Productivity Metrics for Business and Regional Aircraft

Conference Paper · September 2003

DOI: 10.4271/2003-01-3063

Askin T. Isikveren
SAFRAN A.S. group

2003-01-3063

Productivity Metrics for Business and Regional Aircraft

Askin T. Isikveren*, Guenther Goritschnig†, Mathieu Noël‡
Advanced Product Development, Bombardier Aerospace

ABSTRACT

The need to measure the relative value of business and commercial aircraft and how the designer/analyst can formulate an initial idea of what should constitute a satisfactory array of aircraft design specifications is presented. This is achieved firstly through the establishment of relevant productivity indexes using key target parameters or macroscopic objective functions. To complement this, a new primal objective function construct designated as the Airframer Paradigm is reviewed in order to ascertain how much a given set of design specifications are worth to the market. Finally, an overview of how new technologies and utility features affect the value of aircraft as well as an assessment of design philosophies for the present and future are discussed.

INTRODUCTION

In every industry, there exists a need to measure the relative value of the product offerings to better understand the dynamics of the given market. For an aircraft manufacturer, it is crucial to evaluate how its current and foreseen proposals fare when compared to the competition. Several marketing tools, such as surveys, can be used, but a method of quickly evaluating a design is critical. A simple index that measures productivity or relative value can be used for comparison purposes, to identify potential market niches or product improvements, to establish the potential of new or future products, as well as identify customer-preferred characteristics.

In defining an index for measuring relative value of products, the fundamental question becomes: what is of value to the market? In the case of business aircraft, customers want, as minimum requirements, an aircraft that will allow them to travel the distance they need in an acceptable level of comfort. Reflecting on this conclusion, one of the early attempts at defining an index suitable to the business aircraft market was performed by Timmons[1], through the "Comfort Index", a product of cabin volume and maximum range. However, this Comfort Index did not capture the fact that most business aircraft users also give value in getting to destination as quickly as possible. To that effect, Killingsworth and Wolz[2] established a relationship between aircraft price (or market value) and an index that consists of aircraft speed multiplied by range and cabin volume.

Although this inference was a significant step forward, incompleteness in representing accurately the fundamentals of business aircraft value still existed. For example, by omitting TOFL and computing only the product of speed, cabin volume and range, Norris[3] predicted a mixed success for the Cessna Citation Sovereign. However, it is clear the manufacturer made a conscious decision to favor excellent field performance at the relative expense of other attributes, e.g. speed. It is believed that this is not an isolated case; field performance is one of the main characteristics that delineates business aircraft. The ability to use secondary airfields and to get out of key airports under hot and high conditions is a crucial argument in favor of business aircraft in relation to commercial transport. TOFL is an appropriate indication of that ability.

Addressing this need, AlliedSignal Aerospace[4], in a business aircraft market analysis, introduced what is referred to herein as the "Productivity Index", or PI, to be defined in the following section. Moghadam and Farsi[5] further developed the findings and introduced several new performance parameters in their "Performance Index". However, this expands dramatically the task of compiling and analyzing required information to a level deemed quite excessive. For instance, the range at maximum payload usually has to be derived from a performance model rather than being found in publications. A higher number of macroscopic objective functions, or MOFs, in an index also makes it practically impossible to understand intuitively the relative influence of each parameter within the overall index value. Fundamentally, the PI will be used in this work as the basic tool to evaluate value, and a new complementary application will be introduced in order to significantly broaden the possibilities of the analysis.

* Technical Focal, Conceptual Design and Benchmarking; Post-Doctoral Researcher, Department of Aeronautics, Royal Institute of Technology (KTH)
† Senior Propulsion System Engineer
‡ Conceptual Design Engineer

MEASURING THE RELATIVE VALUE OF AIRCRAFT THROUGH PRODUCTIVITY INDEXES

The PI is one of the most useful tools for the business aircraft industry. It covers in simplistic terms what a customer pays for in a business aircraft, that is the MOFs of range, speed and cabin volume normalized by takeoff field length, as described in Eq. (1).

$$PI = \frac{R_{LRC} \, M_{LRC} \, V_{cab}}{B} \qquad (1)$$

Here, R_{LRC} is the range at LRC speed (payload of 4 PAX for very light to super-large categories, 8 PAX for ultra-long range aircraft[6]), M_{LRC} represents LRC speed (Mach number), V_{cab} is the cabin volume (cockpit divider to aft cabin, no baggage volume) and B is the TOFL (sea level, ISA, MTOW). When plotted against price, PI gives an indication of the relative "value-for-money" of aircraft.

VARIATION OF THE BUSINESS AIRCRAFT PRODUCTIVITY INDEX OVER THE YEARS

It is of particular interest to see how the PI has varied over the last decade or so in relation to price, i.e. how much value for given price is available to the customers. Figure 1 shows PI versus actual market price for in-production business jets in 1990, 1996 and 2002. All data was taken from B&CA's Planning and Purchasing Handbooks[6] (cabin volume was estimated using internal cabin dimensions), and prices were normalized to year 2002 equivalent.

One would expect that as time goes by and technology and solutions improve, potential owners should get more for their money. But this is not exactly what is shown in Figure 1; in fact, the graph demonstrates that for a fixed PI, prices are for all practical purposes equivalent between 2002 and 1990, although price variations can be observed for particular market segments. This differs somewhat from the results of Moghadam and Farsi[5] who showed a slight increase in the Performance Index for fixed price between 1990 and 1995 across all market segments. The relatively constant level in value-for-money shown in Figure 1 can perhaps be explained by the great demand for business jets in mid to late 1990s and early 2000s, hence, has not pressured manufacturers to adopt much lower prices for an improving blend of aircraft characteristics. Looking at specific segments, aircraft priced above $25M appear to be getting more expensive for given productivity. This is attributable to a strong demand for these products and further indicates that the market sets price, i.e. the actual aircraft cost (recurring and/or non-recurring) to the manufacturer is not necessarily the only driver.

On closer scrutiny, the chart also shows that quite a few points for 2002 models lie distinctively on the right side (better value) of the best-fit lines, especially in the $10M - $25M price range. This is tentatively explained by three factors. Firstly, the emergence of "corporate shuttles" or regional jet conversions. These offer a somewhat biased mix of characteristics, typically favoring a very large cabin volume at the expense of range and speed. The design characteristics of corporate shuttles will be discussed in more details later in this text. Secondly, there was the introduction of several new, well-balanced platforms that present higher PI values than older types through incremental improvements in speed, volume, range and TOFL. Finally, the increased popularity and number of offerings in this market segment probably has to some extent forced manufacturers to keep profit margins and prices relatively low, even for the new aircraft models.

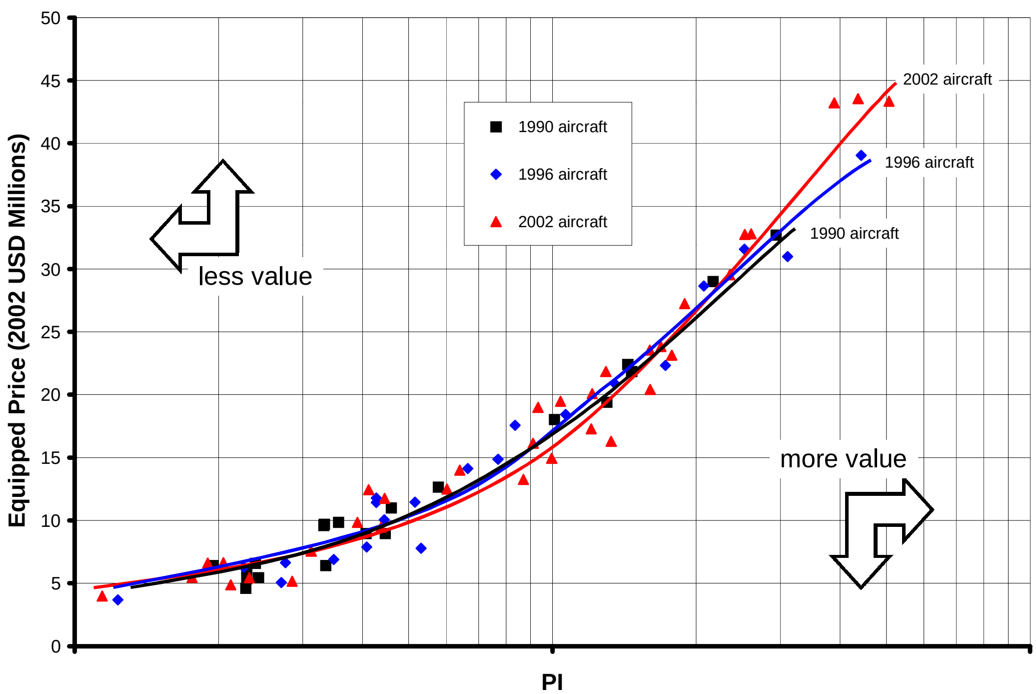

Figure 1 – Business Aircraft Productivity Index versus Price for 1990, 1996 and 2000.

