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IDENTIFYING THE BEST DESIGN FOR UNCERTAIN MARKETS

Abdullah Desai*, Peter Hollingsworth*, Phani Chinchapatnam**
*** University of Manchester, Manchester, England M13 9PL, United Kingdom**
**** Rolls-Royce plc, Derby, England DE24 8BJ, United Kingdom**

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Abstract

This paper demonstrates the development and operation of a basic value-driven design framework to help identify the best airframe and engine options for non-traditional niche markets. Using data collected by The Bureau of Transportation Statistics, the size and scope of unfulfilled markets can be determined. Using the methodology, the user can evaluate airline, airframe and engine combinations for the best value solution. Value model optimisation can take place within each system, subcomponent and component model and keeping all things equal how one (or a set of) variable(s) would affect the overall design solution. Using the models, a number of Middle of the Market example cases were investigated, demonstrating the principle of the approach. While the modeling is incomplete the initial results highlight the challenges of selecting the proper configuration for uncertain, non-traditional markets.

1 Introduction

Design, certification and tooling costs to introduce any new aircraft with new engines can exceed one billion dollars [1]. For aircraft manufactures to make such an investment responsibly, engineers must focus on creating a product that will succeed [2]. Common aircraft manufacturer design process utilises Systems Engineering (SE) and Multidisciplinary Design Optimisation (MDO).

Using MDO and SE, design teams lack the economic tools to translate engineering parameters, market needs, and costs [3]. Therefore, industry has showed an interest in Value Driven Design (VDD) [4] as an alternative or supplementary procedure for preliminary and detailed design. VDD goes beyond the limits of SE by replacing the requirements environment, and incorporates a system level value function known as Surplus Value (SV). SV relates aircraft performance and manufacturing cost to aircraft, airline, and engine profitability [3].

A VDD research agenda [5] identifies five main areas of challenges: the system, the stakeholders, the value function, finding the best value and identifying the enablers. The research proposed herein will attempt to address issues associated with the SV method and develop a methodology to include competition within the supply chain, manufacturers and airlines portfolio [6].

2 Aim

Within the initial design stages, information and requirements are uncertain and susceptible to change with design maturity. However, using an enhanced Value Driven Design approach would provide a method for engineers and designers to rank different design options to find the best solution, for the manufacturers themselves and the operators.

This methodology will provide a detailed relationship of the value split amongst the operators and manufactures, including the effect of changing unit profit and/or the manufacturing cost of either the aircraft or engine. In other words, creating a design space for the product through relationships between model parameters rather than a flow down of set requirements.

The mechanism for distributing value is competition, and markets have a powerful effect on the allocation of profit [7]. Therefore, the optimisation will enable to find the best split of value to maximise the profit for the airline, the airframe and engine manufacturer, and their suppliers. Ultimately minimising the likelihood of deadweight loss decision-making.

The competition model will incorporate a number of airline models, supplied by multiple airframes with a selection of engine options to simulate a simple scenario of competition. Using this methodology, the user can investigate and play out the effects of a competitive environment with uncertainty of market requirements.

3 Value Driven Design Process

Figure 1 demonstrates where potential design parameters are included and how a SV figure is found. The simulation feeds through the subcomponent and component models, to generate a specific aircraft model for a particular airline/traffic demand. The attributed value from each model is combined into the product value model. Optimisation can take place within each component to find the best solution within each model or investigate keeping all things equal how one, or a set of, variable(s) would affect the overall product design.

3.1 Capturing the Potential Market

The market for a proposed commercial aviation system ultimately comes from providing a transportation service, either people or cargo. However, in most cases for commercial aircraft, it is possible to view the market as the aircraft operators; the airlines. In order to develop a value model for these systems it is necessary to understand the current state of the travel market and the potential path of the future. In order to develop this for the case presented in this paper a model was developed using publicly available airline industry data: The U.S. Department of Transportation Form 41 (U.S. DOT Form 41) from the Bureau of Transportation Statistics (BTS) [8], and relevant filings to the Securities and Exchange Commission (SEC).

The U.S. DOT Form 41 from BTS is used to create important trends and generate forecasts for analysis. The data provides key parameters to identify the drivers for different types of costs and identify potential revenues specific to aircraft types and airlines. For the purposes of this research the payload and range are the key variables for analysis. The long time series of the data, starting in 1995, provides a great breadth of information to allow investigations over time for specific routes, identifying aircraft types that service it and payload demand over time.

