

Statistical Time and Market Predictive Engineering Design (STAMPED) Techniques for Aerospace Preliminary Design: Regional Turboprop Application

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As aircraft design techniques become more and more automated with greater numbers of more powerful computational machines becoming available, exacting approaches like “knowledge based design” and “knowledge based engineering” (KBE) are becoming quite commonplace. Indeed, the field of KBE has roots stretching back many decades [1-3]. These KBE tools have in the past decade been systematically moved from detailed component design towards the arena of preliminary aircraft design [3-6]. While KBE and other computational tools are compatible with structural optimization with highly defined loads and operational conditions, such techniques are fundamentally challenged when loads are ill defined or when highly nonlinear factors are included. Another issue challenging such tools as they are being integrated into preliminary design is that they highlight a “computational mismatch” in that expensive, computationally costly methods are being used to arrive at the third and fourth significant figure of aircraft weights, when in preliminary design, only two are generally needed or appropriate for the task at hand.

If one examines weights of legacy aircraft like the Lockheed Electra, one will see that its wing accounts for only 6.6% of the total aircraft gross weight while the fuselage structure is 8.6% [7]. If one looks to more modern aircraft, the weight of the Boeing 787-8 fuselage structural is very close to the percentages of these legacy aircraft at only 9.4% [8]. When one contrasts these numbers to the weight fraction of the furnishings of a Boeing 787-8 at 8.8%, it becomes clear that the weight of foam headrests and seat buckles are just as important to calculate as the weight of stringers and longerons [8]. Given that the weights of interiors are estimated in preliminary design by using historical trends and marketing brochures from third party suppliers to arrive at no greater accuracy than two significant figures, one has to ask, if it really makes sense to use exacting high order tools like KBE to arrive at three or four significant figures of weight accuracy in structural weight in preliminary design.

Instead of applying these expensive, exacting tools for preliminary design which result in aircraft gross weight estimates that are no more accurate than two significant figures, a new addendum to a long-standing historical approach has been proposed. This Statistical Time and Market Predictive Engineering Design (STAMPED) method as it accounts for the effects of highly nonlinear and dubiously predictable weights (like interiors). Because of its global approach, it can also take into account the truly unpredictable effects like “market preference” and “style trends” (which are all but impossible to predict using KBE type tools). If one examines a “classical” approach to aircraft preliminary design embodied in foundational volumes like Reference [9], then it can be seen that global trends are accounted for including aircraft type and weights. However, two critical pieces of information are missing: i) success in the market, and ii) time. The recently developed STAMPED techniques account for both and thereby give the user a high level of utility. The basics of the STAMPED techniques were laid out in [10] and show that a high level of knowledge about a given type of aircraft is required to start.

While [10] described the basic premise of the STAMPED techniques, this paper puts forth an example of how these techniques may be used and how they are being reviewed by professional aircraft design engineers. The example which was implemented over this past year was centered on a Regional Turboprop commuter aircraft. The first step in using STAMPED techniques for simply sizing an aircraft is to analyze the engineering variable of interest along with the market. If one considers regional turboprops, the primary aircraft under consideration include those of Table 1.

Figure 1 shows the principal regional turboprop market trends along with empty-to-takeoff weight ratios over the past twenty years. One will see that the market itself evolved considerably away from some designs, towards others over that time, with median empty-to-takeoff weights shifting over time [11].

If one continues to examine principal engineering variables against the market, then trends of wing and power loading become apparent. Figure 2 shows the trends of these two variables over the past two decades.

The reader will note from the above figure that several things

Aircraft	Max Takeoff Weight (Lbs)	Empty Weight (Lbs)
Faichild Metro III	14000	8790
EMB 120	23800	14400
Dornier 328	30842	19665
BAE ATP	50600	29970
ATR 42-500	34725	21986
ATR 72-500	48501	28550
SAAB 2000	50265	30423
IL-114	51808	33070
Dash 8 Q-300	41000	26042
Dash 8 Q-400	61700	37717
An-140	47399	29101
Fokker F27	43592	24701
Fokker F50	45900	27000

Table 1: Principal Regional Turboprop Aircraft used in STAMPED Analysis.

