 NM) would exceed the Dolphin's overall range of 350 NM. Therefore, a mission radius of 90 NM was used, per comparable CG mission planning criteria (CG-711, 2022).

These mission capability range rings were plotted in GIS around current Dolphin and Jayhawk assignment locations, along with the MISLE data set, creating baseline mission capability maps (see Figures 18 and 19).

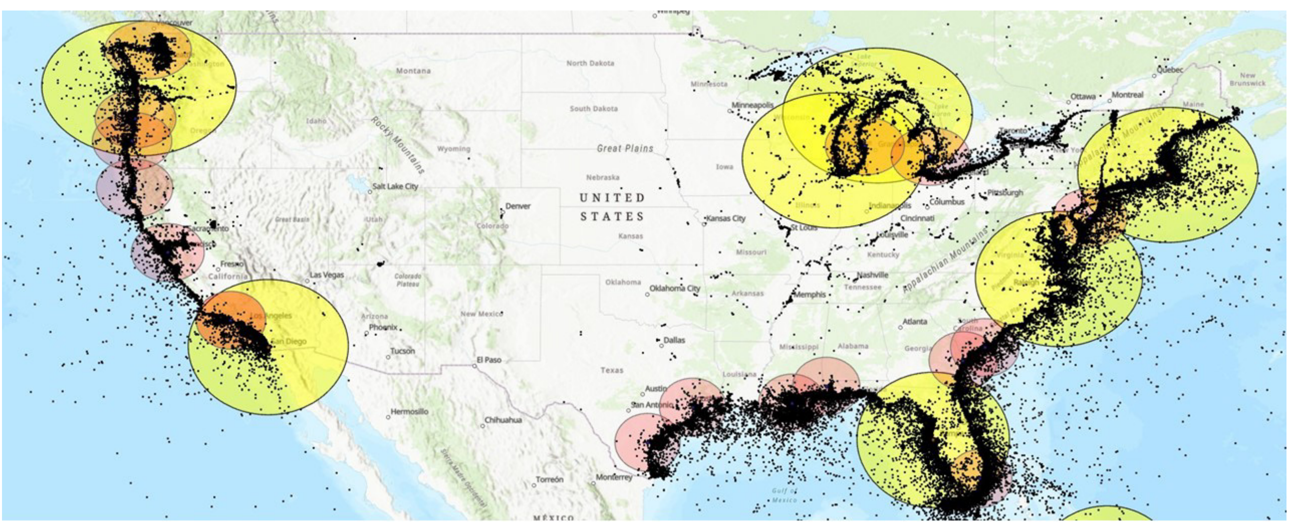

Figure 18: CG Mission Data & Current RW Mission Capability Rings; Contiguous US

(Contiguous US)
Yellow Rings=Jayhawk Range Rings; Red=Dolphin Range Rings

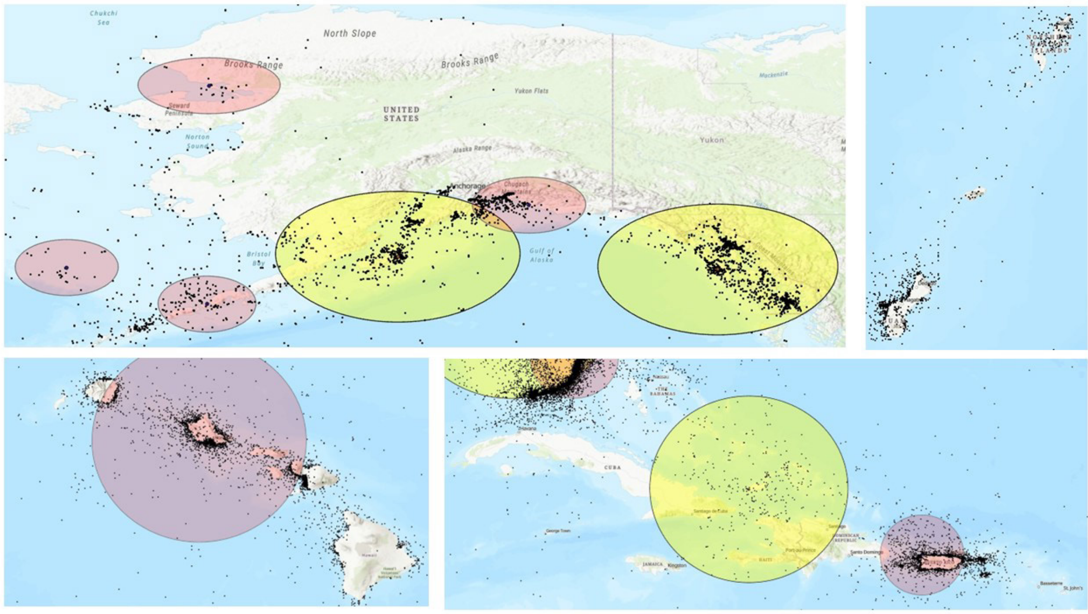

Figure 19: CG Mission Data & Current RW Mission Capability Rings, Outlying Regions

(Outlying US Regions: Clockwise: Alaska, Guam & the Marianas Islands, Puerto Rico & the Southern Bahamas, and Hawaii)
Yellow Rings=Jayhawk Range Rings; Red=Dolphin Range Rings

Queries were performed in GIS, and the locations and counts of mission points which were encompassed by the range rings were found. 157,384 mission locations were found within the range rings of all current Air Stations, and for the purposes of this thesis, these missions are assumed to be 'covered'. Dividing 157,384 by the 167,180 total search and rescue missions in the ten-year period yielded a 94.14% baseline mission coverage. These mission locations were also compared to the CG's aviation locations to determine an average overall distance to mission of 77.3 NM. This distance was used to calculate fuel costs as discussed above. This same technique was then used in Chapter 7 for global assignments of the all-Jayhawk Fleet, but only with Jayhawk range rings (yellow range rings). This baseline mission coverage will be further refined, based on the availability of aircraft, using the CG's Operational Availability Metric.

Operational Availability

The idea of Operational Availability was used to incorporate levels of service into this model. Colloquially, the idea is described as 'three makes one;' the idea reflects the reality that aircraft will not always be mission ready (Eberly, Interview with CG-8-PAE, 2023). During periods of planned or unplanned maintenance, as well as time awaiting parts, helicopters will not be ready or available for missions. The CG's target Operational Availability is 71%, meaning the aviation program's goal is to maintain aircraft so that they are available for missions 71% of the time (US Coast Guard, Aeronautical Engineering Maintenance Management Manual, CIM1320.1H, 2019, p. 13). Taking this a step further, the CG has predicted aggregate Operational Availability for units with two or more aircraft. For example, units with two or three aircraft are predicted to have at least one Operational Asset available for missions 85.6% and 97.6% of the time, respectively. An Operational Availability of 97.6% being so close to 100%, this is where the idea of 'three makes one' comes from; if an Air Station hosts three aircraft, it is assumed that at least one will be mission ready nearly 100% of the time. Operational asset availability probabilities for aviation units with one or more RW assets were calculated with the CG's prescribed method and are listed in Table 14. For the use of this thesis, the Operational Availability figures were assumed to be the same for satellite units as at Air Stations.

Table 14: Aviation Unit Operational Asset Probabilities

Support Construct	# Assigned Aircraft	Probability of One Aircraft being Operationally Available
Air Station	1	71.00%
Air Station	2	85.61%
Air Station	3	97.56%
Air Station	4	99.29%
Air Station	5	99.79%
Air Station	6	100.00%
Air Station	7	100.00%
Air Station	8	100.00%
Air Station	9	100.00%
Air Station	10	100.00%
Air FOL	1	71.00%
Air FOL	2	85.61%
AIRFAC	1	71.00%
AIRFAC	2	85.61%
Air FOB	1	71.00%
Air FOB	2	85.61%

The Operational Availability idea was incorporated into this thesis' global assignment model by multiplying it by the baseline mission coverage percent described above, for each aviation unit and location. Therefore, for the above baseline mission coverage of 94.14%, the count of missions found within the range rings of each location were multiplied by the average Operational Availability of all aviation locations (92.5%), resulting in a final current mission coverage of 87.08%. Due to the CG not promulgating a threshold or target mission capability percentage like this, this mission coverage percent of 87.08% for the current set of RW assignments was used as the target or threshold mission coverage percent while modeling global assignment of the future All-Jayhawk Fleet.

Coverage of the CG's Fleet from 1968-1985

For comparison, a similar GIS visualization was created to showcase the capabilities of the CG's RW aircraft before the deployment of the Dolphin and Jayhawk fleets. At this time in the early 1980's, the CG's RW fleet consisted of 99 HH-52A Seaguard and 54 HH-3F Pelican (Pearcy A. , 1991, pp. 105 - 328). In total, this fleet of 153 helicopters which operated from approximately 1968-1985 was actually larger than today's fleet of 147 Dolphins and Jayhawks. With assignment locations found on the Coast Guard historian's records and with aircraft capabilities known, this information was input into GIS, creating Figure 20 (See Table 8 for aircraft capabilities).

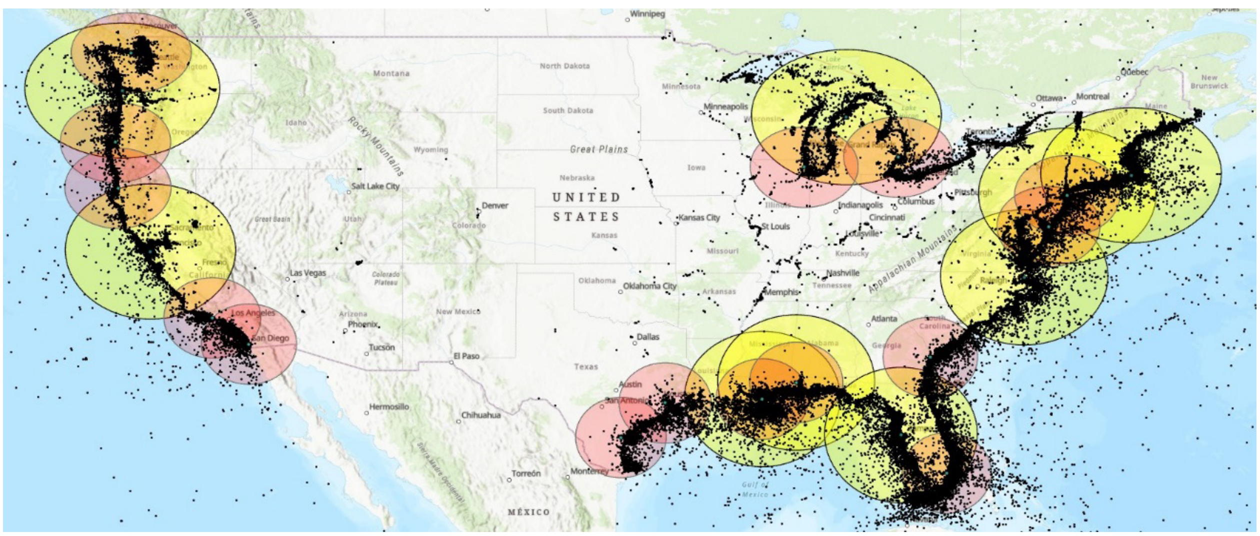

Figure 20: 1968-1985 Seaguard and Pelican Fleet Mission Capability Rings; Contiguous US

(Contiguous US)
Yellow Rings=Pelican Range Rings; Red=Seaguard Range Rings
(Not pictured: Pelican range rings around Kodiak, Cordova, Sitka and Borinquen; Seaguard range rings around Kodiak and Barbers Point)

The FY2012-2021 mission data was input into GIS and compared to the range rings with the same technique described above, yielding a baseline mission coverage of 95.07%, higher than the modelled 94.14% baseline coverage of the modern fleet. Technology and training advancements ignored; it is intriguing to see that the CG's RW aviation fleet may have had superior overall coverage from 1968-1985.

Knowing that the NCRAD mission (6 aircraft) did not exist during that time-period, and assuming the same number of aircraft were assigned for training at ATC (13), maintenance at ALC (18), and assigned primarily for shipboard deployments (14), this indicates an average of 3.6 aircraft per location in this past fleet, vs an average of 3 aircraft per location for the current fleet. This indicates that the current Dolphin/Jayhawk fleet is, on average, more dispersed than the past Seaguard/Pelican fleet, possibly because of the growth of satellite facilities since 1985 (see Figure 12). With the fleet's 1985 locations including only two satellite facilities (Cordova and OPBAT), and all other locations assumed to maintain an average of 3.6 aircraft, the fleet's average Operational Availability was estimated at 97.18% (see Tables 6 and 7). This resulted in a final 1985 coverage of 92.39%, again higher than the CG's current mission coverage percent of 87.08%. Since the actual count of aircraft assignments to each location at any one time between the late 1960's and the early 1980's was unknown, there is some residual uncertainty on this estimate of 92.39%. Visually comparing the CG's coverage map in 1985 (Figure 18), and its current coverage map (Figures 18 and 19), confirms this mathematical comparison. From a visual standpoint, the CG's current assignments leave gaps in coverage near Wester Louisiana, Northern and to both the North and South of San Francisco. While the CG has established seven new satellite locations since 1985 in places like Western Alaska, this growth was unable to make up for the reduced coverage and range imposed as the CG transitioned from the Pelican/Seaguard fleet to the Dolphin/Jayhawk fleet. The Dolphin's minimal mission radius of 90NM is less than that of its predecessor, the Seaguard with its 128NM mission radius, likely contributing significantly to this reduction in global mission coverage from 1985 to 2023.

