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March 1, 2019

Dr. C. MeSoar
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Dear Dr. MeSoar,

As a part of Avigator Consulting Ltd., through thorough research and substantial examination, we have attached a report with an economic and technical analysis justifying that The Boeing Company (Boeing) should build a Middle of the Market (MOM) Airplane and how it is beneficial to The Boeing Company and future airline companies.

This report begins with a background of a typical MOM airplane. Boeing has developed many different types of aircraft and variants for most. Using information found on different types of aircrafts, we were able to create a variety of graphs in which we established gaps in the market and areas where the market was already saturated with aircraft varieties. These gaps refer to the analyzation of what could be an ideal MOM aircraft.

Our goal was to to use all the specifications within the gap to begin and complete an aircraft that falls under the MOM aircraft category in which Boeing and its buyers would highly benefit. The report is split into two major sections, the economic analysis and the technical analysis. Using the data we obtained, we were able to make decisions on each aspect of the aircraft. We were able to include an overview of interior and exterior dimensions and how we obtained our values. This created a change in cost, amount of passengers, and many other beneficial factors.

This report is meant to help Boeing determine if building a MOM aircraft would be financially viable. Boeing should be able to use our findings to make a feasible conclusion. If there are any questions or comments please feel free to contact our team representative Georgia Williams by phone (321) 867-5309 or email at genericemail@ufl.edu.

Best,

Georgia Williams, Christopher Crouch, Matthew Alliss, Guilherme Gobbo Pilotto, Brandon Walker
Avigator Consulting Ltd
University of Florida

EAS2011 Introduction to Aerospace Engineering: Team Report 1

Georgia Williams
Christopher Crouch
Matthew Alliss
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Brandon Walker

“On my honor, I have neither given nor received unauthorized aid in doing this report”

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Executive Summary

This report has been divided into two major headings, the economic analysis and the technical analysis. The economic analysis describes the research portion of this report, while the technical analysis describes what the ideal MOM aircraft would resemble.

The team's economic analysis began with a list of airplanes that are currently used by a variety of airlines. The types of aircraft chosen to be represented in the research was based off of certain characteristics such as size of the aircraft and if the aircraft was in operation. They are used across a variety of airlines and have many different characteristics such as maximum take off weight, length, height, wingspan, etc. All of the different types of airplanes allowed us to make plots based off of their characteristics, in which gaps were found. The axes on each graph was chosen based off relation. If two characteristics were related to each other, we graphed them to see where in the graph showed us a hole in the market in that particular relation.

We will be analyzing details such as the Oswald efficiency factor, parasite drag coefficient, maximum take off weight and many other details that will help in Boeing's creation of the MOM aircraft if they do so choose to build one.

The technical Analysis gives specifications to what we believe is a MOM aircraft in which Boeing and the people they sell too would benefit. Each specification was chosen based off of the data collected from airplanes that are currently in use and resemble a MOM aircraft. Every graph showed us a gap in the market allowing us to pinpoint what was missing to make an aircraft an ideal MOM aircraft. Every specification had a restriction that needed to be taken into account. For example, we had to take into consideration the max takeoff weight as it relates to the number of passengers on board and how much baggage each person is allowed to take.

All in all, this report will help Boeing in the decision of whether or not to make a MOM aircraft and if they choose to build one they will already have specifications to use in the creation of a new airplane.

Introduction

This report involves research on data from a variety of airplanes. The aircrafts being designed today all involve similar characteristics. Creating graphs with different axes, allowing us to identify gaps in the market helped us with the formation of the ideal MOM aircraft.

Airplanes come in different shapes and sizes. Two major differences are wide-bodied vs. narrow bodied airplanes. Wide-bodied aircraft have a longer and wider fuselage, and can accommodate more people as they consist of two aisles unlike the narrow-bodied aircrafts which only consist of one aisle. Every airline is different in how they decide to choose the layout of their aircraft. Some airlines choose to have anywhere from one to four typical types of cabin classes. The typical types of classes on an aircraft include first class, business, premium economy and economy. The amount of passengers on a plane depends on the number of classes and types of class an airline decided to use in their layout.

Each airline must also take into account passenger safety. There are nine different types of emergency exit doors that need to be considered based off the number of passengers and airplane size. Emergency exits are meant to be placed where they will be the most effective in the event of an emergency [1]. Airlines can also choose amenities, such as food or alcoholic beverages, that may increase their revenue. Airlines that want to have high revenue may consider being a low cost carrier in which they offer lower fares and extra amenities at an extra charge and are not included within the fare itself.

Every airline has their own route network that works best for them in terms of beginning and ending locations. Two types of systems are the hub-and-spoke system and the point-to-point system. The hub-and-spoke system involves one airport being the main location in which an airline flies out of to go to other locations around the world. For example, United Airlines' has 7 hubs located across the United States. The point-to-point system means an airline goes from one airport to another nonstop without having to stop at a major hub destination first. For example, Southwest Airlines has flights from Tampa, Fl to Hartford, Ct. All of these factors were taken into consideration when designing the ideal MOM aircraft.

Each specification is taken into consideration. It allows us to create an aircraft, if Boeing chooses to build a MOM aircraft, that will fill in the gaps that are in the market and will benefit Boeing and its potential buyers.

Economic Analysis

Introduction

In order to tell whether or not Boeing should develop a new plane, the team is to perform an economic analysis. In this section, the goal is to find out what the big picture of the planes usage and its sizes would look like and from there, determine if there is room for another plane or even if there is a need of it. Starting from size and capacity, other graphs will support more detailed characteristics of a possible gap in the current market. The foundation of this analysis is a collection of airplanes data that allow the team to produce graphs that will provide enough information to analyze the current situation of aircrafts market.

After the data collection, certain characteristics were chosen to plot against each other and then analyzed to determine whether or not the gap in the market existed and if so what the parameters for this gap would be. The team decided that some of the most important specifications for the current aircrafts were range, passengers, maximum takeoff weight, fuel load, and cost per available seat mile. With these values graphed against one another, it will be easier to determine the gap visually and decide on certain parameters based on the data.

When the analysis of whether or not the gap in the market exists and what the parameters would be is finished, the team will determine whether or not designing and building a plane in this gap would be economically worth it. The team will mainly use data on cost and research and development for this part of the analysis.

Range vs Other Specifications

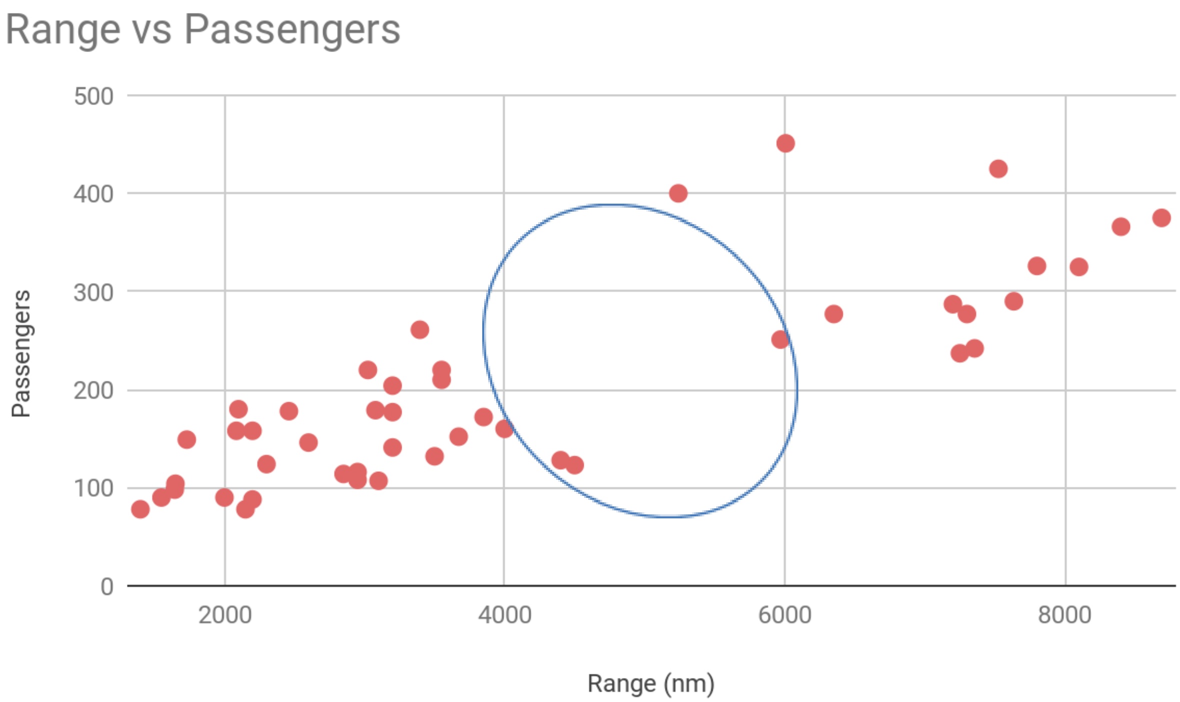


Figure 1 - Range vs Passengers Graph

With the goal of having a big picture of the size of planes that are currently in operation, the team plotted the passengers versus the range and, as expected, the trend line slope was positive. One of many reasons for this is that because long haul flights are more expensive, these flights should carry more passengers so that the flight is more economically profitable for the company and cheaper for the consumer.

