VSTOL Aircraft market analysis

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ABSTRACT

This paper describes the market for air vehicles that offer Very Short Take Off and Landing (VSTOL) capabilities, also known as VSTOL aircraft. A commercial VSTOL aircraft will only succeed if it provides profits to both manufacturers and airlines. Being able to operate out of shorter fields offers airlines greater flexibility and therefore provides a benefit to the airline. However, adding VSTOL performance also adds cost. Successful VSTOL aircraft designs must balance the added cost against the additional benefits VSTOL performance will provide.

The first problem in any new VSTOL design is determining what field length provides the maximum benefit relative to cost. In order to be able to determine this one needs to know not only what it will cost to design and build the new aircraft, but its value to the airlines, as reflected by the demand for it and the price they are willing to pay. Only then is it possible to design the aeroplane the market wants at a sustainable price and in sufficient quantities to optimise the manufacturer's return on investment.

This paper is a comprehensive parametric analysis of helicopters and aeroplanes that shows how much the market values short field performance by determining how much airline customers have been paying for it and how the market reacts to changes in its price. The analysis simultaneously considers over 230 currently produced models of fixed wing and rotary commercial aircraft, ranging in size from a Cessna 172 to an Airbus A380 and with balanced field lengths ranging from less than 150 to over 10,500ft.

The data show that a single, statistically significant demand curve exists for all of these vehicles, with prices that range across several orders of magnitude. This curve consists of several segments or sub-markets including those for regional and rotary wing aircraft. Both of those markets offer vehicles over a wide range of prices. The analysis shows that VSTOL price is a function of the balanced field length provided by the vehicles within these market segments. Comparing demand and sustained price against cost reveals particular field lengths for which it will be possible to make a profit building VSTOL aircraft.

Because the sustained price for a VSTOL aircraft is a function of its field length performance, and the quantity of a model sold is a function of its price, it follows that it is possible to predict the profit potential for a given VSTOL design in advance of its development. A thorough study of potential configurations therefore offers manufacturers the ability to design VSTOL aircraft that provide the maximum possible profit while fully satisfying the requirements of their airline customers.

1.0 INTRODUCTION

While it may seem obvious that the VSTOL markets should be analysed before manufacturers enter them, what that analysis means is not so obvious. If VSTOL vehicle prices are high, VSTOL manufacturer profits per unit may be high as well. But higher prices force lower quantities of VSTOL vehicles purchased. That may drop overall profits or even force losses, or, in the most extreme example, prevent programs from being launched. These worst cases are not to

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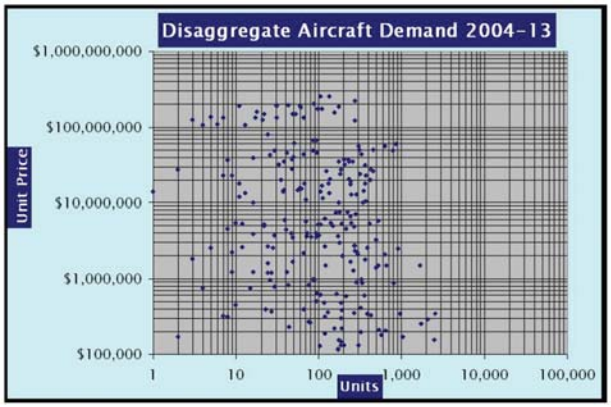


Figure 1. Disaggregate total aircraft demand 2004-13.

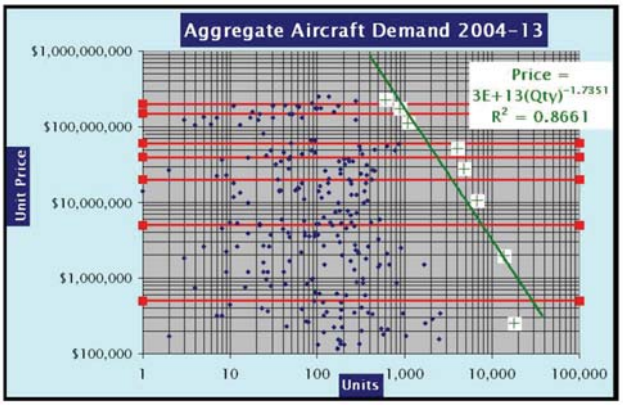


Figure 2. Aggregate total aircraft demand 2004-13.

be considered hypothetical. A few years ago, although not a VSTOL aircraft, the Boeing Company tried to launch what they called their Sonic Cruiser. The company stated confidently that the plane would 'change the way the world flies,' but in the end, Boeing received no orders for it[1] and the program was cancelled[2]. Clearly, whatever price they were asking for it was too high.

Conversely, if vehicle prices are too low, profit margins drop. This, too, may eventually force losses or create impossibly thin profit margins. Eclipse Aviation began working on its Eclipse 500 in 2000, initially proposing to build the four or five place jet for $775,000[3]. In September of 2007, after taking over 2,600 orders for the vehicle, and as their list price reached $1·6 million, their president, Vern Raburn stated that it would take 600 aircraft a year just to break even[4]. Just the month before, in August of 2007, a Danish businessman bought a new Eclipse 500 on auction over the Internet, paying $1·83 million for it [5]. It is plain to see that under-pricing planes has serious financial ramifications as well.

Because changes in prices for VSTOL have important implications to manufacturers' bottom lines, knowing the demand curve for VSTOL aircraft is important. This paper will show that the VSTOL demand curves for regional aircraft and helicopters are subsets of the overall demand curve for all new commercial aircraft. Demand curves for any VSTOL vehicles in production or for any VSTOL vehicles proposed to go into production can be drawn if their attributes are known.

As a class of aircraft, VSTOL air vehicles offer a wide range of minimum balanced field lengths requirements. They also provide allow airlines the ability to varying numbers of passengers at various speeds. Each of these features or attributes, short field performance, passenger capacity and maximum cruise speed, carry a certain cost to provide them. At the same time, airlines need to have these features to offer attractive service to their customers. A primary facet of VSTOL market analysis is thus determining the value of VSTOL vehicle features compared their cost.

Demand, value, cost and physical limits form boundaries around potential VSTOL aircraft designs. This paper will show how to calculate VSTOL demand, value and cost given their physical limits and show a path to optimise VSTOL vehicles given the constraints that face them.

2.0 VSTOL DEMAND

Consider 233 fixed and rotary winged commercial air vehicles ranging in price from under $100,000 to over $250 million for sale over the course of decade. As Forecast International saw them in 2004, their projected sales quantities and prices populated Fig. 1[6].

Included in the Fig. 1 data are vehicles as diverse as the Cessna 172, which sold for about $155,000 in 2005, and the Airbus A380, which sold for over $250 million. Clearly, with the data all scattered about in Fig. 1, there is little knowledge that can be gained about the demand for all vehicles. That is, there is little information we gain if we do not attempt to reorganise the data.

We remedy this by placing the data within groups based on their sales price. If we divide the aircraft into classes by price, from, say, $0 to $500,000, $500,000 to $5 million, $5 million to $20 million, and so on, we'll have the data aggregated into bins. If we then add up all of the revenue for in each class and then divide it by the number of unit within it, we get a much different picture of aircraft demand, as shown in Fig. 2. This statistically significant equation means that the Cessna 172 and Airbus A380 are on the same aggregate demand curve (see Appendix A for more details).

Our problem at hand is the analysis of the VSTOL market. Since aggregating the data worked for the entire market, one might wonder if that method would work for sub-markets. As shown in Fig. 3, we can see that it does.

In Fig. 3 we have taken those vehicles falling into the regional aircraft category and placed them into price ranges that have a price to and including $25 million, from $25 to $30 million, from $30 million to $40 million and those that cost more than $40 million. The demand for the Regional Aircraft submarket, as shown Fig. 3 by the gold line, is well-correlated, as is the demand for helicopters as indicated by the dark red line. There, the bins began with those helicopters that have price tag of less $7·5 million, those that cost from $7·5 to $15 million, those from $15 million to $25 million, and a final category for those vehicles that were priced above $25 million. Thus, these two separate VSTOL markets, the market for regional aircraft and the market for helicopters, each have their own demand curves.

