OPTIMIZING DESIGN SPECIFICATIONS FROM AIRCRAFT MARKET ECONOMICS

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Abstract

Aircraft designers often agonize over the most useful set of attributes to include in new aircraft models. Determining the value of aircraft features and extrapolating that information to potential sales figures approaches the haphazard. New methods, described in this paper, remove much of the guesswork in this process.

1 The Ways and Means of Aircraft Buyers

Before studies of new aircraft programs begin, designers must know how their markets react to product offerings. The viability of new programs depends in large measure upon the interaction of how buyers weigh the contribution of vehicle features (the ***ways*** that markets financially assess those products brought to them) versus the monies that they have to purchase them (the ***means*** those markets have to buy those new products). This is true not only for new commercial aircraft, but for new military air vehicles as well.

Multiple factors enter into the markets' estimates of the sustainable prices for new aircraft. We will find it useful to examine the ways customers make these assessments in Value Spaces. Simultaneously, those same buyers, faced with limited funds, are beholden to their means along matching Demand Planes.

1.1 Demand Planes

If we plot the projected sales quantities for 50 business aircraft models for the decade running from January 1, 2005 to December 31, 2014, along with their respective prices in log space, we obtain Figure 1.

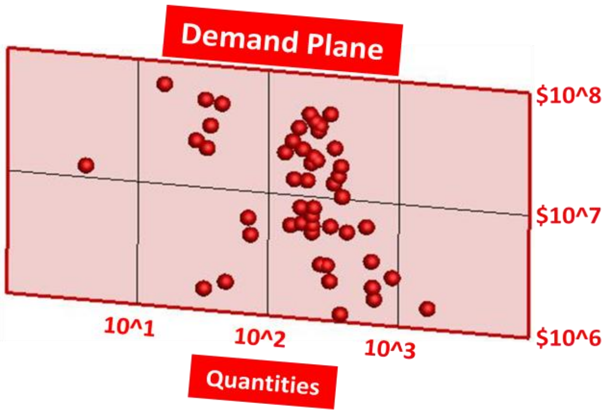

Fig. 1. Projected sales quantities & prices for 50 business aircraft models, 1-1-2005 - 12-31-2014

Noting that there is no apparent correlation between these points, we remedy the situation in Figure 2, where we place the data into bins.

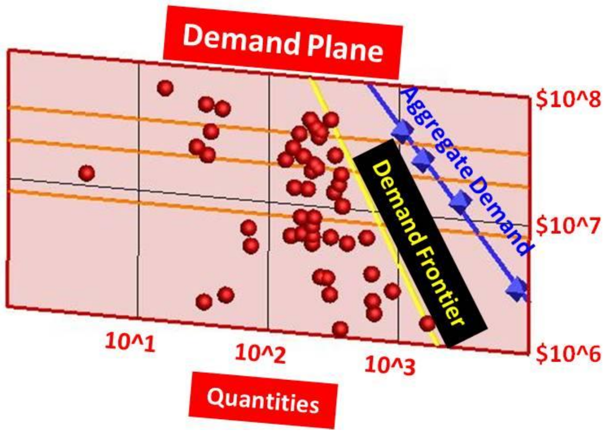

Fig. 2. Aggregate Demand, Demand Frontier for business aircraft, 1-1-2005 to 12-31-2014

In Figure 2, we have a lower bin (represented by the lowest horizontal orange line) that gathers the total quantity and average price for all vehicles priced less than or equal to $8 million. We simply add the projected quantities sold for all vehicles to form the horizontal component. At the same time, we add all up of the revenue in this bin and divide that by the total quantity to get an average price within this bin. Therefore, the rightmost and lowest blue point represents the total quantity priced less than or equal to $8M (8086 units), and the average price of the vehicles in this bin ($3.16M). In the same fashion, we do the same type of data reduction on the next highest bin, which captures vehicles priced less than or equal to $20M but more than $8M (the next highest orange line), where we find the next highest blue point, which represents 2,969 vehicles with an average price of $13.7M. The two upper bins split the remainder of the data into a bin less than or equal to $36M but more than $20M, and all of those vehicles priced more than $36M (the uppermost orange line). The penultimate bin has 1,532 vehicles priced at an average of $27.3M, while the uppermost bin has 1064 vehicles at an average price of $44.3M.