From a quick analysis, one can conclude that most planes in the lower left corner are narrow body and most planes in the upper right corner are wide body. Again, as expected, there is a gap in between the two regions, but only between the range. There are planes at the higher end of the narrow bodies who carry the same amount of passengers as the low end wide bodies. So, from this graph it is hard to see the gap in the market for passengers but there is clearly one for range. According to the graph, the lower and upper ends of the graph are, respectively, 4400 nm and 6200 nm for range and somewhere between 200 and 300 for passengers.

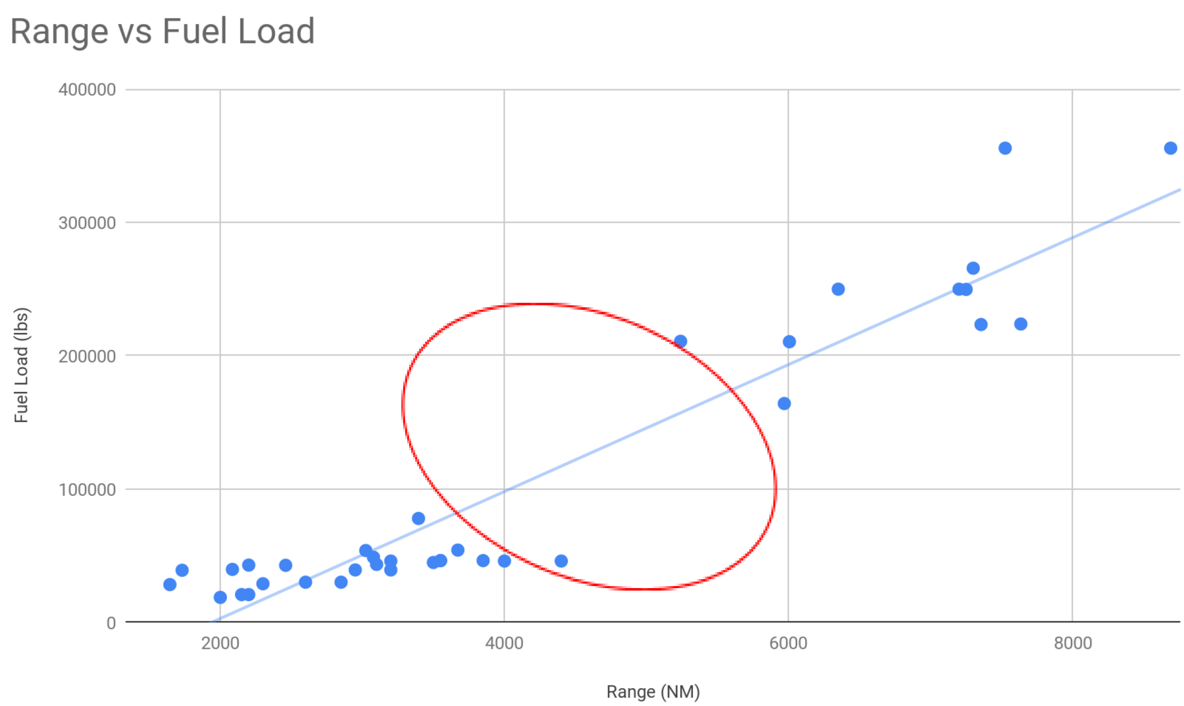


Figure 2 - Range vs Fuel Load Graph

Once the team found the characteristic range of the gap in the market, the graph above can be used to get the characteristic fuel load in pounds for the region of the gap. The graph has a positive trendline, which sustains the fact that the larger the range, the more fuel it requires. Again, it is notable that above figure also has a gap and by using the range lower and upper ends from the Range vs. Passengers graph, we can find the lower and upper ends of fuel load by comparing the Fuel Load versus Range graph. Therefore, with assistance of a trendline, the Fuel Load lower and upper ends of the gap are 80,000 lb and 160,000 lb.

Something to note about this graph is that there are no planes currently that enter the gap as we can see in the graph. The team will aim to find the most profitable point inside this gap along the trendline and compare to the existing specifications to see if entering this gap would be worth it for the manufacturer. In order to determine more narrow parameters for the gap in the market, the team will plot and analyze range vs other specifications of the same aircrafts.

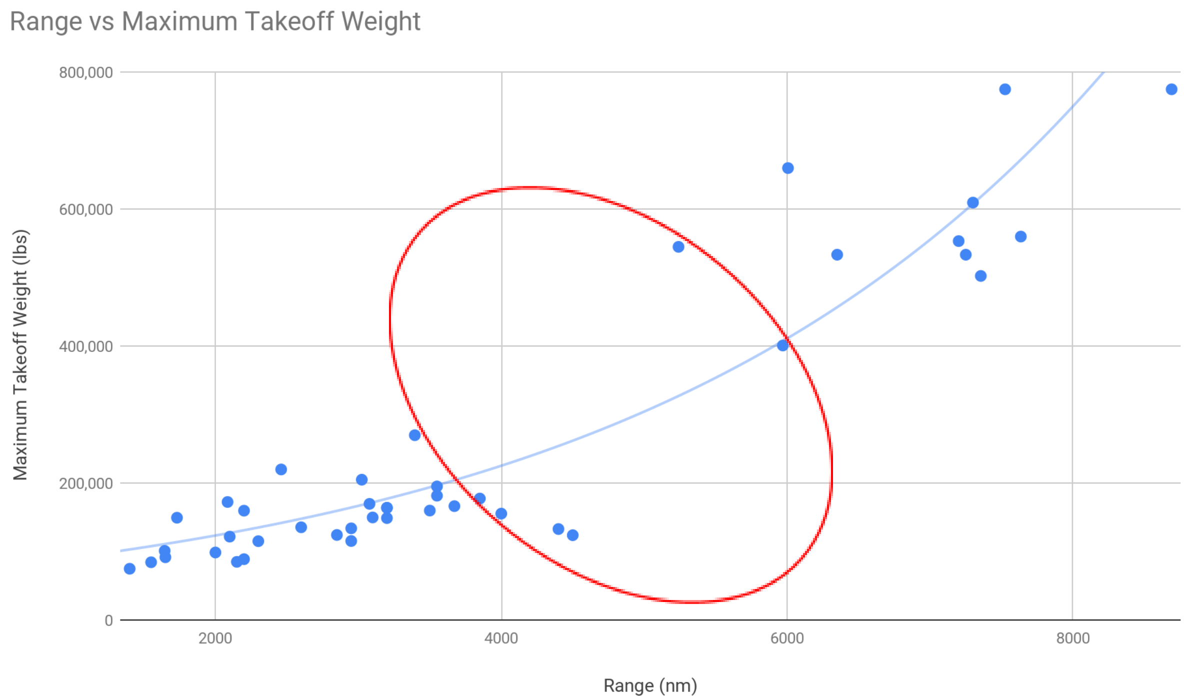
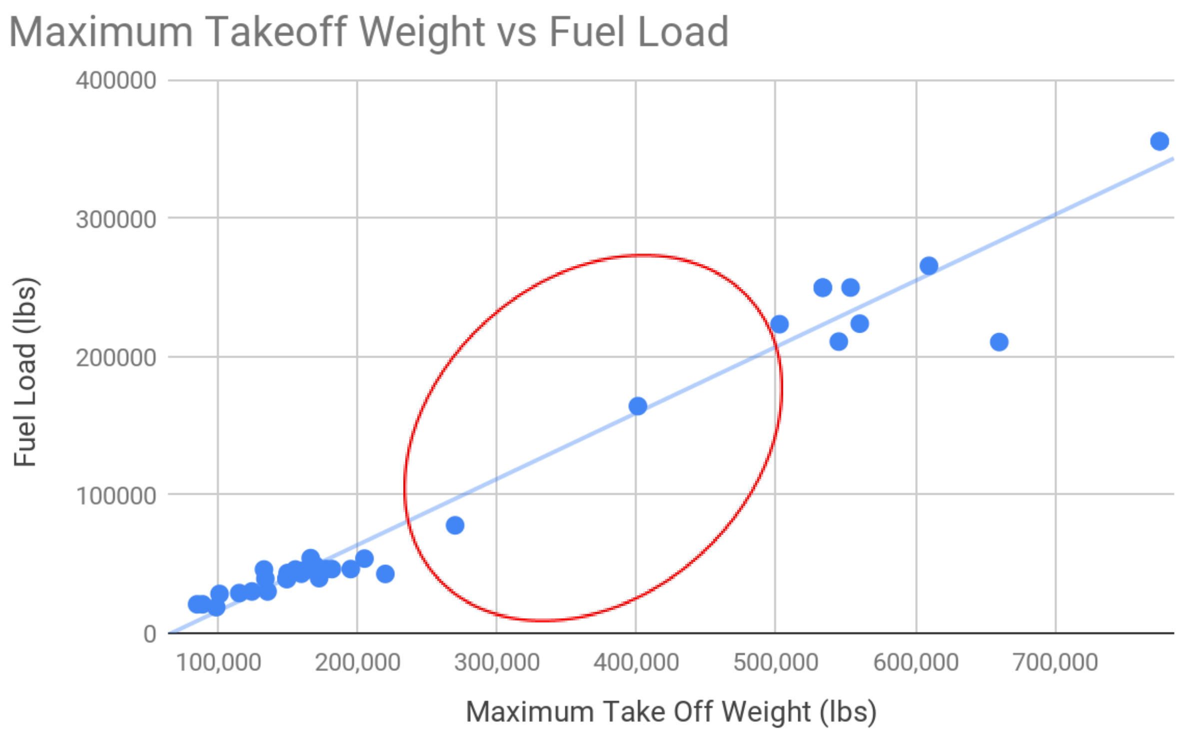


Figure 3 - Range vs Maximum Take Off Weight Graph

This graph uses range vs maximum takeoff weight to try and find the upper and lower bounds for the maximum takeoff weight of the middle of the market. There is a clear gap between 210,000 lbs to 400,000 lbs. The narrow bodied aircrafts, located in the bottom left corner of the graph show much less separation between one another compared to the much more sporadic data for the wide bodied aircrafts in the top right. With the narrow bodied aircrafts, their maximum takeoff weight almost never goes above 210,000 lbs but once you reach the wide bodied, they range from 400,000 lbs to over 750,000 lbs. The team will determine whether this occurs because of economic reasons or the physical capabilities of the smaller aircrafts. One possibility is that there is a positive exponential relationship, as shown by the trend line, meaning a longer range might not be the most profitable option.