As we'll see later on, it is possible to further characterise a demand curve for a single proposed or existing vehicle. In order to understand that concept, it will first be incumbent upon us to understand what supports the vehicle price in the first place.

Classical price theory might hold that for every downward-sloping demand curve within a market there is an upward sloping supply curve and that equilibrium in that market occurs where supply and demand intersect. Clearly, however, such a framework does not work for the market for new commercial aircraft. There is no single supply curve that explains why some customers buy aircraft costing $250 million or more (as for the A380) at the same time those same or other customers buy Cessna 172s for less than $200,000. In order to understand the mechanisms that support prices, we'll need to understand the concept of value.

3.0 VSTOL VALUE

What features or attributes do VSTOL customers want? How do those features or attributes relate to VSTOL value? How does VSTOL value relate to VSTOL demand? These are important questions. The answers to these questions are knowable using a wide-ranging database of VSTOL aircraft to include their features

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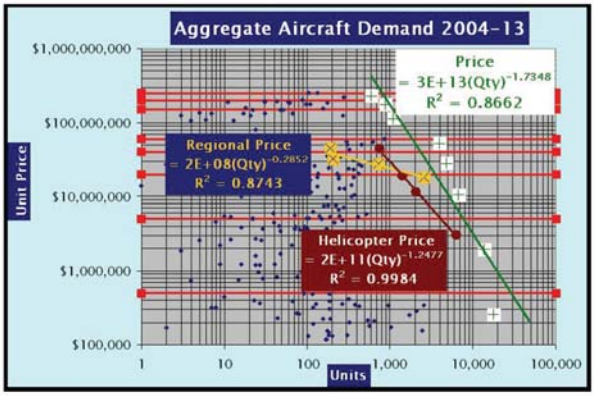


Figure 3. Regional aircraft and helicopter aggregate demand 2004-13.

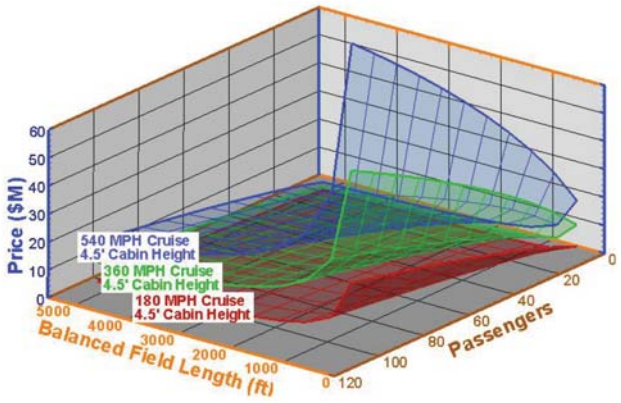


Figure 4. VSTOL value varying max cruise MPH.

and sustained prices. Given a suitable platform upon which to run analysis upon this database, the market reveals what it values.

When considering which plane to buy, it seems reasonable to suppose that airlines would consider the attributes or features of the vehicles available to it as important factors in their purchase decisions. One vehicle may be able to carry more passengers than another. Another goes faster, but carries fewer customers. Yet another model has an even slower speed, but since it is a small helicopter, it can land in many more places than the other two vehicles. As all of the customers make all of the purchase decisions concerning all of the vehicles, it seems reasonable to hypothesise that for VSTOL aircraft, value is a function of the attributes offered. Specifically, let's suppose that;

$$V_M = A_1 * A_2 * \ldots A_n \quad \ldots (1)$$

Where:

V_M = market value of VSTOL aircraft
A_i = contribution of the i^{th} attribute

As used here, the market value of the VSTOL Aircraft variable represents the projected median sales price of a business aircraft given the contribution of its attributes. Within the boundaries of this value exceeding the cost of the product in question and that of sufficient demand (as to merit production of a business aircraft), this term stands in for the average price as:

$$V_M = \overline{Pr} \quad \ldots (2)$$

Where:

$\overline{Pr}$ = Median Clearing Price of VSTOL Aircraft (in millions of $2005)

Performing stepwise, multiple log-linear regressions upon a mixed dataset of 27 helicopters and regional and short field aircraft[6] yields several statistically significant predictors of the median clearing price of VSTOL aircraft. One of the more useful equations is Equation (3), below:

$$\overline{Pr} = 0{\cdot}001 * FL^{(-0{\cdot}48)} * P^{0{\cdot}69} * S^{1{\cdot}24} * H^{01{\cdot}93} \quad \ldots (3)$$

Where:

FL = balanced field length, in ft
P = typical number of passengers seats
S = maximum cruise speed, in MPH
H = cabin height in ft

The adjusted R^2 for Equation (3) in Unit Space is 95%, (The R^2, or coefficient of determination, is the ratio of the variation of the dependent variable explained by a regression equation over the total variation of the dependent variable. A perfectly correlated regression equation has an R^2 of 1; an equation with no predictive ability has an R^2 of 0). Its F-Statistic (F-Stat) for it is 194 (the F-Statistic is the ratio of the variation from the mean explained by the equation over the variation not explained by the equation). Its mean absolute deviation (MAD) (the 'average miss' of the equation in predicting actual data in absolute terms) is 14·5%. Each independent variable influences value, as the probabilities for each of their T-Statistics not being zero are 1·000, 1·000, 1·000 and 0·997 for balanced field length, passenger capacity, maximum cruise speed and cabin height, respectively (T-Statistics 'probabilities of not being zero' measure contributions of individual independent variables. If T-Statistic 'probability not zero' values exceed 0·95, this indicates that the independent variable in question contributes to the dependent variable).

Equation (3) forms what is known as a value estimating relationship (VER) for VSTOL vehicles. value estimating relationships for VSTOL aircraft form highly significant statistically-based predictors of market-supported price.

The dataset considers vehicles that have a maximum cruise speed below 200 miles per hour, and above 500 miles per hour. At the same time, it also contains vehicles with a cabin height of 4·5ft or less. Equation (3) allows us to compare the projected value of vehicles of varying field length requirements and speed given a cabin height of 4·5ft, as shown in Fig. 4.

Figure 4 visually depicts the results from Equation (3). Importantly it reveals that while going faster and offering more passenger capacity yields more money, taking up less field length is hugely important for VSTOL aircraft. Collectively, Equation (3) and Fig. 4 validate statistically and visually what we knew intuitively, namely, that the shortened field length VSTOL aircraft requires offers value to their customers.

Many of the regional aircraft airlines use offer cabin heights of six feet or more, as they try to offer stand up room for the vast majority of their passengers. Figure 5 shows the contrast in the value a vehicle offering a cabin height of 6·25' to those offering a cabin height of 4·5'.

Notice the substantial improvement in projected vehicle value going from 4·5ft to 6·25ft. This suggests that producers considering any given cruise speed ought to check the cost of given cabin heights against the prices those cabin heights will garner in the marketplace.

Further investigations into the data reveal other important information as well. In 2005, the Sikorsky S-92 helicopter sold for about $14 million, while the Bombardier Q300 regional turboprop sold for about $15 million. Despite their similarities in price, the features that they offer are much different from one another: The S-92 can cruise about 176 miles per hour and carry up to 19 passengers with a cabin height of 6ft, while the Q300 cruises at 330 miles per hour and carries up to 50 people with a cabin height of 6·42ft. At the same time, Equation (3) explains the sustainable price for both vehicles reasonably well, as it predicts the sustainable price for the S-92 to be $14·2 million, and that for the Q300 to be $14·6 million.