Trade Space Plotting & The Pareto Front

With costs estimated and the mission coverage percentage established, these two were then plotted to create a trade space of capability against cost. A Pareto Frontier, or Pareto Front was then drawn to suggest the 'edge of the envelope' of the CG's aviation system. The Pareto Front line is a line drawn on trade space plots that "showcases the architectures that are 'good' and represent good tradeoffs between the metrics" (Crawley, Cameron, & Selva, 2016, p. 334). The line was drawn to connect all trade space points which represent either the best utility (mission coverage percentage) achievable at the same cost, or vice versa. A general purpose of the Pareto Front line is to define trade-space points that are good and worthy of consideration, since it may be much more difficult to objectively find one architecture that is uniquely, 'the best.'

Assumptions

It is necessary to define and list the assumptions made while building a model to classify the model's accuracy and logic. The following assumptions were made while building this model for many reasons including, but not limited to available computing power and capabilities, the limitations in available data, and time constraints:

1) It is assumed that the 2012-2021 SAR mission data used for defining the capability of each suggested fleet assignment was representative of all Coast Guard missions which RW helicopters might respond to. For example, it is assumed that this data set is representative of oil spill, law enforcement, and fishing fleet reconnaissance missions. It is similarly assumed that all missions are of the same value or importance to the CG.
2) It is assumed that the reasons behind the 2012-2021 SAR mission data used in building this model are stable and will not change in the future out to as far as the year 2049, when the All-Jayhawk fleet may be retired and replaced. This generally assumes recreational and commercial activities of US citizens and maritime companies are stable and consistent.
3) It is assumed that all missions included in the 2012-2021 SAR mission data set are *able* to be successfully responded to by one Jayhawk helicopter, if on scene. This includes the assumption that all missions would not require any services which one Jayhawk aircraft could not provide, for example towing boats to safety or rescue of excessive quantities of victims.
4) It is assumed that all missions within range of Coast Guard Aviation locations would be responded to by Jayhawk assets, and not surface assets (i.e., Cutters or small boats). This also discounts the potential future use of drone assets to perform vertical list missions in the future. This assumption is made regardless of the Aviation Support Construct.
5) All Coast Guard Reservist assignments are ignored. While minimal in number, the quantity of reservist members may grow in the future, thus, potentially reducing labor costs of aviation units.
6) It is assumed that all current costs including construction, housing, military pay, capital acquisition, labor, fuel, maintenance, and other costs will not change in future years. Stated another way, inflation is ignored.

7) It is assumed that all RW aircraft fly to the mission location and back at their cruise speed, rather than maximum or other speeds.
8) It is assumed that all RW missions depart from and return to the same location.
9) It is assumed, per opinion from a Subject Matter Expert, that Jayhawk helicopters that can fold their tails and blades will be stored and protected from the elements in hangars in an *unfolded* configuration, per current procedures (Maccumbee, CAPT, 2022). The reason for this is likely to maintain operational readiness of response helicopters, and to avoid the otherwise necessary approximately 30-minute, 4-man procedure to unfold the helicopter.
10) General regional assignments of Jayhawks intended for predominantly shipboard/afloat assignment were based on the Coast Guard's potential geographic assignments for the All-H60 fleet, wherever more than three are currently assigned (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 54) (Jamros & Minopoli, 2023). This includes RW aircraft detailed for shipboard deployments at Barbers Pt, HI (1), Kodiak, AK (3), Sitka, AK (1), Port Angeles, WA (1), North Bend, OR (1), San Francisco (1), San Diego, CA (2), New Orleans, LA (1), Miami, FL (2), Elizabeth City, NC (1), Cape Cod, MA (1), and Borinquen, PR (1). It was assumed that these locations would not change, and that if any of these locations are eliminated, that the Jayhawks assigned for shipboard use could easily be re-allocated to the next nearest Air Station.
11) It is assumed that current Coast Guard hangars or hangar space assigned to fixed wing assets will not change.
12) It is assumed that current CG owned or leased hangars are in satisfactory condition, and if available for use by RW aircraft and if large enough for one or more Jayhawk Helicopters, can be suitably modified as required to support that same quantity of aircraft.
13) It is assumed that ALC, ATTC, ATC, HITRON, and NCRAD will not be relocated, due to their specialized functions. This analysis assumes there will be no relocations for the helicopters assigned for maintenance and training purposes at ALC and ATTC in Elizabeth City, NC, the helicopters assigned for training purposes at ATC in Mobile, AL, the helicopters assigned for specific interdiction purposes at the HITRON location in Jacksonville, FL, and the helicopters assigned for National Capital defense at

NCRAD in Washington, DC and Joint Base Andrews, MD. Based on notional plans provided by the CG, it is assumed that 16 Jayhawks are required at ALC/ATTC, 8 are required at ATC, 12 are required at HITRON, and 10 are required at NCRAD (Eberly & Guido, Strategic Study: Aviation Asset Mix, 2022, p. 54). Even though the primary purpose of these locations is for logistics, training, and specialized missions, each of these locations will be considered for operational deployment of Jayhawks for normal mission purposes in Chapters 7 and 8.

14) For simplicities sake, it is assumed that all missions within proximity of the legacy seasonal satellite locations only occur during the seasonal time periods. This includes missions around the seasonal location in Kotzebue, AK (deployed June-Aug), Cordova, AK (May-Oct), Cold Bay, AK (Oct–Mar), Muskegon, MI (June-Sep), and Waukegan, IL (June–Sep) (Kenshalo, 2023) (Helis.com, 2016). This excludes the satellite location in Great Inagua, Bahamas, AIR FOB Point Mugu, CA, AIRFAC Charleston, SC, and AIRFAC Newport, OR which currently operate year-round. Also note that the location in St Paul, AK is not listed here, as it is used on an ad hoc basis.

15) It is assumed that national political leaders and senior CG leaders are solely interested in mission capabilities, mission performance, and costs. Subjective topics like qualities of life in different locations, the effect of deployments on family life are ignored. Except for one specified exception in Auction D, the effect of politics is ignored. For example, it is ignored that politicians from certain states or regions, or who hold leadership positions often exert political pressure to garner military construction or emergency response capabilities in their states or locations.

Chapter 7: Aircraft Assignment Concepts & Auctions

Exercising this model was performed in two ways. First, 30 'Concepts' for global assignment of the future Jayhawk fleet were individually suggested by the author to seek out a Pareto Front and determine the relative value of various locations and Support Constructs. Next, and more objectively, 5 Assignment Problem Auctions were conducted to seek the best available set of global assignments based on different objective criteria. Each auction incrementally created and assessed new Concepts for the fleet's global assignment, with each Trial of the Auction creating a new Concept. Both the 30 author-suggested Concepts, and the Concepts created by the five Auctions sought out a best value set of global assignment, value being the best overall mission capability at total NPV cost. Following creation of these suggested and auctioned Concepts for the Jayhawk Fleet's global assignment, their utility was plotted against their 26-year NPV (2024-2050 projected fleet lifespan), to create a trade space plot. A Pareto Front was then proposed to identify the best Concepts for consideration. As established in Chapter 6, the threshold baseline 'Utility' for these trade-space plots was 87.08%, the mission coverage percentage the CG achieves with its currently mixed fleet.

Incrementally Suggested Concepts for Global Jayhawk Fleet Assignments

The author began exercising the model with 30 incrementally suggested Concepts for global assignment of the Jayhawk fleet. The first (Concept 1) was exercising the model for its baseline which included Jayhawk assignments at all operational locations where they are currently assigned today. Included in all Concepts, Concept 1 also includes the model's built-in cost-assumption of 42 planned Jayhawks at four unique locations: 8 for training at ATC (Mobile, AL), 12 for the Aerial Use of Force mission at HITRON (Jacksonville, FL), 16 for planned fleet maintenance at ALC (Elizabeth City, NC), and 10 for Capital Defense at NCRAD (Washington, DC). Concept 1 only included one satellite location: OPBAT in the Bahamas. Suggested as the 'status quo' option, Concept #1 reflects a possible global fleet assignment alternative which avoids major investment for new hangars. Concept 1 was estimated to cost \$119M for capital construction (for non-hangar facilities), \$927M for aircraft capital acquisition, \$84M/year for personnel costs, \$13M/year for TDY costs at OPBAT, \$6M/year for facility maintenance costs, and \$44M for annual fuel costs. The estimated capital costs totaled \$1,046M and the annual operating costs totaled \$148M/year, resulting in a 26-year NPV of \$3,404M. Concept 1 was input into GIS, resulting in a mission coverage of 59.8%. With a fleet average of 98% Operational Availability, Concept 1 yielded a final mission coverage of 58.35%, much lower than the target threshold mission coverage of 87.08%. GIS also determined an average distance to mission of 111 NM, inferior to the current mixed fleet baseline distance of 77 NM. Figures 21 and 22 show the mission coverage of Concept 1.

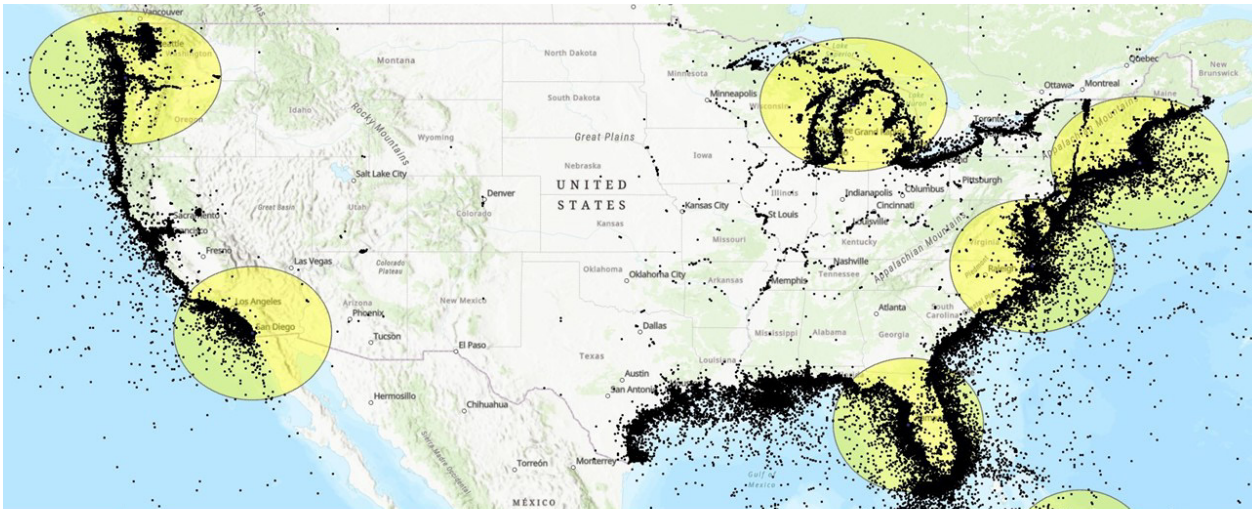

Figure 21: Concept 1: All-Jayhawk Fleet Mission Capabilities; Contiguous US

(Contiguous US)
Yellow Rings – 210 NM Jayhawk Range Rings-around all locations where Jayhawks are currently assigned

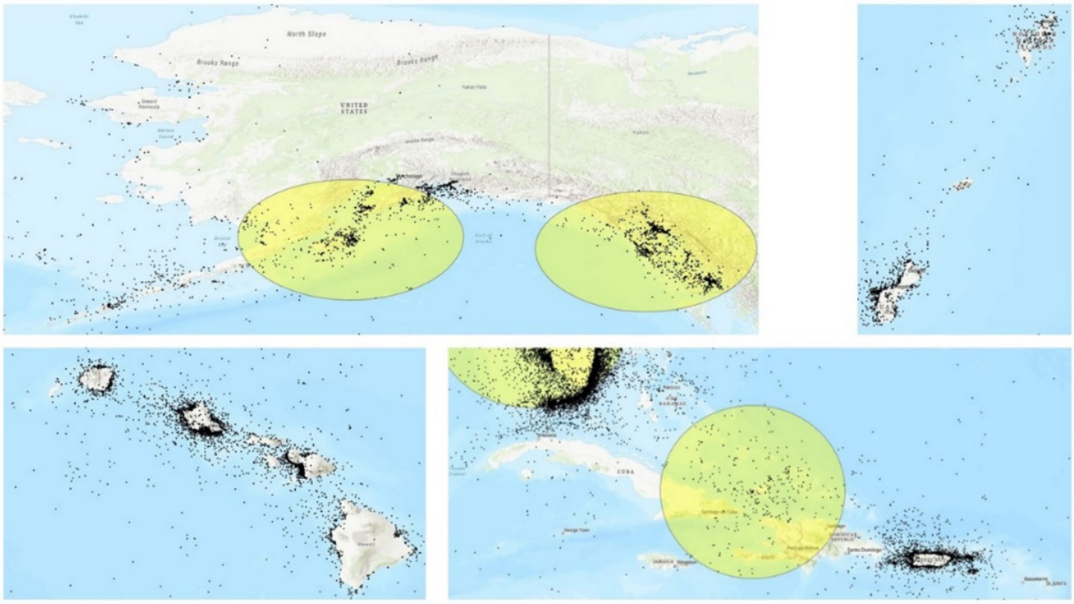

Figure 22: Concept 1: All-Jayhawk Fleet Mission Capabilities; Outlying Regions

(Outlying US Regions: Clockwise: Alaska, Guam & the Marianas Islands, Puerto Rico & the Southern Bahamas, and Hawaii)
Yellow Rings – 210 NM Jayhawk Range Rings; around all locations where Jayhawks are currently assigned

Reviewing Concept 1 in GIS visually helps find opportunities for future investment to achieve stronger mission capabilities. While visualizations can be subjective, these opportunities may include California, the Gulf Coast, the Eastern Great Lakes, Oahu, Puerto Rico, South Carolina, and Guam.

