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Assessing National Airspace System Impact of the Hybrid Electric Turboprop Commercial Freighter

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Assessing National Airspace System Impact of the Hybrid Electric Turboprop Commercial Freighter

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The Hybrid Electric Turboprop Commercial Freighter (HETCOF) is a large turboprop aircraft using hybrid electric propulsion designed to reduce cost and emissions for narrowbody cargo operations capable of carrying 35,000 lb up to 2,400 NM. This paper analyzes a day of high-volume traffic identifying cargo aircraft as potential candidates for replacement with HETCOF, many of which require more than one HETCOF to replace aircraft with greater payload capacity. Then NASA's National Airspace System Digital Twin is used to perform fast-time simulations to assess the fuel and energy savings and impact to flight time and airport operations. Of three aircraft replacement groups considered, the group designed to maximize energy savings (19% compared to baseline, totaling to 6.15 GWh) also enabled the greatest percent fuel savings (36% totaling to 2.15 Mlb) without negatively impacting airport operations. This group replaced 401 existing aircraft cargo flights with 822 HETCOF flights carrying the same aggregate payload. With a long-range cruise speed roughly half that of the aircraft replaced, the HETCOF flight times are roughly double. The additional fight time required departure schedule adjustments for about a third of the replaced flights to maintain reasonable cargo aircraft turn times between flights performed by the same tail. Overall, these results support HETCOF as a promising aircraft concept for further study.

I. Nomenclature

A306 = Airbus 306
B738 = Boeing 737-800
B752 = Boeing 757-200
B762/3 = Boeing 767-200/300
BADA = Base of Aircraft Data
BTS = Bureau of Transportation Statistics

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FDX = FedEx Express Airlines
GASP = General Aviation Synthesis Program
HETCOF = Hybrid Electric Turboprop Commercial Freighter
IFF = Integrated Flight Format
MD11 = McDonnell Douglas MD-11
MEM = Memphis International Airport
NAS = National Airspace System
PMTG = Point Mass Trajectory Generator
SDF = Louisville Muhammad Ali International Airport
TAS = True Air Speed
UPS = United Parcel Service Airlines

II. Introduction

NASA is working with industry partners to verify and validate new aircraft concepts designed to reduce energy use, emissions, noise, and transportation costs thereby broadening the accessibility of air transportation to the public and creating U.S. jobs [1]. The Hybrid Electric Turboprop Commercial Freighter (HETCOF) [2] is a large turboprop aircraft using hybrid electric propulsion designed to reduce cost and emissions for narrowbody cargo operations. HETCOF market analysis shows potential for competition in market space currently served primarily by conversion narrowbody freighters [3]. To further understand the fleet-wide impact of introducing HETCOF into the National Airspace System (NAS), detailed simulation of various NAS-wide aircraft replacement strategies is needed [4]. Prior NAS-wide analysis of hybrid electric aircraft operations relied on existing models of conventional aircraft types and an assumed percent reduction fuel consumption when made hybridized to estimate NAS-wide impact [5]. More recently, a high-fidelity model of a conceptual combustion engine aircraft was integrated into NAS-wide simulation to produce a more accurate NAS-wide fuel savings estimate [6]. These methodologies and metrics have been merged and extended to incorporate high-fidelity hybrid electric aircraft models into NAS-wide simulation. This paper presents a NAS-wide impact assessment simulating HETCOF replacement of aircraft types of select cargo flights from a historical day of traffic.

III. Flight Scenario

This study simulates and compares the results from two flight scenarios, a *baseline* scenario of a day of historic flight traffic in the U.S., and a *replacement* scenario which substitutes the aircraft types of select cargo flights with HETCOF aircraft. The baseline flight scenario consists of a high volume, low weather impact day (7/11/2024) of NAS-wide flights departing within 24 hours, starting at 0:00 UTC. Each flight in the scenario must include origin and destination airport, aircraft type, cruise altitude and True Air Speed (TAS), a sequence of latitude/longitude waypoints constituting a route, and a departure time relative to the start of the simulation. These and other data facilitating processing and filtering were extracted from Integrated Flight Format (IFF) data from NASA's Sherlock Data Warehouse [7]. Flights were filtered if their aircraft type or origin or destination airport was unrecognized, departure time was outside the 24-hour time range, or parsed route errors were detected. After analysis of flight networks associated with the same tail number, detected flight duplicates were removed and missing flights added. The original 52,326 IFF flights were processed into the final 41,451 flight baseline scenario. For more details on baseline scenario development, the reader is referred to a previous NAS-wide impact assessment [6] utilizing the same baseline scenario.

The baseline scenario is analyzed to identify candidate cargo flights for aircraft type replacement with HETCOF based on a maximum flight range of 2,400 NM and a maximum payload of 35,000 lbs. A flight's range is the distance along its route extracted from its flight plan. Only baseline flights with route distance within the HETCOF maximum design range of 2,400 NM may have their aircraft type replaced. However, this is a *segment* specific requirement. Because the same tail number may fly multiple flights in a day, a *network* requirement may be applied such that each flight within a tail's network must be within 2,400 NM to be eligible for aircraft type replacement. This method of analyzing tail *network* replacement vs flight *segment* replacement was developed and implemented in previous work [6] to enhance the real-world applicability of replacing aircraft in an existing fleet.

Baseline flight payload is estimated for each aircraft type based on Bureau of Transportation Statistics (BTS) data. BTS T-100 Segment data [8] includes number of departures performed and transported passengers, freight, and mail segregated by non-stop segment (city pair), aircraft type, and carrier. First T-100 Segment (US Carrier Only) data from 2024 is filtered to just segment city pairs within 2,400 NM of one another, transporting cargo weight (freight + mail) > 0 and passengers = 0. For each (segment, aircraft type, carrier), the per flight cargo payload weight is estimated as total pounds of transported freight and mail divided by the number of departures performed. Figure 1 shows 2024 cumulative distributions of cargo payload per flight for all cargo carrying aircraft types found in the baseline scenario capable of exceeding half the HETCOF maximum payload. For each aircraft type, the 90th percentile cargo payload weight (highlighted in yellow and tabulated to the right) is selected as the simulated payload weight for that aircraft type. All aircraft types with 90th percentile payload below 40,000 lb except A333 are narrowbody jets. A333 and all higher payload aircraft types are widebody jets.