Maximum Takeoff Weight vs Other Specifications



Another relationship used to determine the parameters for a gap in the market was the Fuel Load to Maximum Takeoff Weight graph. As shown above, there is a clear gap between around 80,000 lbs to 170,000 lbs for fuel load of the aircrafts currently in the market. Assuming that Jet-A fuel has a density of 6.8 lbs/gallon [4], this comes out to roughly 11,765 to 25,000 gallons of fuel. The trend between the two is that the more fuel load an aircraft has, the higher the maximum takeoff weight would need to be. Conversely if an aircraft had a higher takeoff weight it would be able to carry more fuel.

These values have been calculated by the manufacturers as efficient ratios for those aircrafts to minimize unnecessary weight, which would have economic benefits. With this in mind, the team analyzed the graph and decided that staying as close to the trend line through the gap in the market would be the most effective way to determine a maximum takeoff weight to fuel load ratio for the MOM aircraft.

From the graph, the team noticed two data points that were either on the edge or inside the gap in the market. These two aircrafts are the Boeing 757-300 and the Boeing 767-300ER. These are the closest aircrafts to breaching the gap in the market, so later in the analysis, the team will determine whether or not creating an aircraft in this gap is economically viable.

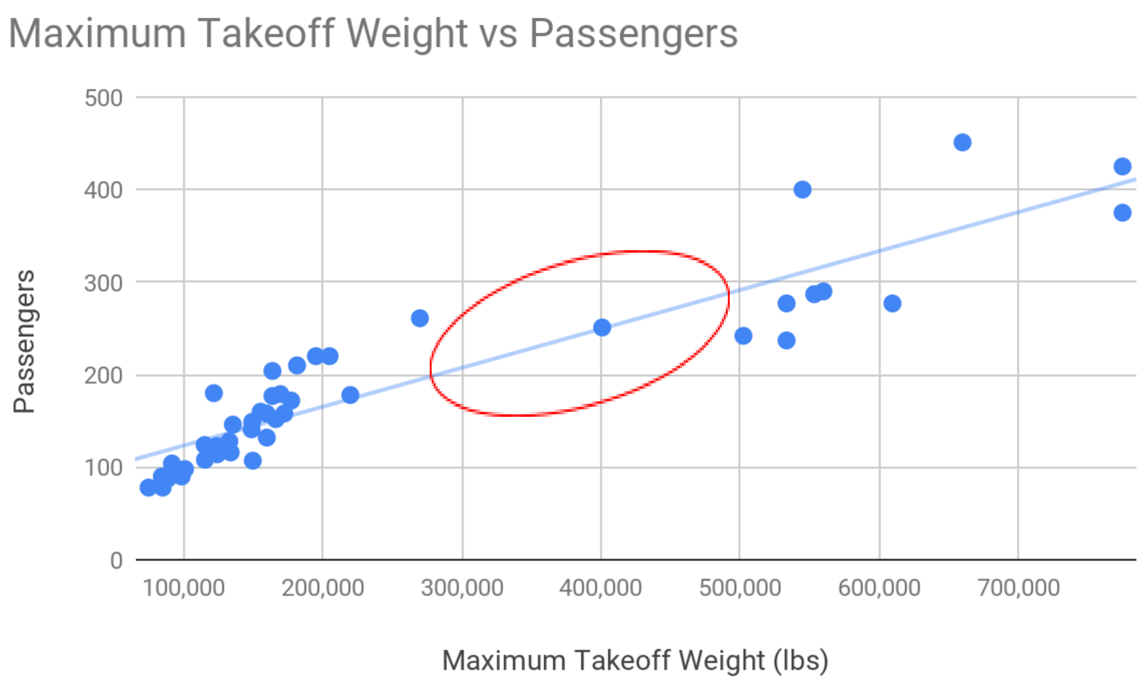


Figure 5 - Maximum Take Off Weight vs Passengers Graph

As the team analyzed maximum takeoff weight vs passengers it was clear there was a linear trend in the relationship. This makes sense because the more passengers on the plane, the higher the maximum takeoff weight would need to be. Notice the two points that somewhat penetrate the gap in between the two zones. The lower point is the Boeing 757-300 and the higher end being the Boeing 767-300ER, showing up again as the closest to the middle of the market.

With regards to passengers, there isn't a clear gap for the market but the team can guess that based on where the gap is for the other specifications like range, maximum takeoff weight, and fuel load, there should be between 220-280 passengers.

Cost per Available Seat Mile Analysis

Cost per available seat mile is an extremely important aspect when companies are looking at investing in an aircraft. If the costs are too high the airline would never buy the aircraft since they would not be able to make money and in turn lose money. There are many factors that go into the CASM of an aircraft, some of the specifications that the team compared the aircraft's CASM to were range, sale price, and passengers in order to analyze the different relationships based on those characteristics.

The team selected a couple aircrafts from the original set that made up the upper bounds of the narrow body and lower bounds of the wide body. This was done to try and pinpoint a CASM for the middle of the market aircraft more accurately.

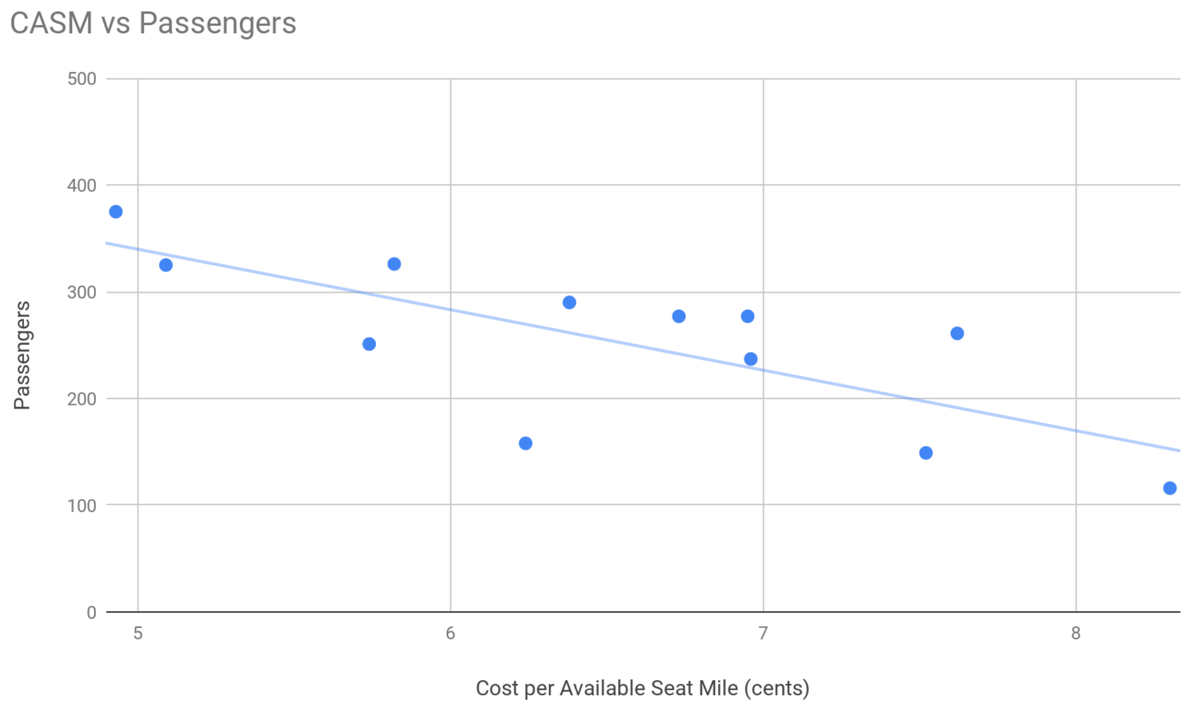


Figure 6 - CASM vs Passengers Graph

The team graphed CASM vs passengers to determine a relationship between the two specifications and estimate what the cost of a middle of the market aircraft would be. After analyzing the trend line, the team found that the more passengers a plane carried, the less it cost per available seat mile. According to this graph, an aircraft would be most profitable carrying the maximum amount of passengers, however when adding more passengers other specifications of the aircraft will be affected, such as maximum takeoff weight, length, and range. For the gap in the market, the team stated earlier in the report that the amount of passengers on a middle of the market plane should be between 220-280. With this value we can estimate the CASM for the middle of the market aircraft with the equation for the trend line plotted. For 220 passengers the CASM would be 7.1 cents and for 280 passengers, it would be 6.1 cents.