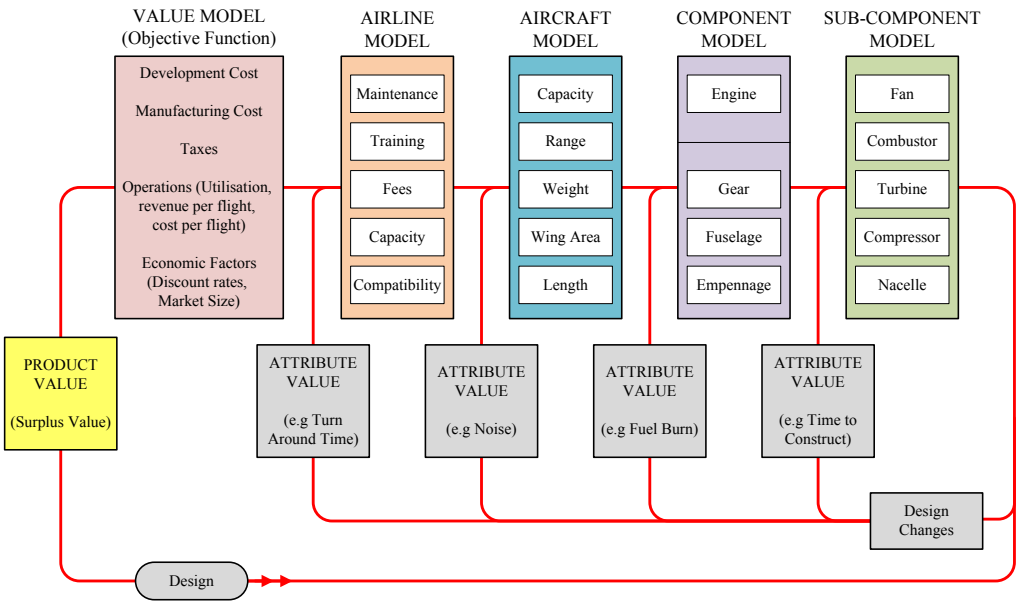

Fig. 1. Value Driven Design Process

3.2 Aircraft Models

In order to estimate the value of a new aircraft programme, especially one that does not neatly fit as a replacement, it is necessary to have a representation of the potential competing models. To do this an initial sizing of 24 different aircraft models was created using NASA's Flight Optimization System (FLOPS) [9]. This includes a representation of both current generation and newer generation aircraft families; e.g. Boeing 737, 757, 767 and 787; Airbus A320, A321, A330 families [10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21].

For the known competitors, a simple regression model is created to find a statistical relationship between the payload and range capabilities of the aircraft. While also estimating the block time and fuel required for each flight. For any new advance technology model a more sophisticated regression model relating design variables and technology parameters can be used.

3.3 Revenue Model

With the presence of a market and the aircraft performance models, it is possible to estimate both the potential revenue and costs. In prior VDD approaches the airline industry has been considered to be monolithic. However, changes to the industry have forced airlines to review many long-standing business approaches. The rapid growth of low cost carriers (LCCs) and shifts to Internet distribution channels put downward pressure on airfares and, in turn, airline revenues. It is therefore necessary to be able to model multiple types of airlines. Again the BTS data provides key revenue metrics for airline profitability and to provide context when expenses, finances and operating characteristics are created.

The revenue that an aircraft can earn for an airline depends on the payload and range capability, in conjunction with the specific route and its passenger and freight demand [4]. The BTS data provides an insight in to how a particular aircraft is operated, with respect to its range and payload capabilities. A relationship between the ticket price and the range of the flight is found and used within the model.

The ticket price is produced as a function of stage length; the total aircraft revenue would be multiplied by the number of seats available. However, the weight of the total passengers including baggage would typically be under the maximum payload capacity, therefore the remainder would be assumed as carrying cargo.

3.4 Cost Model

The cost data within BTS is much like the revenue section, which examines the system performance of each airline and aircraft type. Each relevant metric has been adjusted for stage-length to include Direct Operating Costs and Indirect Operating Costs. The main drivers of cost include labour, fuel and maintenance.

Using FLOPS to prescribe a mission, the following data can be used to generate a typical operating and maintenance cost for the flight. The only costs that are excluded from the calculation are the acquisition/leasing costs and the effects of fleet size and age. These factors will need further investigation.

3.5 Value Model

Using data collected by BTS to create both revenue and cost models for different aircraft types, it is then possible to explore and select potential candidate solutions for specific market requirements. Firstly, by analysing the size and scope of a particular market, it possible to identify a number of replacement aircraft to fulfil the required route. This information is included in the VDD approach.

Figure 2 is the proposed methodology; it includes different System Levels, which incorporate together to represent the civil aviation market. All the system levels then feed in to a Surplus Value (SV) model. The method is adapted from Cheung [22], which focuses on the whole supply chain.

The work created using FLOPS represents the engine and airframe portfolios whereby a number of different airframe and engine options are available to integrate into an airline and travel model. This information will be found from the BTS Data to provide information regarding airline and fleet utilisation as well as the market demands on specific routes.