Concept 2 was then suggested which included additional Jayhawk assignments in Barbers Pt, HI, Humboldt Bay, CA, Ventura, CA, Corpus Christi, TX, Miami, FL, Detroit, MI, Savannah, GA & Borinquen, PR. Concept 2 resulted in a 26-year NPV $5,084M and a final mission coverage of 83.12%, still below the threshold target mission coverage percentage of 87.08%. With this logic, 30 Concepts were then incrementally suggested, as listed in Table 15. Note that Concepts 1 through 19 are sequential with their ideation representing a design walk, each building on each other to seek a better tradeoff between mission capabilities and cost. Concepts 20 through 30 represent individual Concepts, some which are unrealistic, used to compare different assignment set angles.

Table 15: Suggested Global Fleet Assignment Concepts 1 through 30

(Mission Coverage Percentages < 87.08% (threshold) highlighted red. > 87.08% highlighted green)

Concept #:	Total Fleet Size (# Jayhawks)	Avg Distance to Mission (NM)	Baseline Mission Coverage Percent	Fleet Average Operational Availability (%)	Final Mission Coverage Pct (Utility)	26 yr NPV Cost ($Millions)	Concept Ideation Rationale	Resulting Commentary
1	80	111	59.8%	97.6%	58.35%	$4,332	Baseline of all current Jayhawk Locations	Insuficient Success Rate, numerous mission capability gaps
2	108	90	85.0%	97.8%	83.12%	$6,754	8 new AirSta's at Barbers Point, Humboldt Bay, Ventura, Corpus Christi, Centura, Miami, Detroit, Savannah & Borinquen	Insuficient Success Rate, large gaps around San Francisco, CA, New Orleans, LA, PA & Southeast AK
3	116	78	93.4%	95.3%	89.02%	$7,632	Added Cordova & Cold Bay FOLs. Added Air Sta NOLA. Replaced Humboldt Bay with SF	Large Gaps in Northern CA & Northern FL. Triple overlap around New Orleans.
4	122	58	93.6%	93.1%	87.11%	$8,193	Added FOLs at Kotzebue, Waukegan & Muskegon	Quadruple overlap in Michigan. Large gap remains in N. CA
5	122	78	93.6%	93.1%	87.11%	$9,237	Changed all 5 FOLs to AIRFACs	Costs increased 17%
6	122	78	93.6%	93.1%	87.11%	$7,974	Changed all 5 FOLs to AIRFOBs	Costs decreased from Concept 4 by 3.5%. FOBs may be the most economic support construct
7	124	76	93.5%	94.2%	88.06%	$8,339	Removed Waukegan to determine its value	With AirSta Traverse City online, Muskegon only improves mission capability by 0.04%.
8	121	78	93.5%	95.0%	88.84%	$8,066	Removed Muskegon to determine its value	With AirSta Traverse City online, Waukegan only improves mission capability by 0.03%.
9	121	80	93.5%	95.0%	88.90%	$8,141	Replaced Detroit, MI with Cleveland, OH	Cleveland represents a 0.06% superior location, for 0.01% additional NPV cost
10	124	79	93.5%	95.1%	88.95%	$8,415	Added Humboldt Bay to close N. CA gap. Replaced Colombia Rvr with Port Angeles	Large gap remains around Newport, OR
11	124	78	93.3%	95.2%	88.86%	$8,399	Replaced Humboldt Bay, CA with Northbend, OR	This concept closed the gap, but achieved inferior mission success
12	125	76	94.3%	94.8%	89.45%	$8,533	Re-added Humboldt Bay & downgraded Northbend to an FOB	0.6% mission improvement for 2% cost increase
13	125	75	93.7%	94.8%	88.87%	$8,573	Replaced Corpus Christi with Houston, TX	Concept 13 achieved worse utility at greater cost than Concept 12. Corpus Christi value is superior than that of Houston, TX
14	126	76	94.3%	94.5%	89.11%	$8,654	Downgraded San Francisco to an FOB (Parent at Sacramento)	Minimal mission improvement for significant cost at due to requirement to build out parent location at Sacramento
15	124	76	94.3%	94.3%	88.92%	$8,414	Converted San Francisco's parent Air Station to Humboldt Bay, CA	Humboldt Bay is a superior parent for San Francisco (vice Sacramento)
16	124	76	94.3%	94.4%	89.01%	$8,428	Converted San Francisco's parent Air Station to Ventura, CA	Ventura is a superior parent for San Francisco (vice Humboldt Bay)
17	127	76	95.0%	94.5%	89.78%	$9,025	Added an Air Station in Guam	Air Station Guam improves capabilities by 0.68% for ~$500M NPV cost.
18	124	76	94.4%	96.9%	91.49%	$8,530	Removed all Alaskan satellite units	The three remote AK unit increase mission capability by 0.63%, very similar to Guam.
19	121	78	94.3%	94.1%	88.75%	$8,044	Removed Ventura from Concept 15	Only a minor 0.2% capability decrease with $300M NPV savings.
20	90	45	28.9%	91.2%	26.37%	$5,471	Individual Trial: Only PACAREA Units with Maximum FOBs	Result created the FOB trendline
21	108	56	54.8%	91.6%	50.17%	$7,156	Individual Trial: Only PACAREA & Gulf Coast Units with Maximum FOBs	Result created the FOB trendline
22	90	45	28.9%	91.2%	26.37%	$6,311	Individual Trial: Only PACAREA Units with Maximum FOLs	Result created the FOL trendline
23	108	55	54.8%	91.6%	50.17%	$8,260	Individual Trial: Only PACAREA & Gulf Coast Units with Maximum FOLs	Result created the FOL trendline
24	90	45	28.9%	90.3%	26.12%	$7,580	Individual Trial: Only PACAREA Units with Maximum AIRFACs	Result created the AIRFAC trendline
25	130	55	54.8%	90.8%	49.76%	$12,006	Individual Trial: Only PACAREA & Gulf Coast Units with Maximum AIRFACs	Result created the AIRFAC trendline
26	127	74	94.3%	95.3%	89.86%	$8,730	Notional Plan under consideration by the CG (see Figure 5)	Documents the cost and capability of the notional plan.
27	145	74	95.4%	90.5%	86.28%	$14,489	Maximum AIRFACs, Nation wide	FAC's are less expensive to construct than AirStas, but TDY costs are significant.
28	145	74	95.4%	92.0%	87.79%	$12,634	Maximum FOLs, Nation wide	Significant operating & capital savings over Air Stations
29	145	74	95.4%	92.0%	87.79%	$11,113	Maximum FOBs, Nation wide	Significant operating & capital savings over Air Stations
30	181	74	95.4%	98.1%	93.61%	$15,340	Air Stations at all 39 Locations	6.4% of missions remain out of reach. Gaps remain near Rochester, NY & Duluth, MN

These thirty Concepts yielded several specific conclusions. Concepts 7 and 8 documented minimal value in the Waukegan, IL and Muskegon, MI locations, if the nearby location of Traverse City, MI with its robust current facility were maintained. The mission prospects of a possible Air Station in Guam were quantified as covering 0.69% of CG missions (1,229 missions) over a 10-year period, at a 26-year NPV of $517M. While minimal, Guam's value proposition (0.69% of missions at a cost of $517M) represents near equal value as does continued operation of three satellite locations in Alaska. FOL Kotzebue, FOL Cold Bay, and AIRFAC Cordova combined enabled 0.63% of CG Missions at a 26-year NPV cost of $415M. Finally, Concepts 20-25 and 27-29, which purposefully prioritize FOLs, AIRFACs and FOBs demonstrate the low cost of FOBs and the high cost of AIRFACs.

In addition to incrementally comparing these suggested Concepts 1-30 on their costs and mission coverage percentages one at a time, they were graphed, and a Pareto Front suggested to seek the best tradeoff between cost and geographic coverage. These 30 suggested global fleet assignment Concepts were plotted and are shown in Figure 22. Figure 24 shows the same plot, overlaid with trendlines for six Concepts which maximized the use of satellite units, rather than traditional Air Stations. Reviewing these trendlines indicated the relatively low costs of FOBs and the relative high costs of AIRFACs.

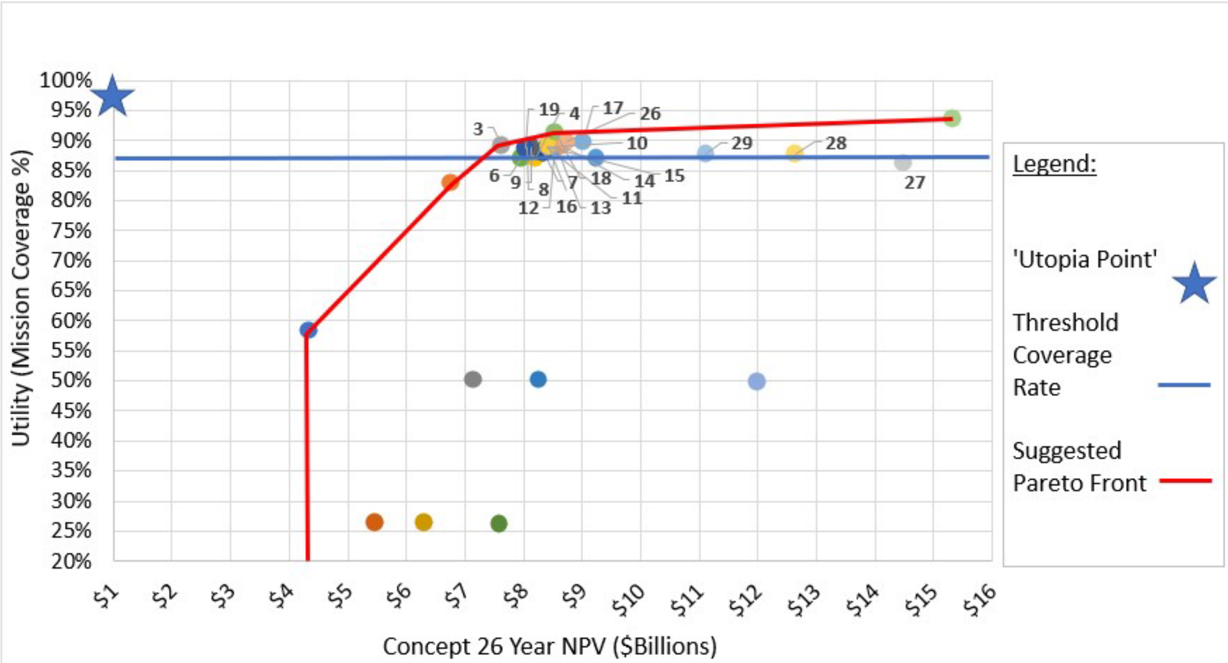

Figure 23: Suggested Global Fleet Assignment Concepts 1 through 30: NPV vs Utility

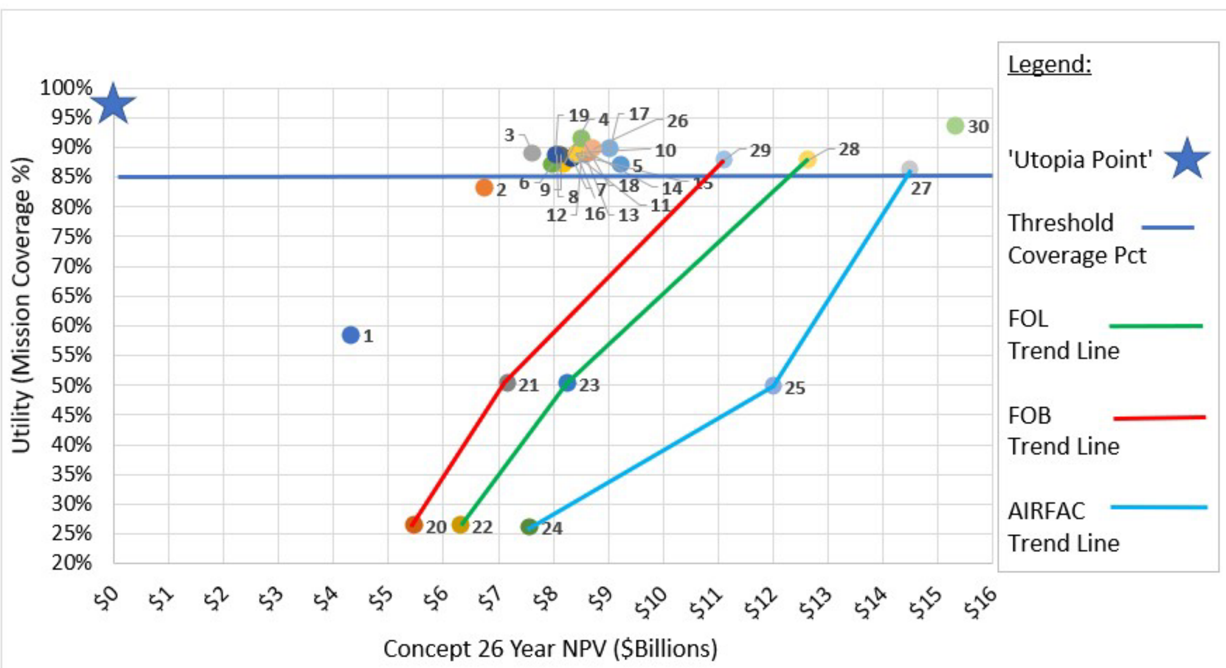

Figure 24: Fleet Assignment Concepts 1-30, Showcasing Satellite Unit Trendlines

Through this plot, a Pareto Front, was suggested, which along with the established threshold mission coverage percentage, suggested Concept 3 as the Concept closest to the Utopia Point. Concept 3 includes Air Stations at Barbers Point, Kodiak, Sitka, Colombia River, San Francisco, Ventura, San Diego, Corpus Christi, New Orleans, Clearwater, Miami, Savannah, Elizabeth City, Atlantic City, Cape Cod, Detroit, Traverse City, and Borinquen, as well as FOLs at OPBAT, Cordova and Cold Bay. Different from today's operational locations, Concept 3 does not include operational Jayhawk assignments in Kotzebue, St. Paul, Port Angeles, Newport, North Bend, Humboldt Bay, Houston, Mobile, Charleson, Waukegan, and Muskegon. While this may seem conclusive, it was recognized that these 30 suggested Concepts do not represent the totality of the possible permutations of different numbers of assigned aircraft, at different mixes of 39 locations. With 30 suggested Concepts representing nearly 0% of the 1.52x10^182 possible combination, they may not even be representative of the total trade space. Therefore, this research turned towards the Assignment Problem's Auction Algorithm.