When we perform regression analysis on these four points, we obtain Equation 1, which expresses Aggregate Demand for the market:

$$Price = 361000 * Quantity^{-1.29} \quad (1)$$

Where:

Price = 2005 Price in $M
Quantity = Projected sales from 1-1-2005 to 12-31-2014

Equation 1 has an adjusted R^2 of 99.2%, with a P-Value for quantity of less than 0.003 and a Mean Absolute Deviation of 5.9%. It satisfactorily represents Aggregate Demand.

Inside of the Aggregate Demand line is the Demand Frontier, a line that represents the outer boundary for sales quantities. No producer will manage to sell more units than this limit, as the market does not have sufficient resources to buy more than this. There are at least two ways that we can find this limit. If we were to discover that one of demand points were to be quite a bit to the right of all others (meaning that the market favored a particular model relative to the others), we could strike the Aggregate Demand slope through that point. Inasmuch as that is not the case here, we can take a different tact and run a line through the two outermost points in the disaggregated demand points. When we do that, we get Equation 2, which describes the Demand Frontier (the yellow line in Figure 2).

$$Price = 5{,}560{,}000 * Quantity^{-2.04} \quad (2)$$

Readers familiar with classical economics may struck by the simple image that is Figure 1. According to Paul Samuelson, whom economic historian Randall E. Parker calls “the Father of Modern Economics [1]”, “the equilibrium price, i.e., the only one that can last, is that at which the amount willingly supplied and the amount willingly demanded are equal. Competitive equilibrium must be at the intersection point of supply and demand curves [2].” Yet, as Figure 1 shows, the market supports 50 aircraft models.

While these aircraft are distinct from one another, in that they have different features and prices, it is abundantly clear that a single point of equilibrium for this market does not exist. But, if the law of supply and demand does not work here, how might we explain what holds up these prices?

1.2 Value Response Surfaces

Each of the points in the demand plane has a matching point in Value Space, as shown in Figure 3. Each point in Value Space has a pair of horizontal components, Value Attribute 1 (here, it is passenger capacity) and Value Attribute 2 (in Figure 3 it is Maximum Cruise Mile per Hour). Note as well that the height of each of those points, measured in dollars, corresponds to its vertical position in the Demand Plane, as shown in Figures 1 and 2. Thus, each point in Value Space is an ordered triple consisting of (Value Attribute 1, Value Attribute 2, Price).

A cursory look at Figure 3 reveals that the data supports some sort of trend, which we confirm with regression analysis as Equation 3.