Any aircraft type exceeding the HETCOF maximum design payload would need to be replaced by more than one HTECOF to transport the same total payload. Therefore, an *n*:1 replacement ratio is estimated for each aircraft type where *n* = ceiling(aircraft type payload / HETCOF maximum payload). Figure 1 also shows the replacement ratios required for a HETCOF maximum payload of 35,000 lbs.

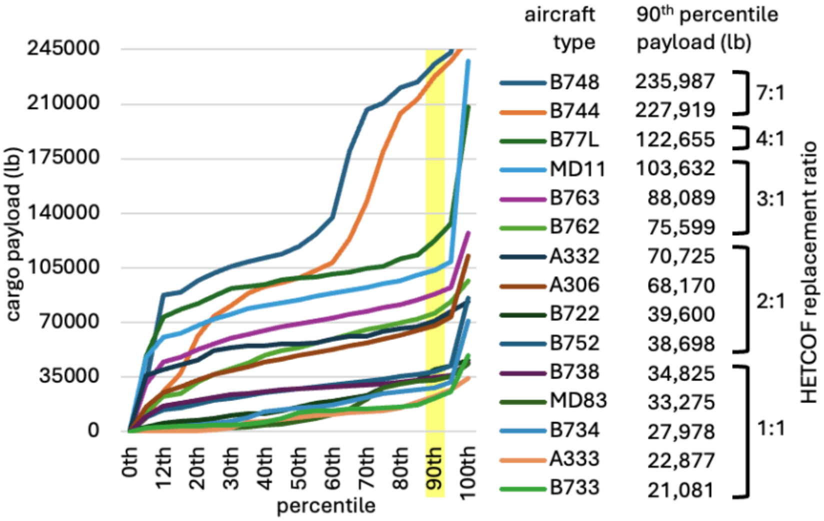

Figure 1. Cumulative distribution of cargo payload per flight per aircraft type

Figure 2 shows numbers of flights and tails per aircraft type found in the 7/11/2024 baseline scenario with segment and network requirement applied. The same tail number may fly multiple flights per day (up to 5 flights per tail for cargo). The number of tails counts the number of unique tail numbers flying the flights specified. The segment case counts all flights and tails for the set of flights with range within 2,400 NM. The network case requires that all flights flown by the same tail have a range within 2,400 NM. The network requirement filters very few flights relative to segment (especially for lower payload aircraft types), indicating that the 2,400 NM maximum design range offers sufficient range flexibility for cargo carriers.

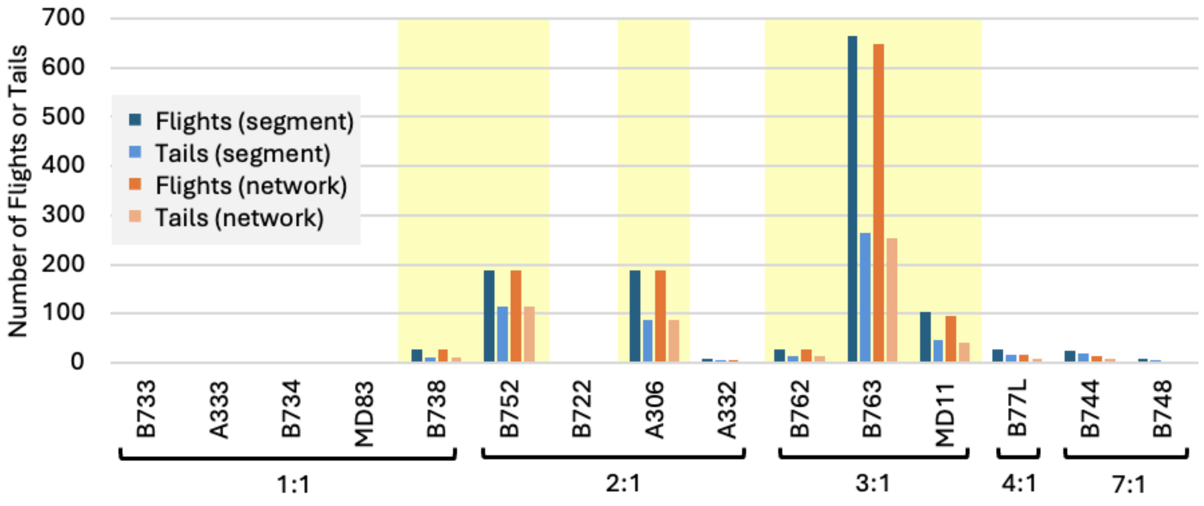

Figure 2. Number of flights and tails for each aircraft type in 7/11/2024 baseline scenario

Six aircraft types (highlighted yellow in Figure 2) were selected for HETCOF replacement in this study because of their relatively high number of flight and low percentage of flights filtered when the network requirement applied. Figure 3 shows the resulting number of network constrained flights (all flights flown by the same tail within 2,400 NM range) performed by one of the two main US cargo carriers (FedEx and UPS) and other carriers per aircraft type. The most numerous aircraft types (B752, A306, B763, MD11) are dominated by FedEx and UPS. Most other carrier flights use B763. All flights in Figure 3 serve as baseline candidates for aircraft type replacement with HETCOF in this study, a total of 1,119 candidates out of 41,451 baseline flights.

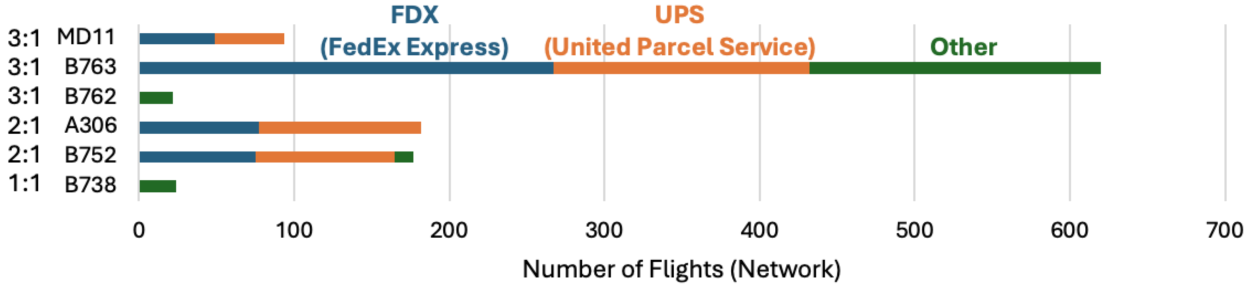

Figure 3. Number of network constrained flights per air carrier and candidate aircraft type