Assignment Problem Auctions

Before initiating auctions to prioritize locations for CG aviation facilities, objective criteria had to be established for each auction. First, the threshold mission coverage percentage was set at 87.08%, and any global set of assignments which resulted in less than 87.08% were rejected. There are many additional objective criteria which could be used including seeking the fewest number of locations, the lowest total NPV cost, inclusion of political topics, or preferring specific locations for other reasons. If this methodology were to be used by the CG, these objective priorities should be carefully crafted based on the organization's strategy and objectives. Due to the inability to glean priorities like this from Coast Guard publications or SME interviews, this research ideated priorities for consideration.

Additional auction rules were applied to ensure process uniformity during each auction. First, all auctions began with operational Jayhawks assigned to all legacy locations in addition to Guam and Cleveland, OH which were suggested by SME interviews. All locations were assumed to be assigned three aircraft and organized with the traditional Air Station Support Construct. The auctions proceeded to eliminate aviation locations which contributed least to the auction's stated objective criteria. To expedite the auctions, without impairing results, the auctions allowed more than more location to be eliminated from consideration during each cycle. But only one location on each coast was allowed to be eliminated per auction cycle to prevent errors caused by changed in overlapping range rings. Once the mission coverage neared 87.08%, only one location was removed per auction trial. Finally, the requirement for the CG to maintain a total of 16 RW aircraft assigned primarily for shipboard deployment was maintained in the locations discussed in Chapter 6 (Assumption # 10). For example, if the Aviation location in Port Angeles, WA was eliminated, which was required to host one Jayhawk primarily for shipboard deployments, that Jayhawk was re-assigned to the next nearest Air Station: Colombia River, OR. This action directly impacts the costs at each location as these additional shipboard-use aircraft were relocated.

With these auction rules in place, five Auctions were conducted with the following objective criteria, in addition to ensuring the threshold Mission Coverage Percent was achieved.

Auction	**Objective Criteria**
A	Seek the fewest number of aviation locations possible, while retaining all legacy OCONUS locations
B	Seek the lowest possible 26-yr NPV
C	Seek the fewest number of aviation locations possible
D	Seek the lowest possible 26-yr NPV, while incorporating known political requirements
E	Seek the lowest possible 26-yr NPV, while considering all legacy locations in addition to 19 new locations

Specific descriptions and results of Auctions A through E are as follows:

Auction A: In addition to achieving an 87.08% threshold mission coverage percentage, Auction A was ideated with two objective criteria: 1) to seek the fewest aviation locations possible, and 2) while retaining all locations Outside the Contiguous US (OCONUS). These OCONUS locations include Barbers Point, HI; Guam, Kotzebue, AK; St. Paul, AK; Cold Bay, AK; Kodiak, AK; Cordova, AK; Sitka, AK; OPBAT, Bahamas; and Borinquen, PR. Auction A proceeded incrementally by removing aviation locations which contributed the least to the mission coverage metric. Results of Auction A's first Trial are shown in Figure 25, resulting in a mission coverage of 95.38%. With all locations assumed to be Air Stations with three aircraft, application of the 97.56% Operational Availability idea takes this Trial to a final mission coverage of 93.05%.

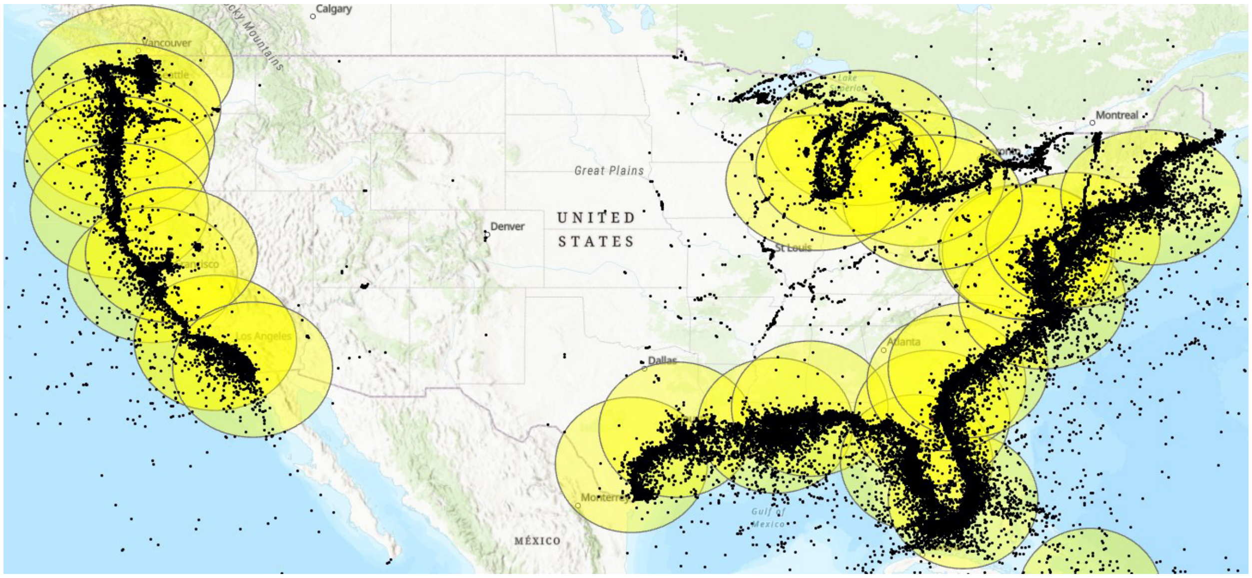

Figure 25: Auction A, Trial 1 Results

(Trial 1 of 9; Objective Criteria: Seek fewest locations while retaining all OCONUS locations)

Next, a GIS query documented the number of missions which were covered by each individual Air Station location, meaning, the number of mission locations only encompassed by one individual range ring. Next, the locations which had the fewest counts of unique mission completions were identified. Auction A-Trial 1 documented that five range rings encompassed zero unique missions (Washington, DC; NCRAD; Muskegon, MI; Newport, OR; and Savannah, GA). Following the auction rules, no more than one location per coastline was removed per trial, therefore, Muskegon, Washington, DC; and Newport, OR were eliminated. With these three locations eliminated, the new list of locations was plotted in GIS as 'Trial 2', and GIS was queried again. It was important to run these auctions on a trial-by-trial basis, because when individual locations are eliminated, the mission potential of their adjacent locations increases as range rings overlaps diminish. For example, the unique potential of the North Bend, OR location increased after its adjacent Newport, OR location was eliminated. Auction A continued through 8 Trials until an unsatisfactory global assignment set was found. Results of Auction A are listed in Table 16, including a final global Jayhawk fleet assignment to 23 locations (10 default OCONUS & 13 CONUS).

Table 16: Auction A Trials & Results

(Auction A's Objective Criteria: Seek fewest locations while retaining all OCONUS locations)

		Auction Trial Number								
AirStation Location	**State**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Barbers Point	HI	x	x	x	x	x	x	x	x	x
Guam	GU	x	x	x	x	x	x	x	x	x
Kotzebue	AK	x	x	x	x	x	x	x	x	x
St Paul	AK	x	x	x	x	x	x	x	x	x
Cold Bay	AK	x	x	x	x	x	x	x	x	x
Kodiak	AK	x	x	x	x	x	x	x	x	x
Cordova	AK	x	x	x	x	x	x	x	x	x
Sitka	AK	x	x	x	x	x	x	x	x	x
Port Angeles	WA	x	x	x	x					
Columbia River	WA	x	x	x	x	x	x	x	x	x
Newport	OR	x								
North Bend	OR	x	x							
Humboldt Bay	CA	x	x	x	x	x	x			
San Francisco	CA	x	x	x	x	x	x	x	x	x
Point Mugu	CA	x	x	x	x	x	x	x	x	x
Ventura	CA	x	x	x	x	x				
Sacramento	CA	x	x	x						
San Diego	CA	x	x	x	x	x	x	x	x	x
Corpus Christi	TX	x	x	x	x	x	x	x	x	x
Houston	TX	x	x	x	x					
New Orleans	LA	x	x	x	x	x	x	x	x	x
Mobile	AL	x	x	x	x	x				
Clearwater	FL	x	x	x	x	x	x	x	x	
Miami	FL	x	x	x	x	x	x	x	x	x
HITRON	FL	x	x	x						
Savannah	GA	x	x							
Charleston	SC	x	x	x	x	x	x	x	x	x
Elizabeth City	NC	x	x	x	x	x	x	x	x	x
NCRAD	MD	x	x	x	x					
Washington	DC	x								
Atlantic City	NJ	x	x	x	x	x	x	x		
Cape Cod	MA	x	x	x	x	x	x	x	x	x
Detroit	MI	x	x							
Traverse City	MI	x	x	x	x	x	x	x	x	x
Cleveland	OH	x	x	x	x	x	x	x	x	x
Waukegan	IL	x	x	x						
Muskegon	MI	x								
OPBAT	Bahamas	x	x	x	x	x	x	x	x	x
Borinquen	PR	x	x	x	x	x	x	x	x	x
	Mission Coverage Percent	90.9%	90.8%	90.6%	90.3%	89.9%	89.5%	88.6%	87.8%	86.6%
	# Locations	39	36	33	30	27	25	24	23	22

Auction B: In addition to achieving at a minimum, a mission coverage of 87.08%, Auction B was ideated to seek the lowest possible 26-year NPV. This was accomplished by estimating the value of each location, repetitively after each trial, with the value being the number of unique missions able to be completed by each location, divided by the 26-year NPV of a 3-Jayhawk Air Station at that location. Then, the locations with the lowest value were eliminated on a Trial-by-Trial basis. Auction B lasted for 13 Trials and resulted in a prioritized list of 14 fleet assignment locations. Auction B's results are listed in Table 17 and shown in Figure 26.

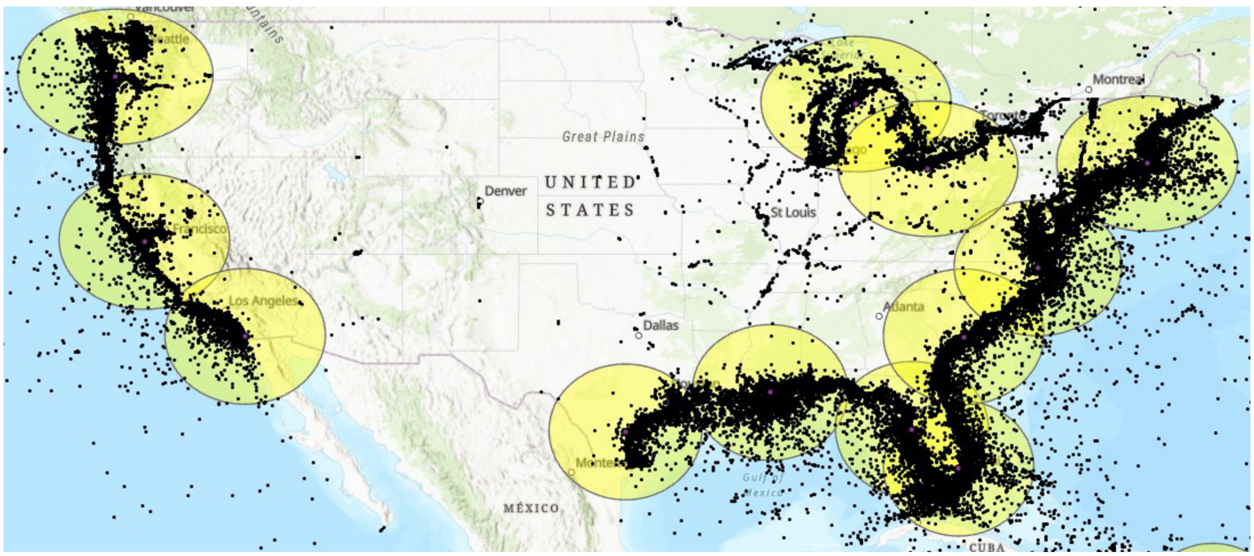

Figure 26: Auction B – Trial 12 (Final) Results

(Not shown: Range rings around Barbers Pt, HI and Borinquen, PR)

(Trial 12 of 13; Objective Criteria: Seek the lowest possible Concept NPV)

Auction C: In addition to achieving at a minimum, a mission coverage of 87.08%, Auction C was ideated to seek the fewest number of aviation facilities. Unlike Auction A, Auction C gave no default priority to OCONUS locations. Auction C lasted for eight Trials and resulted in a prioritized list of 15 locations. Auction C's results are listed in Table 17.

