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ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Exploring Commercial Airplane Introduction with Multiple Regression – Then Comparing Range and Material Composite Percent Parameters with Linear Regression and Pearl Growth Curve

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Abstract

Airplane technology is undergoing several exciting developments particularly in avionics, material composites, and design tool capabilities. There are many studies conducted on subsets of airplane technology, market and economic parameters; but few in multiple regression. This study focuses on three technology forecasting techniques: Multiple regression; linear regression; and the Pearl growth curve. They are applied to long-range commercial aircraft with the result giving a valid model for multiple regression and linear regression on range and composite material %. Growth curve analysis resulted in a valid model for range forecasting, but not for composite material %. This study also provides value in extending a previous descriptive paper on airplane parameters.

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I. ABSTRACT

Airplane technology is undergoing several exciting developments particularly in avionics, material composites, and design tool capabilities. There are many studies conducted on subsets of airplane technology, market and economic parameters; but few in multiple regression. This study focuses on three technology forecasting techniques: Multiple regression; linear regression; and the Pearl growth curve. They are applied to long-range commercial aircraft with the result giving a valid model for multiple regression and linear regression on range and composite material %. Growth curve analysis resulted in a valid model for range forecasting, but not for composite material %. This study also provides value in extending a previous descriptive paper on airplane parameters.

II. INTRODUCTION

Increasingly, not only are commercial airplane manufacturers needing to account for high technological barriers, but growing financial, economic, environmental, and government concerns as well [1-3]. There is a long history of airline manufacturers needing to make not only technical tradeoffs, but to also make those tradeoffs with high priority given to potential profits and other non-technical characteristics of the industry with the effect of an ever-increasing technical and financial bar. In the 1950s the cost to build a Boeing long-range transport plane (B707) was US$2 billion; whereas the development cost of the Airbus A380, introduced in 2007 was US$12 billion (estimate from 2001).[2]

This multitude of parameters affecting the decision to introduce not only a new plane, but whether to take on the high development costs of changing the structure of the airplane model has created one of the many challenges for forecasting airplane technology. Airplane models were often introduced in order to meet a market or competitive need; however, the new model might be a slightly re-configured model from 20 years previously introduced, with a new engine to gain a 1000 km range increase, only to sacrifice the use of newly developed composite materials to get the plane to market. Often, forecasters overcome the challenge of airline industry dynamics by focusing on one or a subset of parameters.[4-8]

Historically, airplanes underwent a large technological change from the old piston engine to the new one based on the jet engine[2] in the early 1960s with new production methods enabling new design methods for greater capacity and speed. Then the 1980s saw a rapid development in airplane technology due to introduction of new materials, new propulsion system, and a much greater use of electronic instruments. [2] These enabled an increased importance on fuel saving, high reliability, safety and speed. A part of the 1990s found researchers believing the airplane was in a mature technology stage.[9] But, more recently the airplane technology is undergoing rapid changes with a focus on information technology enabled new design tools, increased aerodynamics, electronic control systems, increasing range, and a rapid growth in composites to replace steel structure enabling even further technological breakthroughs.[5, 9, 10] A review of the decision complexity around whether to introduce a new airplane model or not is provided under the literature review section.

Forecasting as complex a product as an airplane [1-3, 9], led to the decision of choosing a set of planes of which to focus in this study; long-range commercial aircraft (>100 passengers). Choosing this category of plane was thought to be a means in which to reduce some of the design, market and economic differences between short, medium, and long-range aircraft.

This paper first explores airplane introduction with multiple regression; then compares linear regression and Pearl growth curve results for two commercial airplane parameters--range and composite material % of airplane structure. This study is structured as follows: 1) A literature review discussing both the airplane parameters at a high-level, then focusing on specific technical and market parameters for measurement, 2) the data collection process is then outlined, 3) multiple Regression results are shown for airplane introduction forecasting, 4) next, a graphical and mean absolute error (MAE) comparison is made between linear regression and Pearl curve forecasting results on two airplane parameters, range and composite material percent(%), 5) limitations of this study are shared, and lastly, 6) conclusions.