Other important independent variables can help predict the values of VSTOL vehicles. One more important of them is the number of vehicles in the market of each specific type. In this case, the number

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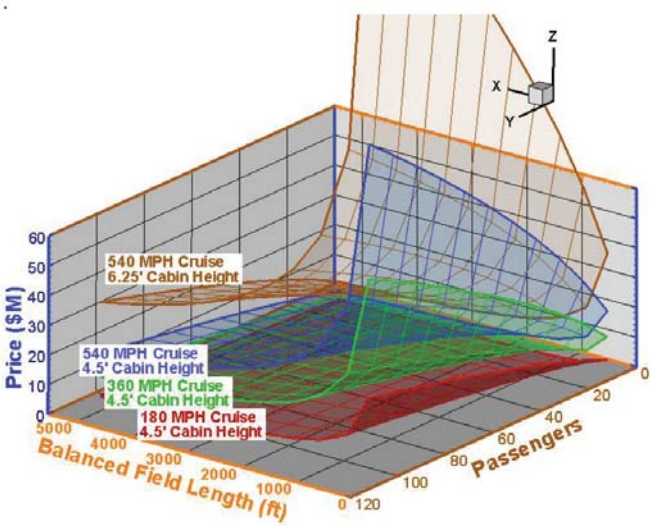


Figure 5. VSTOL value varying cabin height.

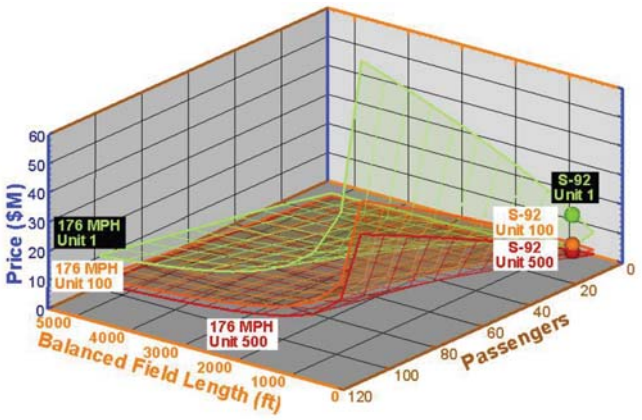


Figure 6. S-92 value falls as units sold increases.

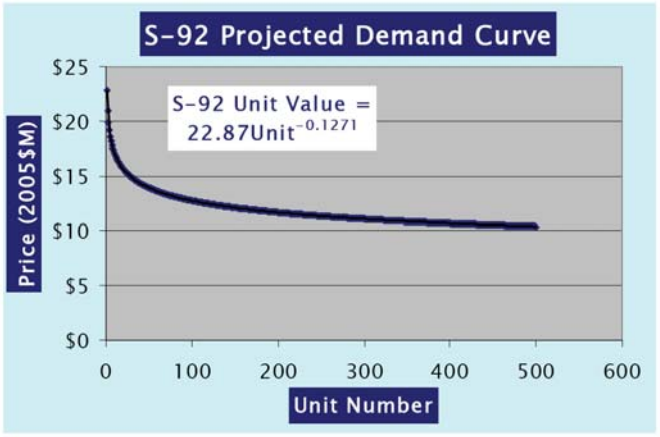


Figure 7. Product demand curve for S-92 helicopter.



Figure 8. Elvis Presley birthplace, Tupelo, Mississippi.

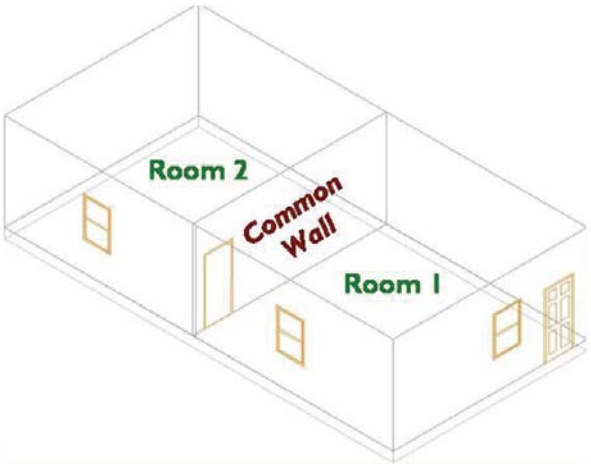


Figure 9. A two room house like Elvis Presley's.

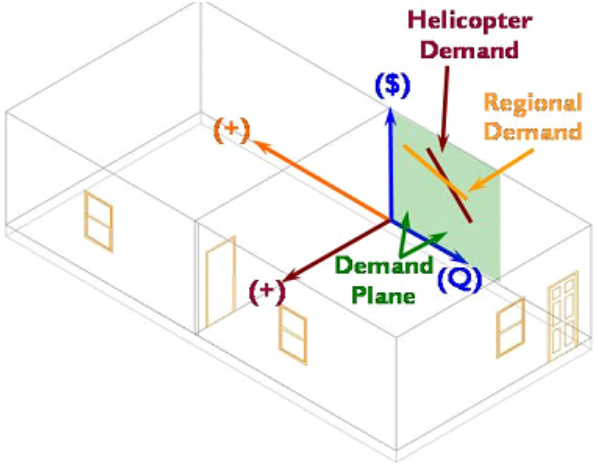


Figure 10. Two rooms form a common intersection.

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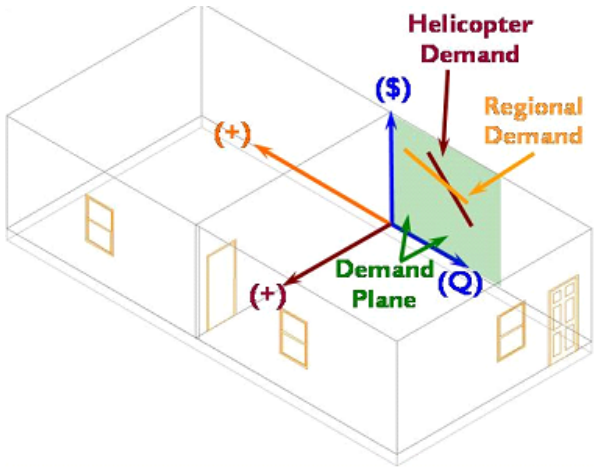


Figure 11. Demand or Q-$ plane in our structure.

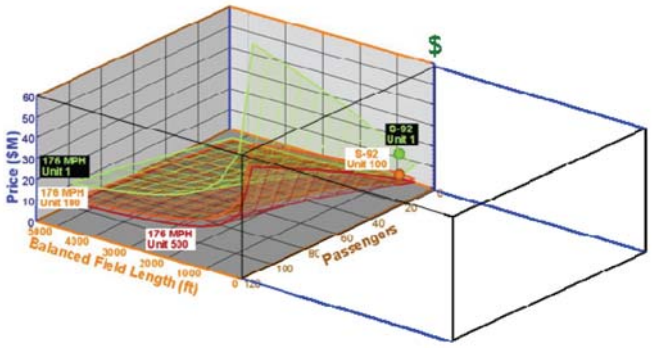


Figure 12. Value space fits a 3-dimensional region.

of vehicles of a given model in the market is another one of its attributes. Specifically, it is a measure of the saturation of the market with regard to the number of units within it. If we add the numbers of units already build for the market to the number of units projected for sale over the a ten year period (the Forecast International projection) we can get a grand total for units produced for all of the 27 vehicles in the dataset. When we do this, and substitute the independent variable cabin height (H) for the grand total available in the market by 2013 (T), we get the following predictive equation:

$$\overline{Pr} = 0{\cdot}011 * FL^{(-0{\cdot}50)} * P^{0{\cdot}87} * S^{1{\cdot}47} * T^{(-0{\cdot}13)} \quad \ldots (4)$$

Where:

T = Projected Total Units Sold by 2013

Equation (4)'s adjusted R^2 in unit space is 91%, its F-Stat is 198, while its MAD is 14·5%. Each of the independent variables are meaningful, as the probabilities for each of their T-Statistics rejecting the null hypothesis are 1·000 for balanced field length, passenger capacity and maximum cruise speed and 0·997 for units. We can use Equation (4) to project the value of any vehicle as more units enter the market, as shown in Fig. 6 for the S-92 helicopter.