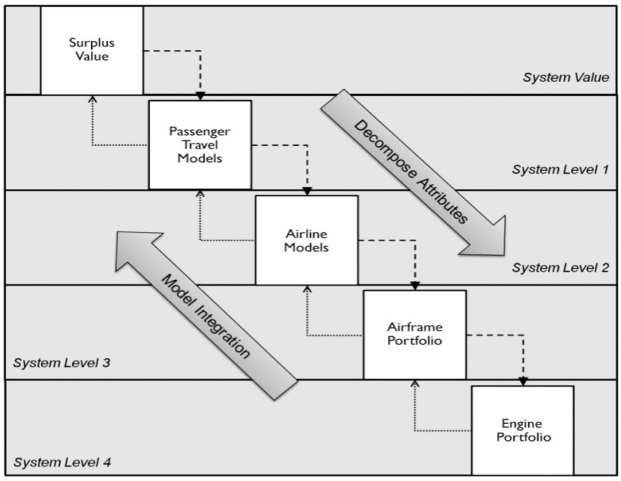

Fig. 2. Aircraft System Hierarchy [22]

3.6 Competition Model

The competition model, shown in Figure 3, incorporates multiple airline models, supplied by a number of airframers with a selection of engine options. It will allow a flow down of attributes to constrain design space for the manufactures. As each optimisation is complete, system level values will be compiled to integrate into a SV model. The competition model incorporates multiple airframe families which compete with each other as well as other airframes. The interactions between the system levels require further investigation, especially to capture and understand the effects of the upstream and downstream supply-chains.

4 Simulation Analysis

Three simulations scenarios have been created using the aircraft models via FLOPS. These scenarios allow the user to determine the best aircraft option for any given range, payload and number of flights. The simulation then provides the SV for the aircraft options available for comparison in the analysis; the highest SV is deemed to be the best in the analysis with all things remaining equal. Furthermore, this type of simulation will contribute to an airline fleet level analysis to maximise the value through a combination of aircraft types, routes/destinations and cargo/payload.

4.1 Payload Satisfying Scenario

The payload satisfying scenario is where the payload for a particular flight segment is fixed and number of flights is adjusted for each aircraft type till the payload demand is met. For example, an aircraft must carry a particular number of passengers and payload per week. This would be regardless to the number of flights it takes to achieve the target payload. This is a very simple scenario but allows the user to determine the utilisation of the aircraft types available. It does not account for the any aspect of desirability or maximum reasonable frequency.

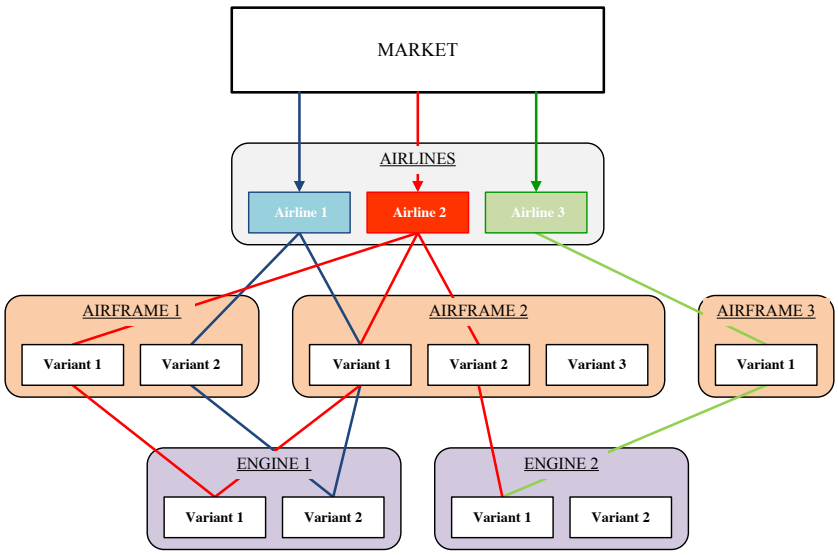

Fig. 3. Competition Model

4.2 Operations Fixed Scenario

The operations fixed scenario is where the number of flights and the amount of payload is specified, but the amount of payload actually carried would vary between aircraft types. If the aircraft type has a low payload capacity then it may be the case it would need to leave payload behind due to the restricted number of flights available, and if an aircraft type has a high payload capacity then it may be the flights operate at a low load-factor.

4.3 Payload Capacity Split Scenario

The payload capacity split scenario is an extension to the operations limited scenario. Rather than the user prescribing the number of flights, it is determined by the stage distance of the particular flight that is being calculated. In the operations limited scenario, the number of flights is fixed for all payloads and ranges. However, this would be impractical to compare long haul vs short haul flights over the same number of flights and not the same amount of time.