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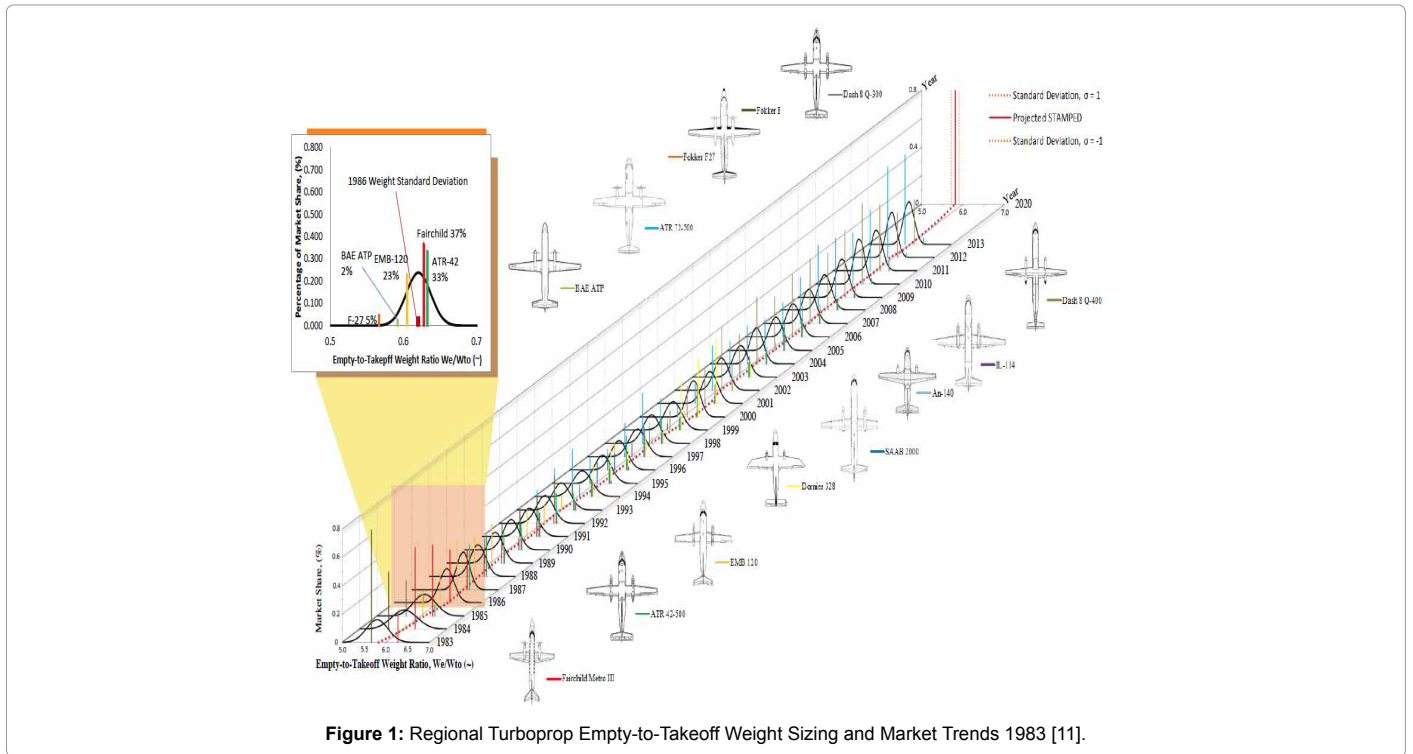


Figure 1: Regional Turboprop Empty-to-Takeoff Weight Sizing and Market Trends 1983 [11].