IV. Modeling and Simulation

NASA's National Airspace System (NAS) Digital Twin is a simulation platform for creating realistic simulations of aircraft and airspace systems [9]. NAS Digital Twin's Point Mass Trajectory Generator (PMTG) uses physics-based aircraft models to generate high fidelity trajectories and fuel burn estimations. This study utilized two sources of aircraft models, Base of Aircraft Data (BADA) and Gascon. BADA 3.8 from Eurocontrol [10], providing over 115 aircraft performance models that map to over 400 aircraft types in current operation, was used to model all baseline aircraft types. However, BADA 3.8 does not provide models for more recent aircraft types developed since 2010. Therefore, any aircraft type not included in BADA 3.8 was mapped to the closest matching BADA model. Fortunately, BADA 3.8 does include direct models for all candidate aircraft types for HETCOF replacement in this study. Therefore, only a few background traffic aircraft types not replaced by HETCOF needed to be mapped to the closest matching BADA model.

As HETCOF is a conceptual aircraft not yet in operation, NASA's Gascon [11], an advanced Python implementation of the legacy aircraft modeling tool General Aviation Synthesis Program (GASP) [12], was used to model it. The HETCOF Gascon model used in this study builds upon prior development [13]. **Error! Reference source not found.** summarizes the HETCOF design and mission parameters for the Gascon model.

Table 2. HETCOF Design and Mission Parameters

HETCOF Design and Mission Parameters	
Maximum Gross Takeoff Weight (lb)	165,000
Normal Takeoff Weight (lb)	155,000
Empty Weight (lb)	91,635
Wingspan (ft)	132.6
Wing Area (ft^2)	1,745
Aspect Ratio	10.08
Design Cruise Speed & Altitude	M0.325 at 14,000 ft
HETCOF EAP System KPP Level	TRL 1-2 [13]
Battery Energy Available, kWh	11.852
Number of Electric Motors	2 x 3.34 MW
Max. Endurance Range, NM	2,400
Design Hybrid-Electric Range, NM	750

Table 1. HETCOF Assigned Payloads

Baseline Aircraft Type	HETCOF Replacement Ratio	HETCOF Assigned Payload
MD11	3:1	34,544 lb
B763	3:1	29,363 lb
B762	3:1	25,200 lb
A306	2:1	34,085 lb
B752	2:1	19,349 lb
B738	1:1	34,825 lb

Because fuel burn estimation is dependent on aircraft weight, NAS Digital Twin includes the capability to estimate the takeoff weight [14] for each flight based on its payload weight and flight plan (route, cruise altitude, cruise TAS), which was applied to all simulated aircraft that were HETCOF or baseline aircraft replaced by HETCOF. This ensured that each flight caried the appropriate fuel weight required for its mission and enabled fair comparison of fuel burn between the different aircraft types performing the same mission (e.g. HETCOF and the baseline aircraft type it replaced). Each of *n* HETCOF replacement flights were assigned a payload of 1/*n* the payload of the baseline aircraft type according to the *n*:1 replacement ratios and baseline payloads (see Table 2). For example, each B738 flight (1:1 replacement ratio, 34,825 lb payload) was replaced with one HETCOF flight assigned 34,825 lb payload. Each MD11 flight (3:1 replacement ratio, 103,632 lb payload) was replaced with three HETCOF flights each assigned 103,632 / 3 = 34,544 lb payload.

Fuel weight estimates also include reserve mission fuel. Whereas conventional aircraft reserve mission fuel is estimated based on empty weight [14], hybrid electric aircraft may not use the same method due to a large portion of empty weight attributed to batteries. Therefore, NAS Digital Twin utilizes an explicitly defined reserve mission fuel weight for hybrid electric aircraft weight estimation, which was determined to be 2,456 lb for HETCOF. The NAS Digital Twin takeoff weight estimation capability is utilized for only candidate flights with aircraft types replaced by HETCOF. All other aircraft in each scenario were allowed to default to the BADA reference takeoff weight (roughly 60% between empty and maximum takeoff weight).

For hybrid electric aircraft, the throttle energy split between electric and combustion engine propulsion also impacts fuel burn. Three HETCOF throttle energy split configurations were utilized: Short, Medium, and Long -range. Short prioritizes electric propulsion to minimize fuel burn, Long prioritizes combustion propulsion to maximize range, and Medium splits both equally. Depending on its unique payload and flight plan range, each HETCOF replaced flight used the shortest-range throttle energy split configuration manageable without running out of battery charge before landing.

As described in [6], baseline aircraft types are assigned a cruise altitude and TAS based on flight plan and track point data and BADA performance tables. The most common baseline candidate cruise altitudes are between 41,000 and 43,100 ft with cruise TAS between 447 and 459 kts. All replacement HETCOFs are assigned a cruise altitude of 14,000 ft and cruise TAS of 226 kts (~Mach 0.36). This is the cruise altitude and speed where thrust is minimized to satisfy the HETCOF's two gas inboard turbine systems without requiring additional power from the electric powertrain for long range cruise missions up to 2,400 NM.

NAS Digital Twin was configured to collect Aircraft State Messages for each flight every 1 minute, including position (latitude, longitude, and altitude), weight, and battery charge as the flight progresses along its route burning fuel and using electric energy. These data were used to compute impact metrics described in the next section.

Two flight scenarios were run in NAS Digital Twin, the *baseline* scenario described in the previous section, and the *replaced* scenario, replacing the aircraft types of the 1,119 candidate flights shown in Figure 3 with HETCOF carrying a payload appropriately scaled to baseline aircraft type replacement ratio.

V. Results

Four metrics comprised of fuel savings, energy savings, flight time, and airport operations rates were selected to investigate the NAS-wide impact of replacing candidate aircraft types with HETCOF.

A. Fuel and Energy Savings

Fuel savings is calculated on a per-flight basis as total or percent fuel burn difference between *baseline* and *replaced* simulations using the weight (lbs) from the first and last Aircraft State Messages of each flight as follows.

$$Total\_Fuel\_Burn_{f,s} = First\_Weight_{f,s} - Last\_Weight_{f,s} \tag{1}$$

$$Fuel\_Savings_{f} = Total\_Fuel\_Burn_{f,baseline} - n(Total\_Fuel\_Burn_{f,replaced}) \tag{2}$$

$$Percent\_Fuel\_Savings_{f} = Fuel\_Savings_{f} \,/\, Total\_Fuel\_Burn_{f,baseline} \tag{3}$$

where *f* represents a given baseline flight mission, *s* represents a given simulation (*baseline* or *replaced*), and *n* represent the replacement ratio applied to the baseline flight.