LIMITATIONS OF THE BUSINESS AIRCRAFT PRODUCTIVITY INDEX

Although the PI is a popular tool for measuring the relative value of current and proposed aircraft, it has limitations that must be kept in mind when analyzing the market. First, the PI is a simple product of the four MOFs it contains; therefore, the fundamental assumption is that each is allotted equal weighting. For instance, an increase of 5% in TOFL will lower the PI by 5%, even if for a particular market segment or aircraft, it is possible that such an increase in TOFL would not have any impact on perceived value. To capture this effect, solutions would include adding weighting factors or step change (switching) functions, but as highlighted by Moghadam and Farsi[5], the generality of the PI is also what makes it widely acceptable.

As an example, consider what happens when an aircraft is simply stretched, with no thrust increase (say because the engine simply cannot produce more without extensive changes and the business case does not justify fitting a different engine). Assume as well that additional fuel can be added to the airplane (auxiliary fuel tanks) to maintain the range constant despite the extra empty weight. Although this new aircraft has more cabin volume as well as similar range and speed to the original model, the penalty in TOFL as a result of the additional weight may result in a constant or even degraded PI. Notwithstanding this, the new product will be perceived as more of an aircraft by the market and may in fact command a higher price, mostly because it is physically larger and offers more habitable volume.

It must also be highlighted that as in doing any analysis, the accuracy and reliability of the data is a prime consideration. In particular, attention must be given to making sure the quoted values conform to a common premise. For example, TOFL under the same conditions: sea level, ISA, cabin volume not including baggage, etc.

ATTEMPTS TO IMPROVE THE BUSINESS AIRCRAFT PRODUCTIVITY INDEX

Other attempts at measuring value have incorporated non-quantifiable and non-aircraft related characteristics like service and product support, cost of ownership, etc. It is believed only intrinsic design-related, quantifiable and tangible qualities of an airplane should be taken into account in any relative value analysis. Otherwise, subjectivity becomes difficult to avoid, and the number of factors that could be considered would become significant: aesthetics, residual value, safety, and reliability, to name a few. Also, many of those characteristics are unknown in the case of in-development projects. Meanwhile, adding parameters has also been explored, notably related to the technology level or features of an airplane. This introduces the danger of incorporating features that almost certainly will not be of equal relevance to customers. Hence, efforts must be expended to determine how much weighting should be given to each of these additional parameters in comparison to the overall value of the product. Thoughts on how new technologies will affect the value of aircraft will be addressed later.

It should be kept in mind that the classic PI is widely accepted in the industry as a tool to measure the relative value of business aircraft, mainly because the characteristics it encompasses are easily quantifiable and known to be of prime importance to most – if not all customers. Previous attempts have demonstrated that such additions hinder the most prominent and useful features of the classic PI, i.e. its simplicity and intuitiveness. A more coherent way of dramatically improving upon the PI, dubbed the “Airframer Paradigm”, will also be presented in this paper.

PRODUCTIVITY INDEX FOR COMMERCIAL AIRCRAFT

So far, the discussion has been limited to the business aircraft market. There does not appear to have been as much research to derive an index that compares on an equitable basis the principal design characteristics or MOFs of commercial aircraft. In general, commercial aircraft are compared with respect to revenue-generating capabilities and costs of operation and ownership, not necessarily on a design basis alone. Therefore, this is an attempt at deriving an expression that encompasses MOFs considered to be of value to the customers of these products, in lieu of the traditional cost aspect. Furthermore, cost information is difficult to predict especially at the early stage of a design project.

By expanding the classic PI, it is proposed to include the specification number of PAX seats to closer reflect the productivity of commercial aircraft. Traditionally, productivity for commercial aircraft is measured in seat miles per hour. Changes in productivity therefore are the result of either a change in number of seats available per aircraft or a change in block speed or a combination of these two. The new index will thus address the effect of seats available, while block speed is a more difficult parameter to represent. Block speed is influenced by stage length flown and defining a characteristic stage length, which will capture all commercial aircraft operations, will be difficult to do and add complexity to the index. The LRC speed when multiplied with number of seats is postulated to give a functional account of productivity. Since block speed is lower than LRC the effect is to reduce productivity from ideal, any change in LRC will translate to a similar change in block speed, thus validating its inclusion in the index for comparison purposes. The index’s simplicity and intuitiveness remains intact. This new measure of value for commercial aircraft, designated as the Productivity Index for Commercial Aircraft, or PIC, is defined in Eq. (2),

$$PIC = \frac{R_{LRC}\ M_{LRC}\ V_{cab}\ N}{B} \quad (2)$$

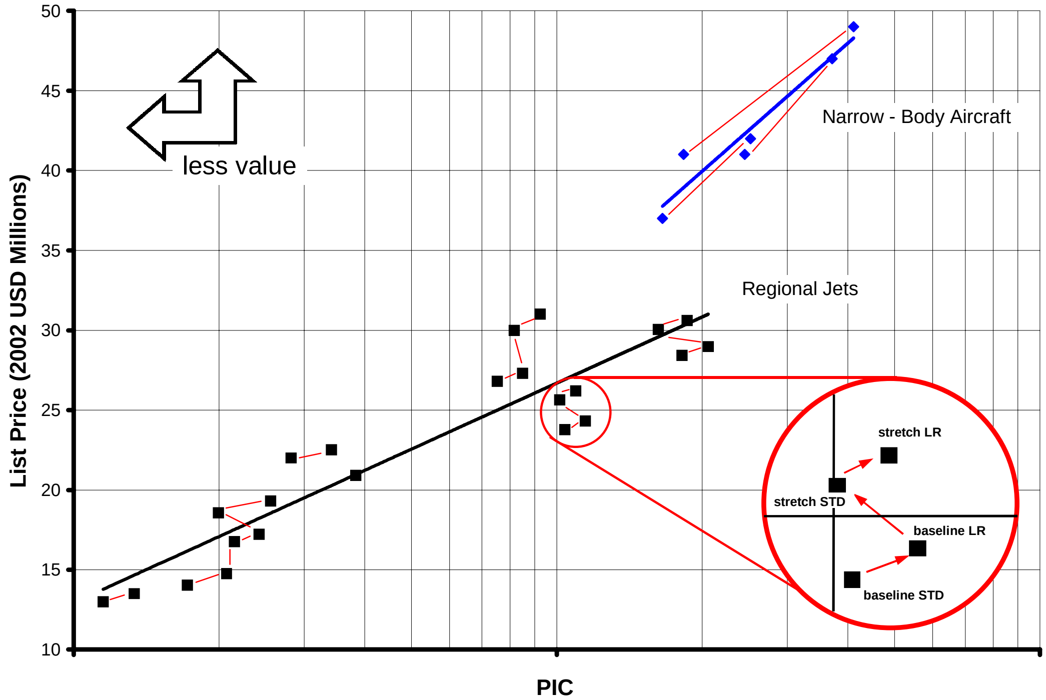

Figure 2 – Productivity Index for Commercial Aircraft versus Price.

where R_{LRC} is the range at LRC speed (payload assuming standard number of PAX), N is the number of PAX in standard configuration and B is the BFL (sea level, ISA, MTOW).