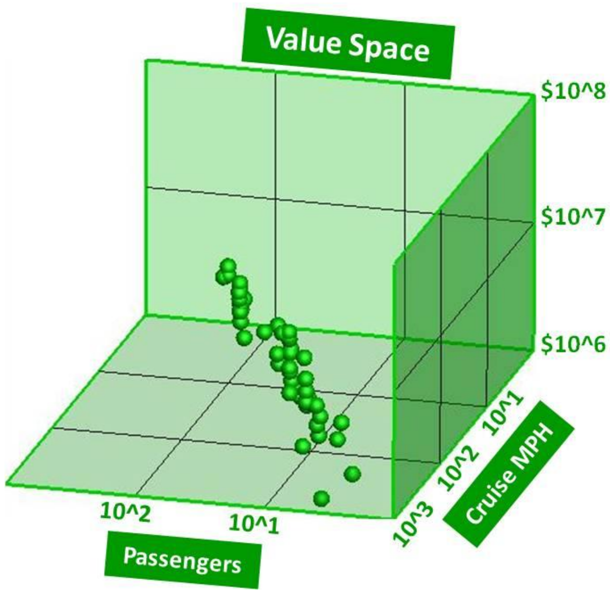

Fig 3. Business Aircraft Value Space

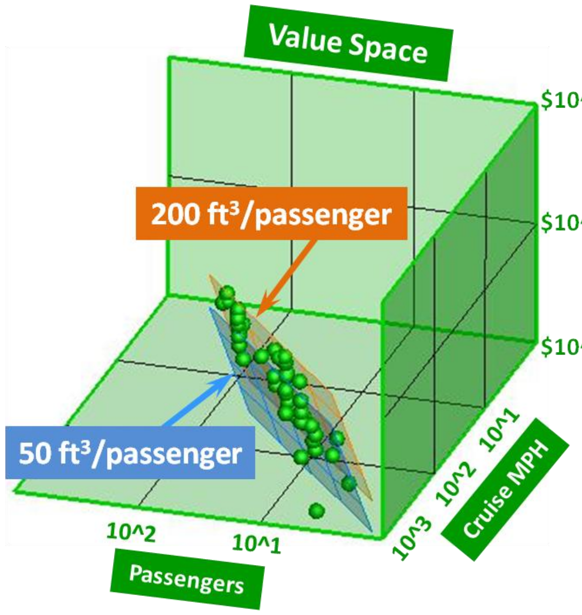

Fig 4. Impact of Cabin Space on Value

$$\overline{Pr} = 7.80E\text{-}06 * P^{0.874} * MPH^{1.68} * Vol/Pass^{0.44} \qquad (3)$$

Where:

$\overline{Pr}$ = Median market clearing price of aircraft given its attributes
P = Typical passenger capacity
MPH = Max cruise MPH
Vol/Pass = Feet^3 of volume per passenger

Equation 3 has an adjusted R^2 of 96.0% and a Mean Absolute Deviation (MAD) 18.5%, with P-Values for Passenger Capacity, Maximum Cruise Speed and Volume/Passenger of 7.02E-17, 1.17E-14 and 2.91E-07, respectively. We can use this strong relationship for analysis.

A previous market study across all civil aircraft performed by the author suggested that exponent for maximum cruise speed was 0.59; meaning that adding 5% more speed was worth only 2.92% more with respect to the value of an aircraft model.[3] Note, however that the exponent for speed for business aircraft, the subject of this study, at 1.68, is especially strong. In the case presented here, going 5% faster adds 8.54% more to the value of an aircraft model. In addition to bragging rights, this can help explain Cessna's and Gulfstream's current push to lay claim to the world's fastest business jet. [4] [5]

Notice that exponent for adding passenger capacity is nearly linear, at 0.874. If the value of the added capacity exceeds the cost to provide it, we can add profitability to new vehicle models as we grow them.

As Equation 5 additionally reveals, there is an added level of comfort in more volume per passengers for which buyers are willing to pay and which Figure 4 depicts. The database has vehicles that range from slightly less 27 feet^3 per passenger to over 270 feet^3/ passenger. The difference in value from going 50 to 200 cubic feet per passenger (or any quadrupling of the volume per passenger) is 84%. Is that worth it? We will need to compare value to cost in order to figure that out. But, before we do that, we need to have an idea about what a potential new entrant in the market might look like.

1.3 Open Space in the Market

Customers for any durable goods in any market are looking for something new and different. Why buy a replica of a good product when you can simply buy the original. An exact duplicate does nothing to increase the options offered to the buyers in the market. A new product, however, provides it potential customers with options. And if that new product is sufficiently different from the others in the market, it may find itself in a region with the least possible amount of competition. All things being equal, this is a preferred position.

In order to avoid the competition, we need to know where it lies. This, in turn, requires that we map out our competitors locations. Since we have already established that the number of passengers carried and maximum cruise speed are important features to business aircraft customers, it makes sense to plot these features against one another.