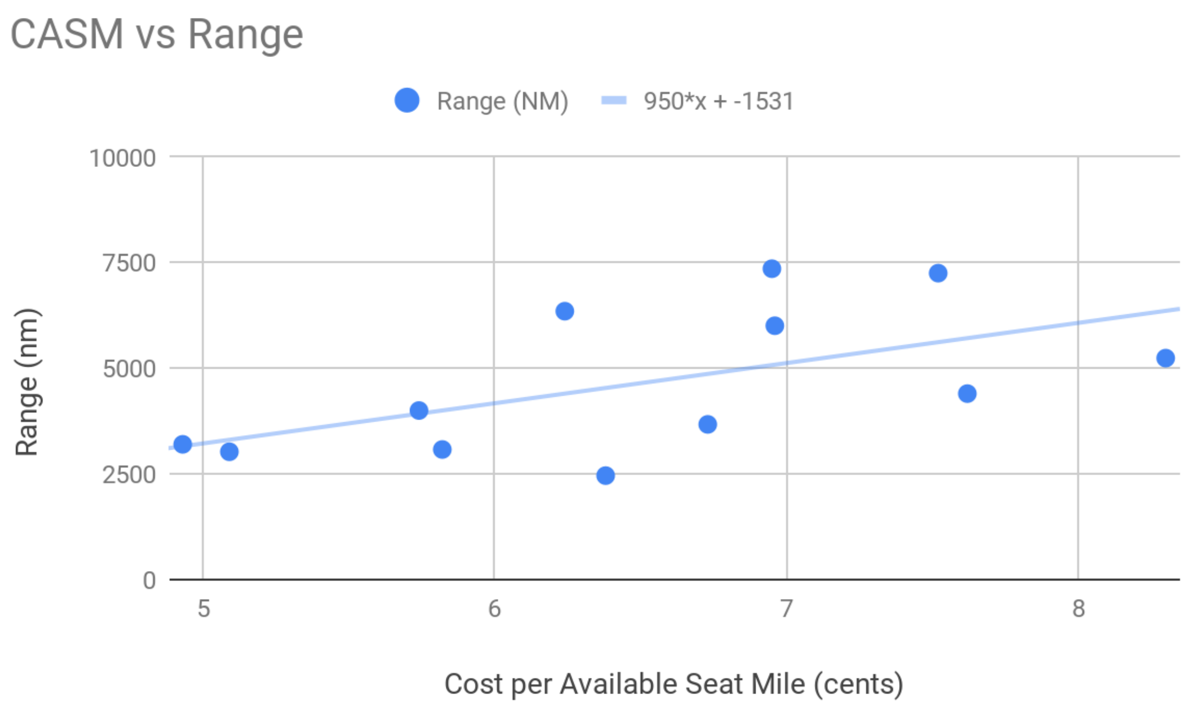


Figure 7 - CASM vs Range Graph

Another characteristic the team plotted against the cost per available seat mile was the range. From this plot, the team can see that the further the range of an aircraft, the higher the cost. This makes sense because the cost of fuel would go up since the plane would need a larger initial amount to account for more thrust required at the beginning of the flight since the weight increased. However, the price for consumers normally increases for farther flights to offset this increase in cost, but analyzing the graph the team saw that the increase in price for consumer did not completely negate the raise in cost for airlines.

In order to more accurately calculate the CASM for our middle of the market we can check the upper and lower bounds for our range parameters. In the beginning of the economic analysis the team stated the gap in the market for range was between 4,400 nm and 6,200 nm. According the trend line equation at a range of 4,400 nm the CASM would be 6.2 cents, and at a range of 6,200 nm it would be 8.1 cents. Averaging the 4 values we acquired, the CASM for a middle of the market aircraft should be close to 6.9 cents.

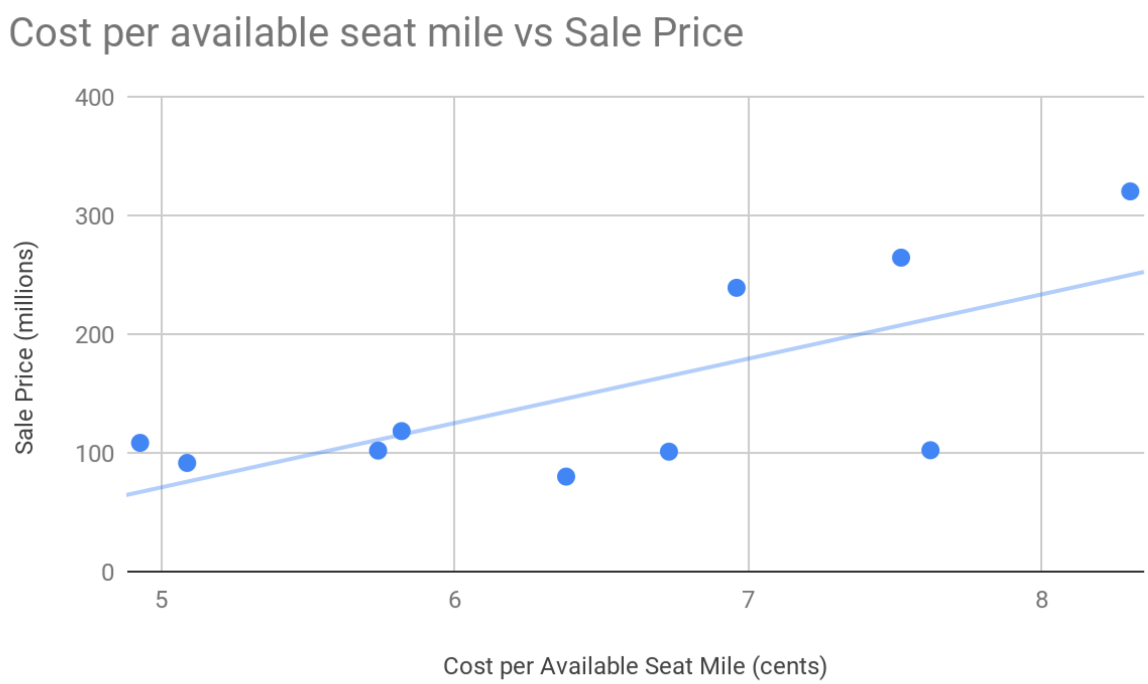


Figure 8 - CASM vs Sale Price Graph

Another impactful marketing characteristic of an aircraft is its sale price, As displayed in the graph, we can see a positive trend between the CASM and Sale price of these specific aircrafts. This is caused by the more expensive planes generally being larger and costing more to operate. The slight variations from the trend line can also be caused by different airlines providing more or less expensive services while on board. The team took averages of a couple different airlines for each aircraft to try and get accurate results.

Using the computed average CASM for a middle of the market aircraft, we can estimate a sale price for the plane. Using 6.9 cents for the CASM value, the trend line equation gives us a sale price of $174 million. Comparing this sale price and amount of passengers to the 767-300ER, which the team described as one of the closest aircrafts to the middle of the market, the price of the MOM plane is $43.9 million cheaper and carries 7 more passengers. However, the range is 570 nm smaller.

Seat Configuration

The aircraft market nowadays offer different cabin configuration so that the customers can model according to each specific airline market, range, and class. Even though most low cost airlines employ a single class configuration, it is usual to find aircrafts with a two or three class configuration that would vary the ticket price. Therefore, to fulfil the most airlines as possible, aircraft manufacturers tend to make it easy to change or customize seat configuration.

Within each class, another variable out there in the aircraft market is the seat pitch. This is the distance between a point on one seat and the same point on the seat in front. After analyzing the current market, the team found that the seat pitch usually ranges between 30 and 32 inches.

Research & Development Analysis

In determining whether a MOM aircraft would be economically viable, an estimated cost of developing this new jetliner should be considered against other options. Firstly, it has been determined that the data points most closely resembling a MOM aircraft that are currently operational are the Boeing 757-300 and the Boeing 767-300ER. As of 2019, Boeing has discontinued production of both of these aircraft types [2-3]. While Boeing is still developing cargo variants of the 767, known as the 767-300F, the aircraft manufacturer is currently in the process of developing a new aircraft to replace the gap left by the 757-300.

In Avigator's quest to determine an estimated cost for a new Middle of the Market airplane, the research and development costs of similar sized commercial aircraft were examined. From 2007 to 2016, Canadian Company Bombardier Aerospace worked on the creation of a new narrow-bodied regional jetliner known as the C Series. The C Series was later taken over by Airbus and renamed to the Airbus A220. Over the course of development, the production of the A220 was reported to be over $6 billion USD. This was vastly over the estimated R&D cost of $2 billion USD.

At the same time starting in 2010, The Boeing Company began development on a new line of 737 type aircraft, the 737 MAX. From 2010 to early 2017, the overall research and development of Boeing's MAX series commercial aircraft cost the company roughly $2.5 billion [5].