Inasmuch as Fig. 6 uses quantity and price as variables, it seems reasonable to speculate that they relate to the S-92 demand curve. In fact, if we plot the predicted price of the vehicle against the unit number, we get the projected product demand curve for S-92 in Fig. 7.

The equation for S-92 unit value

$$\text{S-92 Unit Value} = 22{\cdot}87 * \text{Unit Number}^{-0{\cdot}1271} \quad \ldots (5)$$

is a function of its valued attributes as shown in Equation (4), i.e., its balanced field length, its passenger capacity, its speed and the number of vehicles of its type in the market.

4.0 CONFLUENCE OF VSTOL VALUE AND DEMAND

To understand how VSTOL value and demand relate to one another, we will need to build and closely examine a framework that will likely be new to many readers. Rather than simply dive into this arrangement with little preparatory background, we will observe a long-standing common structure in a new but useful format. Then, armed with this new method of observation, we will apply that method to our problem of understanding the relationship between VSTOL Value and Demand.

This long-standing structure is the house where Elvis Presley was born in Tupelo, Mississippi, USA, in 1935.

As it happens a simple two-room house provides a useful way to look at an old problem in a new way. To be able to understand to the problem first requires that we must be able to visualise it, and in order to that, we need a better view of it. We do that by changing our vantage point and by removing the roof from this house (and by ignoring the porch and the windows on the opposite long wall, and guessing that the door between the rooms is on the near side of the common wall). With that accomplished, we get a structure like that in Fig. 9 below.

While you may have never visited this structure, you can certainly relate to others like it you have seen. You understand that two room structures have exactly one common wall, which forms a common intersection between both rooms, excepting only the depth of the common wall, as shown in Fig. 10.

This common intersection forms a useful point of reference within the structure. Note that both rooms share the green vertical axis, which only runs in the positive direction as measured from the common intersection. Room 1 has another positive direction running from the common intersection towards the front door, which is a measure of its length, as indicated by the blue line. Room 2 has a positive length to it as well, as measured by orange line running from the common intersection, as well as a positive width measured by the dark red line.

In our case at hand, we need not concern ourselves with Room 1's width. However, we must take notice of at least three beneficial concepts. The first concept is that each of the four dimensions considered is positive as measured from the common intersection. The second concept, a slight restatement of the first, is that although Rooms 1 and 2 seem to share the rear wall or plane, the lengths in each room are positive. Room 1 length, as measured by the blue line, is positive and does not subtract from positive Room 2 length as measured by the orange line. The third concept is that excepting only the thickness of the common wall, Rooms 1 and 2 share a common vertical axis. For our purposes here, we will assume that this is a wall with no depth, and that the common vertical axis is one in the same.

Recall that our work on VSTOL demand curves amounted to depictions of relationships on a two dimensional plane, which is a lot like a wall. Specifically, we calculated the relationship between the number of VSTOL units sold on a horizontal axis and their respective prices on a vertical axis. Our two-room structure can make room for that. If we place our demand curve against the back wall of Room 1, we now have a structure in which we can call the vertical distance currency (or dollars, or pounds sterling, or euros) and denote the horizontal distance as quantity, as shown in Fig. 11.

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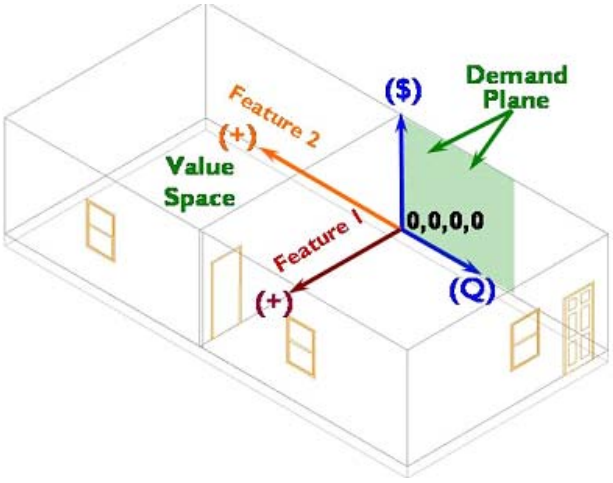


Figure 13. Value space adjacent to demand plane.

Remember the work we did regarding the value of VSTOL vehicles. While we entertained both regional aircraft and helicopters, we examined the Sikorsky S-92 helicopter in a little more depth. Specifically we discovered that its value derives from at least four features or attributes: balanced field length, passenger capacity, maximum cruise speed and the number of units purchased. In addition, we discovered we could portray that value in a vertical direction using currency (or dollars, or pounds sterling, or euros). If we then use a pair of horizontal axes, balanced field length as one and passenger capacity as the other, both of which drive a vertical currency axis, we can then place those relationships within our structure, as shown in Fig. 12 (with the doors and windows removed).

Clearly then, since each of Figs 11 and 12 share a common currency axis, what we have in the broadest sense is a structure that contains a demand plane and a co-joined value space, as in Fig. 13.

In the general model, at least two features or attributes, called Feature 1 and Feature 2 in Fig. 13, drive the value of a product depicted as a currency. These two features and resulting currency response form the value space. Currency and quantity, in turn, by definition form the demand plane. Since the value space and demand plane share the currency axis, the two co-join to one another. The point previously denoted the common intersection is an origin that begins at 0,0,0,0 (for quantity, valued feature 1, valued feature 2, and currency, respectively).

The purpose of this effort is to explain VSTOL value and demand simultaneously, as shown in Fig. 14.

5.0 VSTOL COST

Several cost models can estimate the cost of VSTOL vehicles, and most of them use manufacturer's empty weight (MEW). If we plot MEW from VSTOL passenger capacity we get the result in Fig. 15 (from a data set similar to, but different than, the one shown in Fig. C-6).

The equation;

$$\text{VSTOL MEW} = 642(\text{Capacity}) - 2607 \quad \ldots (10)$$

has a correlation of 94·2%. We can use this as an independent variable in a variety of cost models.

For the case at hand, we will use the development and Procurement costs of aircraft (DAPCA) IV cost model developed by the Dan Raymer[7] and the Rand corporation[8,9] (for more detail on this topic, see Appendix C, Depicting Cost). From the referenced cost model, we find that for a given MEW, maximum speed and number of Flight test aircraft (five aircraft assumed here), the average aircraft cost falls as the production quantity increases.