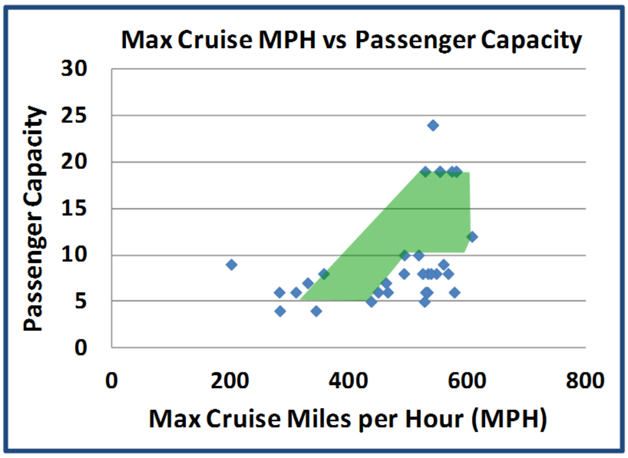

Fig 5. Max MPH vs. Passenger Capacity

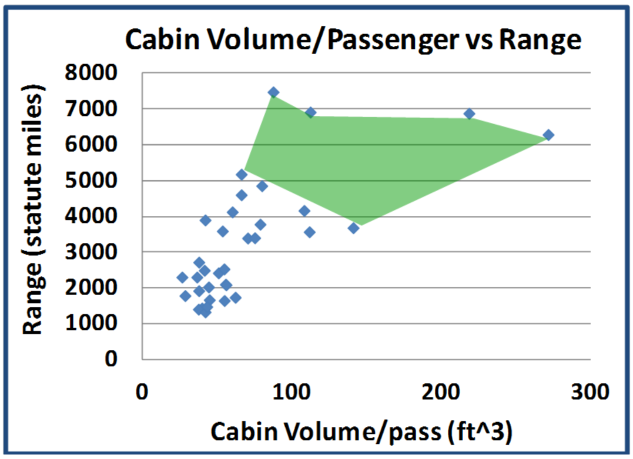

Fig 6. Volume/Passenger vs. Range

In Figure 5, we plot the maximum cruise speed against the typical passenger capacity for the business aircraft available in 2005. Note the rather large green zone, a region in which no competitor has an offering. If we create a vehicle with features in this region, at the very least we have distanced ourselves from the competition with these two features that prove valuable with business aircraft customers.

We noted in Equation 3 that the cabin volume per passenger added to aircraft value too. While we did not specifically identify range as another feature affecting value (as range cross-correlates with passenger capacity for this dataset), we can plot cabin volume per passenger against range in Figure 6 and find that there is a similarly large region in which no competitor has place an aircraft to date.

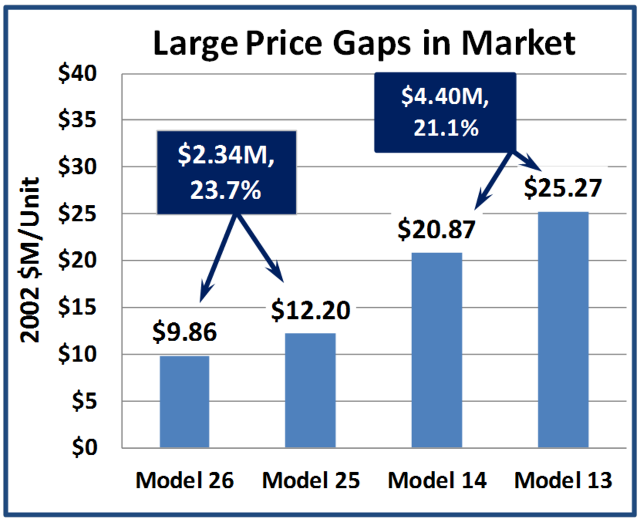

Fig 7. 2 Large Price Gaps in the Market

In addition to the gaps in features, as Figure 7 indicates, there are similar spaces relative to the business aircraft prices. The upper gap is of interest to us here, as it reveals a space of $4.4 million (from $20.9M to $25.3M) in which no product competes. Imagine if we dropped a comma from those numbers and discovered like phenomena in the automobile market, namely, that no manufacturer competed between $20,900 and $25,300. One could surmise that there ought to be a group of buyers that do not have $25,300 to spend on a car, but would prefer not to settle for one with features worth $20,900. With nothing offered in this region, however, buyers would have to choose something else of greater or lesser value. For us, that target will be $23 million, as shown in Figure 8.