In the payload capacity split scenario, a duration is fixed e.g. one week, and the number of flights within this duration is calculated. Therefore, the longer the flight, the lower number of flights that can be carried out over the week and vice versa. As previously the amount of payload actually carried would vary between aircraft types dependent on its payload capacity. It is variations on this model that produce the most realistic representation of potential markets.

5 Case Study: Middle of the Market

Using the current commercial aircraft market as an example, plotted in Figure 4 are a number of available aircraft with their respective payload and range capabilities. A number of gaps within the overall market can be identified but one stands out above the rest. The Middle of the Market, the cross-over point between single-aisle and twin-aisle aircraft, between 180 and 250 seats.

The quintesential example of this space is the Boeing 757 family, a mid-size, narrow-body twin-engine jet aircraft. The Boeing 757-200 is mainly used on short to medium range routes up to 4000nm, while seating 208 passengers. The Boeing 757-300 is a stretched version, carrying approximately 245 passengers with an increased maximum take-off weight (MTOW).

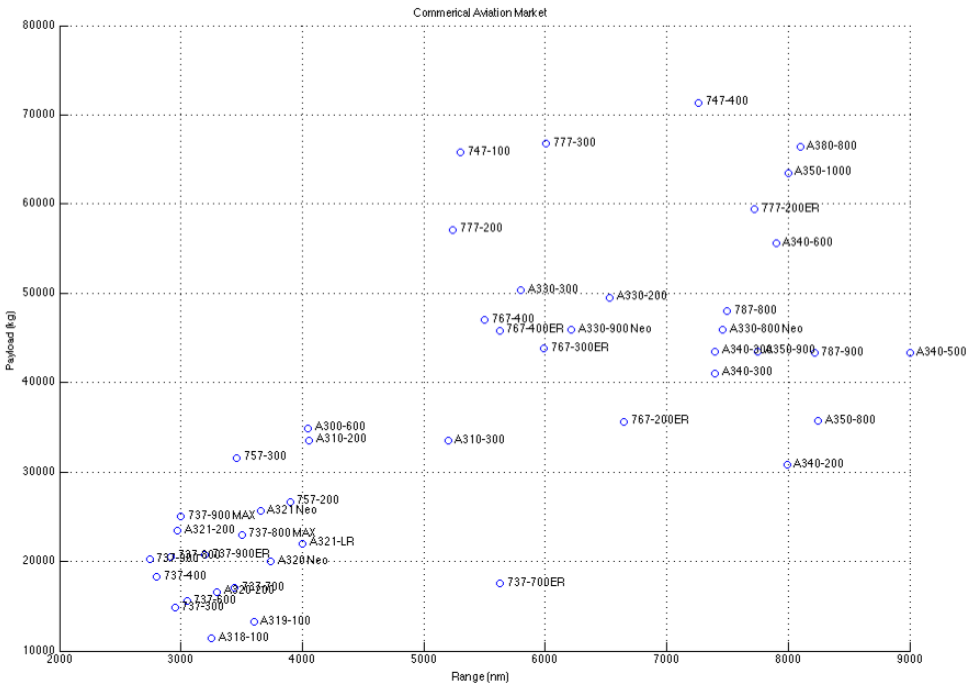

Fig. 4. Commercial Aviation Market

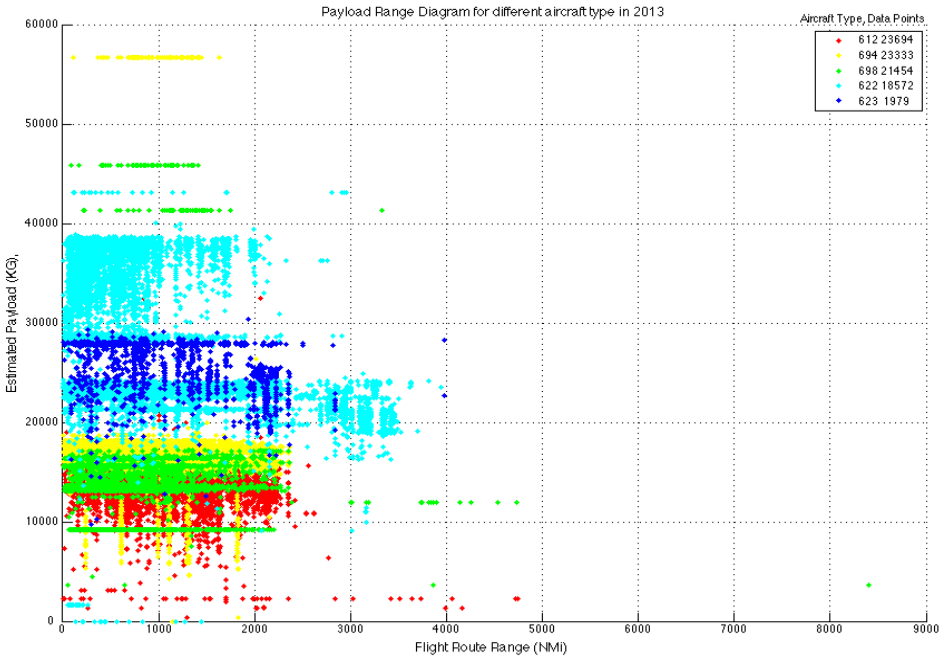

Fig. 5. Potential Boeing 757-300 replacement Options [8]