The stark difference between the developmental costs of the A220 and 737 MAX arise from each companies design of their respective aircraft. For Boeing, the 737 MAX was founded upon earlier variants of the 737, with a very similar airframe, range, and powerplant. For Airbus, the A220 had no similar predecessor. And with the project beginning under Bombardier, costs increased due to the partnership between two companies spreading resources more thin.

Production Cost Analysis

To determine if production of a new series of aircraft would be financially beneficial for Boeing, an approximate cost per unit of MOM aircraft must be made. This MOM aircraft must be comparable in unit price to current aircraft that are used to fill similar roles as a future MOM aircraft. As of 2019, three Boeing aircraft near the middle of the market are the Boeing 737 MAX-7, MAX-8, and 757-300, with a sale price of roughly $96 million, $117 million, and $80 million, respectively [6]. Current Airbus aircrafts include the A220, A320, and A321, with a unit price of roughly $91.5 million, $101 million, and $188.3 million, respectively [7]. In any attempt by Boeing to create a MOM aircraft, unit cost must mirror that of similar aircrafts to be viable. In the event that unit cost is notably greater than that of previous aircraft similar, new technologies integrated into the MOM aircraft should allow for airlines to regain their losses through decreased operational costs.

Economic Analysis Conclusion

Through the analysis of plots comparing range, MTOW, CASM, and other values of current commercial aircraft in service, there was a definitive gap in the market between most current wide-bodied and narrow-bodied aircraft. In several of these graphs that showed a gap in the market, there were 2 aircraft that always fell very near this gap. These aircraft are the Boeing 767-300ER and the Boeing 757-300. The Boeing 737 series aircraft also outlines the lower bound of several gaps, such as the MTOW vs Range graph and Fuel Load vs Range. Because of these findings, and the fact that Boeing has ceased production of both 757 and 767 series jets, a new MOM aircraft should resemble similar qualities of these aircraft. The MOM aircraft was found to have similarities and differences to the 767-300ER, such as a slightly larger passenger capacity with a smaller range. Based on the economic data, these differing characteristics were found to be more profitable.

While there are regions we have found that a MOM aircraft should fit within, these conditions alone do not define what the specifications of a new aircraft should be. From the gaps found in graphs of this analysis section, the range, passenger capacity, fuel load, and maximum takeoff weight can be approximated and used later to find precise values of these qualities in the MOM aircraft. When pinpointing the values of the new MOM plane, the MOM should fall within the approximate parameters found through these graphs.

Technical Analysis

Introduction

In order to determine the aircraft characteristics, the team will perform a technical analysis. In this section, the goal is to compare the different parameters of the current planes, such as wingspan, wing area, flight ceiling, etc., while working with the economic analysis to determine what characteristics of the MoM plane are needed. The support of this analysis is data collected from various aircraft and will be used to determine what parameters a new MoM aircraft should have.

As a conclusion of the economic analysis, the team established that the passengers capacity defined the team is 258. Similarly, the range can also be estimated based on the economic analysis. It was estimated to be 5400 nm. Not including the ascending and descending portion of the flight, the range at cruising altitude will be roughly 5000 nm.

After the data collection, certain characteristics were chosen to plot against each other and then analyzed to determine what kind of characteristics a new proposed MoM plane should have. Some of the details that are going to be analyzed are the Oswald efficiency factor, parasite drag coefficient, maximum lift coefficient, wingspan, wing surface area, maximum takeoff weight, fuel efficiency and fuel parameters, cruising speed, and flight ceiling. It will be easy to determine what these values should be based off the tables and graphs of the data that was collected about the current aircrafts.

Length

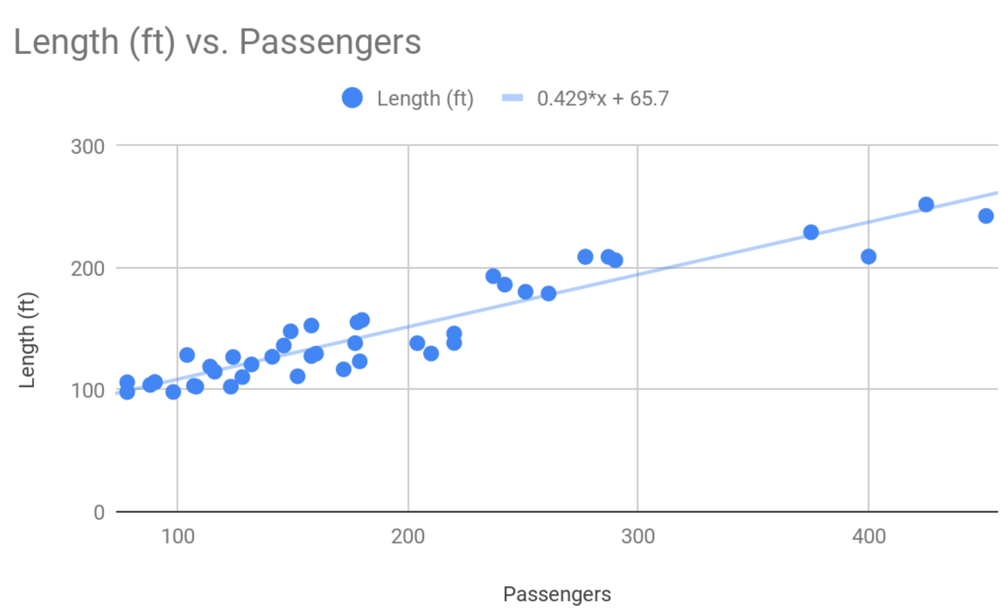
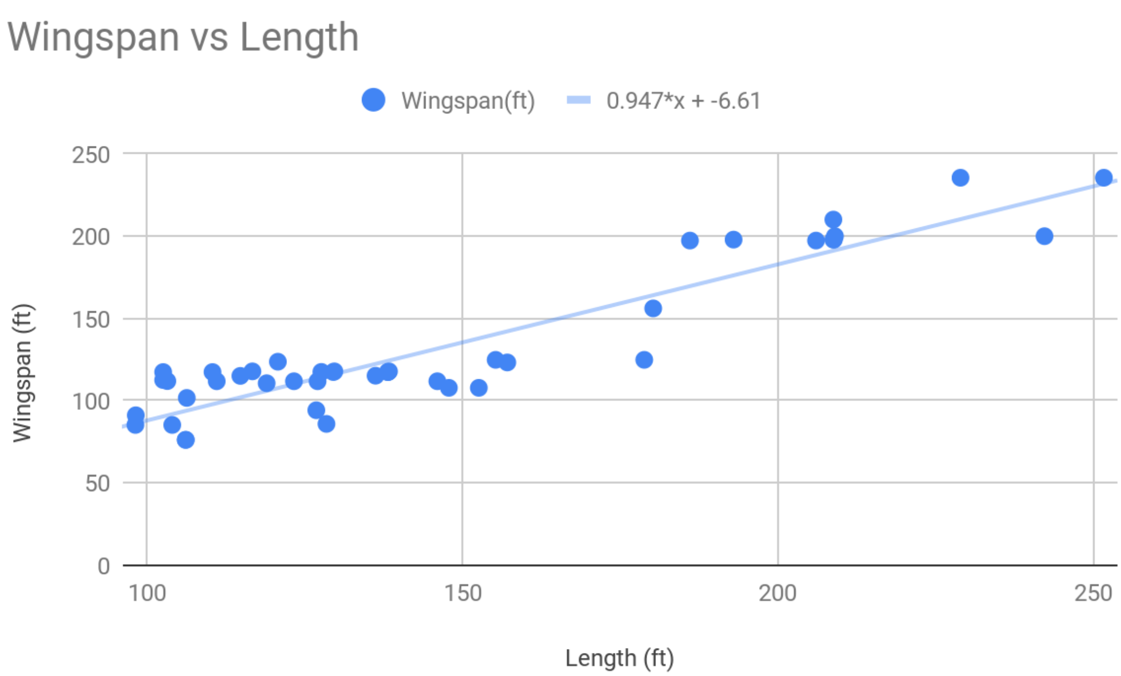


Figure 9 - Length vs Passengers Graph

With that being said, the team used another graph to estimate the length of the plane based on a predefined maximum passengers capacity. By plotting a trend line, the team found the length that corresponds to 258 passengers on the graph above. As a result, the team found the aircraft length to be 181 ft.

Based off 258 passengers as reported above, it falls within the gap of the MTOW vs Passengers graph (Figure 5). Based off the graph, then a MTOW of 350,000 can be determined. This max takeoff weight also falls within the gap on the MTOW vs Range graph (Figure 3) which is 5400 nm.



Based off the figure above, wingspan can be determined by following the trendline shown. Using a value of 181 feet for the length of our suggested MoM airplane, it correlated with a wingspan of 165 feet.