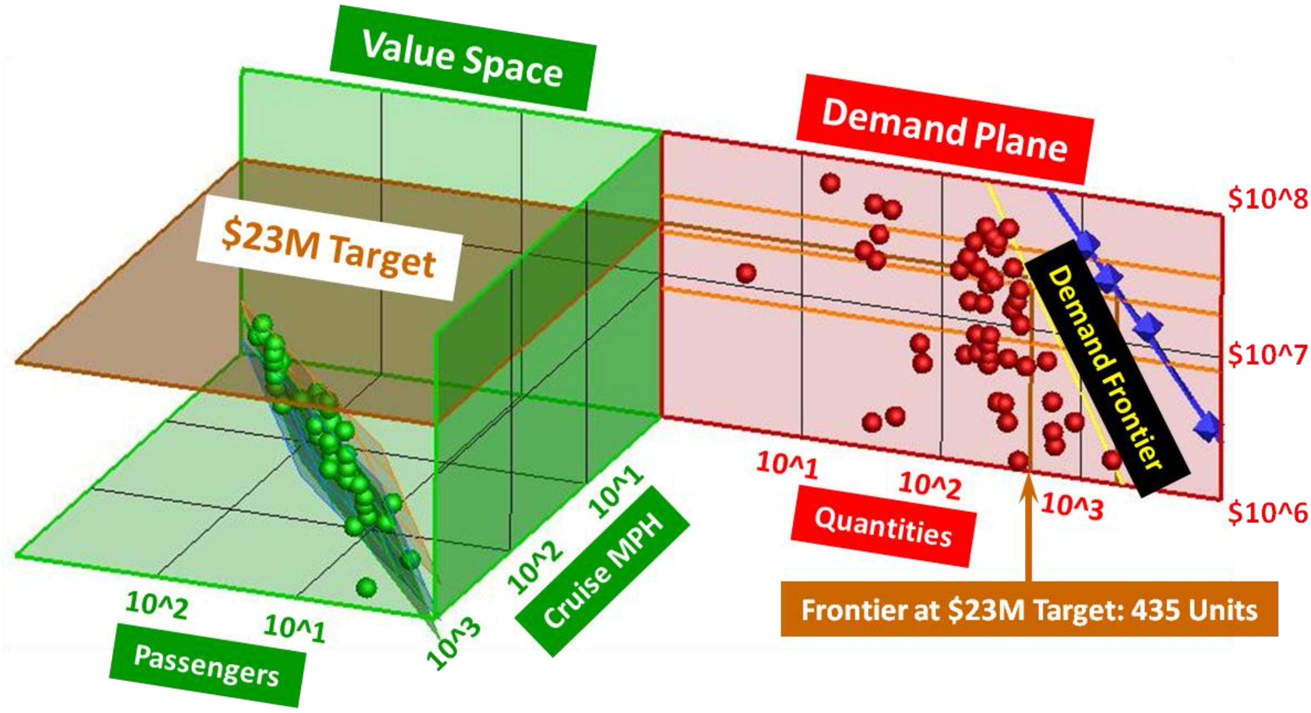

Fig 8. Value Space & Demand Plane Abut at Dollar Axis – Demand Frontier Acts on Both Regions

2 Interaction of Value and Demand

Value Spaces and Demand Planes are either side of four-dimensional constructs that applies to all markets. Value Spaces and Demand Planes share the Dollar (or the currency of choice) Axis with one another. Understanding the forces on either side of this common line allows designers to optimize market entry based upon available monies, customer values and open spaces in the markets.

2.1 Demand as an Independent Variable

Many analysts working on new products use an approach known as Cost as An Independent Variable, or CAIV (pronounced "Cave"). With this, those preparing estimates and designing products try to live within a certain limit set by the target cost. This, however, misses the mark. Firms are not in business to minimize costs. If that were the case, they could set all costs to zero and not make anything. Of course, if they did that, there would be no products or profits.

Instead, firms are in business to make money. They must incur costs to provide goods and services. Importantly, the prices their products command has nothing to do with costs to incur them but rather the features of those products, as we saw with Equation 3 and Figure 4. Buyers purchase products based on their features – note that Equation 3 has no terms for producers' costs. At the same time, collectively, customers have limits on how many products they can afford. We can see these limits in action in Figure 8, where we use Demand as An Independent Variable, or DAIV (pronounced "Dave") to develop targets for ourselves.