The Boeing 757 has been in operation for 33 years and the last model rolled-off the assembly line in 2005 and it is still in a class of its own as the largest narrow body aircraft. The ageing aircraft has no direct replacement, creating an unknown for the future of this market. Known as the Middle of the Market (MoM), airlines will need to replace the current Boeing 757 operating over the next decade. Before considering which aircraft is a suitable substitute, the need for a replacement must be examined.

In the past both Boeing and Airbus offered aircraft in this class, both single and twin aisle. Replacement options include the traditional smaller narrow body aircraft such as the Airbus A320 and Boeing 737 or larger wide body aircraft such as the Airbus A330 and Boeing 787.

5.1 Market Analysis

Using Form 41 data, the Boeing 757 traffic patterns, payloads, routes and ranges are analysed. A potential MoM synopsis can be created to identify past trends to predict potential future markets. This data presented combines domestic and international segment data reported throughout the U.S. by all air carriers, and contains non-stop segment data by aircraft type.

Using the model, a number of Middle of the market study examples was created to demonstrate the principle of the simulation. These include four key options in terms of replacement of the Boeing 757:

Option 1: Routes experiencing weaker passenger volumes and yields would utilise a smaller aircraft (dependent of route range) and operate them at the same frequency.

The Airbus A320 and Boeing 737 families contain variants only slightly smaller than the Boeing 757-200 and can operate a large percentage of the current Boeing 757 block distances with no payload penalty.

Figure 5, shows the Airbus A320 (yellow), Airbus A319 (green) and Boeing 737-700 (red) as potential replacement options for the Boeing 757-200 (light blue) and Boeing 757-300 (dark blue). Each data point represents one flight over the course of the year at a particular average payload and range for that route.

The BTS data demonstrates the broad use of the aircraft with the Boeing 757-300 at the higher payload of 28t while the Boeing 757-200 operated at larger range 3500nm. A band above the Boeing 757-300 shows the converted Boeing 757-200 freighters, carrying up to 38t.

	2000 Pax	3000 Pax	4000 Pax	5000 Pax	6000 Pax	7000 Pax	8000 Pax
500nm	A320-200	A320-200	B737-800	B757-300	B757-300	B757-300	B757-300
1000nm	A320-200	A320-200	B737-800	B757-300	B757-300	B757-300	B757-300
1500nm	A320-200	A320-200	B737-800	B757-300	B757-300	B757-300	B757-300
2000nm	A320-200	A320-200	B737-800	B757-300	B757-300	B757-300	B757-300
2500nm	A320-200	A320-200	B737-800	B757-300	B757-300	B757-300	B757-300
3000nm	A320-200	B737-800	B757-300	B757-300	B757-300	B757-300	B757-300
3500nm	B737-800	B757-300	B757-300	B757-300	B757-300	B757-300	B757-300
4000nm	B757-300	B757-200	B757-200	B757-200	B757-200	B757-200	B757-200
4500nm							

Table. 1. Boeing 757 Replacement Options: Smaller Aircraft (Old Generation)

By reducing the capacity offered on a route with weak passenger volumes and yields, it should result in operating cost savings and improved operating profit.

Table 1, shows the simulation model evaluation between 500 nm and 4500 nm, with payload between 2000 passengers to 8000 passengers. In this case the number of flights is restricted to 21, simulating 3 flights a day over a week. The simulation demonstrates an improved operating profit by the newer generation smaller narrow body class aircraft such as the Airbus A320neo and Boeing 737-8MAX.

From the initial results, see Table 1, it is evident that even with the newer generation technology the Boeing 757-300 with its higher payload capability still shows a potential operating advantage on high volume routes.

Table 2 shows the newer generation Airbus A320NEO and Boeing 737MAX options. The next generation variant aircraft are more capable than their predecessors and subsequently prove more profitable on additional routes. This is shown in Table 3. On particular routes in this scenario, the newer generation aircraft can offer potential savings of up to 35% over the Boeing 757 aircraft. However, there are still a number of routes where significantly older technology has an operating advantage.