Energy savings is calculated similarly by first converting fuel burned to its energy content and adding it to battery charge used to get energy used as follows.

$$Energy\_Conversion = (43.28\,MJ/kg)\left(\frac{1kWh}{3.6MJ}\right)\left(\frac{1kg}{2.20462lb}\right) = 5.4532\,kWh/lb \tag{4}$$

$$Battery\_Charge\_Used_{f,s} = First\_Charge_{f,s} - Last\_Charge_{f,s} \tag{5}$$

$$Energy\_Used_{f,s} = Battery\_Charge\_Used_{f,s} + Energy\_Conversion(Total\_Fuel\_Burn_{f,s}) \tag{6}$$

$$Energy\_Savings_{f} = Energy\_Used_{f,baseline} - n(Energy\_Used_{f,replaced}) \tag{7}$$

$$Percent\_Energy\_Savings_f = Energy\_Savings_f / Energy\_Used_{f,baseline} \tag{8}$$

where 43.28MJ/kg is the typical gravimetric energy content of kerosene jet fuel [15].

Figure 4 and Figure 5 show individual flight percent fuel and energy savings, respectively, vs the track distance flown. Color is used to identify the baseline aircraft type replaced and marker shape identifies the energy split configuration the HECOF flight used. The leading edge of each cluster of flights with the same baseline aircraft type and HETCOF energy split configuration represents the range limit of that energy split configuration for the assigned payload to complete the flight without running out of battery charge. The Short-range limit is where flights start using the Medium rather than Short energy split configuration, which occurs at track distances of ~520-560 NM. The Medium-range limit is where flights start using Long rather than Medium, which occurs at track distances of ~1330-1470 NM. The Long-range is limited only by how much fuel the flight can carry, which is just enough to carry a 35,000 lb payload 2,400 NM plus reserve.

For all baseline aircraft types, there is a substantial decrease in percent fuel savings as we progress through Short, Medium, and Long energy split configurations. All baseline aircraft types replaced show positive fuel savings for Short and Medium configurations. For the Long energy split configuration, HETCOFs replacing B738 and A306 have very similar fuel burn to the flights they replace (~ 0% savings), and HETCOFs replacing other aircraft types burn more fuel (negative percent savings).

Energy savings shows similar trends to fuel savings, only with less pronounced decreases in savings between Short, Medium, and Long energy split configurations. The energy savings is substantially lower than fuel savings for the Short configuration flights prioritizing electric propulsion as battery charge used is taken into consideration in the energy savings calculation. However, the energy savings is almost identical to fuel savings for the Long configuration prioritizing combustion propulsion. All baseline aircraft types replaced still show positive energy savings for the Short configuration. However, HETCOFs replacing B752, B762, and B763 use more energy than the flights they replace in the Medium configuration, even though they burn less fuel. Note that the three aircraft type replacements with greatest savings, B738, A306, and MD11, are also the ones with HETCOF assigned payload closest to the maximum 35,000 lb (see Figure 1 right column).

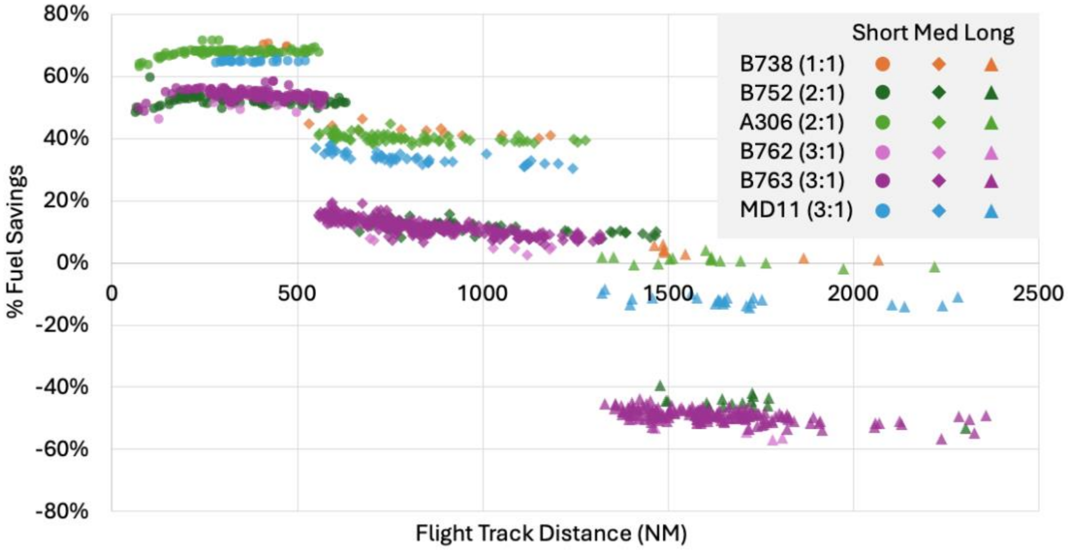

Figure 4. Individual flight percent fuel savings vs track distance by aircraft type and energy split

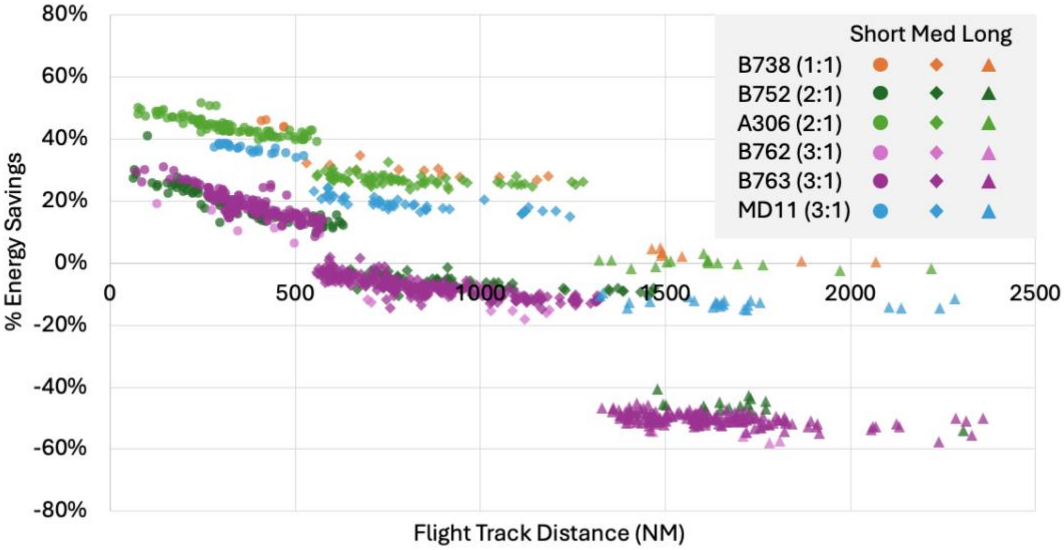

Figure 5. Individual flight percent energy savings vs track distance by aircraft type and energy split