Auction D: In addition to achieving at a minimum, a mission coverage of 87.08%, Auction D was ideated to seek the lowest possible 26-year NPV, while also incorporating known political requirements. While challenging to parse out political desires, priorities, requirements, or objectives, two requirements were identified. First, congress requires the CG to maintain a flight deck equipped cutter and aircraft capabilities in the Bering Sea at all times to support the safety and security of Alaskan fisheries (US Coast Guard, Bering Sea and Arctic Region Coverage, 2016, p. 1). While this requirement does not list a corresponding Air Station to support this aircraft out of, it is assumed to be Kodiak, AK due to its current status as the only full-service CG aviation location in western Alaska. Secondly, the current OPBAT, Bahamas location is required due to an international agreement between the US, British, and Bahamian governments to partner in the Bahamas on drug interdiction missions (CGAviationHistory.org, n.d.). Auction D lasted for 9 Trials and resulted in a prioritized list of 15 fleet assignment locations. Auction D's results are listed in Table 17 and shown in Figure 27.

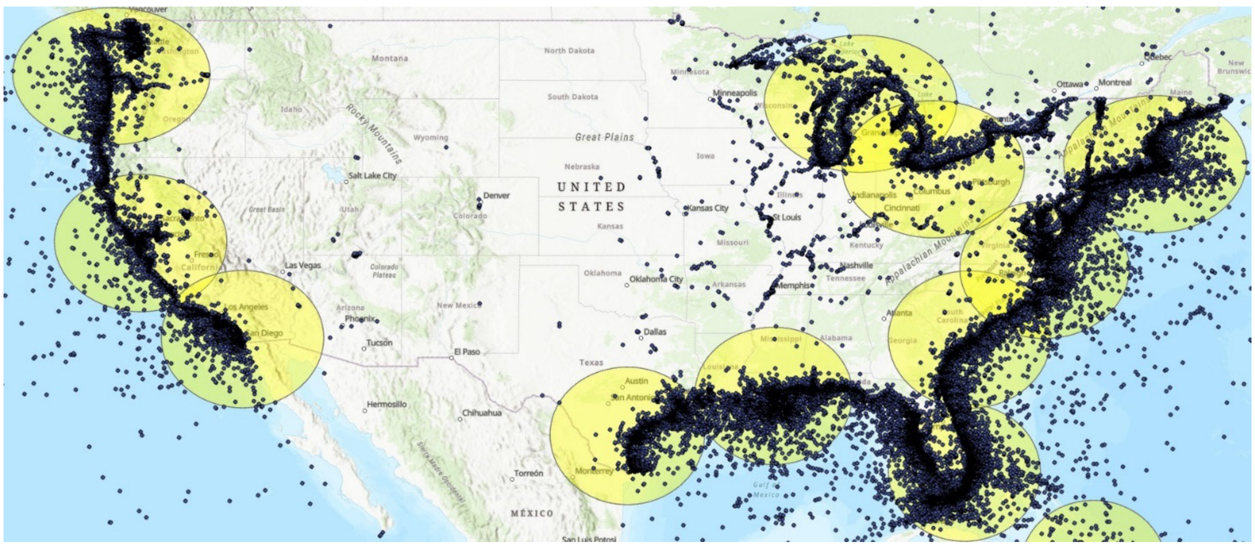

Figure 27: Auction D – Trial 9 (Final) Results

(Not shown: Range rings around OBPAT; Barbers Pt, HI, Kodiak, AK & Borinquen, PR)

(Trial 9 of 10; Objective Criteria: Seek lowest possible NPV while incorporating known political requirements)

<u>Auction E:</u> In addition to achieving at a minimum, a mission coverage of 87.08%, Auction E was ideated to seek the best value (mission capability at NPV cost) while also considering 19 new locations, for a total of 58 candidate locations. Since costs were not thoroughly estimated for these new 19 locations, Army Corps Area cost factors were used as stand-ins for the costs of all locations. The ideation of these 19 new locations was performed by reviewing the Army Corps' Area Cost Factors list and seeking the lowest costs in each region and coastline,

specifically searching for major military installations nearby to current aviation locations. As examples, these included Elmendorf AFB (Anchorage, AK); Travis AFB (near San Francisco, CA); Vandenberg AFB (between San Diego and San Francisco, CA); and Key West NAS. Additional locations were selected wherever there was a gap in current CG aviation capabilities, for example, the island of Hilo, HI; Buffalo, NY; and Guantanamo Bay, Cuba. Additional locations included Joint Base Pearl Harbor, HI; Bethel, AK; Eareckson AFB, AK; Dutch Harbor, AK; Tacoma, WA; St. Augustine, FL; Sunny PT, NC; Brooklyn, NY; Quonset PR Air National Guard Base, RI; Portland, ME; and Duluth, MN. Auction E lasted for 14 Trials and resulted in a prioritized list of 14 fleet assignment locations, including three new locations not previously considered (Buffalo, NY; Portland, ME; and Sunny Point, NC). Auction E's results are listed in Table 17 and shown in Figure 28.

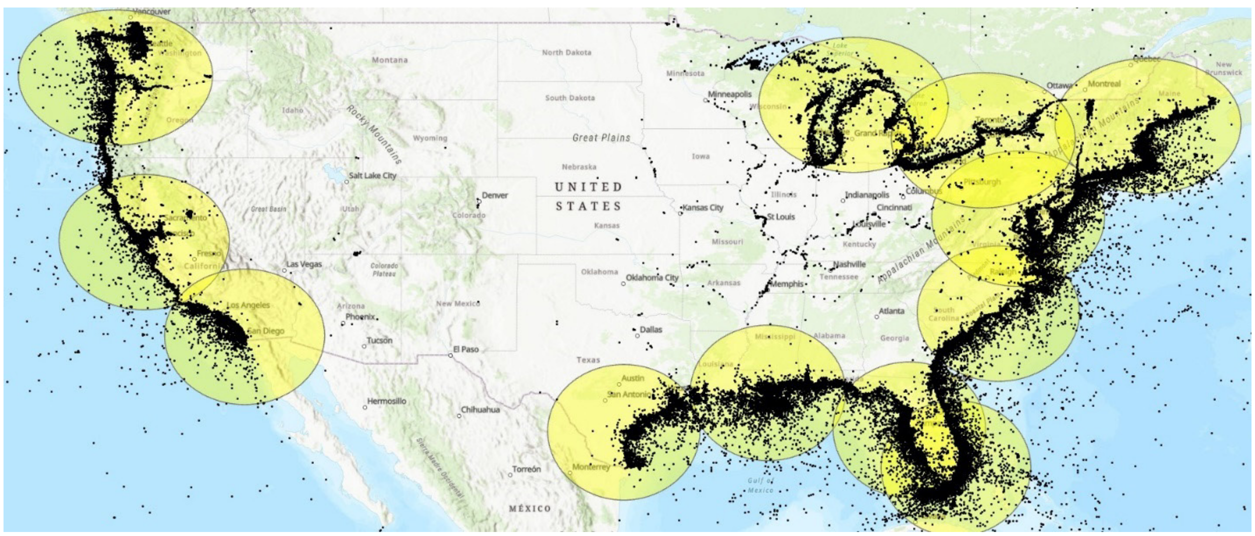

Figure 28: Auction E – Trial 13 (Final) Results

(Not shown: Air Station Borinquen, PR)

Table 17: Auctions A thru E Results

(*Auction E Results do not list 3 additionally preferred locations: Sunny Point, NC; Portland, ME; & Buffalo, NY. Auction E final NPV not calculated.)

		Auction						
AirStation Name	State	A	B	C	D	E*	Common Inclusion	Common Exclusion
Barbers Point	HI	x	x	x	x	x	Yes	
Guam	GU	x						
Kotzebue	AK	x						
St Paul	AK	x						
Cold Bay	AK	x						
Kodiak	AK	x			x			
Cordova	AK	x						
Sitka	AK	x		x				
Port Angeles	WA							Yes
Columbia River	WA	x	x	x	x	x	Yes	
Newport	OR							Yes
North Bend	OR							Yes
Humboldt Bay	CA							Yes
San Francisco	CA	x	x	x	x	x	Yes	
Point Mugu	CA	x						
Ventura	CA							Yes
Sacramento	CA							Yes
San Diego	CA	x	x	x	x	x	Yes	
Corpus Christi	TX	x	x	x	x	x	Yes	
Houston	TX							Yes
New Orleans	LA	x	x	x	x	x	Yes	
Mobile	AL							Yes
Clearwater	FL	x	x	x		x		
Miami	FL	x	x	x	x	x	Yes	
HITRON	FL							Yes
Savannah	GA							Yes
Charleston	SC	x	x	x	x			
Elizabeth City	NC	x	x	x	x			
NCRAD	MD							Yes
Washington	DC					x		
Atlantic City	NJ							Yes
Cape Cod	MA	x	x	x	x			
Detroit	MI							Yes
Traverse City	MI	x	x	x	x	x	Yes	
Cleveland	OH	x	x	x	x			
Waukegan	IL							Yes
Muskegon	MI							Yes
OPBAT	Bahamas	x			x			
Borinquen	PR	x	x	x	x	x		
Mission Coverage Percent		87.8%	89.1%	88.7%	87.7%	90.0%		
26 Year NPV ($ Billions) *		$8.291	$5.621	$6.337	$6.339	-		
Total Number of Locations:		23	14	15	15	14*		

Reviewing Table 17 provides several preliminary conclusions. First, the CG could achieve the same mission coverage as it does today, with only 14 aviation locations, as opposed to the current 37. Furthermore, commonalities are found across the five auctions with 7 locations prioritized in each and 14 unprioritized in each.

Auctions A through E were also plotted as a design walk to understand the relationship between mission coverage & the quantity of aviation locations. Shown in Figure 29, this design walk shows how the mission coverage percentages decrease slowly at first as aviation locations are eliminated and locations with overlapping range rings are eliminated. But later mission coverage drops off precipitously as range rings no longer overlap. This indicates that the CG could eliminate several aviation locations with minimal mission impact but reducing the count of locations below 25 would begin to significantly impact mission capabilities.

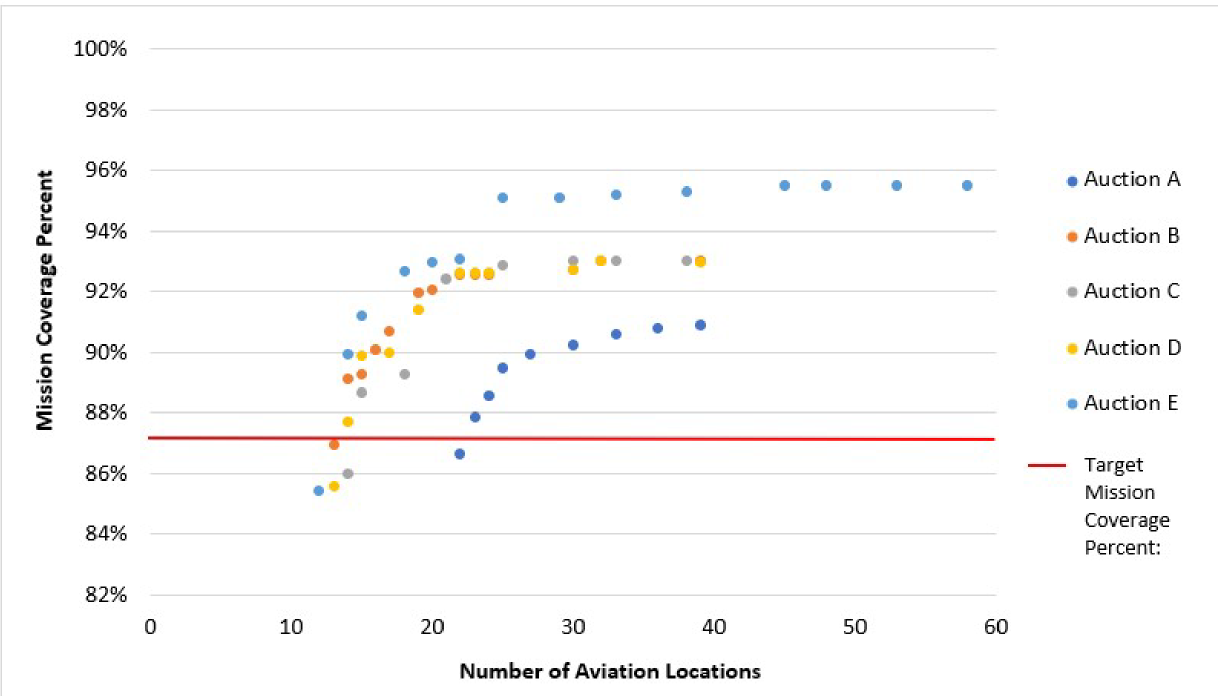

Figure 29: Auction Design Walk, Auction A through E

An Updated Pareto Front

The results from these five auctions revealed new previously unimagined possibilities. The iterative results from Auctions A through D were added to Figure 24 to create an updated Trade

Space and are shown in Figure 30. Figure 31 shows the same graph but is enhanced to focus attention on those Concepts closest to the Utopia Point.