	2000 Pax	3000 Pax	4000 Pax	5000 Pax	6000 Pax	7000 Pax
500nm	A320-200neo	A320-200neo	B737-800MAX	B757-300	B757-300	B757-300
1000nm	A320-200neo	A320-200neo	B737-800MAX	B757-300	B757-300	B757-300
1500nm	A320-200neo	A320-200neo	B737-800MAX	B757-300	B757-300	B757-300
2000nm	A320-200neo	A320-200neo	B737-800MAX	B757-300	B757-300	B757-300
2500nm	A320-200neo	A320-200neo	B737-800MAX	B757-300	B757-300	B757-300
3000nm	A320-200neo	A320-200neo	A320-200neo	B757-300	B757-300	B757-300
3500nm	A320-200neo	A320-200neo	A320-200neo	B757-300	B757-300	B757-300
4000nm	A320-200neo	B737-800MAX	B737-800MAX	B757-200	B757-200	B757-200
4500nm						

Table. 2. Boeing 757 Replacement Options: Smaller Aircraft (New Generation)

Aircraft Type	Range (Nm)	Payload Carried (total lbs)	NOF	Max Pay (pf lbs)	Fuel (pf lbs)	Operating Profit (total $ 000)
A320-200	3500	Nan	Nan	Nan	Nan	Nan
A320-200neo	3500	841,626	21/25	40077	40838	108
B737-800	3500	441,705	21/48	21034	46000	21
B737-800MAX	3500	1,000,000	21/21	48048	44275	104
B757-200	3500	1,000,000	21/21	49516	69600	89
B757-300	3500	1,000,000	21/20	51839	74512	108

Table. 3 Analysis of Simulation at 3500nm, 4000 passengers over 21 flights/week

Option 2: Routes experiencing stable passenger volumes and yields would utilise a narrow body aircraft (range dependent) and potentially increase frequencies to maintain total capacity. This will maintain the overall balance resulting in a similar operating costs and revenue.

Both the Airbus A321 and Boeing 737-900ER are nearly capable of directly replacing the Boeing 757-200 on the vast majority of sectors.

A similar BTS outlook of this option showed the Airbus A321 as being operated within the Boeing 757-200 and some Boeing 757-300 routes. However, neither the Boeing 737-900 or Airbus A321 can match the extended range capability of the Boeing 757-200. As a direct replacement for shorter routes, the Airbus A321 and Boeing 737-900ER aircraft will maintain the overall capacity and provide lower operating costs and improved profitability. Furthermore, the new A321NEO and 737-9MAX cover an even larger percentage of routes on which the 757-200 was used.

Table 4 shows the model evaluation between 500 nm and 4500 nm, with payload ranges between 2000 passengers to 7000 passengers. The number of flights is restricted to 21, simulating 3 flights a day. The aircraft used in this analysis includes the Airbus A321/NEO/LR, Boeing 737-900ER/-9MAX and the Boeing 757-200/300. The simulation results demonstrate an improved yield by the newer generation equivalent narrow body class aircraft such as the Boeing 737-9MAX and Airbus A321LR with a similar and higher frequency across all the ranges and passengers.

For longer ranges and higher passenger demands the 757 holds an advantage over the original replacements. However, Table 5

	2000 Pax	3000 Pax	4000 Pax	5000 Pax	6000 Pax	7000 Pax
500nm	B737-900ER	B737-900ER	B737-900ER	B757-300	B757-300	B757-300
1000nm	B737-900ER	B737-900ER	B737-900ER	B757-300	B757-300	B757-300
1500nm	B737-900ER	B737-900ER	B737-900ER	B757-300	B757-300	B757-300
2000nm	B737-900ER	B737-900ER	B737-900ER	B757-300	B757-300	B757-300
2500nm	B737-900ER	B737-900ER	B737-900ER	B757-300	B757-300	B757-300
3000nm	B737-900ER	B737-900ER	B737-900ER	B757-300	B757-300	B757-300
3500nm	B737-900ER	B737-900ER	B757-300	B757-300	B757-300	B757-300
4000nm	B757-200	B757-200	B757-200	B757-200	B757-200	B757-200
4500nm						

Table. 4. Boeing 757 Replacement Options: Equivalent Aircraft (Old Generation)

represents the same simulation with the new generation Boeing 737-9AX and A321LR. As expected, the new generation aircraft are better for a broader range of possible missions. However, the 757-300 still fills a niche by virtue of its higher maximum payload.

Table 6 represents the simulation at 3500nm with 4000 passengers over 28 flights. The new generation Boeing 737-900MAX performs as the best yielding aircraft for this 3500nm mission. It produces almost double the yield of the Boeing 757-300, this is partly due to the higher number of flights.

As the number of flights is increased, adding frequencies, the improved operating economics allow the NEO/MAX aircraft to dominate further. Reducing the number of flights to 21 still results in the 737-900MAX as the best candidate but the yield is reduced to only 5% greater.