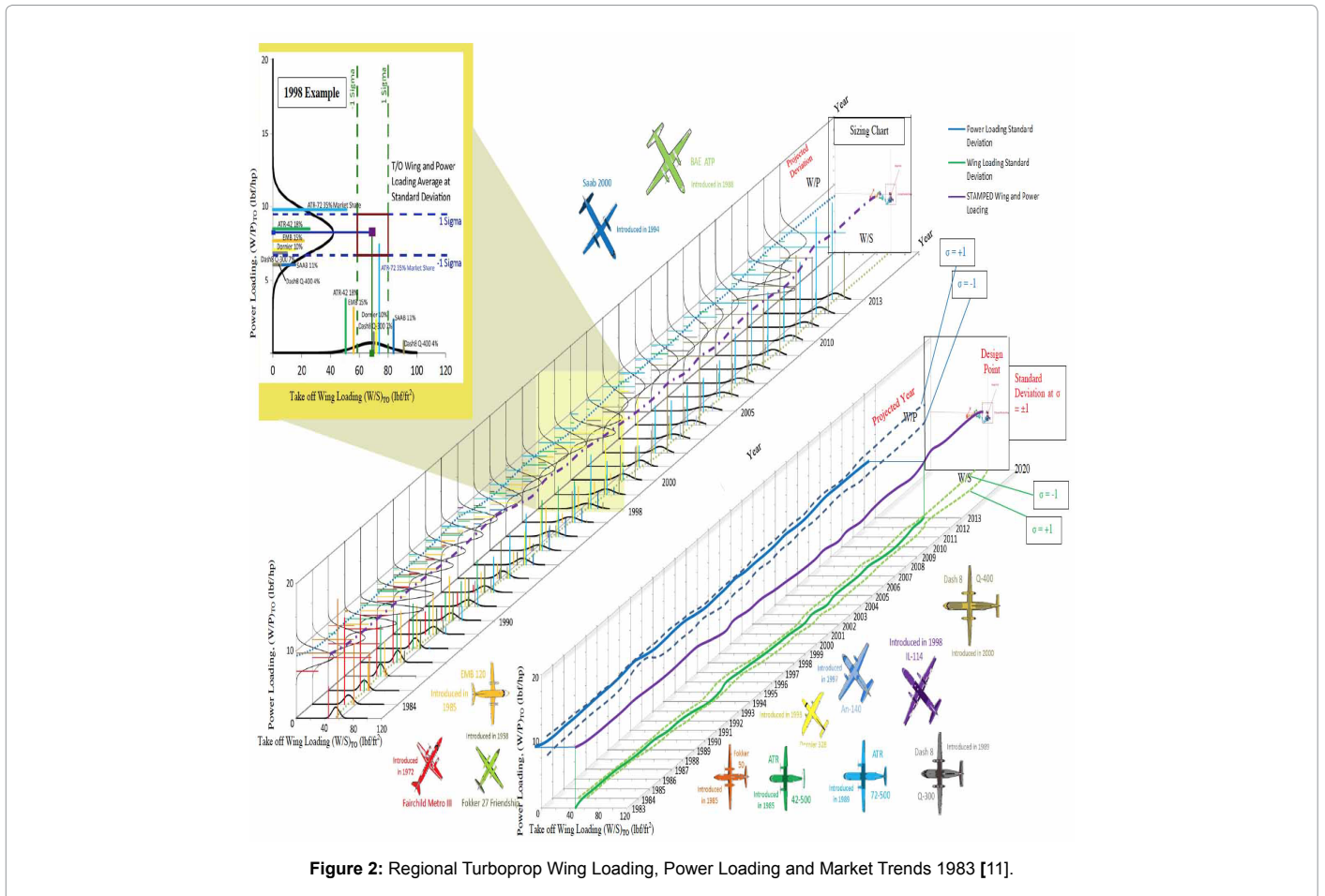


Figure 2: Regional Turboprop Wing Loading, Power Loading and Market Trends 1983 [11].

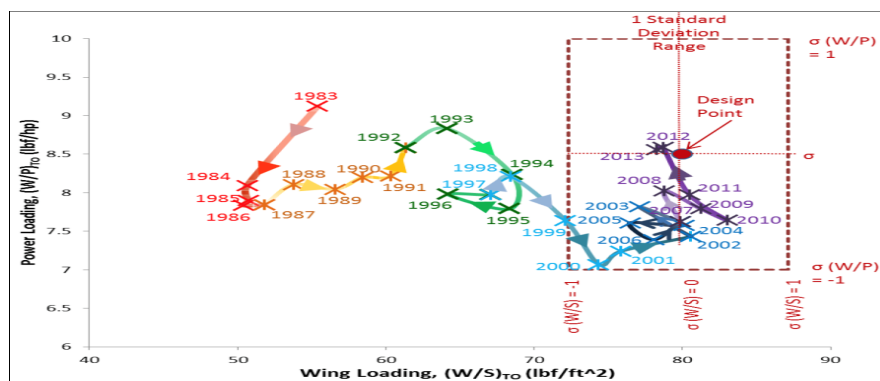


Figure 3: Regional Turboprop Wing Loading, Power Loading with Time [11].