III. LITERATURE REVIEW

There appears to be not one set of holistic parameters in which to use for focused decision-making on airplane technology studies [1-3]. A couple papers describe the use of technological and economic parameters for jetfighters [11, 12]; and although there are some shared parameters between jetfighters and commercial aircraft such as speed and range, there are large differences in what is important to manufacturing each with jetfighter more focused on weaponry and non-detection and less so on economics.[3] Given the general trend of commercial aircraft research on specific areas of the technology; it is difficult to get a big picture view of the multitude of parameters, and how they interplay. In 1995, Gillett and Stekler [3] provided a fairly wide-reaching descriptive paper on the strategic process of introducing a new airplane and the many variables which affect that feed into that decision. This literature review extends the Gillett and Stekler paper by pulling the parameter inputs and description of how they interplay into an illustration [Figure 1] and adds additional parameters emphasized by other researchers. It must be noted that even this compilation is not one hundred percent comprehensive; but more of an attempt to show a bigger picture of the complexity surrounding the decision of whether to introduce a new airplane or not.

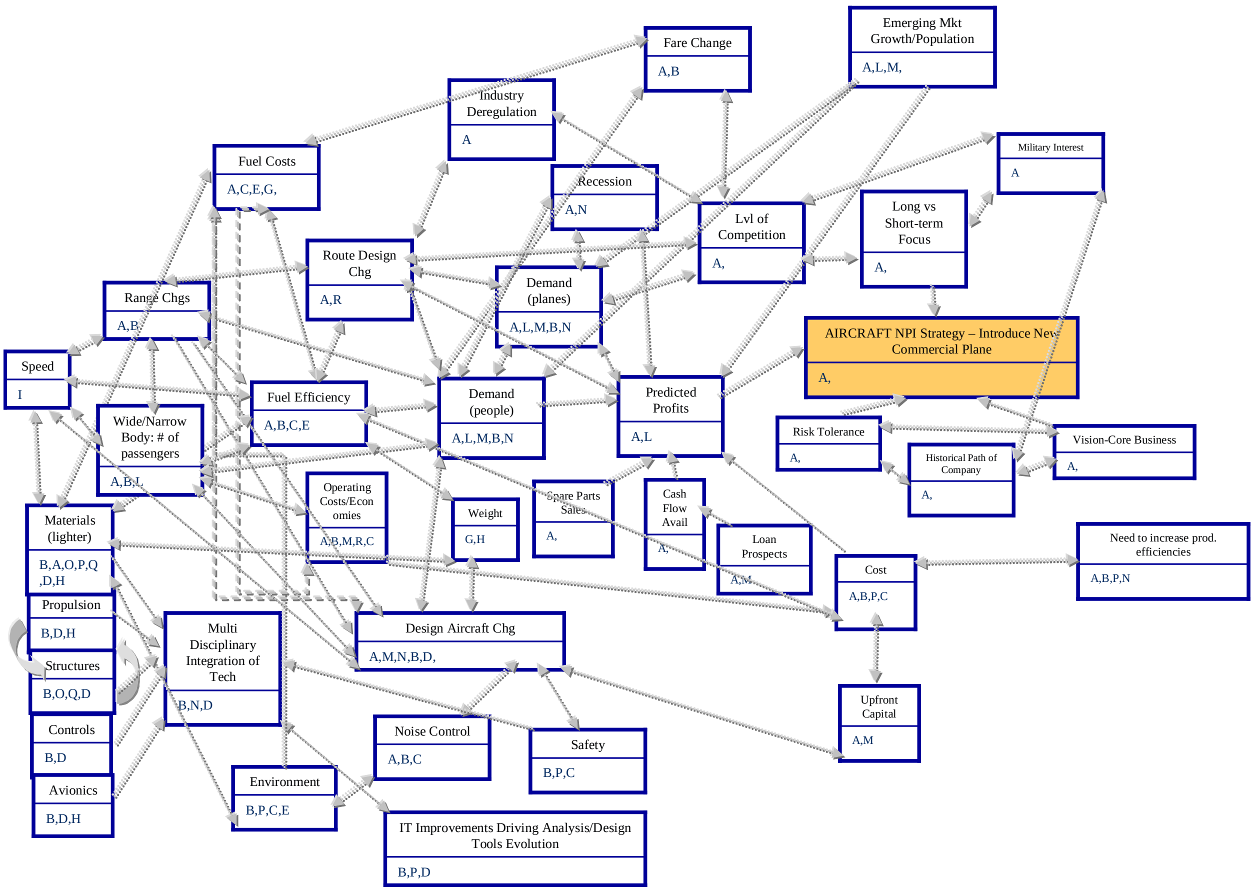

Figure 1: Illustration of Compiled Research on Parameters Affecting Commercial Aircraft Introduction