The focus of this work is on regional aircraft, but it is surmised the index developed is universally applicable to all commercial aircraft. Results of this proposed index for in-production and in-development regional aircraft appear in Figure 2 above, which plots PIC versus list price. Data was taken from B&CA's Planning and Purchasing Handbooks[6], Airclaims[7] and aircraft manufacturer brochures. Also included in the chart are some of the smaller narrow-body twinjets currently available. The chart clearly shows they are a different price to value proposition, but a distinct trend still occurs nonetheless. The chart includes variants and derivatives.

An interesting paradigm can be observed for a given family of aircraft that share a given wing and hence fuel volume (typically, regional aircraft carry all their fuel in the center tank and wings). First, when an IGW of a given aircraft is introduced (ER or LR versions for example), the result is in most instances an increase in the value of PIC for a small increase in price, thereby moving the data point to the right and slightly up. If a stretch of the platform is considered, then the point moves purely vertically or sometimes even backwards and up. This is because the result of a simple stretch is of course an increase in the number of PAX and cabin volume, but also a reduction in range and possibly a higher BFL as a consequence of higher MTOW. This phenomenon is shown in the inset of Figure 2 for a four-member aircraft family. Consequently, product families tend to be represented on a PIC versus price chart as a relatively tight group of points forming a vertical "zigzag".

THE AIRFRAMER PARADIGM

One of the most difficult tasks in the competitive environment of aircraft manufacturing and sales is to produce a vehicle that employs a particular combination of design specifications, that is, amenities, performance, efficiency and flexibility, at a price the market is willing to absorb. Rather than adhering to a technology-driven edict solely dictating what makes sound economic sense, there exists a vital requirement that some sort of impartial methodology can be utilized such that both engineering and strategic product development departments can plan for new design proposals with some confidence. Factors such as reliability, maintainability, utility, perceived safety, efficiency, operating costs, brand name loyalty and aesthetics affect the propensity for a customer to purchase an aircraft. In addition, it is erroneous for one to postulate that costs associated with research, design, testing, manufacturing and certification play a significant role in setting price; in the long run it is the market that dictates price.

As previously discussed in detail, the PI (used hereon to describe both the business aircraft PI and the commercial aircraft PIC, unless otherwise specified), by means of its elementary functional relationship with speed, range, cabin volume and takeoff performance (plus number of PAX in the case of PIC), continues to be the most popular means of analyzing market coverage. This parametric equation promotes suitable trend progression and, by virtue of this characteristic, can be utilized to identify latent pockets of revenue potential not currently serviced by a given aircraft manufacturer's contemporary aircraft portfolio. This also includes the more dramatic possibility of identifying new market niche opportunities. To reiterate the point, although the PI is considered to be very useful in measuring the value of aircraft, it must be used with great caution. Due to the way the index is defined, the observer does not easily capture the relative weighting or influence each MOF has to the global aircraft result as well as the niche the product will occupy. For this reason, a complementary toolkit that would coalesce out such weightings in an objective manner was deemed necessary.

CONSTRUCTING THE AIRFRAMER PARADIGM

As a facilitator for the market niche identification equations given by Eq. (1) and Eq. (2), the next step requires finding a method where aircraft equipped/acquisition price can be quantified based on a given combination of aircraft design related MOFs with adequate accuracy and appropriate sensitivity. One way this requirement can be fulfilled is through the use of Geometric Programming. First devised by Zener of Westinghouse in 1961, the original goal of Geometric Programming was to permit a computationally convenient non-linear optimization technique, which, even in a restricted form, would offer a number of advantages over conventional techniques based on classical calculus. Zener noted that the sum of component costs of a process sometimes can be minimized almost by inspection provided these costs are functions of the product of the variables involved in each cost term, with each of the variables raised to arbitrary real exponents. One example of the method's success that can be cited is based on McMasters'[8] work. This mathematical technique was used to find solutions of various optimization problems related to aircraft performance.

In order to exploit the potential benefits of adopting the Zener approach, a new primal objective function construct known hereon as the Airframer Paradigm was created in an effort to ascertain how much a given set of design specifications are worth to the market. Recognizing that a given aircraft manufacturer intrinsically defines its own unique primal objective function (in this instance referring to aircraft equipped/acquisition price), a multivariate model based on the build-up and summation of component "costs" of an assembly (or MOFs) can be constructed. Through experimentation[9], one suggested form that showed promise was

$$\Gamma = f_1\, R_{LRC}^{w_1} + f_2\, B^{w_2} + f_3\, V_{cab}^{w_3} + f_4\, S_{cab}^{w_4} + f_5\, M_{MCRZ}^{w_5} \qquad (3)$$

Γ is the aircraft equipped/acquisition price, M_{MCRZ} is the maximum cruise Mach number and S_{cab} represents a cabin slenderness ratio parameter comprising the cabin length (l_{cab}) divided by the addition of cabin width (w_{cab}) and cabin height (h_{cab}), or,

$$S_{cab} = \frac{l_{cab}}{w_{cab} + h_{cab}} \qquad (4)$$

A simple procedure is available to approximate the gross cabin volume of any type of cross-section, whether circular or ovoid in shape[9]. Assuming the cross-section is uniform throughout the length of the cabin, V_{cab} is then given by

$$V_{cab} = \frac{l_{cab}}{4}\left[w_{cab}\left(\pi h_{cab} + \theta_c w_{cab}\right) + h_s\left(2w_{flr} - \pi w_{cab}\right)\right] \qquad (5)$$

The parameter w_{flr} is the cabin floor width. Assuming the maximum cabin radius remains approximately constant from the maximum width line to the floor, the residual vertical height from the maximum width line to the floor, h_s, is found using

$$h_s \cong \frac{1}{2}\sqrt{w_{cab}^2 - w_{flr}^2} \qquad (6)$$

The angle θ_c swept out between the maximum width line and cabin floor for any fuselage cross-section is given using basic trigonometry

$$\theta_c = \tan^{-1}\frac{2h_s}{w_{flr}} \qquad (7)$$

One can appreciate a very useful and important by-product of Eq. (3) is the notion individual or even multi-parametric macroscopic objective function sensitivity of the paradigm equation can be examined.

INSPECTION OF DERIVATIVES

As a general curiosity, it would be of interest to examine the sensitivity of the paradigm equation assuming various combinations of design specifications. A more insightful investigation could be identification of what direction in its domain Γ increases most rapidly from the starting point $P_o(R_{LRCo},B_o,V_{cabo},S_{cabo},M_{MCRZo})$. The importance of this question becomes quite evident if one considers point P_o in the domain represents a known baseline aircraft design. If the partial derivatives of the primal objective function $\Gamma(R_{LRC},B,V_{cab},S_{cab},M_{MCRZ})$ are defined at the baseline aircraft design condition $P_o(R_{LRCo},B_o,V_{cabo},S_{cabo},M_{MCRZo})$, then the gradient of Γ at P_o is the vector

$$\nabla\Gamma = \frac{\partial\Gamma}{\partial R_{LRC}}i + \frac{\partial\Gamma}{\partial B}j + \frac{\partial\Gamma}{\partial V_{cab}}k + \frac{\partial\Gamma}{\partial S_{cab}}l + \frac{\partial\Gamma}{\partial M_{MCRZ}}m \qquad (8)$$

Using Eq. (3) as a basis, expanding out Eq. (8) produces the following result

$$\nabla\Gamma = f_1\, w_1\, R_{LRC}^{w_1-1}\, i + f_2\, w_2\, B^{w_2-1}\, j + \vartheta_{cab}\, k + \Theta_{cab}\, l + f_5\, w_5\, M_{MCRZ}^{w_5-1}\, m \qquad (9)$$

Recalling the partial derivatives for cabin volume and cabin slenderness are themselves compound functions of cabin metrics, specifically the cabin length, cabin width and cabin height, a series of conditional partial derivatives needs to be defined, thus giving some freedom in electing what design variables shall be observed for sensitivity studies.