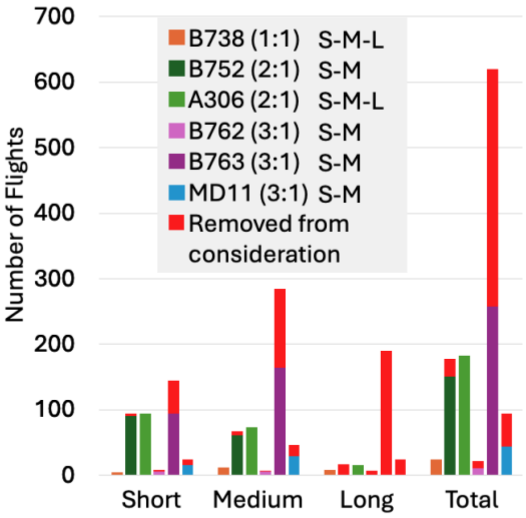

Figure 6. Number of flights by baseline aircraft type and HETCOF energy split

Using more energy may be acceptable if fuel is saved due to the lower cost of electric energy [3] and reduction of CO_2 released. However, it is assumed that B752, B762, B763, and MD11 flights requiring Long HETCOF energy split configuration are not acceptable for replacement due to their consistently negative fuel savings. Therefore, a final set of candidates removes from consideration replacement of all B752, B762, B763, and MD11 flights performed by tails including a flight in the Long configuration. Figure 6 shows the number of final candidates of baseline flights considered for HETCOF replacement, totaling 670 of the original 1119. The red bars represent the numbers of flights that were removed from consideration. The “S-M-L" in the key next to B738 and A306 indicate that all Short, Medium, and Long configuration flights are considered. Note that there is no red portion of the bars representing these aircraft types (no flights removed from consideration). The “S-M" next to the remaining baseline aircraft types indicates that only flights for tails using exclusively Short or Medium configurations (no Long) are considered. Note that in addition to the removal of all Long B752, B762, B763, and MD11 flights, a few Short and Medium flights were also removed because they belonged to a tail that included at least one Long flight.

Figure 7 shows aggregate fuel and energy savings for three replacement groups. The Flight Count on the left illustrates how flight candidates from each baseline aircraft type are combined to form replacement groups. As HETCOF is envisioned for the narrowbody cargo flight market, the Narrow group includes all flights with narrowbody baseline aircraft types B738 and B752. The Energy group includes all flights with baseline aircraft types resulting in mostly positive energy savings, A306 and MD11 in addition to the narrowbodies. The Fuel group includes all flights with baseline aircraft types resulting in mostly positive fuel savings, which adds B762 and B763 to include all 670 of the final candidates. Notice how the Fuel group maximizes aggregate Fuel Savings, and the Energy group maximizes aggregate Energy Savings (Figure 7 center column). However, the Energy group maximizes both % Fuel Savings and % Energy Savings (Figure 7 right column). This is because the Fuel group consists of relatively large number of aircraft with relatively low % Fuel Savings. As the aircraft type with lowest HETCOF assigned payload of 19,349, B752 replacement fuel and energy savings could be greatly improved if the HETCOF maximum payload could be increased from 35,000 lb to ~40,000 lb allowing 1:1 HETCOF replacement of B752. This would substantially improve the performance of the Narrow replacement group as well.

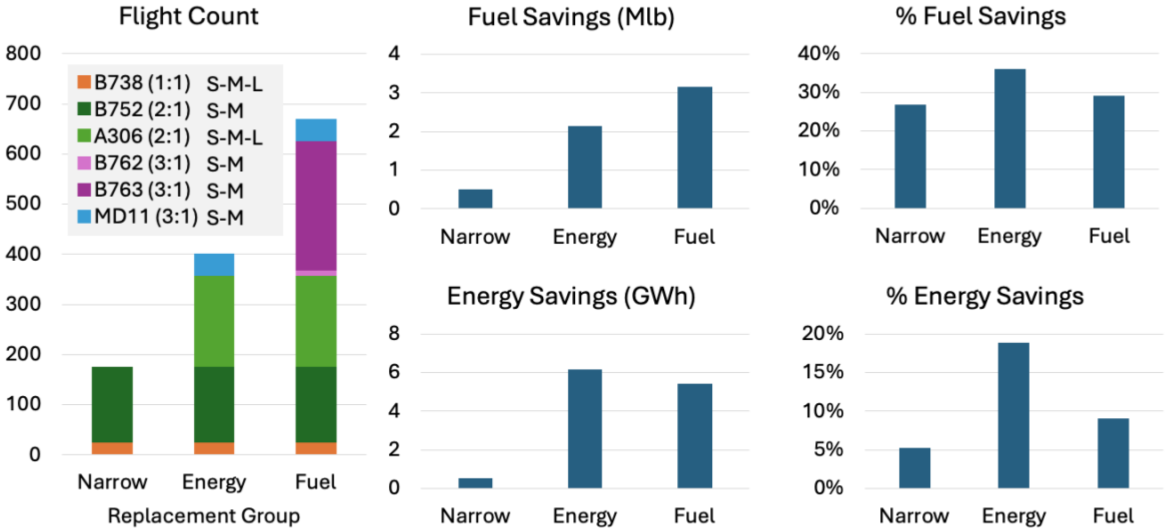

Figure 7. Aggregate fuel and energy savings for Narrow, Energy, and Fuel replacement groups

B. Flight Time

Flight time savings is calculated as the time stamp difference between the first and last Aircraft State Messages of each flight as follows.

$$Flight\_Time_{f,s} = First\_Time\_Stamp_{f,s} - Last\_Time\_Stamp_{f,s} \tag{9}$$

$$Time\_Savings_{f} = Flight\_Time_{f,baseline} - Flight\_Time_{f,replaced} \tag{10}$$

$$Percent\_Time\_Savings_{f} = Time\_Savings_{f} \, / \, Flight\_Time_{f,baseline} \tag{11}$$

Figure 8 shows percent flight time savings vs distance for each flight. As the flight track distance grows and flights spend a greater portion of time in cruise, the percent flight time savings begins to level off to ~ -100% savings indicating that HETCOF flights have roughly twice the flight time as their baseline counterparts. This is not surprising considering that the HETCOF cruise speed is roughly half that of the baseline candidate aircraft types.