Option 3: Routes experiencing high load factors and traffic growth would likely utilise a larger wide body aircraft and operate them at the optimum frequency, which could be less or more depending on route, range and block times.

Larger wide body aircraft are usually used in medium to long-range routes. These include; A330-200, seating 293 for 7200nm fully loaded;

	2000 Pax	3000 Pax	4000 Pax	5000 Pax	6000 Pax
500nm	B737-900MAX	B737-900MAX	B737-900ER	B757-300	B757-300
1000nm	B737-900MAX	B737-900MAX	B737-900ER	B757-300	B757-300
1500nm	B737-900MAX	B737-900MAX	B737-900ER	B757-300	B757-300
2000nm	B737-900MAX	B737-900MAX	B737-900ER	B757-300	B757-300
2500nm	B737-900MAX	B737-900MAX	B737-900ER	B757-300	B757-300
3000nm	B737-900MAX	B737-900MAX	B737-900MAX	B757-300	B757-300
3500nm	B737-900MAX	B737-900MAX	B737-900MAX	A321neoLR	A321neoLR
4000nm	B737-900MAX	A321neoLR	A321neoLR	A321neoLR	A321neoLR
4500nm					

Table. 5. Boeing 757 Replacement Options: Equivalent Aircraft (New Generation)

Aircraft Type	Range (Nm)	Payload Carried (total lbs)	NOF	Max Pay (pf lbs)	Fuel (pf lbs)	Operating Profit (total $ 000)
A321-200	3500	1,000,000	28/28	36061	52098	90
A321-200neo	3500	1,000,000	28/21	48819	45677	98
A321-200neoLR	3500	1,000,000	28/19	54992	45996	98
B737-900ER	3500	1,000,000	28/27	38106	50798	112
B737-900MAX	3500	1,000,000	28/23	45403	43470	122
B757-200	3500	1,000,000	28/21	49516	65830	57
B757-300	3500	1,000,000	28/20	51839	70870	74

Table. 6 Analysis of Simulation at 3500nm, 4000 passengers over 28 flights/week

A350-800, designed for 8000nm; and Boeing 787 designed for 9000nm.

The BTS data demonstrates a clear envelope area where the Boeing 757 operates but none of the smaller aircraft can. Therefore, larger aircraft such as the Airbus A330, A350 and Boeing 787 must be considered for these specific routes. However, it is important to note, these aircraft are not designed for relatively shorter distances.

Using a similar approach, the Boeing 757 was compared against current and next generation aircraft on routes between 500 nm and 4500 nm, with payload ranges between 2000 passengers to 7000 passengers. Again the number of flights is fixed at 21/week. In the first analysis, see table 7, includes the older generation Boeing 767 and Airbus A330, and the second analysis, see Table 8, uses the newer generation Boeing 787 and Airbus A330NEO.

When comparing like generation aircraft the Boeing 757 shows up as the best aircraft for routes with up 5000 passengers and up to 4000nm. This makes sense as the larger aircraft are better suited for the longer range and higher payload scenarios. When comparing to the new generation aircraft, see Table 8, the 757 continues to hold its own providing narrow body economics even though the 767s and original A330s are replaced.

	2000 Pax	3000 Pax	4000 Pax	5000 Pax	6000 Pax	7000 Pax
500nm	B757-300	B757-300	B757-300	B757-300	B767-300ER	A330-300
1000nm	B757-300	B757-300	B757-300	B757-300	B767-300ER	A330-300
1500nm	B757-300	B757-300	B757-300	B757-300	B767-300ER	A330-300
2000nm	B757-300	B757-300	B757-300	B757-300	B767-300ER	A330-300
2500nm	B757-300	B757-300	B757-300	B757-300	B767-300ER	A330-300
3000nm	B757-300	B757-300	B757-300	B757-300	B767-300ER	A330-300
3500nm	B757-300	B757-300	B757-300	B767-300ER	B767-300ER	B767-300ER
4000nm	B757-200	B757-200	B767-300ER	B767-300ER	B767-300ER	B767-300ER
4500nm	B767-300ER	B767-300ER	B767-300ER	B767-300ER	B767-300ER	B767-300ER

Table. 7. Boeing 757 Replacement Options: Larger Aircraft (Old Generation)

	2000 Pax	3000 Pax	4000 Pax	5000 Pax	6000 Pax	7000 Pax
500nm	B757-300	B757-300	B757-300	B757-300	B787-900	A330-900
1000nm	B757-300	B757-300	B757-300	B757-300	B787-900	A330-900
1500nm	B757-300	B757-300	B757-300	B757-300	B787-900	A330-900
2000nm	B757-300	B757-300	B757-300	B757-300	B787-900	A330-900
2500nm	B757-300	B757-300	B757-300	B757-300	B787-900	A330-900
3000nm	B757-300	B757-300	B757-300	B757-300	B787-900	A330-900
3500nm	B757-300	B757-300	B757-300	B787-800	B787-900	A330-900
4000nm	B757-200	B757-200	B787-800	B787-800	B787-900	A330-900
4500nm	B787-800	B787-800	B787-800	B787-800	B787-900	A330-900