For 100 production aircraft:

$$\text{Ave Cost} = 1{\cdot}65 * \text{CrsMPH}^{0.55} * (642 * \text{NoPass} - 2607)^{0.6} \quad \ldots (8)$$

For 500 production aircraft:

$$\text{Ave Cost} = 0{\cdot}282 * \text{CrsMPH}^{0.38} * (642 * \text{NoPass} - 2607)^{0.50} \quad \ldots (9)$$

Where:

CrsMPH = Aircraft Maximum Cruise MPH

NoPass = Aircraft Typical Passenger Capacity

Average Cost = Average Fully Amortised Cost

In millions of 2008$

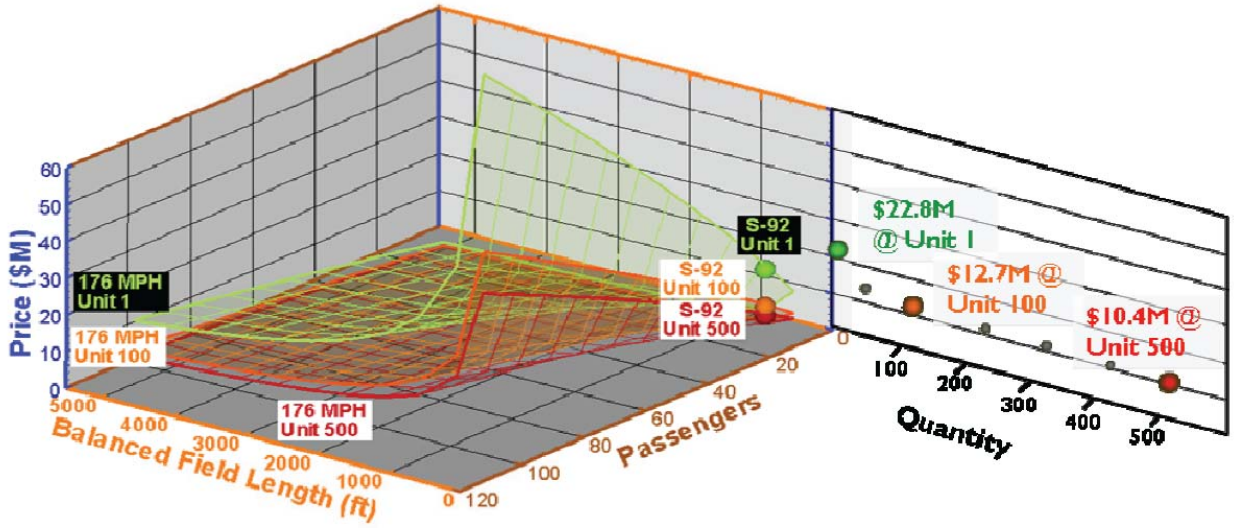


Figure 14. Demand and value for S-92.

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Note that the independent variables here are cruise speed and manufacturer's empty weight and that the costs are figured in 2008 dollars (it will take about five years to build our plane and we will choose the midpoint for average wages and procurement costs). Since DAPCA IV does not include avionics or engine requirements, the surfaces shown add values for each element (as described in Appendix C).

If we put the Sikorsky S-92 attributes into the DAPCA IV cost model, and calculate its fully amortised cost and compare them to its demand curve, we derive Fig. 16.

Figure 16 indicates that;

$$\text{S-92 Cost} = 52{\cdot}04 \text{ unit number}^{-0{\cdot}289} \quad \ldots (10)$$

We can derive the unit at which value = cost by setting them equal to one another noting that the results from Equation (10) match those from Equation (5) at the break even point:

$$22{\cdot}87 \text{ Unit}^{-0{\cdot}1271} = 52{\cdot}04 \text{ Unit}^{-0{\cdot}289}$$
$$22{\cdot}87 = 52{\cdot}04\text{Unit}^{-0{\cdot}1616}$$
$$0{\cdot}439 = \text{Unit}^{-0{\cdot}1616}$$
$$\ln(0{\cdot}439) = -0{\cdot}1616 \ln(\text{Unit})$$
$$5{\cdot}088 = \ln(\text{Unit})$$
$$162 = \text{Unit}$$

Thus, using the DAPCA IV cost model and the VSTOL value model, we can derive the breakeven point for a given aircraft model (note that since the cost derives from the DAPCA IV model, discussions about cost correlations coming from it are meaningless). In the case of the Sikorsky S-92, these models suggests that the breakeven unit number is 162 (without, of course, any consideration to the time value of money).

In practice, each aircraft manufacturer has its own cost structure. Each potential new aircraft model has its own configuration specific trade space. At the same time, the VSTOL aircraft market determines its value structure and rewards to the VSTOL aircraft attributes offered to it in accordance with the market's value response equations. Critical independent VSTOL value variables such as balanced field length, passenger capacity and maximum cruising speed depend upon equally important independent cost variables such as on wing sweep, installed horsepower, fuselage diameter and wingspan. The best balance of cost and value, given demand offer the best entry points for the market, given the constraints that face the VSTOL market.

6.0 VSTOL CONSTRAINTS

No analysis of the VSTOL (or any) market would be complete without some discussion about the constraints facing it. When considering a new VSTOL aircraft design, airframe manufacturers are immediately confronted with a major decision: should the vehicle take off vertically or horizontally? There are challenges and payoffs for either decision.

In Fig. 17, the cost response surfaces derived the cost model depict the cost of producing 25, 50, 100 or 500 units for an aircraft that cruises at 176 miles per hour. Our by now familiar Sikorsky S-92 cost points show up on the right side of that figure, and costs fall as more units are produced, as expected. Two other phenomena are worth noting here. First, observe that it is virtually impossible to build a fixed wing vehicle with a balanced field length of less than 1,000ft. This forms a barrier at that value, as shown by the blue plane at that distance in Fig. 17. Any vehicle with a balanced field length of 1,000ft will likely be a helicopter, any vehicle with a balanced field length of 1,000ft or greater will likely have fixed wings. Notice as well that as the balanced field length decreases from 5,000ft to 1,000ft, the cost to produce it rises, as manufacturers have to implement increasingly complex and costly lift and drag devices to improve short field performance[10]. This added cost may be worth it, however, if the added cost is less than the benefit of the short field performance.

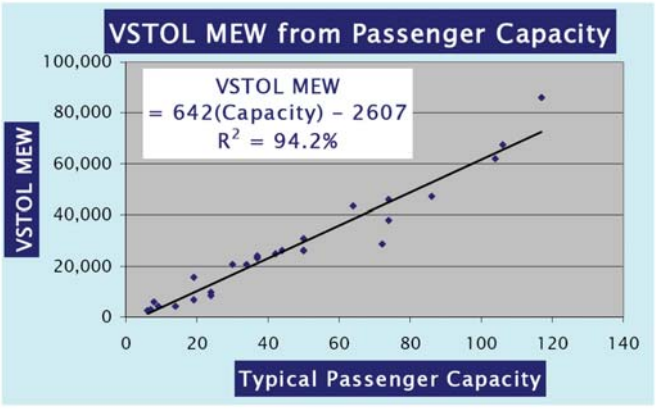


Figure 15. VSTOL MEW from passenger capacity.

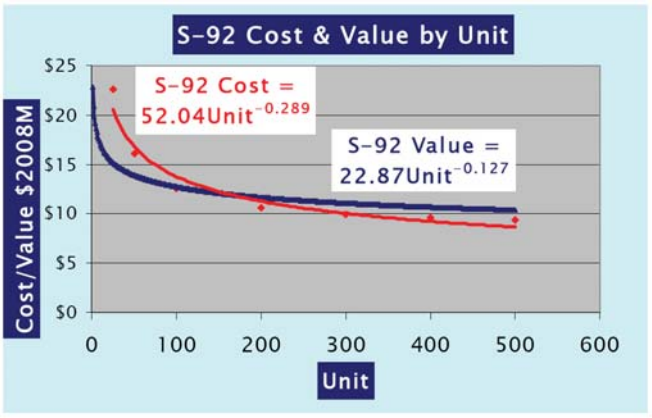


Figure 16. Predicted S-92 cost and value.

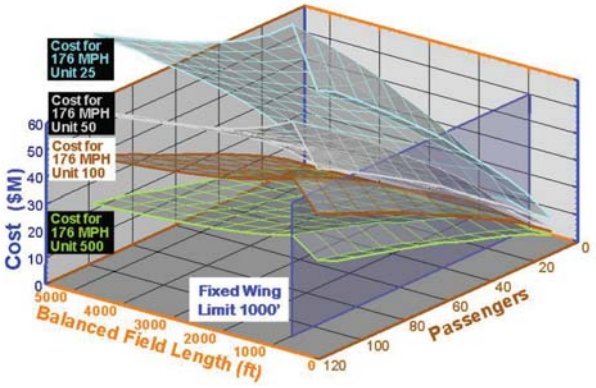


Figure 17. VSTOL physical constraint.