The letters contained in each box represent authors who emphasized that parameter in their writing. A key to each author-by-letter can be found in [Appendix 1]. Initial observations show generally how wide-reaching Gillett and Stekler (letter A) are compared to many other authors. Their paper, nearly 15 years later, should still be a starting basis for anyone interested in learning about this topic. Gillett and Stekler cover strategic aircraft new product introduction (NPI) variables such as a manufacturer's tolerance for risk in this high development product market, their vision of what is their core business, how much military interest or available business there is at the time, whether the company has a long or short-term focus on their products and the market, the level of competition, and the historical path of the company. They also cover, in some detail, the importance of cash flow dynamics and availability, industry deregulation, and whether a plane design has spare parts which can provide additional revenue or not.

Financial/cost parameters include the need to reduce production costs/increase efficiencies [1, 3, 9, 10], overall cost of new plane introduction [3, 8-10], upfront capital needed [3, 13], loan prospects [3, 13], fare changes [3, 9], predicted profits [3, 14] and operating costs/economies [3, 4, 8, 9, 13].

Socio-economic parameters feeding into the commercial aircraft NPI strategy include demand (consumer level and planes for airline companies) [1, 3, 9, 13, 14]. A recession [1, 3] or substantial decrease in consumer wealth has a strong impact on demand and profitability. Fuel efficiency [3, 7-9], fuel costs [3, 7, 8, 15] and route changes [3, 4] are parameters which straddle economics and technical design influences.

Range [3, 9], speed [2], number of passengers[3, 9, 14], and weight of aircraft [15, 16] appear to have been strong drivers and technological measurements over the last few decades. These also have a strong interaction with material composite advances [3, 5, 9, 10, 16-18] which along with information technology (IT) advances in recent times driving analysis/design tool evolution [5, 9, 10] are increasing the rate of design aircraft changes [1, 3, 5, 9, 13]. Environment [7-10], noise control [3, 8, 9] and safety concerns [8-10] are three external influences driving design aircraft change. The analysis/design tool evolution is also enabling what several researchers thought were needed to move from more mature technology which was the increased need for a multidisciplinary integration of technology [1, 5, 9]. This multidisciplinary approach was particularly needed with the advancements in materials (mentioned above), propulsion technology [5, 9, 16], structures (closely related to materials advancements) [5, 9, 17, 18], electronic controls technologies [5, 9] and avionics [5, 9, 16].

In reviewing this network surrounding airplane introduction strategy, a researcher can better understand both the dynamics which could affect their research as well as have a better tool in which to review where their own interests may lie. After reviewing the industry and technology in this light; it became simpler, for this study, to make the decision to concentrate on some of those parameters which are technically influencing design directly as well as those which straddle the economic and market influences which can create trade-offs with design features. These are discussed below in the data collection section. The multitude of parameters, it should be noted, creates a higher risk for good results from many analytical study methods. [12] Some analytical methods studies which attempt more than one or two parameters of commercial airplane technology include: Computer technology as a leading indicator to avionics controls advancements [5]; simulation for selected design and economic factors [15]; simulation for four design factors [16]; integral calculus function to study technological change-same used for intensity of earthquakes [19]; and the building of an efficiency method for studying state of art technology [20].

IV. Data Collection

As described in the literature review section above, parameters to try and measure were chosen from options covering economic/market factors influencing technology design of commercial aircraft as well as those technological parameters with closer impact to design change. There is no one standard for a researcher doing a study of this type on commercial aircraft; therefore rationale will be tied with the literature review findings above on which parameters to focus on. Additionally, caution was paid to derived variables which could increase likelihood of collinearity of data. Perfect collinearity is defined as "at least one predictor is a perfect linear combination of the others" [21] thus creating difficulties in pulling out individual influence on the dependent variable being measured.