Initially one can examine the partial differential

$$\vartheta_{cab} = \Gamma_{V_{cab}} = f_3 \, w_3 \, V_{cab}^{w_3 - 1} \quad (10)$$

for an independent V_{cab}, otherwise,

$$\vartheta_{cab} = \Gamma_{l_{cab}} = f_3 \, w_3 \, A_{cab}^{w_3} \, l_{cab}^{w_3 - 1} + f_4 \, w_4 \frac{l_{cab}^{w_4 - 1}}{(w_{cab} + h_{cab})^{w_4}} \quad (11)$$

for an independent l_{cab}. The parameter A_{cab} represents the cabin cross-sectional area and can be quantified using the relation $A_{cab} = V_{cab} / l_{cab}$. Finally, to complete the expansion of Eq. (8)

$$\Theta_{cab} = \Gamma_{S_{cab}} = f_4 \, w_4 \, S_{cab}^{w_4 - 1} \quad (12)$$

for an independent S_{cab}, or $\Theta_{cab} = 0$ for an independent l_{cab}.

In order to appreciate how much the function Γ changes for excursions from point P_o to another point, the rate change of Γ is calculated by finding the dot product between the gradient vector of Γ by **u**, which is the direction of the tendency away from P_o. The direction of the tendency towards another point from baseline P_o is algebraically described by the unit vector **u** = $\nabla\Gamma / |\nabla\Gamma|$.

To illustrate what role inspection of derivatives plays, a working example is presented as an addendum to this paper.

A METHOD TO FORMULATE NEW PRODUCT DESIGN SPECIFICATIONS

A transport aircraft conceptual design may be defined as a very tentative engineering proposal, which meets the requirements of a current (or envisioned) market niche with facility for accommodating perceived future needs constrained by the realities of contemporary and foreseeable economic forces. Disciplines, or subspaces, of structures, weights, thermodynamics and aerodynamics must be traded with each other in order to produce a balanced design candidate, which not only conforms to airworthiness and operational requirements, but also, if it is destined to be a commercial transport, gives wide scope of revenue potential. The analytical processes that aid in bringing a conceptual design into fruition are primarily based on methods that are simple to moderately high in complexity. Notwithstanding efforts for simplification, interactions between the multitudes of free variables that go into defining a configuration commonly result in a rather complex array of objective functions. These criteria are subsequently inspected via sensitivity studies in order to foster an optimized vehicle layout. The traditional approach to conceptual design problems, particularly in industry, is to conduct simplified MVO exercises and then compare the collective outcome each set of design parameters has produced, such as MTOW or where sufficient sophistication is available, DOCs.

The ever-increasing requirement for complexity of the aircraft system definition at the conceptual design phase demonstrates the importance of establishing an appropriate set of aircraft design specifications from the outset, a task usually performed by the market research function of the company. The design specifications are often collectively referred to as the MR&O. This endeavor becomes progressively more difficult when a concurrent family concept is undertaken; therefore, the task here is to formulate a new methodology whereby the MR&O of a new aircraft project can be defined with emphasis placed on minimizing subjectivity in the process. In accomplishing this goal, the MR&O can now be thought of as an additional subspace that not only couples, but also serves to lead into the global aircraft system problem. When steps are taken to declare the MR&O, or notably the constituent MOFs, as a subspace in the aircraft design scheme, it is prudent to emulate the principles and practices synonymous with conceptual design methods utilized for the core technical disciplines. Such themes include the adoption of rather simple analytical constructs, thus, allowing for the optimization of objective functions that are moderately high in complexity. Note that the word “optimum” for MR&O formulation should not be interpreted in the same sense as minimizing tangible properties like weight, fuel burn or drag, but should be understood to mean suitability.

FOUNDATION OF THE METHODOLOGY

The procedure should demonstrate qualities such that it is possible to integrate the proposed algorithm into any modular aircraft synthesis computer program with minimal effort. Furthermore, it is reasonable to conclude from the outset that analyzing the MR&O as a subspace implies the constituent MOFs will also be subject to the usual array of mathematical governance applied to core technical disciplines. One such example is inequality constraints and these are applicable to individual MOFs as well as the primal objective function of equipped/acquisition price. Ideally, only a small number of constraints will affect the final MR&O outcome and it is necessary in exploiting this fact to reduce the number of mathematical operations. The underlying concept is to retain only those constraints that are presupposed to play an active role in the design process. As a result, the selection of these critical constraints requires an element of subjective decision-making to build a consistent strategy in identifying the optimum.

Upon inspection of both the PI and Airframer Paradigm parametric equations, it is evident that the former relies on the visual cues of geometric progression whilst the latter is analytical in nature. Although great emphasis is placed on the fact that PI’s greatest virtue lies in the ability to identify pockets of interest with relative simplicity, there still exists a more powerful untapped tool. One fundamental conclusion drawn from PI plot is any correlation that displays some semblance of geometric progression has the ability to be described by an analytical model. Proceeding with this key inference, if the analytical representation of any PI geometric progression is thought of, instead, as a constraint function, then it is plausible to convert the seemingly arbitrary process of design specification formulation into an optimization problem. For instance, such a problem can be outlined mathematically in the following manner:

Find a set of MR&O design specifications or MOF values, X = $\{R_{LRC}, B, V_{cab}, S_{cab}, M_{MCRZ}\}$, which will either minimize or maximize the aircraft equipped/acquisition price primal objective function

$$\Gamma(X) \tag{13}$$

which is subject to the condition

$$g_l(Y) \le G_j(Y) \le g_u(Y) \tag{14}$$

for j = 1,…,number of constraints, the MOF set Y = $\{R_{LRC}, M_{LRC}, V_{cab}, B\}$, and, threshold values of $g_l(Y)$ and $g_u(Y)$ representing the lower and upper boundaries respectively, which are used to limit the region of identification for the optimum.

OVERVIEW OF THE METHODOLOGY

With the mathematical foundations mapped out, the process commences by surveying the PI plot in question. This operation requires identifying the range of market segments (whether dictated by an interval of PIs or aircraft equipped/acquisition price) deemed appropriate to the study, and then proceeding with the establishment of a pertinent constraint(s) condition. The constraint condition needs to be described analytically and there is no real impediment to the type of model that can be utilized; experience has shown that if the interval of

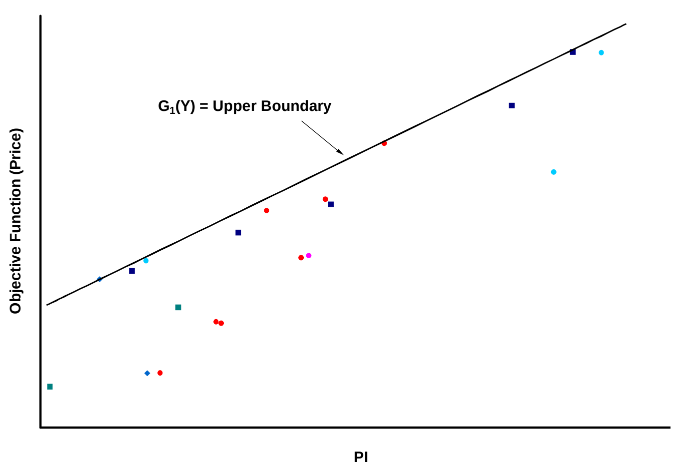

Figure 3 – Establishing and analytically defining constraint functions using a PI plot.

interest is sufficiently narrow, the condition can be adequately represented by a linear function. Figure 3 (above) supplies an example of how constraint functions can be defined. As illustrated, the presented example nominates definition of a single constraint. In this instance, it is supposed to describe an upper boundary of aircraft equipped/acquisition price for given PI.