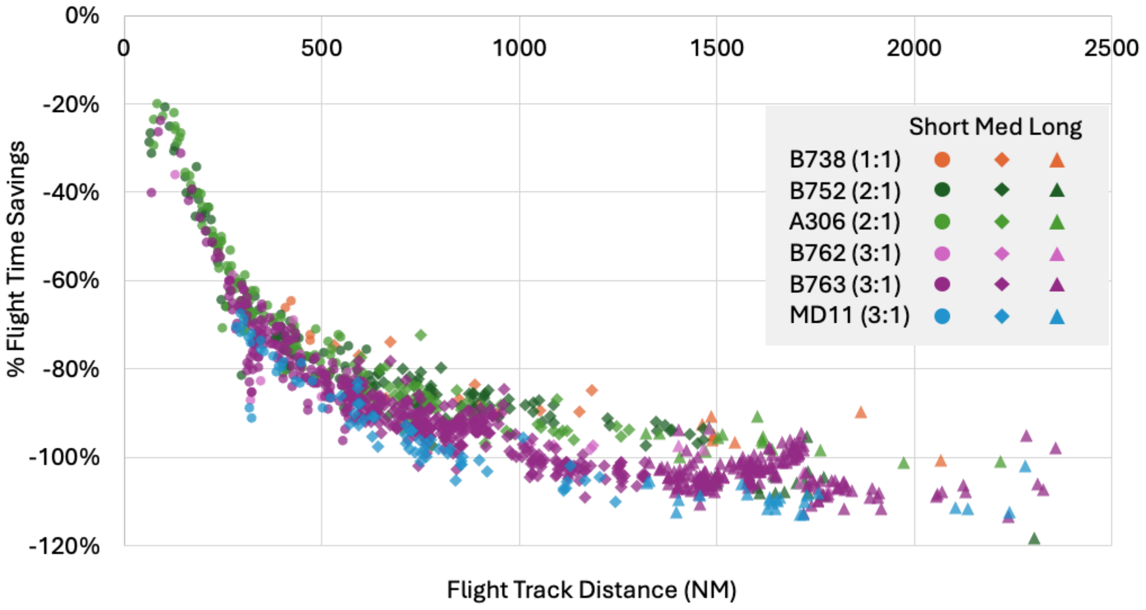

Figure 8. Individual flight percent flight time savings vs track distance by aircraft type and energy split

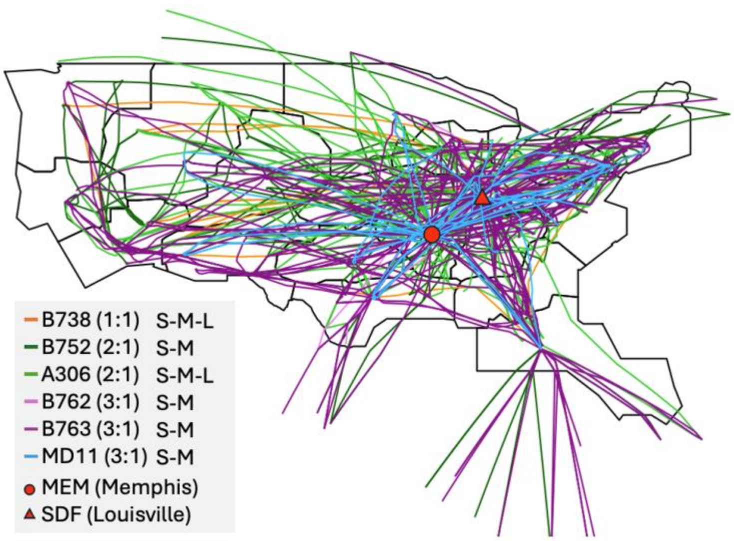

Figure 9. Baseline candidate flight routes and hub airports

Longer flight time may be more acceptable for cargo flights than passenger flights provided a given tail can perform all its flights in sequence with sufficient turn time in between to unload and load cargo, refuel, and recharge. Therefore, the turn times between arrivals and departures of sequentially adjacent flights performed by the same tail were analyzed and adjusted if needed. Figure 10 (a) shows a histogram of baseline turn times segregated into 5-min bins identifying 80 minutes as the most common turn time for baseline flight candidates. Although many baseline turn times are greater than 80 minutes (perhaps related to facility, crew, or ground transportation constraints which we will consider out-of-scope for this analysis), 80 minutes was assumed to be a reasonable minimum turn time for a HETCOF to unload/load cargo and refuel/recharge in between flights. Therefore, a HETCOF departure time was shifted forward if needed to achieve a turn time equal to their baseline counterpart or 80 minutes if the baseline counterpart turn time was greater than 80 minutes. Figure 10 (b) shows a histogram of schedule shifts segregated into 15-min bins required for 192 of the 670 HETCOF flights.