Aerodynamics

TAB. A2 List of aircraft and aircraft characteristics

Aircraft / Aircraft category	Type	λ	A	φ_{25}	d_F	b	d_F / b	M_{CR}	M_e	e
Jet airliner										
A 300-600	Twin jet airliner	0.293	7.73	28	-	-	-	0.78	0.78	0.749
A 319	Twin jet airliner	0.240	9.40	25	-	-	-	0.78	0.78	0.753
A320	Twin jet airliner	0.24	9.50	25	4.04	34.1	0.118	0.76	0.76	0.783
B 737-800	Twin jet airliner	0.219	9.45	25	3.88	34.32	0.113	0.78	0.78	0.660
MPC 75	Twin jet airliner	0.260	9.6	23.5	3.45	29.72	0.116	0.77	0.77	0.553
B767-300	Twin jet airliner	0.306	7.99	31.5	-	-	-	0.80	0.80	0.670
MD 90-30	Twin jet airliner	0.193	9.62	24.5	-	-	-	0.76	0.76	0.811*
B 707-320B	Twin jet airliner	0.288	7.05	36	-	-	-	0.82	0.82	0.700
DC 9-30	Twin jet airliner	0.206	6.80	24	-	-	-	0.75	0.30	0.810

Table 1 - Aircrafts Aerodynamics Characteristics: Oswald Efficiency Factor

According to table (Table 1) [8], as shown above, the Oswald Efficiency factors, *e*, are given for various twin jet middle of the market aircraft. The ranges value from .553 to .811. If we average these efficiency factors, we can establish an Oswald Efficiency factor of .721 that can be used for a new MoM aircraft.

Aircraft	$C_{D0,clean}$	$C_{D0,taxi}$	$C_{D0,to}$	$C_{D0,ic}$	$C_{D0,ap}$	$C_{D0,ld}$	k
A319	0.020	0.051	0.074	0.040	0.050	0.116	0.0334
A320	0.023	0.055	0.078	0.043	0.053	0.120	0.0334
A321	0.033	0.069	0.091	0.053	0.063	0.133	0.0344
A332	0.024	0.049	0.074	0.044	0.054	0.118	0.0343
A333	0.026	0.051	0.075	0.046	0.056	0.120	0.0344
A359	0.027	0.051	0.075	0.047	0.057	0.120	0.0364
A388	0.012	0.034	0.059	0.032	0.042	0.104	0.0456
B734	0.021	0.060	0.081	0.041	0.051	0.122	0.0372
B737	0.024	0.053	0.077	0.044	0.054	0.120	0.0366
B738	0.021	0.053	0.076	0.041	0.051	0.119	0.0365
B739	0.024	0.057	0.080	0.044	0.054	0.122	0.0365
B744	0.025	0.052	0.076	0.045	0.055	0.119	0.0435
B748	0.028	0.056	0.079	0.048	0.058	0.123	0.0408
B772	0.033	0.059	0.083	0.053	0.063	0.127	0.0396
B77W	0.033	0.062	0.085	0.053	0.063	0.129	0.0396
B788	0.022	0.046	0.071	0.042	0.052	0.115	0.0361
B789	0.024	0.050	0.074	0.044	0.054	0.118	0.0359
E75L	0.022	0.053	0.076	0.042	0.052	0.119	0.0371
E190	0.020	0.050	0.073	0.040	0.050	0.116	0.0387
E195	0.032	0.062	0.085	0.052	0.062	0.128	0.0389

*Table SEQ Table * ARABIC 2 - Aircrafts Aerodynamics Table: K and CD0*

According to table (Table 2) [9], as show to the right, the parasitic drag coefficient, C_{D0}, and *k* values are shown for various aircraft and their different phases of flying such as taxi, takeoff, cruise, approach, and landing. For the team's purposes, the parasitic drag coefficients for the aircraft in cruise, or steady level flight, are considered.. We only included the values for the A319, A320, A321, A332, A333, B734, B737, B738, B739, B772, B788, and B789, simply because they are best represent the MoM aircraft that Boeing should design. Averaging these values gives an estimate C_{D0} value of .0445 and a *k* value of .0356. Since C_{Lmax} changes with the weight of the plane, the C_{Lmax} was determined by analyzing the C_{Lmax} for various aircrafts at their maximum takeoff weight [10], and a C_{Lmax} value of 2.06 was determined for our MoM Aircraft. However this value will change as the aircraft consumes fuel and decreases in weight. For the dimensionless air density exponent, *m,* a value of .6 was established [11].

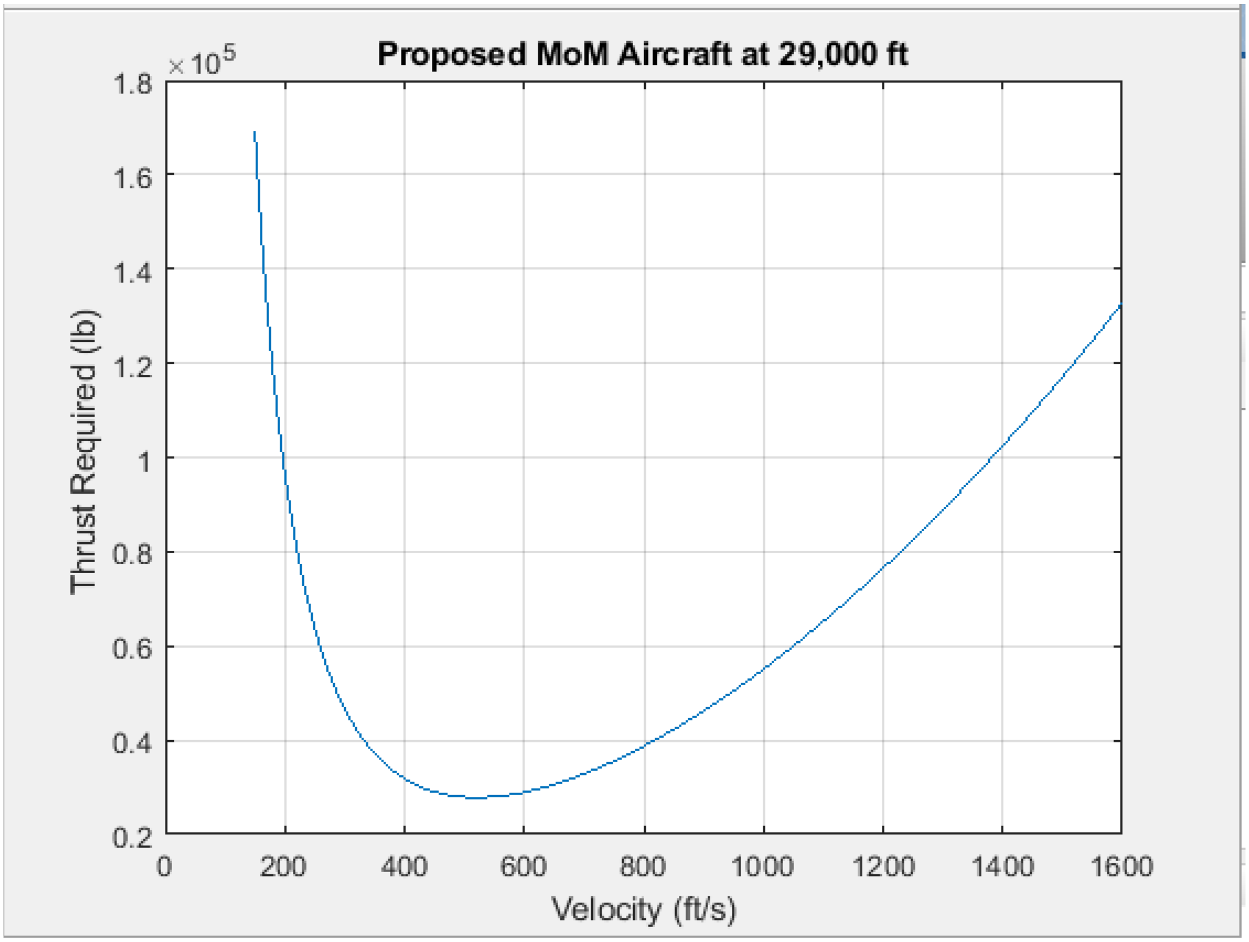


Figure 11 - Proposed MOM Aircraft Thrust vs Velocity Graph at 29,000 ft

Using MATLAB and the previously found values for *k,* C_{D0}, W, and the air density at cruising altitude, a velocity vs thrust curve can be obtained for steady level flight at cruising altitude, as shown in figure 11. The altitude of 29,000ft was chosen since it is the average between the floor of the Class Alpha airspace (18,000 ft) [12] and an estimated maximum nominal cruise ceiling of 40,000.