As mentioned previously, the Airframer Paradigm model permits the flexibility of not only predicting aircraft equipped/acquisition price the market is willing to absorb for given aircraft manufacturer and combination of MOFs, but can also be utilized as a sensitivity analysis tool. Such an investigation is akin to the MVO trade-study plot generated for aircraft conceptual design sizing purposes. In order to produce a two-dimensional “carpet plot”, the Airframer Paradigm needs to be simplified with justification, thus facilitating the variation of only two MOFs. These two primary parameters can be identified from inspection of the partial derivatives as presented in Eq. (9) through Eq. (12). A general notion of the sensitivity study can be obtained upon perusal of Figure 4. Each solid line denotes the variation of a second MOF with successive darker shade lines representing an increase in the parameter value.

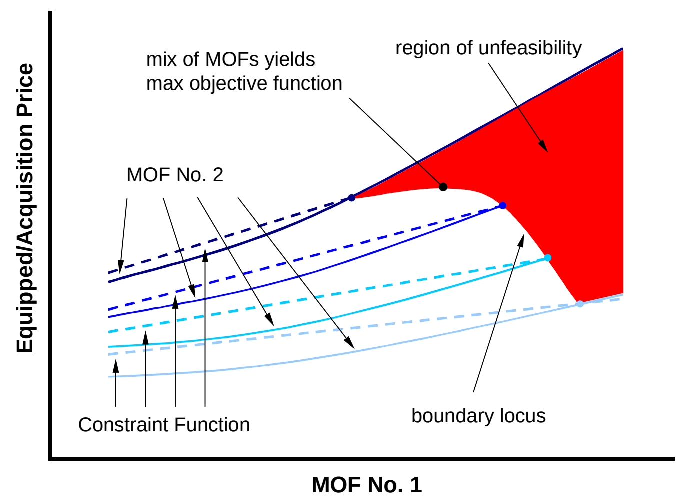

Figure 4 – Investigating sensitivities and optimizing for aircraft equipped/acquisition price using MOFs and constraint functions.

At this juncture, recalling the definition of an upper boundary constraint function $G_1(Y)$ from the PI diagram in Figure 3, by virtue of introducing this into the sensitivity analysis means the problem can become a constrained optimization exercise. A representation of the influence the constraint function imposes on the Airframer Paradigm sensitivity can be observed from the dashed lines of constant $G_1(Y)$ parameter values for given value of MOF No. 2 in Figure 4. Again, an increasing shade of dashed line denotes increasing magnitude of MOF No. 2. Additionally, when perusing Figure 4, it is evident that regions exist where the constraint function generates aircraft equipped/acquisition price values greater than or equal to that of the Airframer Paradigm. Such zones indicate those particular combinations of MOFs do not violate the upper boundary shown in Figure 3. By constructing a locus of the points at which crossover occurs between $G_1(Y)$ and MOF No. 2 for each respective magnitude, it is possible to define a distinct boundary. Using Figure 4 as a guide, the zone above this threshold can be categorized as a region of unfeasibility, and thus, should not be considered to set the MR&O of any future design exercise. An interesting feature of this method is the potential to generate stationary points, where a constrained minimum or maximum in aircraft equipped/acquisition price occurs.

There is no real limitation to the number of constraint functions that can be considered for the Airframer Paradigm sensitivity plot. A pragmatic approach would be to define two constraint functions, namely, a lower and upper bound of aircraft equipped/acquisition price for given PI. This procedure would permit good transparency because the designer/analyst has an opportunity to appreciate whether a given combination of MOFs violates an assumed aircraft equipped/acquisition price threshold. Another important consideration is it ensures minimum goals do not become excessively aggressive. A combination of MOFs wherein a very high collective PI results for given aircraft equipped/acquisition price could necessitate the incorporation of more advanced engineering techniques to realize the minimum goals, thereby increasing risk.

Having an ability to conduct selection through a logical sequence of mathematical operations that generate figures of merit means the problem of formulating MR&O design specifications can be designated as a supplementary subspace coupling to the global aircraft system during automated mathematical optimization searches. Notwithstanding this potential, the most common use for the PI and Airframer Paradigm would certainly be as one of the subset guidelines for producing a well-balanced design, that is, ensuring the aircraft product/family proposal adheres to the design core philosophy from as many conceivable perspectives as possible. Irrespective of this possibility, it is advisable to limit the complexity of analysis to the most rudimentary level. Since the majority of the time requires consideration of no more than two constraint functions concurrently, this circumstance is amenable to direct identification via inspection of a single “trade-study” or sensitivity plot. Figure 4 demonstrates one such example of a constrained optimization approach to MR&O design specifications definition. Finally, by keeping the entire optimization manual, the designer/analyst has complete freedom in the amount of experimentation that goes into searching for the most practical combination of MR&O design specification values for a single development candidate or a collection of family members.

APPLICABILITY AND LIMITATIONS

The procedure discussed here does have one important caveat. This process is not advocated as being, and should never be construed as a substitute for the valuable and insightful work conducted by dedicated strategic planning, marketing and sales departments. The method has been conceived in order to address a pivotal obligation during the contemporary aircraft product development process. More often than not, an initial guess of what should constitute the MR&O is mostly subjective even with expenditure of an extensive amount of preparatory work. The combined PI or PIC and Airframer Paradigm sensitivity analysis permits the utilization of a somewhat more objective method in establishing this all-important starting point, which usually requires simply a target range, speed, cabin and takeoff performance.

EMERGING TRENDS IN AIRCRAFT VALUE

By inspection of the PI and PIC vs. price charts of Figures 1 and 2, and especially when one considers the entry into service date of the products surveyed, several trends can be identified. This section highlights those developments and attempts at projecting them into the future.

BUSINESS AIRCRAFT

Three emerging trends that impact business aircraft value today have been identified: the multiplication of offerings, the emergence of a two-tier market comprising luxury and more utilitarian aircraft, as well as corporate shuttle applications. It is believed these classifications of the market will continue into the future and may, in time, require a periodical evaluation of the validity of the PI to appropriately cover these distinctive applications.

Multiplication of Offerings

Introduction of derivative models and variants in terms of changes to range, payload, speed and other performance parameters have permitted the aircraft manufacturer to offer the customer a product tailored to specific needs. As an indication of this, Figure 1 shows that 20 business aircraft models were surveyed in 1990, 21 in 1996 and 34 in 2002. Several new models were introduced in the lower as well as the larger spectrum, redefining entry-level and top-of-the-line markets. Also, customer needs in terms of aircraft transport capacity, number of PAX over distance carried or more space per PAX, are addressed through fuselage plugs or de-plugs and additional fuel carried. On the PI diagram, these changes are captured through a shift along the horizontal axis, providing an approximate indication of how much the equipped price needs to be adjusted in order to deliver the same value for performance. The same is true for older aircraft as newer aircraft of same PI and equipped price enter the market. A decision has to be made to add enhancements and/or increasing PI modifications to the old aircraft or lower the equipped price to stay competitive in the market. If lowering the equipped price is not an option, then it will only be a matter of time before demand for these aircraft will disappear and lead to an end of production. The PI diagram helps to identify where consolidation of the market may occur in the future.

Two-Tier Market

The increasing popularity of fractional ownership of business aircraft and the emergence of charter companies, an on-demand construct similar to fractional ownership programs, had a significant impact on the operational use of business aircraft. While individual ownership was traditionally characterized by low yearly utilization rates (around 400 hours per year), the new operational model demands increase in utilization and same dispatch reliability, and therefore, positions the business aircraft operation closer to that of a commercial airline. Indeed, "charter by demand" may significantly intrude into the low tier regional and longer range point to point service. As a consequence, dispatch reliability, quick turnaround and operating costs have become factors of higher importance. This is in contrast to the luxury segment, which emphasizes passenger comfort through customization of cabin, speed and range.