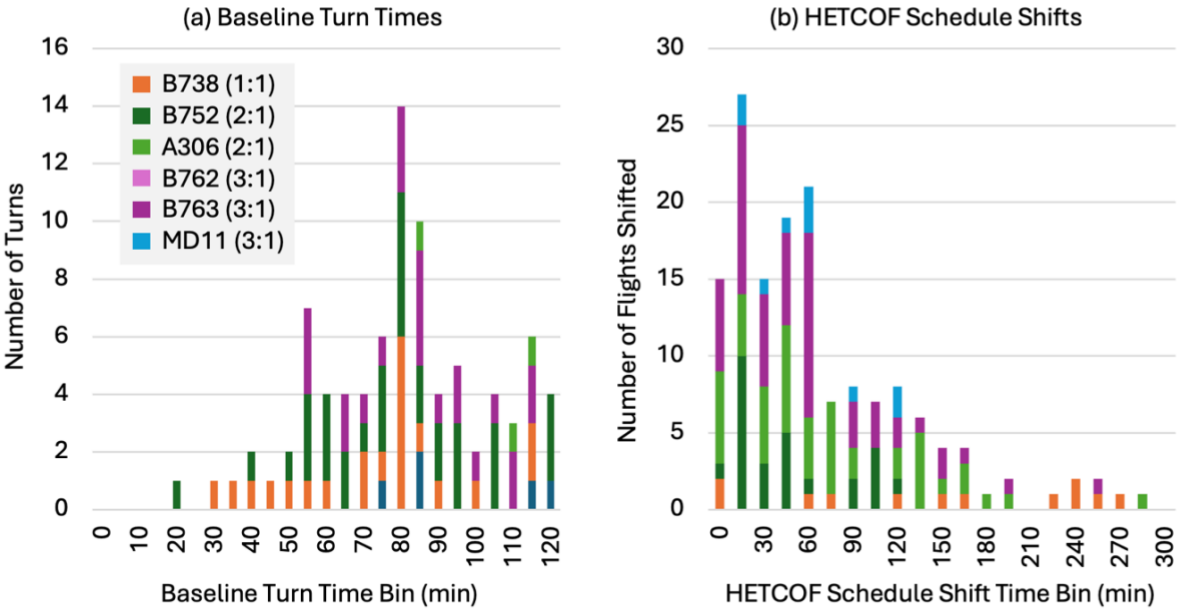

Figure 10. Histograms of baseline turn times (a) identifying 80 min as most common, and HETCOF schedule shifts (b) required to achieve at least baseline equivalent or 80 min turn time.

C. Airport Operations Rates

Figure 10 shows the flight routes along with the locations of the two most common airports utilized by the baseline candidate fights. Memphis International Airport (MEM) and Louisville Muhammad Ali International Airport (SDF) are the global hubs for FDX and UPS airlines, respectively.

Airport operations rates at MEM and SDF are calculated as numbers of operations (departures and arrivals) per hour. The simulated departure and arrival times (first and last flight track point time stamps) of all flights (including background flights as well as replacement candidate flights) are binned by hour and counted for each airport to get total operations per hour. For HETCOF replaced flights, the first HETCOF uses the same departure schedule as its baseline counterpart time shifted if needed as shown in Figure 10 (b). For 2:1 and 3:1 replaced aircraft types, the second and third HETCOF uses the first HETCOF departure schedule shifted backward by 30 and 60 min, respectively. With the additional HETCOF flights imposed by *n*:1 replacement, the Narrow, Energy, and Fuel groups replace 175, 401, and 670 baseline flights with 326, 822, and 1629 HETCOF flights, respectively.

Figure 11 shows hourly airport operations at MEM and SDF for the baseline and the three replacement groups shown in Figure 7. The MEM operations graph also includes colored bands representing airport capacity rate ranges according to [16]. Similar airport capacity rates were not available for SDF. Both airports display similar trends with stronger trends for MEM as the busier airport. The baseline operations peak at hours 9 and 21. As more aircraft are replaced from Narrow to Energy to Fuel replacement groups, peaks appear at hours 10 and 22 just after the original baseline peaks. This is caused by an increasing number of flights replaced at greater *n*:1 ratio, with the additional flights trailing by 30 and 60 minutes and impacting the next hourly bin. Whereas Narrow and Energy replacement peaks remain below the most conservative MEM Instrumental capacity of 111 operations per hour, the hour 9 Fuel replacement group peak jumps above the maximum MEM Visual capacity of 160 operations per hour. This suggests that replacement strategies on the scale of the Narrow and Energy groups could be made without negatively impacting airport operations, but that the dominant cargo airline would need to take care to distribute flight schedules more for the airport to accommodate replacement strategies on the scale of the Fuel group.

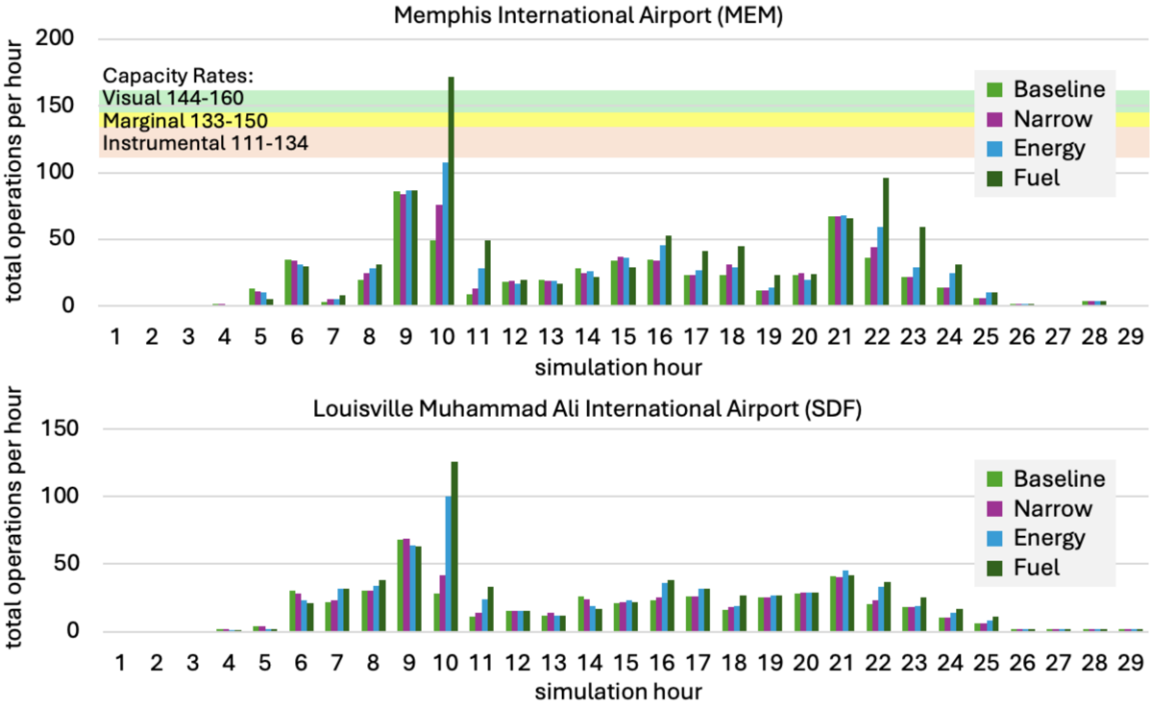

Figure 11. Airport operations rates at MEM and SDF for the baseline and three replacement groups