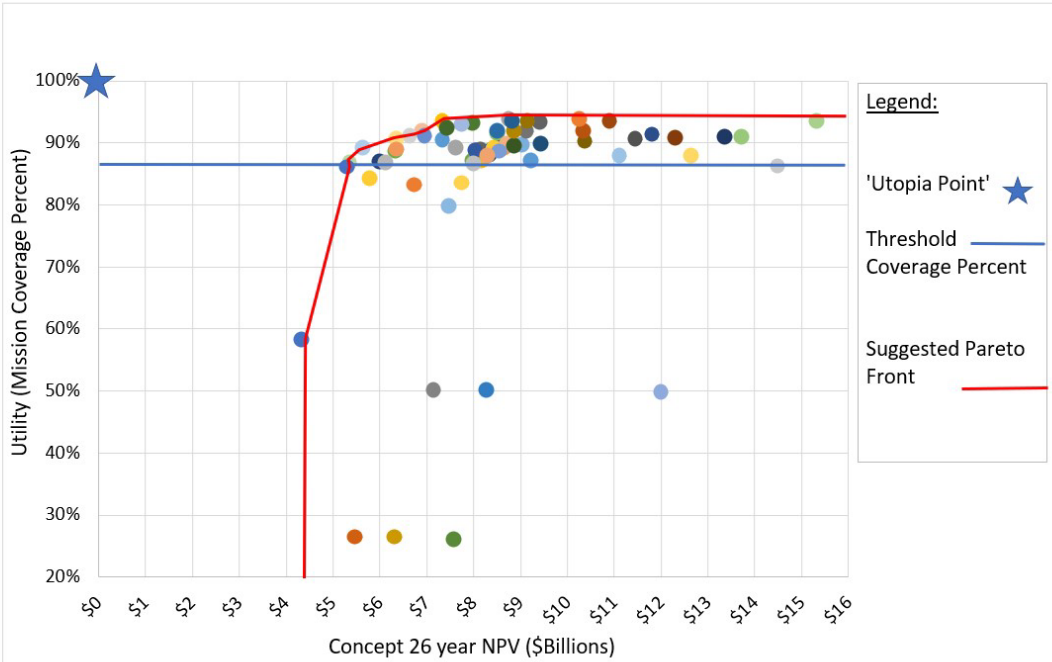

Figure 30: Fleet Assignment Concepts 1-70: Utility vs 26 Year Cost Trade Space

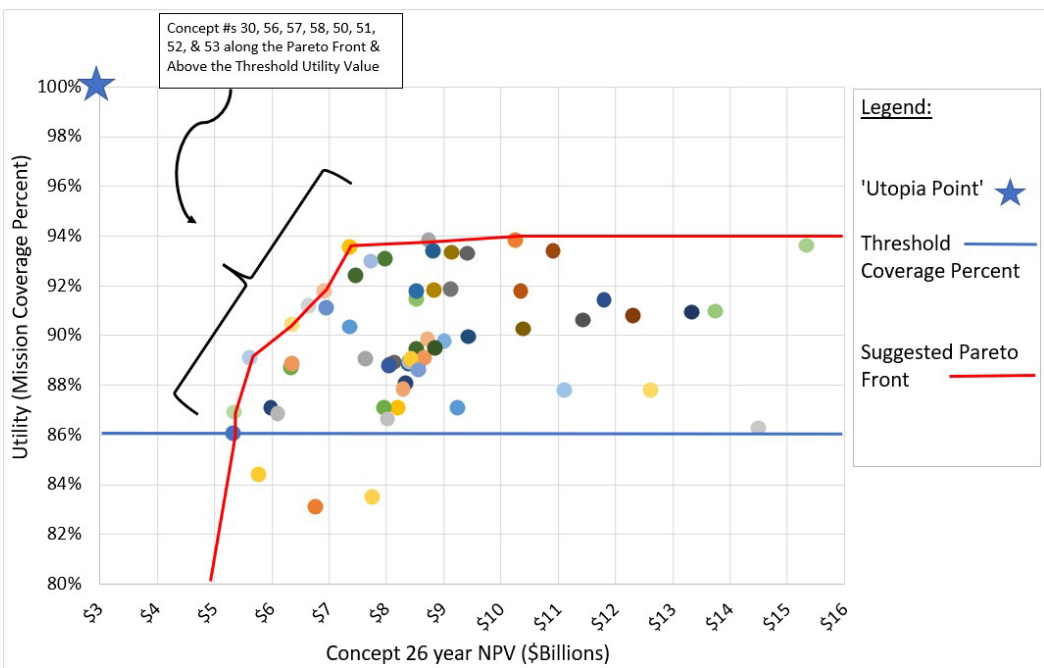

Figure 31: Global Fleet Assignment Concepts 1 - 70 (Enhanced along the Pareto Front)

Figures 30 and 31 provide a visualization of the results of Auctions A through D, alongside the 30 Concepts initially suggested. A list of the Concepts along the Pareto Front is shown in Table 18. At first glance these show that Auctions A through D derived superior fleet assignment Concepts that were not imagined by the author. Reasons for this likely include subjectivity in the author's suggestions regarding the mission value proposition of certain locations. These two figures also provide the CG a short list of Concepts along the Pareto Front which represent Concepts with desirable combinations of low costs and high values. Taking mission capabilities and total costs as the primary objective criteria, Concept #53 (Auction B, Trial 12), achieves the target mission coverage of 87.08%, at the lowest NPV cost ($5,621M), and should be strongly considered by the CG. It may be easy to simply recommend the CG to pursue this result of Auction B, but it is recognized that the CG may have other undisclosed additional priorities. As such, it is recommended that the CG to strongly consider all Concepts along this Pareto Front, or to create its own Auction based on customized objective criteria as it makes global fleet assignment decisions for the future All Jayhawk Fleet.

Table 18: Fleet Assignment Concepts Along the Pareto Front & Above 87.08% Coverage

		Concept Number							
AirStation Name	State	30	56	57	58	50	51	52	53
Barbers Point	HI	x	x	x	x	x	x	x	x
Guam	GU	x	x	x	x				
Kotzebue	AK	x	x	x					
St Paul	AK	x	x						
Cold Bay	AK	x	x	x	x				
Kodiak	AK	x	x	x	x				
Cordova	AK	x	x	x	x				
Sitka	AK	x	x	x	x	x	x	x	
Port Angeles	WA	x							
Columbia River	WA	x	x	x	x	x	x	x	x
Newport	OR	x							
North Bend	OR	x	x						
Humboldt Bay	CA	x	x	x	x	x	x		
San Francisco	CA	x	x	x	x	x	x	x	x
Point Mugu	CA	x							
Ventura	CA	x	x	x					
Sacramento	CA	x							
San Diego	CA	x	x	x	x	x	x	x	x
Corpus Christi	TX	x	x	x	x	x	x	x	x
Houston	TX	x	x						
New Orleans	LA	x	x	x	x	x	x	x	x
Mobile	AL	x	x	x					
Clearwater	FL	x	x	x	x	x	x	x	x
Miami	FL	x	x	x	x	x	x	x	x
HITRON	FL	x							
Savannah	GA	x							
Charleston	SC	x	x	x	x	x	x	x	x
Elizabeth City	NC	x	x	x	x	x	x	x	x
NCRAD	MD	x							
Washington	DC	x	x						
Atlantic City	NJ	x	x	x	x	x			
Cape Cod	MA	x	x	x	x	x	x	x	x
Detroit	MI	x							
Traverse City	MI	x	x	x	x	x	x	x	x
Cleveland	OH	x	x	x	x	x	x	x	x
Waukegan	IL	x	x						
Muskegon	MI	x							
OPBAT	Bahamas	x	x	x					
Borinquen	PR	x	x	x	x	x	x	x	x
	Auction & Trial #	n/a	C-3	C-4	C-5	B-9	B-10	B-11	B-12
	Mission Coverage Percent	93.84%	93.84%	93.84%	93.55%	91.73%	91.18%	90.46%	89.11%
	26 Year NPV ($ Millions)	$15,340	$10,255	$8,744	$7,350	$6,915	$6,639	$6,349	$5,620
	Value (Coverage % / 26yr NPV $)	0.006	0.009	0.011	0.013	0.013	0.014	0.014	0.016

Chapter 8: A Future Look

As a final line of inquiry, this research looks to the future, at one possible candidate aircraft to replace the Jayhawk. As discussed above, the Jayhawk fleet is projected to last until the early 2050's and CG hangars on average last over 45 years. Thus, it is likely that any hangars built now for the All-Jayhawk fleet will be available for possible use by the Jayhawk's replacement. Meanwhile, the US Navy has already formally begun the process to replace the UH-60 Seahawk, its similarly aging version of the Jayhawk via the DoD's Future Vertical Lift-Maritime Strike (FVL-MS) program. For primary reasons of interoperability, mission similarities and procurement efficiencies, the CG is a partner to the program (Eberly, Interview with CG-8-PAE, 2023). The US Navy released a Request for Information to industry in 2021, receiving responses from over 30 manufacturers and suppliers and completed its Analysis of Alternatives in 2022 (Decker, 2022). While the Navy has yet to down select to any program finalists, there is still helpful information for this thesis. Two key pieces of information are the Navy's preliminary requirements for the Seahawk replacement to achieve 170-270 knots in speed and a mission range radius of 300-440 NM (GlobalSecurity.org, n.d.). With these notional capabilities, the same auction process as performed in Chapter 8 could be re-run to visualize possible futures for the CG's aviation facilities portfolio. Through an auction like this, the CG could seek synergy with its future requirements. Through hangar and facility construction today in synergized locations, the CG could achieve significant future savings in construction and fuel costs. This Chapter will perform one Assignment Problem Auction for one candidate replacement to the Jayhawk and Seahawk, the Sikorsky-Boeing 'Defiant X' aircraft. It is important to note that this is only one possible candidate to replace the Jayhawk, but it is one of the few announced candidates with advertised capabilities.

Auction F: An Air Station Auction for a Potential Defiant X Fleet

While design is still underway, the Defiant X is promoted with a 256-knot speed and an 833NM total range (MilitaryFactory.com, Sikorsky-Boeing Defiant X, 2022). With the 90-minute response timeline established in Chapter 6, a 256-knot speed creates a response range radius of 384 NM. Auction F was run with the same auction rules as Auction C, with the objective to seek `the fewest aviation facilities while achieving the threshold mission coverage of 87.08%. Costs were not considered due to the uncertainties with estimating operating costs 26 years in the future, the uncertainty about where hangars will be constructed for the All-Jayhawk fleet, as well as the

Defiant X's aircraft's unknown fuel economy. Only the original 39 locations were considered. Auction F gave no default preference for OCONUS locations or political requirements. Auction F lasted for 11 Trials and resulted in a prioritized list of eight assignment locations. Auction F's results are listed in Table 19 and shown in Figure 33.

Figure 32: The Sikorsky-Boeing Defiant X and Sikorsky UH-60 Blackhawk

(The UH-60 Blackhawk and MH-60 Jayhawk are variants of the same aircraft)
Source: (Lockheed-Martin, n.d.)