Based on the business aircraft market price gap we observed in Figure 7, we decided to set a target for ourselves roughly in the middle of it, at $23 Million. Our intention is figure out the best possible configuration that will command that price and distance ourselves from our competitors. In Value Space, our $23M target serves as a vertical goal as shown in Figure 8 – we want to add features that allow us to reach a sales price that our market will sustain based on our observations about how the buyers react to those features, but we do not attain a sales price much higher or lower than that. If we stray very far from our target, we will start to encounter more competition, and with this approach, one of our goals is to avoid that.

As DAIV implies, this method addresses the volume of products that we can sell, and Figure 8 reveals that to us as well. Notice that as we extend our vertical $23M limit from Value Space into the Demand Plane, this boundary runs into our Demand Frontier at 435 units (projected to be sold over the decade starting 1-1-2005 and ending 12-31-2014), which becomes a horizontal limit for us. We do not mean to say that it is impossible to sell more than 435 units in ten years, we are simply noting that at the time we examined the market, we projected that no one else will manage to break this barrier. If we had a business plan that called for sale of 1000 planes at that price during that time span, we would need to understand the mechanisms that were going to allow for that sales figure given the history to date. In addition, if our business plan does call for the absolute limit that the market will bear, we might question that assumption as well. Only a few models reach or approach the Demand Frontier. A more realistic supposition might call for something less than limit, which we could model as well.

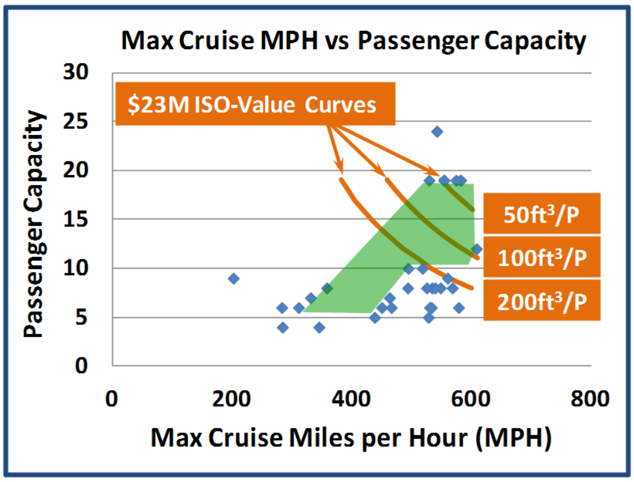

Fig. 9 Iso-Value Lines for $23M Aircraft

Given the work we have done on figuring out the estimated value of new aircraft models, we should put that use, as we do in Figure 9. Here, given our self-imposed target of $23M per unit, we work out the combinations of maximum cruise speed, passenger capacity and cabin volume per passenger needed to sustain that price. Vehicles with 200 cubic feet per passenger and above are uniformly airliners. A new entrant into the business aircraft market, unless it were derived from an airliner, would likely never have that much capacity per passenger, as the development cost would rival that for a new airliner, which, as Figure 10 reveals, is substantial. [6][7][8][9][10][11][12][13][14][15]

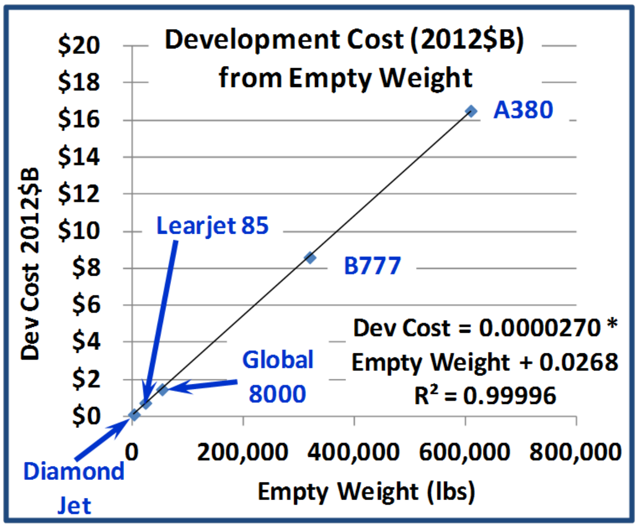

Fig. 10 Aircraft Development Costs

*Dev Cost 2012$B = 0.0268 + 2.7E-05 * Empty Wt* (4)

Where:

Dev Cost 2012$B = Development Cost in 2012$

Equation 4 has an adjusted R^2 of 0.9999, a P-Value of 1.24E-07 and a Mean Absolute Deviation of 4.2%, which taken together means that the equation is highly significant. The equation results state that in order to develop a new aircraft, we must spend $26.8 million to get started, and that every pound of vehicle empty weight will cost us $27,000. Inasmuch as the time from start of a new program and the first revenue-generation from customers may be lengthy, we must take into careful consideration the value of the vehicles that we offer versus what it costs to offer them as well as the schedules to produce them.