VI. Conclusion

NAS Digital Twin fast-time simulations were used to assess the NAS-wide impact of replacing select cargo aircraft from a single day of historic traffic with a HETCOF designed to carry 35,000 lb up to 2,400 NM. Six baseline aircraft types were identified as candidates for HETCOF replacement. After analysis of 1119 individual flight fuel and energy savings, final flight candidates were filtered to 670 and three replacement groups were selected for aggregate impact analysis. The Narrow group (175 flights) included the two narrowbody candidate aircraft types B738 replaced by HETCOF 1:1 and B752 replaced 2:1. The Energy group (401 flights), designed to maximize energy savings, added A306 replaced 2:1 and MD11 replaced 3:1. The Fuel group (all 670 flights) maximizing total fuel savings added B762 and B763, both replaced 3:1. The Energy group yielded the most favorable HETCOF replacement results. Replacing a combined 401 mix of B738, B752, A306, and MD11 flights with 822 HETCOF flights carrying equivalent aggregate payload saved 2.15 Mlb of fuel (36% within the group) and 6.16 GWh of total energy (19% within the group) without negatively impacting airport operations. An analysis of the airport operations impacts at the two airports most heavily used for cargo operations, MEM and SFD, revealed that although the Energy replacement group increased the peak hourly airport operations rate, the peak was still below the most conservative published capacity rate for MEM. Whereas the Fuel group replacing all candidate aircraft types increased the peak above the maximum airport capacity in the best of conditions.

Due to the relatively low cruise altitude and speed required for HETCOF to achieve the design mission, HETCOF flight times tended to be double that of the flights they replaced. This required adjusting some flight departure schedules to ensure reasonable turn time between the arrival and departure of sequential flights performed by the same tail. Of the 607 final candidate flights, 192 needed departure schedule adjustment to allow for at least 80 min turn time.

This study showed that substantial fuel and energy savings may be gained by replacing select cargo aircraft types with HETCOF provided the additional fight time is acceptable and schedule adjustments are made. Future studies may investigate the opportunity and benefits of replacing a portion of ground cargo movements with HETCOF flights.

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References

[1] Federal Aviation Administration, "United States 2021 Aviation Climate Action Plan," 2021. [Online]. Available: https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf.

[2] R. H. Jansen, P. De Bock, E. Stalcup, T. Dever, J. M. Wilhite, D. Pham and J. M. Wishart, "Hybrid Electric Turboprop Commercial Freighter Opportunity," in *AIAA SCITECH Forum*, Orlando, FL, 2025.

[3] J. M. Wishart, R. H. Jansen, K. Mahavier and K. Coppinger, "Hybrid Electric Turboprop Commercial Freighter (HETCOF) Market Study," in *AIAA SciTech Forum*, Orlando, FL, 2025.

[4] R. Fong, K. James, A. Meade, K. Palopo, G. Zilliac, C. Recine, D. Pham, T. Lauderdale, R. Windhorst, A. Kiak, A. E. Washburn and B. Sridhar, "Framework for National Airspace System (NAS) Level Sustainability Assessment of New Aircraft," in *AIAA Aviation Forum and Ascend*, Las Vegas, Nevada, 2024.

[5] R. Windhorst, T. Lauderdale, A. Cone, R. Fong, K. Palopo, D. Pham and J. Phillips, "Analysis of Hybrid Electric Aircraft Operations in the National Airspace System," in *AIAA Aviation Forum*, Las Vegas, NV, 2024.

[6] S. Zelinski and C. Recine, "Asessing National Airspace System Impact of the Transonic Truss-Braced Wing Aircraft," in *AIAA Aviation Forum*, Las Vega, NV, 2025.

[7] NASA Sherlock Data Warehouse, "Integrated Flight Format (IFF)," 2024. [Online]. Available: https://sherlock.datawarehouse.arc.nasa.gov/browse/docs/#/products/IFF.

[8] Bureau of Transportation Statistics, "Air Carriers : T-100 Segment (US Carriers Only)," [Online]. Available: https://www.transtats.bts.gov/Fields.asp?gnoyr_VQ=GDM. [Accessed 2025].

[9] T. A. Lauderdale, R. D. Windhorst, R. A. Coopernbarger, D. P. Thipphavong and H. Erzberger, "Overview of the National Aispace System (NAS) Digital Twin Simulation Environment," in *AIAA Aviation Forum and Ascend*, Las Vegas, Nevada, 2024.

[10] Eurocontrol, "Aynonym Aircraft Report for the Base of Aircraft Data (BADA) - Revision 3.8," 2010. [Online]. Available: https://www.eurocontrol.int/publication/synonym-aircraft-report-base-aircraft-data-bada-revision-38.

[11] B. W. L. Margolis, K. R. Lyons, J. A. Garcia, D. D. V. Pham, N. S. Listgarten, C. A. Natividad, J. V. Bowles, E. Chang and N. Bridges, "General Aviation Synthesis Program Advancements with Symbolic Computations, Optimization, and Decoupled Numerical Methods," in *AIAA Aviation Forum*, Las Vegas, NV, 2024.

[12] D. Hague, "GASP - General Aviation Synthesis Program. Volume 1: Main Program. Part 1: Theoretical Development," NASA-CR-152303-VOL-1-PT-1, National Aeronautics and Space Administration, Jan. 1978.

[13] D. D. V. Pham, N. S. Listgarten, G. G. Zilliac, S. Go, J. V. Bowles and R. H. Jansen, "Parametric Modeling and Mission Performance Analysis of a True Parallel Hybrid Turboprop Aircraft for Freighter Operations," in *AIAA Aviation Forum*, Las Vegas, NV, 2024.

[14] H.-T. Lee and G. B. Chatterji, "Closed-Form Takeoff Weight Estimation Model for Air Transportation Simulation," in *10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, Fort Worth, Texas, 2010.

[15] Chevron Products Company, "Aviation Fuels Technical Review," 2007. [Online]. Available: https://www.chevron.com/-/media/chevron/operations/documents/aviation-tech-review.pdf. [Accessed 2025].

[16] Federal Aviation Administration, "Memphis International (MEM) Airport Capacity Profile 2014," 2014. [Online]. Available: https://www.faa.gov/sites/faa.gov/files/airports/planning_capacity/profiles/MEM-Airport-Capacity-Profile-2014.pdf. [Accessed September 2024].