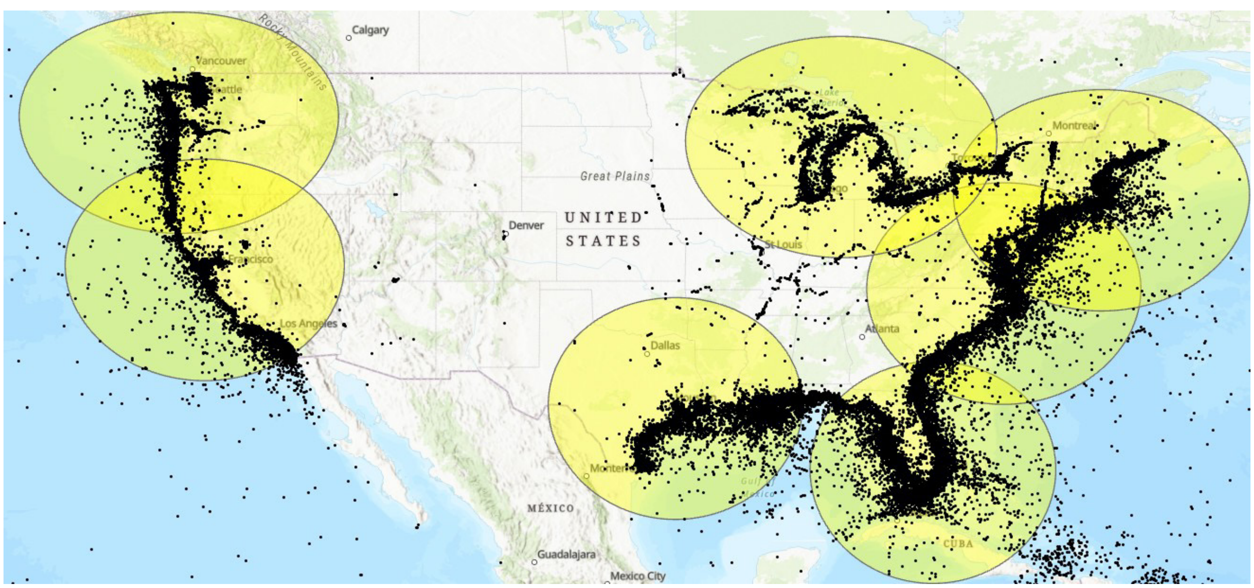

Figure 33: Auction F – Trial 11 (Final) Results (Defiant X Range Rings)

(Not shown: Range ring around Barbers Pt, HI)

Table 19: Auction F Trials and Results

		Auction Trial Number											
AirStation Name	State	1	2	3	4	5	6	7	8	9	10	11	12
Barbers Point	HI	x	x	x	x	x	x	x	x	x	x	x	
Guam	GU	x	x	x	x	x	x	x					
Kotzebue	AK	x	x	x	x	x	x						
St Paul	AK	x	x	x	x	x	x	x					
Cold Bay	AK	x	x										
Kodiak	AK	x	x	x	x	x	x	x	x				
Cordova	AK	x											
Sitka	AK	x	x	x	x	x	x	x	x	x			
Port Angeles	WA	x	x										
Columbia River	WA	x	x	x	x	x	x	x	x	x	x	x	x
Newport	OR	x											
North Bend	OR	x	x	x									
Humboldt Bay	CA	x	x	x	x	x							
San Francisco	CA	x	x	x	x	x	x	x	x	x	x	x	x
Point Mugu	CA	x	x										
Ventura	CA	x	x	x	x								
Sacramento	CA	x	x	x									
San Diego	CA	x	x	x	x	x	x	x	x				
Corpus Christi	TX	x	x	x	x	x							
Houston	TX	x	x	x	x	x	x	x	x	x	x	x	x
New Orleans	LA	x	x	x	x	x	x	x	x	x	x		
Mobile	AL	x											
Clearwater	FL	x	x	x	x								
Miami	FL	x	x	x	x	x	x	x	x	x	x	x	x
HITRON	FL	x											
Savannah	GA	x	x										
Charleston	SC	x	x	x	x	x							
Elizabeth City	NC	x	x	x	x	x	x	x	x	x	x	x	x
NCRAD	MD	x											
Washington	DC	x											
Atlantic City	NJ	x	x										
Cape Cod	MA	x	x	x	x	x	x	x	x	x	x	x	x
Detroit	MI	x	x										
Traverse City	MI	x	x	x	x	x	x	x	x	x	x	x	x
Cleveland	OH	x	x	x									
Waukegan	IL	x	x	x	x	x	x						
Muskegon	MI	x											
OPBAT	Bahamas	x	x	x	x	x	x						
Borinquen	PR	x	x	x	x	x	x	x	x	x			
Mission Coverage Percent:		96.2%	96.2%	96.2%	96.2%	96.2%	96.2%	95.8%	94.9%	93.1%	92.5%	87.9%	85.4%

Combining Auction F's results for the Defiant X aircraft with results from Auctions A through E (Table 17) for the Jayhawk created Table 20.

Table 20: Auctions A through F Results

(*Auction E Results do not list 3 additionally prioritized locations: Sunny Pt, NC; Portland, ME; & Buffalo, NY)

		Auction							
AirStation Name	State	A	B	C	D	E*	F	Common Inclusion	Common Exclusion
Barbers Point	HI	x	x	x	x	x	x	Yes	
Guam	GU	x							
Kotzebue	AK	x							
St Paul	AK	x							
Cold Bay	AK	x							
Kodiak	AK	x			x				
Cordova	AK	x							
Sitka	AK	x		x					
Port Angeles	WA								Yes
Columbia River	WA	x	x	x	x	x	x	Yes	
Newport	OR								Yes
North Bend	OR								Yes
Humboldt Bay	CA								Yes
San Francisco	CA	x	x	x	x	x	x	Yes	
Point Mugu	CA	x							
Ventura	CA								Yes
Sacramento	CA								Yes
San Diego	CA	x	x	x	x	x			
Corpus Christi	TX	x	x	x	x	x			
Houston	TX						x		
New Orleans	LA	x	x	x	x	x			
Mobile	AL								Yes
Clearwater	FL	x	x	x		x			
Miami	FL	x	x	x	x	x	x	Yes	
HITRON	FL								Yes
Savannah	GA								Yes
Charleston	SC	x	x	x	x				
Elizabeth City	NC	x	x	x	x		x		
NCRAD	MD								Yes
Washington	DC					x			
Atlantic City	NJ								Yes
Cape Cod	MA	x	x	x	x		x		
Detroit	MI								Yes
Traverse City	MI	x	x	x	x	x	x	Yes	
Cleveland	OH	x	x	x	x				
Waukegan	IL								Yes
Muskegon	MI								Yes
OPBAT	Bahamas	x			x				
Borinquen	PR	x	x	x	x	x			
Mission Coverage Percent		87.8%	89.1%	88.7%	87.7%	90.0%	87.9%		
Total Number of Locations:		23	14	15	15	14*	8		

Reviewing Table 20 finds certain commonalities between Auctions A through E for the Jayhawk, and Auction F for the Defiant X. Specifically, each of the 6 auctions prioritized Barbers Point, HI; Colombia River, OR; San Francisco, CA; Miami, FL; and Traverse City, MI as good locations for Air Stations. One significant difference between Auction F, and Auctions A through E: Auction F prioritized Houston, vice Corpus Christi and New Orleans. Auction F similarly deprioritized all the same 14 locations which Auctions A through G deprioritized.

Auction F Conclusions

As the results of the FVL-MS acquisition program will not be known for a few years, the results of Auction F should be taken with some skepticism. It is not known if the Defiant X will replace the Jayhawk, or even if the replacement will be capable of responding to missions at a radius of 384 NM. Much will change in 26 years potentially including more use of unmanned aerial vehicles, more dispersed construction, and use of vertiports around the coastlines, or increased partnership between federal, state, and local governments. Therefore, this thought experiment into the future should not be seen as recommendations to deprioritize, defund, or otherwise dismantle the 31 locations Auction F de-prioritized. Changes in the future could make them valuable for unforeseen reasons. This logic, following the trends found in Chapter 3 and Figure 12, however, does recommend performing similar Auctions for any aircraft under consideration for future acquisition, and to seek out commonalities between auctions for its global assignment, and global assignment of the Jayhawk. Once common locations are identified between Jayhawk auctions and candidate future aircraft auctions, those locations should be considered for investment with long-life facilities with lifecycles 50+ years, so that they can support the Jayhawk fleet and its replacement fleet. Even if the CG can conclusively determine that it will require the next generation of aircraft to have an increased mission range, then this idea of an auction to help future proof the CG's aviation footprint could yield significant future savings.

Chapter 9: Conclusions, Recommendations and Future Work

Conclusions

This study of the costs and merits of different global assignment Concepts for the CG's future 'All Jayhawk' Fleet as well as the different satellite Aviation Support Constructs created a model that helps understand the tradeoffs between geographic coverage, Support Constructs, and overall costs. In addition to answering the Research Questions, the following conclusions were found.

A historical review of the history of CG RW aircraft and aviation facilities revealed trends that the CG has been growing its portfolio of satellite aviation facilities since 1980. Conversely, the CG has eliminated a net of five Air Stations since 1988, three of them purposefully eliminated for reasons to consolidate mission capabilities with other regional Air Stations. Plotting these changes alongside the growing RW aircraft range capabilities over the past 50 years decades showcases possible correlation between these facility trends and RW aircraft capabilities, and a possible predictor for the future. While this does not prove correlation due to a limit on data points, this demonstrates that the CG has the capacity and decision-making ability to open or close Air Stations as situations evolve.

The results of all six Auctions resulted in five commonly prioritized locations: Barbers Point, HI; Colombia River, OR; San Francisco, CA; Miami, FL; and Traverse City, MI. This indicates that these locations are priorities based on six different sets of objective criteria, including Auction E which considered 23 new locations, and Auction F which prioritized locations for the Defiant X aircraft. As such, these five common locations should be considered not only for Jayhawk assignments, but also for long term investments which may have a 26+ year lifecycle, for example, permanent 'brick and mortar' hangars, and capital utility maintenance projects.

The value propositions for each location considered were summarized and are shown in Tables 21 and 22. These two tables list and compare the unique and maximum mission coverages, capital construction costs to enable an Air Station with three Jayhawks, and the results from Auctions B and E. As a reminder, Auction B was created with the objective criteria of seeking the baseline mission coverage percent with the lowest possible 26-yr NPV cost, and Auction E was run with 19 additional locations and a simpler cost model. The "Unique Mission Coverage" percentages in column three describe the percentage of missions achievable only by that location. For example, even though Port Angeles and Tacoma, WA are only 66 NM apart, there were no missions from FY12-FY21 which could only have been achieved by either of those locations. In fact, even though Air Station Columbia River (located in Astoria, OR) is 83 NM SW of Tacoma, WA, Jayhawks range rings around Columbia River are large enough to cover all but two missions from FY12-FY21 which are covered by Tacoma and Port Angeles, WA. Thus, the Unique Mission Coverage Percents listed in Tables 21 and 22 should be reviewed by the CG, and any location with a Unique Mission Coverage Percent higher than its geographic neighbors should be strongly considered for retention and investment. The "Maximum Possible Mission Coverage" percentages in column 4 describe the maximum coverage capabilities of the locations. These figures assume that each location would respond to all missions within their Jayhawk range rings, even if nearby aviation locations were closer. Tables 21 and 22 also list the capital costs required to upgrade each location to a full-service Air Station with three Jayhawks. Note that all existing locations require less capital construction investment due to their current existence. Clear trends are found when comparing these metrics in Tables 21 and 22 to the results of Auctions B and E. Auctions B and E regularly prioritized locations with regionally high 'Maximum Possible Mission Coverages,' more-so than the locations with the lowest required capital construction costs.

Table 21: Aviation Location Value Propositions: Pacific & West Coast Regions

(Colors Scaled from Green to Red, from Good (higher mission coverage or low costs) to Bad)

City	State	Unique Mission Coverage %	Maximum Possible Mission Coverage %	Capital Construction Cost for a 3x Jayhawk Air Station ($ Millions)	Prioritized by Auction B (Concept #53)?	Prioritized by Auction E?
Barbers Point	HI	0.0000%	2.4907%	$0	x	x
Joint Base Pearl Harbor	HI	0.0000%	2.5117%	$215	Not considered	
Hilo	HI	0.0287%	2.0218%	$287	Not considered	
Guam	GUA	0.5802%	0.6879%	$299		
Kotzebue	AK	0.0550%	0.0658%	$193		
Bethel	AK	0.0353%	0.0849%	$271	Not considered	
Elmendorf AFB	AK	0.0000%	0.4911%	$207	Not considered	
Eareckson AFB	AK	0.0209%	0.0329%	$271	Not considered	
Dutch Harbor	AK	0.0078%	0.2429%	$221	Not considered	
St Paul	AK	0.0239%	0.0652%	$271		
Cold Bay	AK	0.0359%	0.2793%	$196		
Kodiak	AK	0.2369%	0.5623%	$0		
Cordova	AK	0.0036%	0.4803%	$179		
Sitka	AK	1.1180%	1.2914%	$27		
Port Angeles	WA	0.0000%	7.7252%	$13		
Tacoma	WA	0.0000%	8.8773%	$120	Not considered	
Columbia River	OR	0.0012%	9.8905%	$22	x	x
Newport	OR	0.0000%	8.3993%	$109		
North Bend	OR	0.0006%	6.9703%	$13		
Humboldt Bay	CA	0.0012%	8.8731%	$28		
Travis AFB	CA	0.0000%	9.5490%	$128	Not considered	
San Francisco	CA	0.0012%	9.4060%	$14	x	x
Point Magu	CA	0.0000%	4.0555%	$95		
Ventura	CA	0.0000%	4.0555%	$39		
Sacramento	CA	0.0000%	9.4658%	$39		
Vandenberg AFB	CA	0.0048%	8.5447%	$120	Not considered	
San Diego	CA	0.0203%	3.1032%	$0	x	x

Table 22: Aviation Location Value Propositions: Gulf Coast, East Coast, Caribbean & Great Lakes Regions

(Colors Scaled from Green to Red, from Good (higher mission coverage or low costs) to Bad)