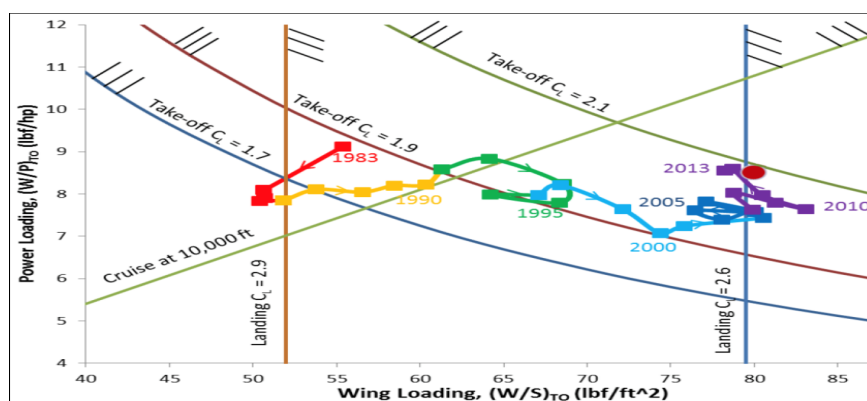


Figure 4: Example Application of Median STAMPED Wing and Power Loading to Arrive at $C_{L_{max}}$ Values for a Hypothetical Aircraft Program IOC of 2020.

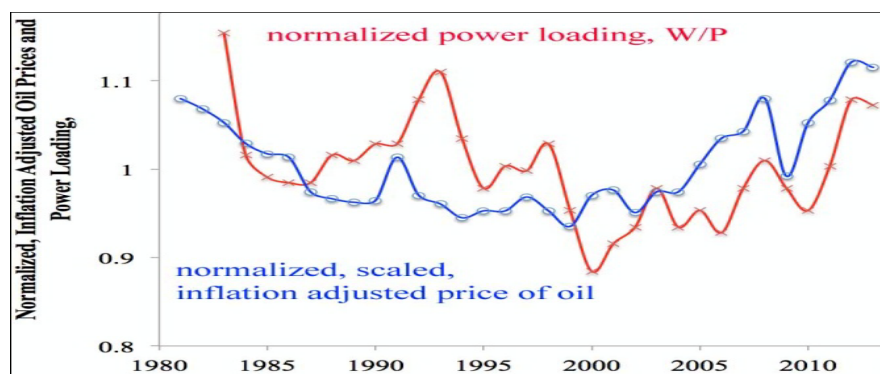


Figure 5: Historical Trends of Normalized Crude Oil Prices and Regional Turboprop Aircraft Power Loading.

become apparent. First is that the engineering variables are fairly leptokurtic, centering on a fairly narrow band of wing loading, while the power loading is more platykurtic. Figure 2 also shows that the top selling aircraft in most years exhibit power loadings which are typically 11-16% above the median and wing loadings that are 5-8% higher than median values. By projecting the trajectories of the aircraft sizing through to the (hypothetical) initial operational capability (IOC) date of 2020 in the given design study, then one can see more clearly the time vector formed by market forces and the technology of the day in Figure 3.

Figure 3 clearly shows that the regional turboprop market steadily marched upwards in wing loading until settling at a range between 72 and 88 psf over the past fifteen years. In that time, the power loading slowly inched upwards as well, eventually settling at a point with a vector-based median market value of 81 psf and 8.5 lbf/hp for an aircraft with an IOC of 2020. If one overlays typical takeoff and landing criteria based on FAR-25, then one can easily arrive at estimates of the takeoff and landing values of maximum lift coefficient as seen in Figure 4.

Although the techniques of [9] call for a range of variables to be included along with estimates of maximum lift coefficient variables to be estimated. The STAMPED techniques as shown in Figure 4 clearly show where the market is headed. What is more, if one steps back in the process, it can be seen that variations in these overall engineering variables are not random or a function of the whims of style or public perception; rather, these overall engineering variables are intimately linked to major market forces which are in great part driven by gross economies and time-averaged oil prices.

As one can imagine, the utility of using STAMPED techniques is undeniable given that vectors may be projected (along with confidence intervals) into the future. For variables which directly affect operating costs, it's not surprising that market forces influence those variables. Indeed, if one tracks the price of oil from 1980 through 2013, then it can be seen that there exists a one-to-two year lag in power loading trends in regional turboprop markets. If one scales the crude price volatility from its twenty year historical trend, then the correlation and time lag between oil price and power loading become painfully clear as shown in Figure 5.

Figure 5 shows a wealth of information on how annualized oil prices affect one especially important engineering variable. Several overall conclusions can be drawn by using a STAMPED technique in preliminary design. The first is that by using STAMPED techniques, one can account for the influence of some overall economic forces in the preliminary design stage, in particular predicted oil price trends. The second is that there exists an ever-decreasing lag between market preference for aircraft with a particular performance-based characteristic and spot oil price. This implies that to keep up with market volatility, it is imperative that the total RDT&E cycle be compressed to match this cycle for maximum market capture and sustenance of a given product line. Finally, that STAMPED techniques can effectively be used to set some of the most important aircraft characteristics like aircraft power loading and wing loading.

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