While commercial aircraft development costs have been consistent across a broad range of the market to date (this may change due to improvement in cost due to new manufacturing techniques that require fewer parts), production costs between firms often demonstrate more variation. These cost differences are due to differences in labor rates, which vary from manufacturer to manufacture and from country to country. However, all manufacturers should be able to develop cost curves in the same context as value curves, inasmuch as aircraft empty weight (a primary independent variable for many cost models) is a function of the number of passengers, cabin volume per passenger and speed, as Equation 5 shows us.

$$Empty\ Wt = 1.9 * P^{0.69} * MPH^{0.80} * Vol/Pass^{0.60} \quad (5)$$

Where:

Empty Wt: Aircraft Empty Weight in lbs

Equation 5 has an adjusted R^2 of 91.6%, and with P-Values for Passengers, Max MPH and Volume per Passenger of 5.15E-11, 8.21E-08 and 2.48E-07 respectively, we know that we can tie the costs of producing new aircraft into the same context as the value that they have in the market.

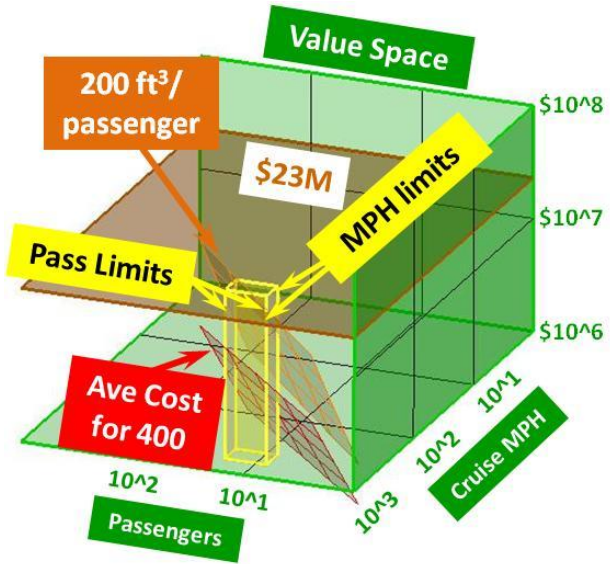

Fig. 11 The Problem Constrained

Figure 11 presents a notional view of how that might look. In it, we have added a notional cost curve that gives the average price for 400 aircraft. Given that we found significant gaps in the upper end of the model, we have further constrained the problem by setting minimum and maximum passenger capacities (8 and 19, respectively) and maximum cruise speeds (400 and 610, again respectively).

The region above the cost surface, below the lower of the demand limit and the value surface and between the constraints forms a Financial Opportunity Space, a region in which it is possible to make profits while satisfying the customers' value requirements. Since our stated goal is to make a profit, we need to solve for it, which we can do with Financial CAT scans, a pair of which appear in Figures 12 and 13.