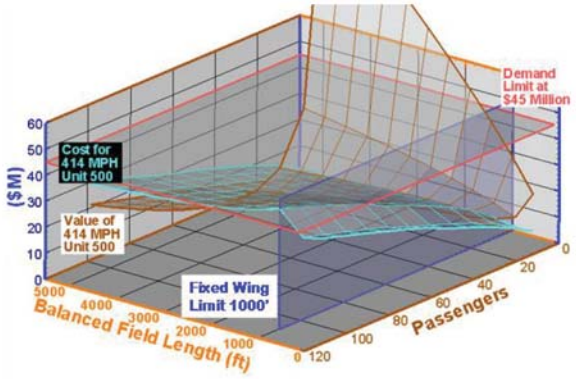


Figure 18. VSTOL physical and financial constraints

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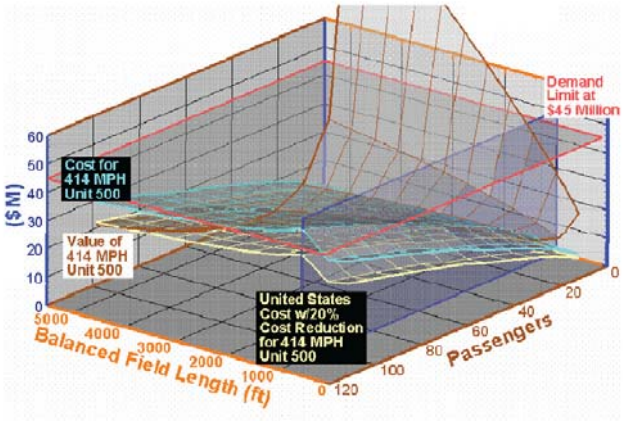


Figure 19. VSTOL constraints and lower costs.

Another important constraint faces the regional VSTOL aircraft market, that of money. Specifically, the upper reaches of the demand curve for this market only extend only to about $45 million[11]. This forms a boundary, or upper limit to the market at that threshold. That limit may affect sales of new aircraft in some situations.

Suppose, for example, that a hypothetical regional jet manufacturer wants to build a vehicle that flies as fast as a Bombardier Q400 (360 knots, or 414 Miles per Hour) but which has a much improved balanced field length. That company would face the constraints shown in Fig. 18.

The value for this hypothetical plane, as shown by the brown surface, rises very quickly as its balanced field length decreases. Its projected value at the 500th unit at a balanced field length of 1,000ft if it carries 110 passengers is $62 million, while its cost (represented by the light blue surface) is just $46·3 million. The problem, however, is that this market demonstrates an upper limit for demand of $45 million. While some sales are possible at that amount, the market has already demonstrated that it does not care to pay more than its limit of $45 million. Trying to sell a vehicle for more than that amount, even though it is demonstrably worth it, dooms the vehicle to low unit sales. That will likely translate into a financial loss.

Given these constraints, our hypothetical regional aircraft manufacturer is not without options, even with his target speed of 414 miles per hour. Suppose, for example, that he could reduce his costs. Specifically, suppose that he could reduce them by 20% at the 500th unit. He could then contrast his previous high-cost position with a new low-cost opportunity, as shown in Fig. 19.

In Fig. 19, the manufacturer displays 20% less cost for the 500th unit across the entire range of possibilities. If he should elect to build a vehicle with, say, a balanced field length of 1,500ft and the capacity to handle 90 passengers, that vehicle is valued at $42·6 million, while the projected cost to produce it is $30·4 million. If instead for his 500th vehicle he were to build a plane with a balanced field length of 2,000ft and a passenger capacity of 110 people, that vehicle would be valued at $43·9 million and it would cost him $33·2 million.

Financial catscans or section cuts through financially viable market regions offer the promise of finding optimal design features with respect to profit[12,13,14]. The influence of shifting demand and changing values over time should also be considered[15,16], as well as the effects of missing design and financial targets[17]. By performing such tradeoffs, manufacturers are able to design vehicles that market demonstrates it wants and which will provide profits to their producers.

7.0 CONCLUSIONS

The demand for all new commercial aircraft follows an aggregate demand curve, of which the VSTOL sub-markets of regional aircraft and helicopters are subsets. Regional aircraft and helicopters each form their own demand curves. Within each of these VSTOL markets, demand curves for individual existing or proposed VSTOL vehicles exist based on their attributes.

One of the most important attributes for VSTOL aircraft is balanced field length. The VSTOL market, that is, the sum total of all of the buyers that purchase VSTOL vehicles, demonstrates that shortened field length requirements have a statistically significant and strong positive impact on the VSTOL aircraft prices that the market will support.

At a certain minimum runway distance, roughly 1,000 to 1,500ft, VSTOL vehicles need to have a thrust to weight ratio of 1·0 or greater. This physical phenomenon forms an economic constraint upon the market. Economically viable vehicles taking off at that threshold distance or less are helicopters, while vehicles requiring longer runways are fixed wing vehicles.

The greater the number of units in the market, the less new customers will be willing to pay for them. However, the demand curve for VSTOL quickly becomes asymptotic with respect to price, at roughly the 200th to 300th unit.

In theory, the value of VSTOL vehicles could rise to well above $100 million. In practice, the market supports no vehicles costing more than roughly $45 million, as demonstrated by the market's demand curve. This forms an upper limit price constraint on the market.

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APPENDIX A: DEPICTING DEMAND

While there has been a great deal of discussion about aggregate demand for a variety of markets over the years, little information exists on how to characterise it. Here is one method to do it. The exercise below groups 233 aircraft models into eight price ranges and then sums up the revenue per segment and divides that figure by the quantity in that grouping (the predicted prices and quantities used here are from Forecast International's 2004 Commercial Aircraft analysis, with the model names dropped here to protect their data). This results in eight ordered pairs, shown as the green crosses inside the white boxes. The regression of that dataset provides Equation (A1).

$$\text{Aggregate Price} = 3E{+}13 * \text{Unit Quantity}^{-1{\cdot}73} \quad \text{(A1)}$$

This equation's correlation of 86·6% is statistically useful for predictive purposes.

The 233 models considered range in size from a Cessna 172 to an Airbus A380.

Aircraft	Engine	Cost	Units	$500,000	Total & Ave Cost	$5,000,000	Total & Ave Cost	$20,000,000	Total & Ave Cost
Model 1	Engine 1	$900,000	281			281	$252,900,000		
Model 2	Engine 2	$2,100,000	295			295	$619,500,000		
Model 3	Engine 3	$3,700,000	71			71	$262,700,000		
Model 4	Engine 4	$3,600,000	92			92	$331,200,000		
Model 5	Engine 5	$3,600,000	81			81	$291,600,000		
Model 6	Engine 6	$2,000,000	191			191	$382,000,000		
Model 7	Engine 7	$18,000,000	11					11	$198,000,000
Model 8	Engine 8	$5,350,000	12					12	$64,200,000
Model 9	Engine 9	$265,000	79	79	$20,935,000				
Model 10	Engine 10	$485,000	115	115	$55,775,000				
Model 11	Engine 11	$595,000	215			215	$127,925,000		
Model 12	Engine 12	$834,000	76			76	$63,384,000		
Model 13	Engine 13	$985,000	88			88	$86,680,000		
Model 14	Engine 14	$105,000,000	4						
Model 15	Engine 15	$105,000,000	13						
Model 16	Engine 16	$45,000,000	94						
Model 17	Engine 17	$45,000,000	41						
Model 18	Engine 18	$50,000,000	452						
Model 19	Engine 19	$50,000,000	306						
Model 20	Engine 20	$55,000,000	300						