City	State	Unique Mission Coverage %	Maximum Possible Mission Coverage %	Capital Construction Cost for a 3x Jayhawk Air Station ($ Millions)	Prioritized by Auction B (Concept #53)?	Prioritized by Auction E?
Corpus Christi	TX	0.5168%	3.9191%	$0	x	x
Houston	TX	0.0227%	4.0310%	$46		
New Orleans	TX	0.0586%	6.3805%	$36	x	x
Mobile	AL	0.0245%	6.3465%	$0		
Clearwater	FL	0.0156%	13.6709%	$0	x	x
Key West NAS	FL	0.0401%	11.2795%	$99	Not considered	
Miami	FL	0.0993%	13.0315%	$0	x	x
St Augustine	FL	0.0036%	9.5645%	$91	Not considered	
HITRON / Jacksonville	FL	0.0000%	9.0346%	$91		
Savannah	GA	0.0000%	4.9988%	$27		
Charleston	SC	0.0000%	4.8804%	$89	x	
Sunny Point	NC	0.0072%	6.1060%	$91	Not considered	x
Elizabeth City	NC	0.0311%	9.1787%	$0	x	
NCRAD	MD	0.0000%	12.7563%	$81		
Washington	DC	0.0006%	12.5224%	$16		x
Baltimore	MD	0.0000%	13.0087%	$152	Not considered	
Atlantic City	NJ	0.0048%	15.3786%	$0		
Brooklyn	NY	0.0000%	16.9919%	$152	Not considered	
Quonset Pt ANG Base	RI	0.0000%	14.6764%	$119	Not considered	
Cape Cod	MA	0.0108%	13.5411%	$0	x	
Portland	ME	0.2153%	9.0687%	$106	Not considered	x
Detroit	MI	0.0000%	9.4353%	$34		
Traverse City	MI	0.1184%	8.3922%	$12	x	x
Cleveland	OH	0.0269%	7.0409%	$102	x	
Buffalo	NY	1.0157%	7.5296%	$116	Not considered	x
Duluth	MN	0.4546%	0.7752%	$113	Not considered	
Waukegan	IL	0.0251%	5.5856%	$118		
Muskegon	MI	0.0000%	9.1494%	$97		
OPBAT	Bahamas	0.0323%	0.1998%	$103		
Borinquen	PR	1.7694%	2.1115%	$0	x	x
Guantanamo Bay Navy Base	Cuba	0.0054%	0.1693%	$219	Not considered	

Summary of Research Questions

1) *Which assignment set of aircraft to legacy facility locations represents the best distribution from which to allocate aircraft. Are there less expensive current locations which can provide the same or similar levels of capability as current locations with higher costs?*

Allocation Auctions A through E produced five resultant global assignment lists for the Jayhawk fleet, based on differing objective criteria. Of those, Auction B, Trial 12 (Concept #53) achieved the lowest NPV for the 26-year lifecycle of the Jayhawk fleet, while also exceeding the minimum mission coverage of 87.08%. Based on the established objective metrics of costs and capabilities alone, this Concept was the best assignment set found through this Auctioning technique. Reviewing the relative costs of differing areas, Concept #53 in fact prioritized the legacy locations with the highest costs on each coastline (San Francisco and San Diego on the West Coast, New Orleans and Miami on the Gulf Coast, and Cape Cod & Elizabeth City on the East Coast. It is notable that Concept #53, has a 26-year estimate of $5,620M, while the Coast Guard's notional proposal for the All-Jayhawk fleet, Concept #26 in this model, has a NPV of $8,730M (55% more expensive).

2) *Are there any facility locations which could be closed with minimal effect on mission performance or capabilities, with the disestablishment objective being cost savings?*

Yes, Concept 53 (Auction B, Trial 12, see Figure 26), the best-found Concept for assignment of the All-Jayhawk fleet, was able to achieve the threshold minimum mission coverage percentage with only 14 locations, 25 fewer than the status quo. If political constraints were incorporated as objective criteria, as in Auction D, then the threshold mission coverage could still be achieved with only 15 locations (24 locations closed). Reviewing the first rounds of Auction B, which considered costs and mission capabilities only, the 10 least valuable aviation locations from a cost per mission perspective included (ranked, beginning with least valuable): Newport, OR; Savannah, GA; Point Mugu, CA (separate from the Ventura location); Washington, DC; Muskegon, MI; Sacramento, CA; Port Angeles, WA; Jacksonville, FL (HITRON); North Bend, OR; and Joint Base Andrews, MD. These ten locations are listed in Table 23, along with their Unique Mission Coverage Percentages, and their estimated capital construction and annual operating costs if assigned as three-Jayhawk Air Stations; indicating significant total savings if eliminated. It is notable that none of these ten locations has a Unique Mission Coverage percentage over 0.0006% (See Tables

21 and 22). With these ten locations closed, and Jayhawks at all other legacy locations, in addition to two newly considered locations (Guam, and Cleveland, OH), the fleet would achieve a mission coverage of 94.87%, more than the 87.08% the current mixed fleet achieves. Reminder that this value ranking does not include RWAI missions in defense of the Capital (NCRAD location).

Table 23: Costs and Unique Coverages of Auction B's 10 Least Valuable Locations

(All Assumed to be three-Jayhawk 'Air Stations')

City	State	Unique Mission Coverage %	Capital Construction Cost for a 3x Jayhawk Air Station ($ Millions)	Annual Operating Costs ($ Millions/ Year)
Port Angeles	WA	0.0000%	$13	$36
Newport	OR	0.0000%	$109	$39
North Bend	OR	0.0006%	$13	$38
Point Magu	CA	0.0000%	$95	$31
Sacramento	CA	0.0000%	$39	$32
HITRON / Jacksonville	FL	0.0000%	$91	$25
Savannah	GA	0.0000%	$27	$24
NCRAD	MD	0.0000%	$81	$29
Washington	DC	0.0006%	$16	$32
Muskegon	MI	0.0000%	$97	$26
	Totals:	0.0012%	$581	$312

3) *Are there new facility locations which could be established which might significantly improve mission capabilities or reduce costs?*

Yes, Auction E considered 21 new locations, ideated based on SME interviews and their low costs. Auction E's result (Trial 13) prioritized Buffalo, NY; Sunny Point, NC; and Portland, ME, in addition to 11 legacy locations (See Table 17). Examining the merits of Buffalo as an example, it was prioritized over nearby Detroit and Cleveland in Auction E, likely due to it having a Unique Mission Coverage of 1.01%, much higher than the 0% of Detroit, and the 0.02% of Cleveland (see Table 22). Reviewing the coverage of Buffalo, NY, is likely that most of its unique mission coverage comes from mission on Lake Ontario, out of reach from any other location (see Figure 28). Similar situations are found in Table 22 for Sunny Point, NC and Portland, ME. It is notable that these three locations are respectively nearby to three legacy locations which Auction E unprioritized: Detroit, MI; Elizabeth City, NC; and Cape Cod, MA, respectively.

4) *Of the current and organically developed models for satellite or forward operating aircraft deployments, including Forward Operating Bases, Forward Operating Locations and Air Facilities, do any achieve superior value at cost? Should any satellite locations be upgraded to full-service Air Stations? Should any full-service Air Stations locations be downgraded to satellite locations, and if so, to which Support Construct?*

The FOB model was found to be superior to FOLs and AIRFACs, based on the established objective criteria of mission capability and 26-yr NPV cost. One significant reason for this is due to the low TDY costs it incurs, as air crews and facilities maintenance/operations crews live in the same location and do not require per diem funding. This annual savings stands in contrast to the elevated capital costs required at FOBs to construct additional office and other support space to support the facility and aircraft. Yes, per Concept #53, the Concept found closest to the utopia point, FOL Charleston is recommended to be upgraded to a full-service Air Station. Per Concept #53, no locations are recommended to be operated as satellite unit status. One significant reason for this is the fuel costs required to transport helicopters to and from FOLs to their parent units on a biweekly basis. As the Auctions eliminated aviation locations, remaining locations became further and further apart. With operating satellite units requiring biweekly round trips over longer and longer distances, their operations become more and more expensive. Additionally, the use of satellite units significantly increases the required capital construction costs, as they require duplicate hangar space at both the satellite unit where aircraft will be staged, and at the 'parent' Air Station where they will be maintained. It is suspected that this result may be different if similar Auctions are run with differing objective criteria.

5) *This research will also exercise this model and auction technique for a similar objective to support the future replacement of the MH-60 Jayhawk in the mid 2050's. This research will consider specifically, the Sikorsky-Boeing Defiant X helicopter, a hypothetical possible replacement for the Jayhawk aircraft which is slightly larger and boasts a more capable range and speed. Under this hypothetical, are there investment decisions that could be co-optimized for both the near future 'All-Jayhawk' fleet, and a potential future Defiant X fleet?*

Yes, Auction F was run with 384NM range rings, representing possible future CG acquisition of the Sikorsky-Boeing Defiant X Helicopter, a potential Jayhawk replacement. Auction F was run with a simplified cost estimation model due to the uncertainties with cost estimates in 26+years in the future. Auction F prioritized eight locations including the above mentioned five common locations, along with Houston, TX; Elizabeth City, NC; and Cape Cod, MA. If the CG can confirm at least that it intends to acquire a future aircraft capable of range rings near to 384NM, then it can be confident that any long-term investment like a permanent hangar or major campus utility system at these eight locations replacement will continue to provide value to the CG after the Jayhawk fleet is retired.

Recommendations

The CG is recommended to use this auction technique and mission-cost model to assist with making assignment decisions for the future All Jayhawk fleet. With this model and auction technique, the CG has the ability to achieve similar levels of mission coverage as they have today, but at 45% of the cost of the notional plan's cost (Concept #53). Specifically, the CG should consider disestablishment of aviation locations which do not uniquely contribute to mission capabilities like Newport, OR; Muskegon, MI; and Savannah, GA. All missions from Fiscal 2012-2021 within a 210 NM radius of these locations were able to be completed by other aviation locations at less cost. While Newport, OR and Muskegon, MI are currently FOLs, the Savannah, GA location is a full-service Air Station, closure of which may create hesitation. It is important to note that the Savannah location could only be closed in this scenario if the nearby Charleson, SC location were maintained and upgraded to support three or more Jayhawks, as its current hangar cannot support even one Jayhawk (See Table 20, Auction B-Trial 12) (Henderson, McClain, Converse, & Henkelman, 2022, p. 8). In comparison to operating Newport and Muskegon as FOLs with one aircraft, and Savannah as an Air Station with three aircraft, closure of these three locations would result in savings of $50M, $40M, and $39M per year in operating costs. Closure of these three locations in comparison to the same counterfactual would avoid $13M, $11M, and $27M in capital construction costs. Again, it is noted that Concept #53 prioritizes upgrading Air FOL Charleston, SC to a full-service Air Station, at costs of $89M in capital construction costs and $31M in annual operating costs. However, the CG is not recommended to make changes like this on a one-by-one basis, it must carefully review how changes like this would impact the entire global assignment set, before finalizing decisions.

The CG should also consider making long term investments into new and potentially more strategic locations, for example Cleveland, OH, Buffalo, NY; Sunny Point, NC; or Portland, ME (See Table 17, Auction E). While capital construction costs are high for these new locations ($102M, $116M, $91M and $106M respectively), they provide superior mission coverage than their nearby legacy locations. Enabling better value at cost, these locations could replace legacy locations like Detroit, MI; Elizabeth City, NC; or Cape Cod, MA (See Figure 28).

Through this model, the CG can also apply refined, confidential, or non-publicly available objective criteria to create auction results more applicable to the CG's actual strategy. Even with SME interviews, it was challenging to parse out the CG's actual objective priorities to base auctions on. Objective criteria are of utmost importance, as they steer assignment problem auctions towards their conclusions. And while the CG has published strategies, nowhere do they rank or contrast priorities, which may include minimizing costs, maximizing mission capabilities, minimizing political friction, minimizing deployment times, or changing the number of satellite aviation units. The CG may also apply unique objective criteria like prioritizing facilities that co-locate aviation and boat locations like Port Angeles, WA, Kodiak, AK or Cape Cod, MA. Once objective criteria are more defined, the Auction technique will create results more tailored to the CG's actual strategy.

The CG could also re-run this auction technique on a more granular basis, auctioning one helicopter off at a time, rather than one location at a time as ran in Chapter 7. This would essentially run the auction with the locations as sources and the Jayhawks as sinks, rather than vice versa. If auctioned in this fashion, this technique may produce a more detailed best-found set of assignments, possibly resulting in a more dispersed fleet.

It is recommended that the CG also refine and utilize this auction technique and mission-cost model, with updated data and cost estimating information. Specifically, this model should be refined once staffing or facilities footprint standards are determined for aviation units with different numbers of Jayhawks. Incorporating these standards would improve upon the empirical techniques used by this model for cost estimating.

Future Research

This research and the model built were based on valid costs, variables, and objective criteria. But additional costs, variables, and objective criteria exist which, if added to this model, could result in different results. Additional costs, not modelled by this thesis include those associated with aviation maintenance at the different aviation units and based on the different numbers of assigned Jayhawks and varying healthcare costs in different locations. Additional variables not incorporated into this research include accounting for the costs of investing into facilities in regions prone to natural disasters like fires, earthquakes, or hurricanes, whether aircraft are stored with their blades folded or how the impact of simultaneous missions in the same general location would impact the model. Future research could expand this model based on these or other costs, variables, or objective criteria for the same Coast Guard topic.

Future research could also expand on this model by adjoining it with other similar federal, state, or local agencies. Modeling in partnership with other agencies, like the Customs and Border Patrol or State National Guards would seek out efficiencies for shared aviation missions like search and rescue and law enforcement. Further research could also repurpose this same model for use for non-aviation subjects, for example emergency services located across a large city, Coast Guard small boat stations which dot America’s coastlines with unique histories, or national guard installations in a large state.

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