The current PI does not address these factors explicitly. However, for a given PI, the more luxurious solutions will tend to be above the mean price-PI line, while the more utilitarian applications will be below the same line. For example, several products aimed more specifically at either of these two markets within the narrow PI bandwidth have been introduced in recent years. By reducing the amount of fuel available and restricting the choice of standard interior and equipment offerings, the price of an aircraft can be significantly reduced for a small reduction in PI, resulting in the product being positioned significantly below the mean line.

Corporate Shuttle

The corporate shuttle offers a potentially superior alternative to commercial flying when one considers the inconvenience typically associated with the latter option. Corporate shuttle aircraft are either based on business aircraft or are derivatives of commercial aircraft. Business aircraft have their executive interiors replaced by a still very comfortable but higher density seating arrangement than typical business aircraft, thus increasing their productivity in terms of available seat miles offered. The commercial aircraft based shuttle offers a reduced amount of seats compared to a configuration for airline use, but may add additional fuel tanks for increased range. Although reducing the number of PAX while keeping other factors the same reduces the relative value of the aircraft, the aircraft equipped price per PAX increases for the shuttle due to more comfortable appointments, hence commands a similar aircraft price amount to the commercial version list price. As previously discussed, corporate shuttles tend to offer a good PI to price ratio, but through a biased mix of characteristics, that is, a large cabin volume, but relatively poor en-route and field performance.

REGIONAL AIRCRAFT

Three distinctive trends can be identified in the design philosophy of regional aircraft: the trend to closely match the PAX seats available for given route demand through the multiplication of offerings, an approach favoring low-cost, and, mainline appearance and mainline PAX comfort.

Multiplication of Offerings

Multiplication of offerings based on a given airframe optimizes the aircraft basic transport capacity, number of PAX seat and range to the route structure of the operator. Stretching and shrinking the fuselage by a few frames and/or limiting or increasing the amount of fuel carried while staying within the overall design limits of the aircraft is a relatively low cost task to the airframer. Nonetheless, benefits to the operator include lower operating costs and greater operational flexibility. It is foreseen that manufacturers will continue to monitor their customers' needs and develop further variants of their platforms if the need arises. This may also push the aircraft manufacturers to plan as many models of a baseline aircraft as possible when a new program is launched.

Low-Cost

This approach promotes characteristics to lower the acquisition and operating costs, and has been indicative of regional aircraft design approach up to this point in time. Great emphasis is placed on achieving a minimum acceptable level of PAX comfort and amenities for typical, relatively short missions. This promotes a smaller aircraft size and hence, minimizes fuel consumption and other size related operating costs. The approach appears to be especially well suited to today's difficult economic climate.

Mainline Appearance and Comfort

Mainline appearance in terms of additional cabin space per PAX and increased amenities such as carry-on volume, in-flight communication and entertainment, and perhaps even improved food service will be reflected in the larger size aircraft (70 PAX and more) entering the market. These features will come at a higher operating cost to the operator, although the availability of more cargo space as a result of larger size may mitigate the increase in cost to the operator on certain routes where demand for cargo space exists.

NEW TECHNOLOGIES

An array of new technology driven equipment and tools are in the process of potentially becoming available to the business aircraft and regional aircraft manufacturer for incorporation in their product offerings. EVS, large HUD units, diagnostic and maintenance tools like AHS are not captured by the existing PI. For inclusion into the PI, a quantifiable parameter must be established. This is particularly true for EVS and HUD. Their main contributions to the operator are a safety enhancement and convenience even if no direct benefits from lowered visibility requirements and thus improved operability can be claimed. Pending acceptance of a proposed amendment by the FAA, EVS will permit under certain circumstances Cat II landings on Cat I beams. It can also be stated that most Cat III qualified aircraft have HUDs installed, although this is not a requirement. Additionally, intelligent diagnostic tools will reduce unscheduled equipment removal rates and thereby reduce flight delays and contribute to higher on time dispatch rates, which are measurable parameters. At issue is the question of how the additional aircraft value attributable to the installation of such equipment can be reflected in the PI without adding unwieldy complexity, or if these features shall be included in the PI in the first place.

Before one is able to answer these questions, a quantifiable parameter has to be found to measure the effect of these new additions on the aircraft productivity. It is desirable with respect to the PI diagram that an increase in the list price is accompanied by a corresponding increase in the PI. It may be feasible to introduce an operability index that will capture the essence of beneficial equipment additions but without introducing undue complexity to the PI. After extensive investigations and experimentation, no such factor has been suitably found yet. On the question of necessity for incorporation of such factors in the PI, it can be argued that these new features are desirable, but are not intrinsic qualities of an aircraft. They add value in a similar way as Centralized Maintenance Systems, Autoland and other features do. Hence, for now, the wide applicability of the PI and Airframer Paradigm parametric tools can justifiably be retained.

CONCLUSION

Measuring the relative value of aircraft using the simplest possible means has been scrutinized and continually improved over the years. The Productivity Index, or PI, defined as the product of range, speed, cabin size and quotient of takeoff distance has emerged as a popular tool throughout the business aircraft industry. Rather than observing an increasing value-for-money trend year over year, an historical survey of business aircraft offerings between 1990 and 2002 has shown that prices essentially remained fixed for given value of PI. This was postulated to be in part a result of the great demand for business jets in mid to late 1990s and early 2000, hence, allowing manufacturers to ask higher prices for progressively improving blend of aircraft characteristics. Notwithstanding limitations due to equal weighting of parameters, the PI it is still the best method to quickly identify latent pockets of revenue potential not currently serviced by a given aircraft manufacturer’s contemporary aircraft portfolio. Further investigations have shown that a modified version of the business aircraft PI is a feasible and quite useful tool for commercial aircraft as well.

An additional parametric model called the Airframer Paradigm was presented with the intention of quantifying aircraft equipped/acquisition prices based on a given combination of aircraft design related macroscopic objective functions with adequate accuracy. It was shown that the Airframer Paradigm model has additional flexibility because it can also be utilized as a sensitivity analysis tool and can be extended to support a more systematic methodology to create a set of aircraft design specifications, or, the Marketing Requirements and Objectives.

A number of emerging trends in design philosophy for business and regional aircraft were also identified. Contemporary business aircraft appear to be classified into three categories: those that offer multiplication of offerings – many variants of the same aircraft to service new market niches; those that cater to a two-tier market – variant aircraft that focus on clientele inclined towards productivity or luxury for a given market segment; and, corporate shuttles – usually converted regional aircraft with higher density yet very comfortable cabin. Regional aircraft can also be classified into three design philosophies: multiplication of offerings; emphasis on low operating cost; and, mainline appearance and comfort. Those trends, as well as the new technologies that enter the business and commercial aircraft markets, must be continually monitored to determine if they have or will have an impact on the validity of the tools described and defined in this work.

REFERENCES

1. Timmons, L.M., “Improving Business Jet Performance: The Mark Five Sabreliner”, SAE Paper 790582, 1979.
2. Killingsworth, E.C., Jr., Wolz, R.R., “Requirements of Business Jet Aircraft”, AIAA Paper 90-2038, 1990.
3. Norris, R., “Measuring the Relative Value of Business Aircraft”, *Professional Pilot*, January and February 1999.
4. AlliedSignal Aerospace, “Business Jet Market Map – 1995”, *Aviation International News*, May 1995.
5. Moghadam, A., Farsi, K., “Business Aircraft: Cost of Performance”, AIAA Paper 95-3955, 1995.
6. *Purchase and Planning Handbook, Business & Commercial Aircraft,* May 1990, May 1996 and May 2002.
7. Airclaims' International Aircraft Price Guide (Summer 2002).
8. McMasters, J.H., “Reflections of a Paleo-aerodynamicist”, AIAA Paper 84-2167 (Invited Paper), AIAA Second Applied Aerodynamics Conference, August 1984.
9. Isikveren, A.T., “Quasi-analytical Modeling and Optimization Techniques for Transport Aircraft Design”, Report 2002-13, Ph.D. Thesis, Royal Institute of Technology (KTH), Department of Aeronautics, Sweden, 2002.