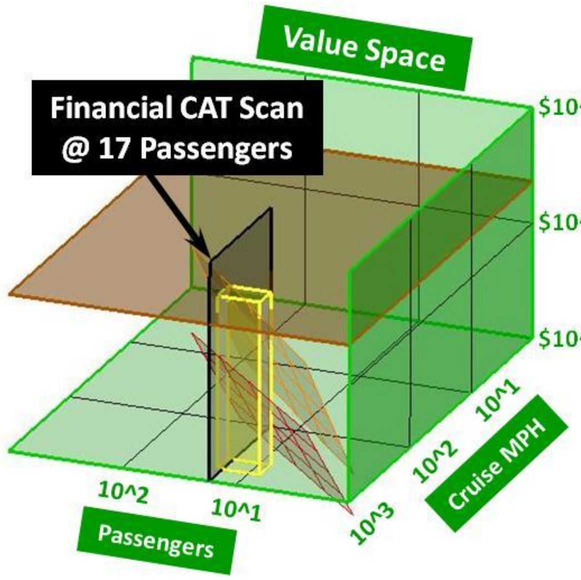

Fig. 12 Financial CAT scan: 17 Passengers

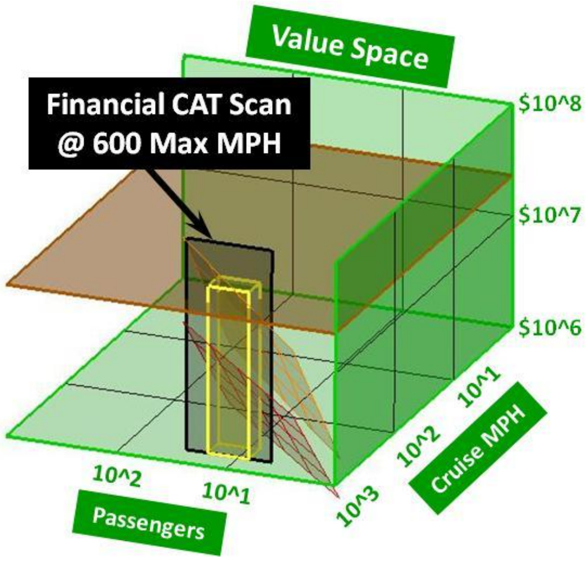

Fig. 13 Financial CAT scan: 600 Max MPH

Financial CAT Scans, done to optimize market entry, mimic those done for people to diagnose physical conditions. In this case, after we reduced the optimization problem from 4 dimensions to 3 (by setting a price target which we used for a vertical limit in Value Space), we now take a series of 2-dimensional section cuts, or Financial CAT Scans. Our goal here will be to find the greatest distance between the cost and the sales price of $23 million. This will be a one-dimensional answer will be a profit line. From it we will able to determine our costs, our price (which we set), our per-unit profit, our cruise MPH and passenger capacity, an example of which appears in Figure 14.

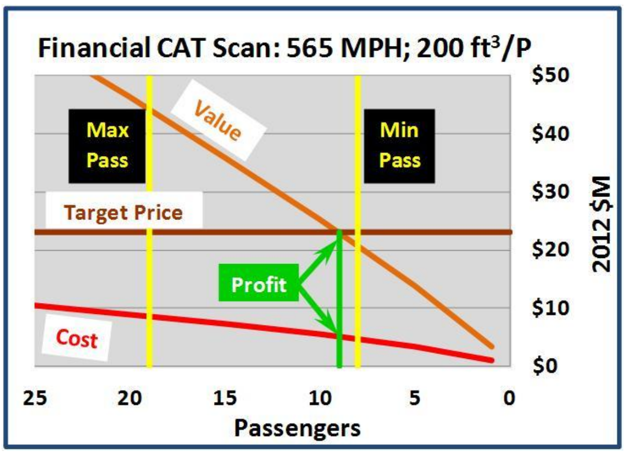

Fig. 14 Financial CAT Scan at 565 MPH

Figure 14 is a section cut looking down the MPH axis, much like our views 11, 12 and 13. Here we have worked out a solution to a hypothetical model, one that will sell for $23 million based on the demonstrated customer values. In this particular case, we have a vehicle that flies at a maximum cruise speed of 565 miles per hour, typically has a capacity for nine passengers and has 200 cubic feet of cabin volume per passenger. If we substitute these values in Equation 5, we get Equation 6:

$$Empty\ Weight = 1.9 * 9^{0.69} * 565^{0.80} * 200^{0.60} = 32{,}800\ lbs \tag{6}$$

Of course, all open areas in the market should be explored using Financial CAT Scans. Wider sweeps of the commercial aircraft market reveal more independent variables that affect cost. If vehicles have potential outside of narrowly defined markets, analysts should include adjacent markets in their analyses.

With value and demand well defined by the buyers in their markets, it falls on manufacturers to put their cost estimating equations into the same context as value variables, to allow useful comparisons between value, demand and cost.

3 References

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