<u>Surface Area</u>

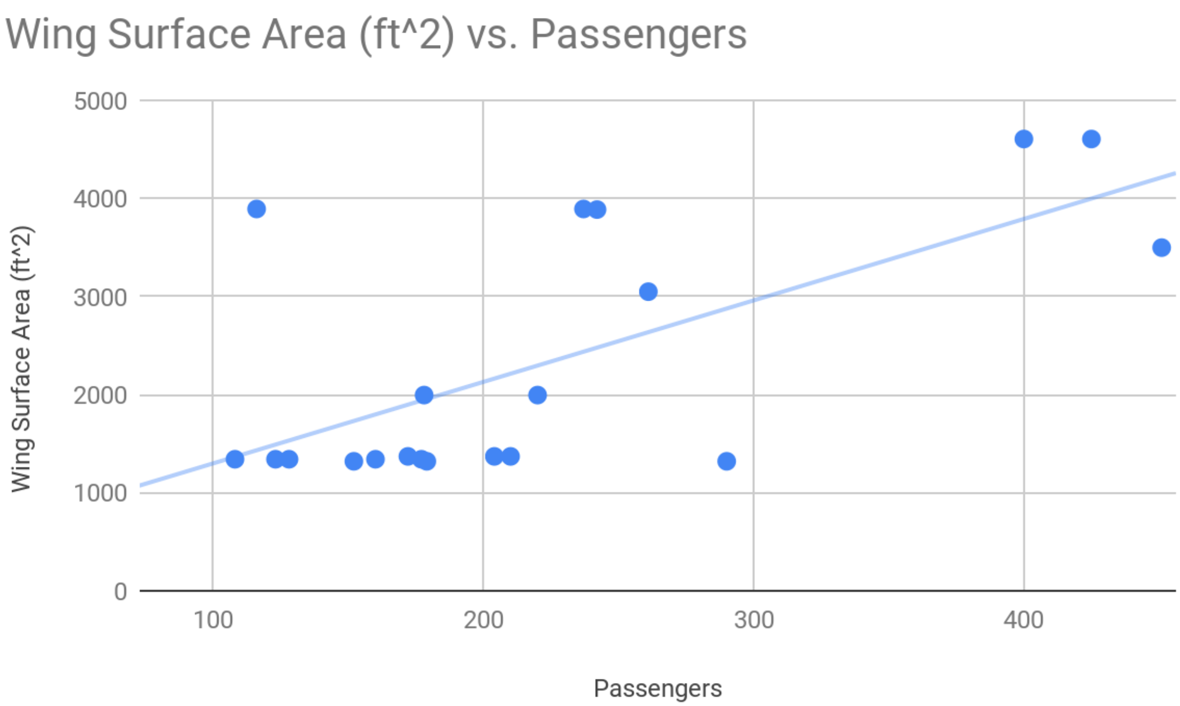
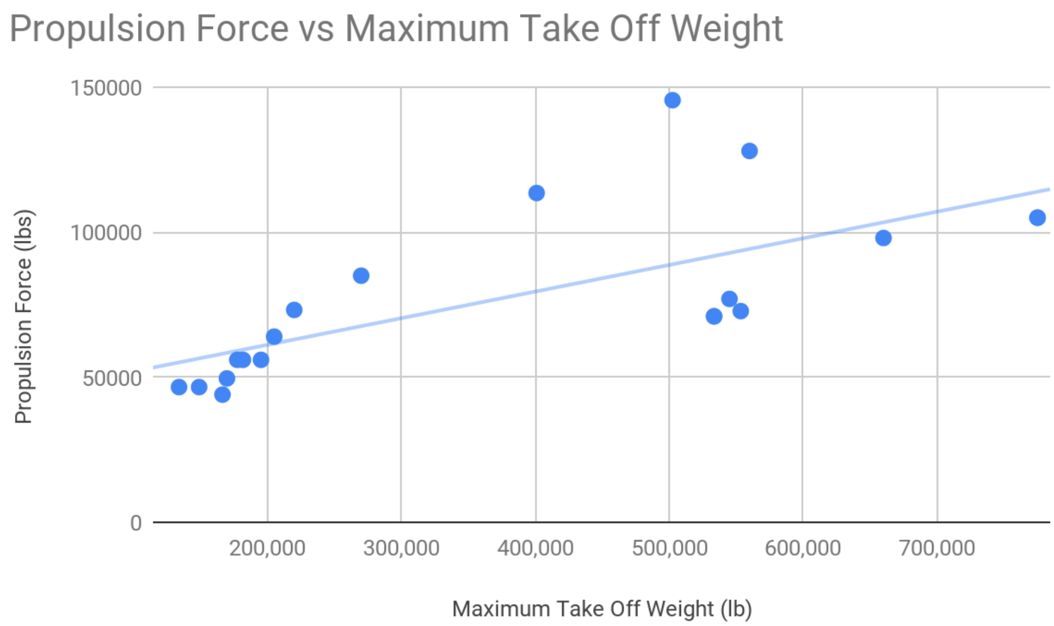


Figure 12 - Wing Surface Area vs Passengers Graph

The wing surface area is a important parameter to get the flight envelope of an aircraft, which is shown later in this report. To find a reasonable wing surface area, the team used the trendline on the graph above. For the passenger capacity found to be 258, a reasonable wing surface area is 2500 ft^2.

Engines Choice



The graph above shows how the required propulsion force tends to increase with maximum take off weight. Since the team, has already specified the MTOW for the MOM aircraft, the graph above can be used to estimate the required propulsion force for the MOM aircraft. As mentioned previously, the maximum MTOW is 350,000 lb. Therefore, following the trendline in the graph, the estimate max propulsion force should be 70,000 lb. Since there this is a twin engine, each engine should provide 35,000 lb. With these engines, a fuel capacity of 120,000 lbs of fuel were established/. For the fuel efficiency rate, *c*, a value of .69 lb fuel/ hr/ lb was used. This number was provided in the textbook. [11]

By analyzing the similar aircrafts, the engines used are roughly the GE/CFM CMF56, LEAP 1A and LEAP 1B, the Pratt & Whitney PW6000, and the International Aero Engines V2500. Through discussion from the team, the chosen engine is the CFM LEAP 1A Engine, due to its efficiency and relatively new technology of production. Such technological and efficiency improvements are 15% reduction in fuel consumption and CO_2 emissions versus current engines, a 50% cut in NOx emissions, and compliance with the most stringent noise standards. [13]