CONTACT

Askin T. Isikveren
(1) Advanced Product Development, Bombardier Aerospace, P.O. Box 6087, Station Centre-Ville, Montréal, Québec, Canada, H3C 3G9
Phone: (514) 855-5000, Fax: (514) 855-7302
Email: askin.isikveren@notes.canadair.ca
(2) Department of Aeronautics, Royal Institute of Technology (KTH), SE-10044 Stockholm, Sweden

Guenther Goritschnig
Advanced Product Development, Bombardier Aerospace, P.O. Box 6087, Station Centre-Ville, Montréal, Québec, Canada, H3C 3G9
Phone: (514) 855-5000, Fax: (514) 855-7302
Email: gunther.goritschnig@notes.canadair.ca

Mathieu Noël
Advanced Product Development, Bombardier Aerospace, P.O. Box 6087, Station Centre-Ville, Montréal, Québec, Canada, H3C 3G9
Phone: (514) 855-5000, Fax: (514) 855-7302
Email: mathieu.noel@notes.canadair.ca

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AHS	Aircraft Health System
BFL	Balanced Field Length as used for commercial aircraft; the distance corresponding to the balance of the accelerate-stop and accelerate-go distances; legal takeoff requires comparison to 115% of the all-engine takeoff distance up to a height of 10.7 m (35 ft)
B&CA	Business and Commercial Aviation
DOC	Direct Operating Cost
ER	Extended Range (variant)
EVS	Enhanced Vision System
FAA	Federal Aviation Administration
HUD	Head-Up Display
IFR	Instrument Flight Rules
IGW	Increased Gross Weight
LR	Long Range (variant)
LRC	Long Range Cruise
MCRZ	Maximum Cruise
MOF	Macroscopic Objective Function
MR&O	Marketing Requirements and Objectives
MTOW	Maximum Takeoff Weight
MVO	Multi-Variate Optimisation
NBAA	National Business Aviation Association
PAX	Passenger; weight allowance for one passenger and baggage equal to 200 lb for business and 220 lb for regional operations
PI / PIC	Productivity Index (for Business Aircraft)
PIC	Productivity Index for Commercial Aircraft
STD	Standard
TOFL	Takeoff Field Length as used for business aircraft (deviates from the FAR definition); the greatest of accelerate-stop and accelerate-go distances

APPENDIX - WORKED EXAMPLE: FORMULATION OF DESIGN SPECIFICATIONS

To give an example of the perceptive power a combined PI and the Airframer Paradigm analysis can produce, a sensitivity study for a generic business aircraft manufacturer will be presented. Here, the imaginary AeroZ Business Aircraft Company, after repeated attempts with a straight derivative of its current product line, has continually failed to enter the large business jet market with a sufficiently impressive offering. AeroZ has finally taken the significant financial risk of producing a three-member family of derivatives from a clean-sheet aircraft proposal using a familiar fuselage cross-section.

After surveying the current market for possibilities to generate new sources of revenue, the Product Development Committee (PDC) of the AeroZ has decided to conduct a conceptual design study for a large business jet. Upon completion of this work, and if a formal go-ahead is granted for product launch, the PDC would still consider this venture to be a very expensive undertaking (around USD 500 mil.). Therefore, the PDC stipulates any final candidate for this proposal must show propensity to act as a progenitive baseline. This means instead of simply providing opportunity to produce a mid-life upgrade to the baseline aircraft, and hence, still servicing the same market segment, increased or decreased gross weight variants, as well as coherent build strategies for fuselage stretch and shrink derivatives must be considered from the outset. Rather than recovering the development cost through pricing an individual design, the idea is to pursue perhaps an additional two variants and/or derivatives. This means that the business case for a new clean sheet becomes more lucrative since the proposal is for multiple aircraft that service a corresponding number of market segments. In order to maximize market coverage, the company would like each of the variant/derivative aircraft products to service the midsize and super midsize business jet market segments.

After a very quick competitor product survey, AeroZ has decided that a set of MOFs can be selected a priori, and therefore, deemed to be hard specifications (cannot be compromised during the selection process). They are itemized as:

- The cabin cross-section is to be the company mainstay with size 3.16 m^2 (34 sq.ft);
- Each family member must be able to take-off from airfields of around 1520 m (5000 ft) long;
- Each family member must demonstrate a typical LRC speed of no less than M0.78;
- Each family member must demonstrate a MCRZ speed of no less than M0.83;
- The large business jet must permit Trans-Atlantic travel; i.e. (westbound) flight between LHR and JFK with 85% probability winds at LRC assuming NBAA IFR mission rules and reserves, and, a standard PAX complement; and,

- The midsize business jet must permit US Trans-continental travel; i.e. (westbound) flight between BOS and SFO with 85% probability winds at LRC assuming IFR mission rules and reserves, and, a standard PAX complement.

The initial step is to define what constraints will be placed upon the candidate combination of MOFs for this particular exercise. The hypothetical AeroZ Business Aircraft Company has decided to emphasize a value-for-money proposition, i.e. follow the $G_1(Y)$ lower boundary line in Figure 5. Notwithstanding this edict, the company does concede that delivering on such aggressive aspirations for a new large business jet and concurrently maintaining a healthy level of profit margin will be a tough proposition at such low equipped prices. In view of this circumstance, AeroZ has decided to promote a product line that will stick to the value-for-money proposition for the midsize offering, secondly, develop a premium large jet that will display a value proposition between the dataset upper and lower boundaries, and finally, a super midsize product somewhere between the premium and value-for-money philosophies.

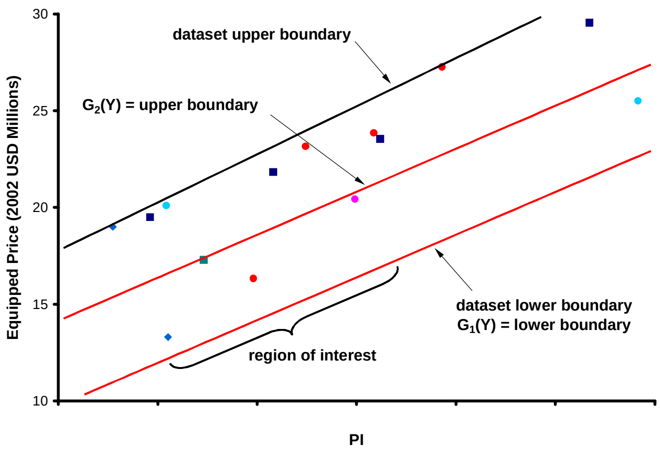

Figure 5 – Identifying pockets of interest and establishing the constraint criteria using a PI plot.

After deciding upon the constraint conditions, suitable analytical models need to be generated. Since the bandwidth of PIs in Figure 5 demonstrates a general linear correlation with equipped price, the lower boundary and upper boundary was derived to be

$$G_1(Y) = 0.221\frac{M_{LRC}\,R_{LRC}\,V_{cab}}{B} + 5.27$$

$$G_2(Y) = 0.221\frac{M_{LRC}\,R_{LRC}\,V_{cab}}{B} + 9.47$$

The next phase is to identify the two most influential MOFs for purposes of constructing the "carpet plot" axes on the Airframer Paradigm sensitivity plot. This is accomplished via the inspection of each constituent that comprises $\nabla\Gamma$ as presented in Eq. (9) through Eq. (12). Assuming the gradient investigation is conducted for the postulated large business jet, i.e. around 3600 nm range, 1520 m (5000 ft) TOFL, 3.16 m^2 (34 sq.ft) cabin cross-sectional area, 8.40 m (27.6 ft) cabin length and MCRZ speed of M0.83, from Table 1 it is discernable that for the AeroZ Business Aircraft Company, an equipped price the market is willing to absorb is chiefly a function of range and cabin length.

Derivative	Result (2002 dollars)
Range: $\Gamma_{R_{LRC}}$ per +1000 nm	+ USD 6.12 mil.
TOFL: Γ_B per +150 m	- USD 0.63 mil.
Cabin Lng: $\Gamma_{l_{cab}}$ per +1 m	+ USD 2.82 mil.
MCRZ: $\Gamma_{M_{MCRZ}}$ per +M0.05	+ USD 0.0020 mil.