8 Ranges

233 Models

>	# A/C	<=	Seg Revenue	Ave Cost
$0	17716	$500,000	$4,527,438,000	$255,556
$500,000	13571	$5,000,000	$26,864,971,865	$1,979,587
$5,000,000	6707	$20,000,000	$70,277,257,000	$10,482,105
$20,000,000	4770	$40,000,000	$133,549,675,000	$27,997,835
$40,000,000	3971	$60,000,000	$205,461,500,000	$51,740,494
$60,000,000	1091	$150,000,000	$123,185,500,000	$112,910,632
$150,000,000	888	$200,000,000	$156,237,500,000	$175,948,181
$200,000,000	599	$250,000,000	$136,806,000,000	$228,390,651
	49213		$857,009,841,865	

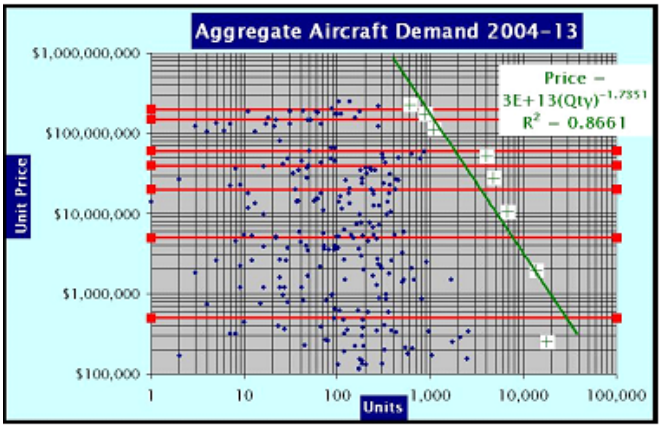


Figure A-1. Build up of 2004-13 aggregate demand.

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APPENDIX B: DEPICTING VALUE

There are several multiple regression programs available throughout industry. The following results come from a dataset of 27 regional aircraft and helicopters with 2005 prices regressed through CO$TAT 7.1, by Tecolote Research. In previous discussions, we have characterised the following result as Equation (4). The R^2 in Unit Space sufficiently high at 90·7% and the F-Statistic (the ratio of the variance explained by regression to the unexplained variance) is very strong at 198·2. The probabilities that the independent variables used in the study, namely, the total number of units in the market (GrdTot), maximum cruise speed (MxCrsMPH), typical passenger capacity (TypP) and balanced field length (BalFL) determine price are 99·7%, 100·0%, 100·0% and 100·0%, respectively.

I. Model Form and Equation Table

Model Form:	Unweighted Log-Linear model
Number of Observations Used:	27
Equation in Unit Space:	Price = 0.01056 * GrdTot ^ (-0.1271) * MxCrsMPH ^ 1.465 * TypP ^ 0.8662 * BalFL ^ (-0.4969)

II. Fit Measures (in Fit Space)

Coefficient Statistics Summary

Variable	Coefficient	Std Dev of Coef	Beta Value	T-Statistic (Coef/SD)	Prob Not Zero
Intercept	-4.5502	0.7319		-6.2169	1.0000
GrdTot	-0.1271	0.0374	-0.1440	-3.3959	0.9974
MxCrsMPH	1.4650	0.2204	0.6112	6.6474	1.0000
TypP	0.8662	0.0911	0.6568	9.5042	1.0000
BalFL	-0.4969	0.0645	-0.5138	-7.7001	1.0000

Goodness-of-Fit Statistics

Std Error (SE)	R-Squared	R-Squared (Adj)	Pearson's Corr Coef
0.2002	97.30%	96.81%	0.9864

Analysis of Variance

Due To	DF	Sum of Sqr (SS)	Mean SQ = SS/DF	F-Stat	Prob Not Zero
Regression	4	31.7657	7.9414	198.1939	1.0000
Residual (Error)	22	0.8815	0.0401		
Total	26	32.6473			

Summary of Predictive Measures

Average Actual (Avg Act)	16.2085
Standard Error (SE)	3.4112
Root Mean Square (RMS) of % Errors	18.48%
Mean Absolute Deviation (Mad) of % Errors	15.58%
Coef of Variation based on Std Error (SE/Avg Act)	21.05%
Coef of Variation based on MAD Res (MAD Res/Avg Act)	14.30%
Pearson's Correlation Coefficient between Act & Pred	97.20%
Adjusted R-Squared in Unit Space	90.72%

Figure B-1. Regression analysis for value estimating relationship.

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APPENDIX C: DEPICTING COST

The following estimates rely mainly on the Development and Procurement Costs of Aircraft (DAPCA) IV cost model developed by the Rand Corporation and described by Raymer and Chaput.

DAPCA IV splits nonrecurring and recurring cost elements.

NONRECURRING

NRE =0.0168 * (EW^0.747) * (Vmax^0.8)
NRT =0.01868 * (EW^0.81) * (Vmax^0.579)
DS =0.0563 * (EW ^0.630) * (Vmax^1.3)
FT =1.54 * (EW^0.325) * (Vmax^0.823) * (NTA ^1.21)

RECURRING (T-100)

RE100 (Hrs) = 0.000306 * (EW^0.88) * (Vmax^1.12)
RT100 (Hrs) = 0.00787 * (EW^ 0.707) * (Vmax^0.813)
RML100 (Hrs) = 0.141 * (EW^0.82) * (Vmax ^0.484)
RMM 100 ($) = 0.54 * (EW^0.921) * (Vmax ^ 0.621)
RQA (Hrs Cargo AC) 0.076 * (RML100)

Terms

NRE = Nonrecurring Engineering Hours
NRT = Nonrecurring Tooling Hours
DS = Development Support Cost
FT = Flight Test Cost
NTA = Number of Test Aircraft
EW = Empty Weight
Vmax = Maximum Velocity in Knots
RE = Recurring Engineering
RT = Recurring Tooling
RML = Recurring Manufacturing Labor
RMM = Recuring Manufacturing Material
RQA = Recurring Quality Assurance
Qn = Quantity of Production Aircraft

Figure C-1. DAPCA cost model (Part 1 of 2).

Note that the recurring estimates above are in terms of T-100 (the 100th Production Aircraft). To allow estimates across all quantity ranges, DAPCA IV offers the following equations for recurring quantities other than 100 units (Q_n), based on the recurring equations for 100 units.

Cost (Qn) = Cost (Q100)*(Qn/100)^exp

Where

exp(engineering hours) =	0.163
exp(tooling hours) =	0.263
exp(manufacturing hours) =	0.66
exp(manufacturing material) =	0.231
exp(quality assurance hours) =	0.714
exp(total program) =	0.356

Figure C-2. DAPCA cost model (Part 2 of 2).

The model form above is for a standard, mostly aluminum aircraft. DAPCA IV has coefficients that adjust estimates based on material content, if it is known. No such adjustments were made for the hypothetical aircraft estimated in this exercise (the assumption was that it was primarily made out of aluminum).

Raymer provided some notional labor rates in 1999 which were escalated to 2008 United States Dollars and used throughout the cost analysis:

DAPCA IV Labor Rates in the Year

	1999	2005	2008
Engineeering	$86.00	$101.00	$109.00
Tooling	$88.00	$103.00	$111.00
Manufacturing	$73.00	$86.00	$92.00
Quality Assurance	$81.00	$95.00	$103.00

Figure C-3. Labour structure.

The DAPCA IV Cost Model yields the results in Fig. C-4 below based on its equations and the premises mentioned. This is done by taking the equations for nonrecurring and recurring costs and extending them for the indicated number of aircraft, yielding a series of cost surfaces (as Equations C-1 through C-12, respectively. As they are all functions of the DAPCA IV, we need not consider their correlation.)