Flight Envelopes

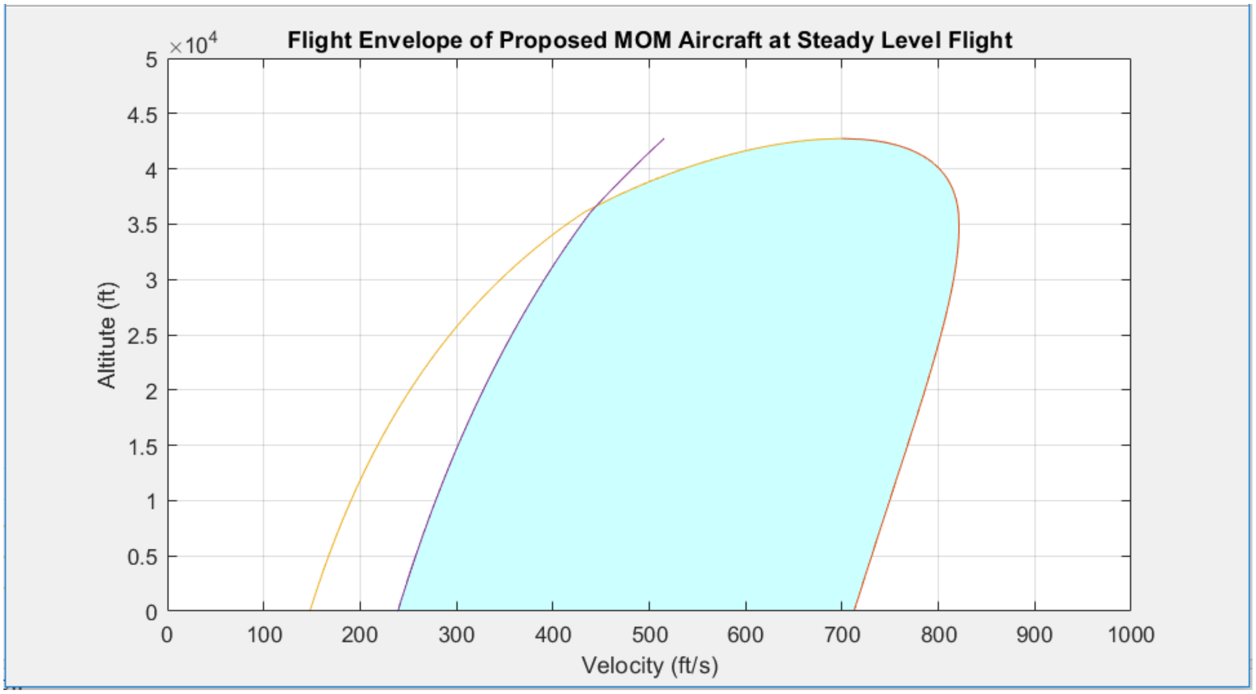


Figure 14 - Proposed MOM Aircraft Flight Envelope at Steady Level Flight

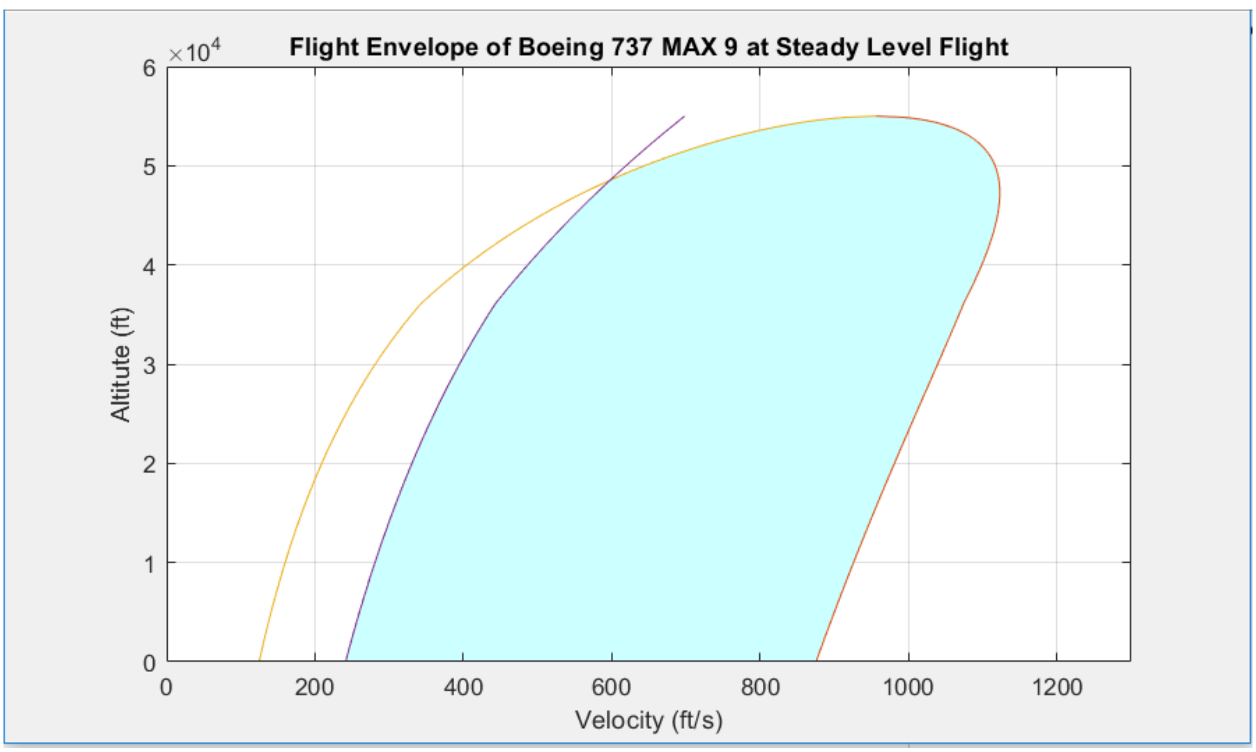


Figure 15 - Boeing 737 MAX 9 Flight Envelope at Steady Level Flight

The proposed aircraft's computed flight envelope, Figure 14, and the Flight envelope for a Boeing 737 MAX 9, Figure 15 show some differences. The values for engines efficiency, required to calculate thrust, 'm', were set to be approximately 0.6 [11]. We chose to use the Boeing 737 MAX 9 to compare because this is an aircraft that breaches the middle of the market graphs. Our aircraft will be larger than the 737 MAX 9, therefore it will not reach the maximum velocity that the 737 MAX 9 can reach. However, with more passengers, there is an increase in revenue, which will make the aircraft more profitable when airlines buy the plane.

From the team's computed flight envelope for the proposed MOM aircraft, a flight ceiling of 42,750 feet can be shown. This is well above the average cruising altitude of 29,000 feet. If the aircraft has to increase in altitude or decrease, it will be able to as long as it does not surpass 42,750 feet. Continuing to analyze the flight envelope, at 29,000 feet the max velocity will be 815 ft/s. The thrust required to maintain steady level flight at this altitude would be 39,500 lbs. The throttle setting would be 99.3%. The minimum speed at cruising altitude will 333ft/s and will require the same amount of thrust. However this is less stall velocity which is 383 ft/s, and the aircraft cannot go below this velocity. The require thrust to fly at V_{Stall} will be 32280 lbs. The required throttle setting to fly with this amount of thrust will be 81.2%. These numbers were computed using MATLAB.

Take Off and Landing Distances

To get the take off and landing distance parameters, the team used information from similar planes that are currently in operation to estimate the values of the proposed MOM aircraft. The team decided that the takeoff and landing distances were going to be compared with maximum take off weight, since the weight has a large impact on the required braking deceleration. Since the proposed MOM aircraft has a MTOW of 350,000 lbs the team had to find an aircraft with similar MTOW such that the take off and landing distances would be the best estimate as possible. The chosen aircraft was the Boeing 767-200 due to the fact its MTOW is 395,000 lb. The take off and landing distances for the Boeing 767-200 are, respectively, 5,600 ft and 4,000 ft. By using a linear approximation, the take off and landing parameters of the proposed MOM aircraft are, respectively, 5,000 ft and 3,500ft.

Airports

This proposed MOM aircraft provides a maximum range of 5400 nm, which can be used for multiple purposes. The table below shows the distance between several airports and a chosen hub in Atlanta, GA. Also, it provides the biggest runway length for each airport. The airport selection was based on different distances airports and its volume of traffic.

City, State	IATA Code [14]	Distance (nm) [15]	Runway Length (ft) [16]
Daytona Beach International Airport	DAB	318	10,500
Dallas Ft. Worth	DFW	634	13,400
Heathrow	LCY	3,648	12,800
Viracopos International Airport	VCP	4,014	10,600
Gainesville Regional Airport	GNV	261	7,500
San Francisco International Airport	SFO	1,854	11,900
Tampa International Airport	TPA	354	8,300

Table 3 - Airport Selection Data

The table above shows that the proposed MOM aircraft can accomplish both regional flight and international since the distance of all of the chosen airports are within the range. Also, all of the chosen airports runways are greater than both the estimated take off and landing distance of the proposed MOM aircraft.

Recommendations

After a thorough analysis of our data, we have come to a conclusion as to what specifications an ideal MOM aircraft should possess. We took into consideration the safety and the comfort of the passengers in the aircraft. We also looked at an economic portion dealing with different types of costs such as the research and development (R&D) costs, unit costs, as well as the cost per available seat mile.

The following specifications were chosen based off gaps located on graphs obtained by researched data. The gaps represent holes in the market, meaning there are specifications in which an aircraft can possess and become the ideal MOM aircraft.

Exterior Dimensions

Starting off, the team looked at the aircraft dimensions, both interior and exterior. The overall length will be 181 feet, and was found by analyzing the graph of length vs passengers. The overall height will be 43.9 feet, and was found by using the mean of the 737 series, 757 series, and 767-300ER height. The team assumed the distance between the tail and main gear is 65 feet, and the MOM aircraft will rotate 10 degrees during takeoff rotation. Those two given values would result in the gear height being 11.5 feet to prevent a tail strike. The wingspan will be 165 feet, and was found by using the Wingspan vs Length graph.

Next, characteristics of the aircraft were examined. The aircraft will have a maximum takeoff weight of 350,000 pounds. The aircraft will have two wing-mounted CFM International CFM LEAP 1A engines, producing up to 32,160 pounds of force each. The fuel tank will have a capacity of 17,647 US gallons, or 120,000 lbs. The winglet type used on the MOM will be the same that Boeing currently uses on their MAX series of 737, the MAX AT winglet. This winglet type is Boeing's newest winglet type. Finally, the range will be 5,400 nautical miles, or 6,214 statute miles. Based on the flight envelope, the cruising speed will be .79 Mach.

Interior Specifications

The cabin will have an interior length of 112 feet and a width of 11.5 feet. This was found by using the 737-800 and finding the ratio between the overall length and the cabin length, then applying this ratio to the MOM aircraft length of 181 feet.

The MOM aircraft will have a total of eight emergency exits: two in the front, four over the wings, and two in the rear. This was decided since Federal Aviation Regulation require airlines to evacuate all passengers within 90 seconds in case of an emergency, and many aircraft of similar size have similar emergency exit configuration [1]. The number of classes can be anywhere between one and three. Budget airlines, such as Ryanair or Southwest, may configure the cabin to only have a one-class cabin centered around budget. Other airlines, such as Delta or United Airlines, usually configure the cabin to have three classes. In descending order of luxury, the three classes would be: first class, business class, and economy.

The passenger capacity will be dependent on the class configuration determined by each airline. For this report, the team has assumed that first class will have a seat pitch of 40 inches, Business class will have a seat pitch of 35 inches, and economy class will have a seat pitch of 31 inches. Seat width for economy and business class will be 18 inches, and seat width for first class will be 24 inches.

In a three-class cabin configuration, first class will have five rows, with four seats on each side of the aisle. Business class will have six rows, with three seats on each side of the aisle. Main cabin will have 32 rows, with three seats on each side of the aisle. In a one-class, budget cabin configuration, there will be 43 rows of economy class, with three seats on each side of the aisle. A three-class cabin and one-class cabin will fit 242 and 258 passengers, respectively.

Lastly, the economic portion of the aircraft was decided. The estimated R&D cost was determined from the R&D costs of the A220 program and 737 MAX program, which came out to be $4.2 billion. The unit cost will be $174 million. This cost was determined by using parameters for range and passengers of middle of the market to average a cost per available seat mile. Then the calculated value for CASM was plugged into the trend line equation of Sale Price vs CASM of current aircrafts The cost per available seat mile will be $0.069.

Response from Airbus

With the release of a new MoM aircraft, there is no doubt that Airbus will respond with their new version of a “Middle of the Market” aircraft. However, being the first company to release, it gives Boeing the advantage over Airbus since it will be the only MoM aircraft in the market. By the time Airbus releases a comeback plane, the Boeing MoM aircraft will already be dominating the market since there is obviously a demand for it by the airlines. In addition, Airbus is currently in the process of the developing and producing the brand new A220 series aircraft, which would delay any attempt to formulate a comeback MOM plane.

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