Table 1 – Identification of the two primary MOFs for hypothetical AeroZ new business jet family of aircraft.

Perhaps surprising to some, the MCRZ Mach number has a weak influence; however, this can be explained by the fact that all AeroZ aircraft products have generally demonstrated relatively high MCRZ speed performance with little spread in the past. Interestingly, increasing the TOFL has a tendency to reduce the potential equipped price value; this result is uncontested since a diminishing ability to takeoff from secondary airfields should intuitively generate less enthusiasm in the market place.

The next move requires the generation of the sensitivity chart. A suitable abscissa was decided as the cabin length; arbitrarily varied between 4.00 m (13.1 ft) and 10.0 m (32.8 ft). The supplementary MOF being range was subsequently varied between 2500 nm and 4000 nm at 500 nm intervals. Both the cabin length and design range variations were intentionally chosen such that both plausible design specification candidates and the competition were catered for, thus, offering a means to conduct comparative surveys as the investigation proceeds.

Figure 6 presents the sensitivity plot used to tentatively nominate the MR&Os for the AeroZ Mk I (midsize),

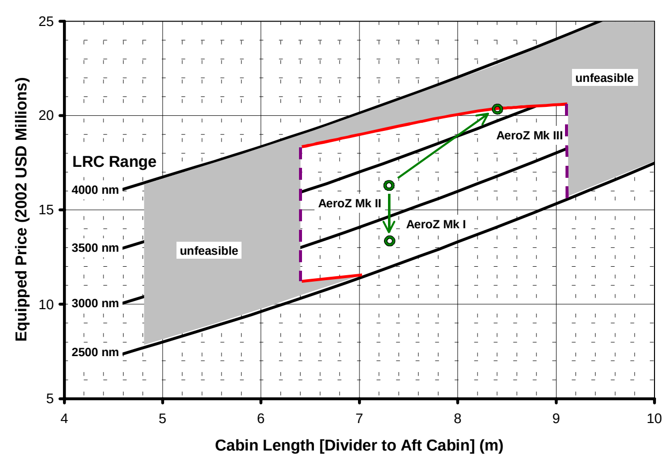

Figure 6 – Sensitivity plot showing the relative influence of primary and secondary MOFs for hypothetical AeroZ new business jet family.

AeroZ Mk II (super midsize) and AeroZ Mk III (large) family concept. Note that the upper and lower constraint boundaries gleaned from the PI chart earlier have been indicated in solid red lines. To further bound the region of feasibility for the family concept, two limits denoting a minimum cabin length of 6.40 m (21 ft) and maximum of 9.10 m (29.9 ft) have also been marked as dashed purple lines. Using these four limiting criteria, the sensitivity plot can now be categorized as either feasible or unfeasible with the latter zone shaded in gray representing a violation of the constraint conditions. The first important observation is that AeroZ should not expect the market to accept their premium product for more than around USD 20.5 mil. Based on the mix of MOFs, the premium product would have a range of 3500 nm to 3600 nm and cabin length between 8.40 m (27.6 ft) to 9.10 m (29.9 ft). Conversely, the greatest value-for-money proposition is one with a 6.40 m (21 ft) cabin length and range of around 2650 nm for an estimated equipped price of just over USD 11.0 mil.

Finally, the large business jet MR&O candidate was selected first. The rationale for AeroZ Mk III primarily hinged on a fundamental requirement that the new large business jet must permit Trans-Atlantic travel. This condition generates a range requirement of at least 3600 nm. Charged with knowledge of this requirement, upon inspection of Figure 6 and following the solid red upper boundary line indicates that a cabin length of 8.40 m (27.6 ft) results. Comparison between the AeroZ Mk III MR&O against the three competitor products, Dassault Falcon 2000EX, Bombardier Challenger 604 and Gulfstream G300, shows an acceptable combination of speed, range and cabin size for the targeted equipped price, thus ratifying the decision. The other two candidates, specifically the AeroZ Mk I and AeroZ Mk II, were surmised to be gross weight variants of a common aircraft size from the outset. In order to size the cabin, a number of criteria were imposed: the midsize aircraft should possess a maximum range of at least 2750 nm, the super midsize range greater than 3200 nm and the equipped price difference between AeroZ Mk I and AeroZ Mk II, and, between AeroZ Mk II and AeroZ Mk III, should be no less than USD 3.0 mil.

Based on the additional set of requirements, a cabin length of 7.30 m (24 ft) is produced. Comparison of the midsize proposal to the five current competitor offerings, Gulfstream G100, Bombardier Learjet 60, Raytheon Hawker 800XP, Gulfstream G150 and Cessna Sovereign, indicates that the AeroZ Mk I will have the second largest cabin and the fastest LRC cruise speed. Similar to the new large business jet, the AeroZ Mk II proposed MR&O displays an acceptable combination of speed, range and cabin for the target equipped price against the six contemporary competitor product offerings, namely, Bombardier Challenger 300, Raytheon Hawker Horizon, Cessna Citation X, Dassault Falcon 50EX, Gulfstream G200 and Embraer Legacy.

To complete the entire exercise, a synopsis of the resulting MR&O for the AeroZ Mk I, Mk II and Mk III family concept is presented in Table 2. This information is complemented by a presentation of each candidate on a PI plot (Figure 7) to show the relative characteristics of each aircraft against the competitor products.

	AeroZ Mk I	AeroZ Mk II	AeroZ Mk III
Predicted Equipped Price (USD mil.)	13.2	16.4	20.3
Cabin Height (m)	1.83		
Cabin Width (m)	2.13		
Cabin Length (m)	7.30		8.40
Cabin Volume (m^3)	23.1		26.6
TOFL, ISA, s.l. (m)	around 1520		
LRC Speed (Mach)	0.78		
MCRZ Speed (Mach)	0.83		
LRC Range, Reserves Assumption (nm)	2750 IFR	3300 NBAA IFR	3600 NBAA IFR

Table 2 – Synopsis of the final selection of MR&O for the hypothetical AeroZ new business jet family of aircraft.

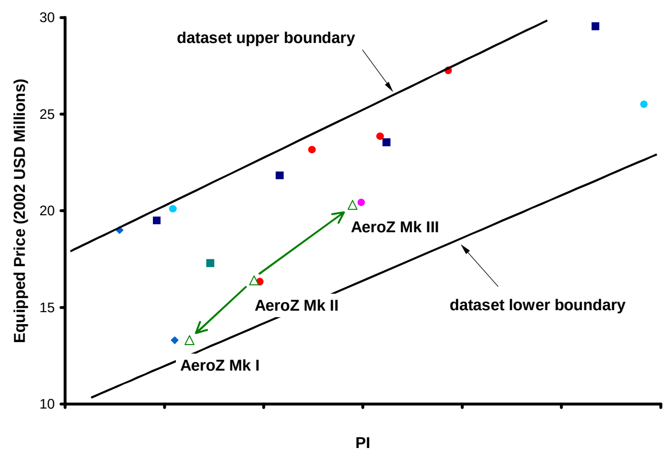

Figure 7 – Gauging the relative competitiveness of proposed MR&Os for hypothetical AeroZ Mk I, AeroZ Mk II and AeroZ Mk III aircraft product candidates.

To echo earlier comments concerning the presented analytical formulation of MR&Os, results of all such studies should always be ratified by the strategic planning, marketing and sales departments. Although the presented methods have been illustrated assuming a business aircraft design, this does not exclude validity for commercial transports as well. In lieu of a more suitable parametric association, the PIC given by Eq. (2) can be used for commuters, regionals, narrow-bodies and wide-bodies as a tool for market niche identification. Furthermore, the Airframer Paradigm given by Eq. (3) and the accompanying protocol for sensitivity studies can be considered as being universally applicable for all transport aircraft types.