Table. 8. Boeing 757 Replacement Options: Larger Aircraft (New Generation)

	4000 Pax	5000 Pax	6000 Pax	7000 Pax	8000 Pax	9000 Pax
500nm	B737-900MAX	B737-900MAX	MoM	MoM	B787-900	A330-900
1000nm	B737-900MAX	B737-900MAX	MoM	MoM	B787-900	A330-900
1500nm	B737-900MAX	B737-900MAX	A321neoLR	MoM	B787-900	A330-900
2000nm	B737-900MAX	B737-900MAX	A321neoLR	MoM	B787-900	A330-900
2500nm	B737-900MAX	B737-900MAX	A321neoLR	MoM	B787-900	A330-900
3000nm	B737-900MAX	B737-900MAX	A321neoLR	MoM	B787-900	A330-900
3500nm	B737-900MAX	B737-900MAX	A321neoLR	B787-900	B787-900	A330-900
4000nm	B737-800MAX	A321neoLR	A321neoLR	B787-900	B787-900	A330-900
4500nm	MoM	B787-800	B787-800	B787-900	B787-900	A330-900
4500nm	MoM	B787-800	B787-800	B787-900	B787-900	A330-900

Table. 10. Boeing 757 Replacement Options: Direct Replacement

Table 9 represents the simulation at 3500nm with 4000 passengers over 21 flights. Ten different aircraft are used in this simulation and the Boeing 757-300 performs as the best yielding aircraft for this 3500nm mission. Narrowly beating the Boeing 767-300. Increasing the number of flights to 28 still results in the Boeing 757 as the best candidate.

Option 4: New Direct replacement. A new direct replacement of the Boeing 757 is likely to leverage mature technologies such as those from the Boeing 787 and 737MAX programmes.

A representative model was created as a direct replacement for the MoM. The MoM aircraft, it has a payload weight of 50,000lbs with an endurance range of 4500nm.

Table 10 shows the model evaluation between 500 nm and 5000 nm, with payload ranges between 4000 passengers to 9000 passengers. This analysis is performed for routes of 28 flights/week and includes all 24 models.

The results show the Airbus A321NEO and Boeing 737-9MAX are attractive options for shorter routes with potentially strong competition. The Airbus A321LR can also operate in the correct high yield circumstances as shown in the replacement option 2. The Boeing 787 and Airbus A330 are better suited for the longer range missions. In this example, the MoM aircraft is preferred in a few specific scenarios.

Aircraft Type	Range (Nm)	Payload Carried (total lbs)	NOF	Max Pay (pf lbs)	Fuel (pf lbs)	Operating Profit (total $ 000)
A330-200	3500	1,000,000	21/10	110000	103993	60
A330-300	3500	1,000,000	21/10	110000	109138	80
A330-200neo	3500	1,000,000	21/8	126000	90856	53
A330-300neo	3500	1,000,000	21/8	127000	94389	74
B767-300	3500	1,000,000	21/15	68643	87254	106
B767-300ER	3500	1,000,000	21/11	97000	85692	89
B787-800	3500	1,000,000	21/11	95500	73777	72
B787-900	3500	1,000,000	21/9	120000	71302	80
B757-200	3500	1,000,000	21/21	49516	69600	89
B757-300	3500	1,000,000	21/20	51839	74512	108

Table. 9 Analysis of Simulation at 3500nm, 4000 passengers over 21 flights/week

This simple first order analysis demonstrates the challenge of developing an MoM aircraft. It only considers reoccurring operating costs and neglects capital and fleet associate fixed costs. In many cases, depending on the airline, it would be profit maximizing to operate larger aircraft in these specific scenarios.

6 Conclusion, Caveats and Future Work

The analysis contained in the paper demonstrates the basic framework for using a VDD approach to design a non-tradition niche market aircraft. In these cases, it is essential the competing, but not directly substitutable products be considered as they will put pressure on the viability of any design.

However, the reader should not take the results contained in this paper as representative of the actual outcome of a MoM market study. To properly undertake this analysis, it is necessary to include more than one airline, fixed and capital costs, and optimise the frequency and capacity for each candidate aircraft and design variables for the MoM aircraft.

These additions when coupled with the manufacturer's cost model can properly estimate potential market size for a MoM aircraft and can help assess which scenarios maximise value. Future activities are focusing on these aspects, plus addressing the multi-stage game that characterizes the contemporary aircraft development, sales and operating environment.

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Contact Author Email Address

mailto: abdullah.desai@manchester.ac.uk

Statement