2008 VSTOL AC Cost from Cruise Speed & Passengers

No. of Aircraft	DAPCA IV Average Aircraft Cost (Ave AC Cost) Equations from Cruise MPH (CrsMPH) & Passenger Capacity (NoPass)	
25	Ave AC Cost = 0.9045 * $CrsMPH^{0.6744}$ * (642 * NoPass – 2607)$^{0.711}$	(C–1)
50	Ave AC Cost = 1.0605 * $CrsMPH^{0.6187}$ * (642 * NoPass – 2607)$^{0.6823}$	(C–2)
100	Ave AC Cost = 1.651 * $CrsMPH^{0.5506}$ * (642 * NoPass – 2607)$^{0.6392}$	(C–3)
200	Ave AC Cost = 3.288 * $CrsMPH^{0.4748}$ * (642 * NoPass – 2607)$^{0.5827}$	(C–4)
300	Ave AC Cost = 5.339 * $CrsMPH^{0.4298}$ * (642 * NoPass – 2607)$^{0.5451}$	(C–5)
400	Ave AC Cost = 7.693 * $CrsMPH^{0.3985}$ * (642 * NoPass – 2607)$^{0.5172}$	(C–6)
500	Ave AC Cost = 10.282 * $CrsMPH^{0.3749}$ * (642 * NoPass – 2607)$^{0.4952}$	(C–7)
600	Ave AC Cost = 13.052 * $CrsMPH^{0.3562}$ * (642 * NoPass – 2607)$^{0.4770}$	(C–8)
700	Ave AC Cost = 15.978 * $CrsMPH^{0.3408}$ * (642 * NoPass – 2607)$^{0.4617}$	(C–9)
800	Ave AC Cost = 19.022 * $CrsMPH^{0.3279}$ * (642 * NoPass – 2607)$^{0.4485}$	(C–10)
900	Ave AC Cost = 22.164 * $CrsMPH^{0.3168}$ * (642 * NoPass – 2607)$^{0.4369}$	(C–11)
1000	Ave AC Cost = 25.370 * $CrsMPH^{0.3070}$ * (642 * NoPass – 2607)$^{0.4266}$	(C–12)

Figure C-4. DAPCA IV cost response surfaces.

DAPCA IV does not address avionics or engines[8], which need to be added to the DAPCA IV model results in order to get all costs included in the analysis.

However, Raymer mentions an avionics cost range of $3,000-$6,000 per pound in 1999, which if we take $5000 as the basis in that year, scales to $6,326 per avionics pound in 2008[7,9,18]. This in turn requires that we have a method to derive avionics weight on a model by model basis. As it happens, for at least one aircraft manufacturer, avionics weight statistically ties to aircraft manufacturer's empty weight. If we take some 23 unnamed aircraft models

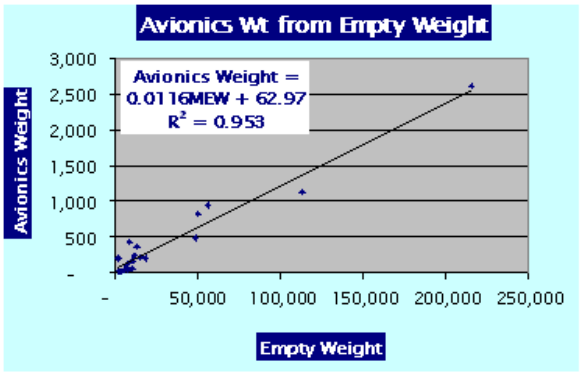


Figure C-5. Avionics weight from empty weight.

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Model	Horse-Power	MTOW (lbs)	Balanced Field Length (ft)	Typical Passenger Capacity
ATR 42	4800	41005	3825	42
ATR 72	5500	50265	4015	72
BN Turbine Islander	600	6600	1250	9
Bombardier Q200	4300	36300	3280	37
Bombardier Q300	5000	43000	3460	50
Bombardier Q400	10142	64500	4265	74
EADS CASA C-212	2240	17850	1925	24
Pilatus PC-12	1200	10450	2300	8
Dornier 328	4360	30840	4535	34
Viking Air DHC- 6	1120	12500	1200	19
Cessna Grand Caravan	600	8785	2420	14
Pilatus PC-6	650	6173	1443	7
Cessna T-206H	310	3600	1740	6
Agsta Wstlnd EH-101	6789	34392	150	30
Eurocopter AS 332	3754	18900	128	24
Kamov KA-32	4450	26400	104	19
Sikorsky S-92	5000	24000	137	19

Figure C-6. Part of VSTOL database.

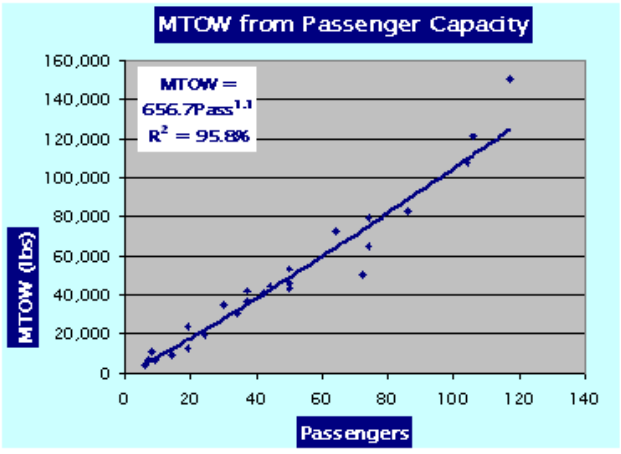


Figure C-7. MTOW from passenger capacity.

from that manufacturer and plot their avionics weight as a function of their empty weight, we get the plot shown in Fig. C-5 (note: each company, or collection of companies, will have their own similar, but not identical, relationships between avionics weights and empty weights.)

In this case, avionics weight is a function of empty weight (or Manufacturer's Empty Weight, or *MEW*), according to this equation.

$$\text{Avionics Weight} = 0{\cdot}0116MEW + 62{\cdot}97 \quad \ldots \text{(C-13)}$$

Note that the equation is well-correlated at 95·3% and can therefore be used for predicting avionics weight. The resulting avionics weights from C-13 were used to derive aircraft avionics costs by multiplying those weights times $5,860 per avionics pound.

The other important cost facet not addressed in DAPCA IV is the cost of engines. A quick review of VSTOL aircraft suppliers' websites yields the table in Fig. C-6.

We might guess that horsepower required is a function of the MTOW and the Balanced Field Length. We can test for that using CO$TAT 7·1, as we did in Appendix B. When we do that we derive Equation C-14, below;

$$HP = 0{\cdot}03906 * \text{BalFL}^{(-0{\cdot}1594)} * MTOW^{1{\cdot}232} \quad \ldots \text{(C-14)}$$

Where:

HP = Horsepower

BalFL = Balanced Field Length (in feet)

MTOW = Maximum Take-off Weight (in pounds)

Equation C-14 is well correlated with an adjusted R2 in Unit Space of 94·6%, and has a Mean Absolute Deviation of 13%. Its independent variable, Balanced Field Length and Maximum Take-off Weight, have T-Statistics of 0·9999 and 1·0000, respectively.

With data from Fig. C-6, we test to see if there is a relationship between the passenger capacity and MTOW:

In Fig. C-7 we observe that

$$MTOW = 656{\cdot}7 * \text{Passenger Capacity}^{1{\cdot}1} \quad \ldots \text{(C-15)}$$

As this equation is sufficiently well-correlated at 95·8%, we can use it for substitution in Equation C-14.

$$HP = 0{\cdot}03906 * \text{BalFL}^{(-0{\cdot}1594)} * (656{\cdot}7 * \text{Pass Capacity}^{1{\cdot}1})^{1{\cdot}232} \quad \ldots \text{(C-14(a))}$$

Equation C-14a predicts the required horsepower across a range of vehicle possibilities ranging from 5 to 125 passengers and Balanced Field Lengths ranging from 125 to 6,000ft. The derivation of the cost of the required horsepower uses cost equations that come out of multiple regression analysis upon the 2002 Forecast International engine database (not shown).

The resulting engine costs add to like avionics costs (discussed above) to form the cumulative additive costs to the cost surfaces predicted by the DAPCA IV cost model.

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