Variable	Unit	Definition
Intro Year	Customer Flight Date	The date the customer (airline) first flies the model.
Max Passengers		The max number of passengers expected to fly on standard model (3 class configuration).
Max Cruising Speed	km/hr	The air speed at which an airplane is designed to operate with maximum efficiency.
Max Range at Full Payload	1000's km	The maximum range at which a standard model can fly carrying a full payload.
Maximum Takeoff Weight	1000's kg	Operating empty weight + fuel weight + payload weight.
Fuel Capacity	Kiloliters	Fuel weight when all tanks are full.
Composite Material%	% of structure	Percentage of composite materials used for plane structure.
Operating Empty Weight	1000s kg	Weight of empty plane with flight crew and operating equipment (no passengers, no fuel).

Table 1: Predictor Definitions

As this is a forecast study, a year of new product introduction was needed and was settled on first customer flight date because that is the first commercial use. Max passenger is the primary payload and goal for a commercial plane. Particularly the long range commercial planes needed the economies with pushing the passenger capacity. [3, 9, 14] Maximizing passenger load is often a tradeoff with range so that is why the three class configuration was chosen because it allows maximum range particularly for the longer overseas flights which were an important market driver. Maximum cruising speed [2] is the typical speed at which a plane is designed to operate over long distances efficiently. Maximum takeoff weight, although a derived variable, was chosen along with operating empty weight [15, 16] because of the natural dynamics of tradeoff between weight and range. Fuel capacity was chosen as a proxy for fuel efficiency [3, 7-9] as fuel efficiency has economic and technology trade-offs such allowing longer ranges and reduced overall weight. Composite material % was chosen as a gauge of technological improvement for reducing fuel cost, increased payload, lower production costs, and reduced maintenance.[3, 5, 9, 10, 16-18] This was the set of predictors scoped for starting this forecasting study on using multiple regression, linear, and growth curves.

Findings were that data was not found in any one section or study. The researcher utilized several company, reports, and aircraft websites to gather the information. Another caution is that a researcher in this field has the further difficulty of ensuring data parameters collected are consistent within each model. An example is that range could be reported with an empty plane – thus skewing the plane model performance. Additionally, a plane could have different performance given a different engine type/manufacturer or passenger configuration. A data measurement system/plan is necessary to avoid easy mistakes in attribute measurement.

Pearson correlation testing was conducted to look for statistically significant predictors; the results of this and the collinearity testing are shown below in Table 2.

Criteria	Model Validation		Composite Material Era Model	
	(RNG,MPC,CM,OEW,FC,MTW)	(RNC,CM)	(RNG,MPC,CM,OEW,FC,MTW)	(RNG,CM)
Significance at 0.01 or .05 level	*Only RNG,CM*		*Only RNG,CM*	
VIF	4 (MPC,MTW,OEW,FC) >10	All<10	4>10	All<10
Condition Index	70 (7^{th} dimension)	All<30	41 (5^{th} dimension) & higher	All<30
Perverse Sign	No	No	No	No
Result	Collinearity	No Collinearity	Collinearity	No Collinearity

Table 2: Significance & Collinearity Testing

Although conservative in determining predictors, it was decided to go with those variables showing both high significance and no collinearity. Future tests could include less conservative testing of collinearity which some technology forecasters provide an argument for doing. From here, a method for multiple regression forecasting model development using mean absolute error and comparing means for validating statistical insignificance (Wilcoxon) will be followed.[22]

The airplane model data is shown below in 2 sets; the first 16 models (2/3rds data) and the remaining 8 models:

Model	YEAR	Range (RNG 1000s km)	Composite Material % (CM)
DC8-55	1965	9.205	0.0
DC8-62	1966	9.620	0.0
747-100	1969	9.800	1.3
747-200	1971	12.700	1.3
DC10-30	1972	10.010	0.5
DC10-40	1973	9.265	0.5
L1011-TriStar 500	1979	9.905	0.7
747-300	1983	12.400	1.3
767-200ER	1984	12.200	3.5
767-300ER	1988	11.065	3.5
747-400	1989	13.450	2.0
MD-11	1990	12.270	4.5
A330-300	1993	10.500	15.0
A340-200	1993	14.800	15.0
A340-300	1993	13.350	15.0
MD-11ER	1996	13.408	4.5
777-200ER	1997	14.260	10.0
777-300	1998	11.135	10.0
A330-200	1998	12.500	15.0
A340-600	2002	14.360	15.0
A340-500	2003	16.100	15.0
777-300ER	2004	14.685	10.0
777-200LR	2006	17.370	10.0
A380-800	2007	15.200	25.0

Table 3: Data used for the forecasting model

V. Multiple Regression Results

The multiple regression equation and variable definition are shown below.

$$Y=(b_1 * X_{Rng}) + (b_2 * X_{cm}) + b_0$$

Y: The year of first commercialization of a long range passenger aircraft

	b_0: Constant
X_{Rng} : Range	b_1: Regression coefficient of range
X_{Cm} : Composite Material %	b_2: Regression coefficient of composite material %

Table 4: Model Validation Equation With Partial Dataset

The following forecasting model is used to fit to the second dataset of commercial aircraft to validate the extrapolation method. R-square of this model is 0.678 and p-value is 0.000. Therefore, this model can explain 68% of the 16 plane designs with two technical parameters.

$$Y=(2.98 * X_{Rng}) + (.877 * X_{cm})+ 1943.482$$

The real years of commercial introduction and forecasted years of models were visually compared in Figure 2: Comparing Real & Forecasted Years of First 16 Airplane Models . It shows there were clusters of new airplanes taking advantage of aerospace developments in the 1960s; then Boeing's 747 dominance in range and passenger load contributed to fewer introductions until McDonnell Douglas and Airbus began challenging in the late 1980s.

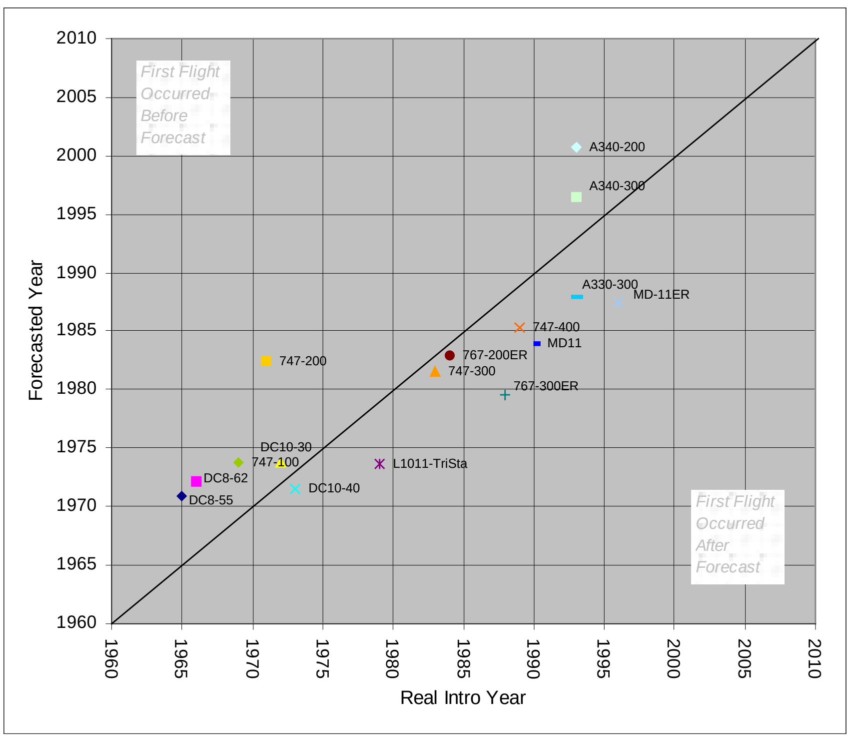

Figure 2: Comparing Real & Forecasted Years of First 16 Airplane Models

The forecasted years of the next 8 airplane models are compared in Figure 3.

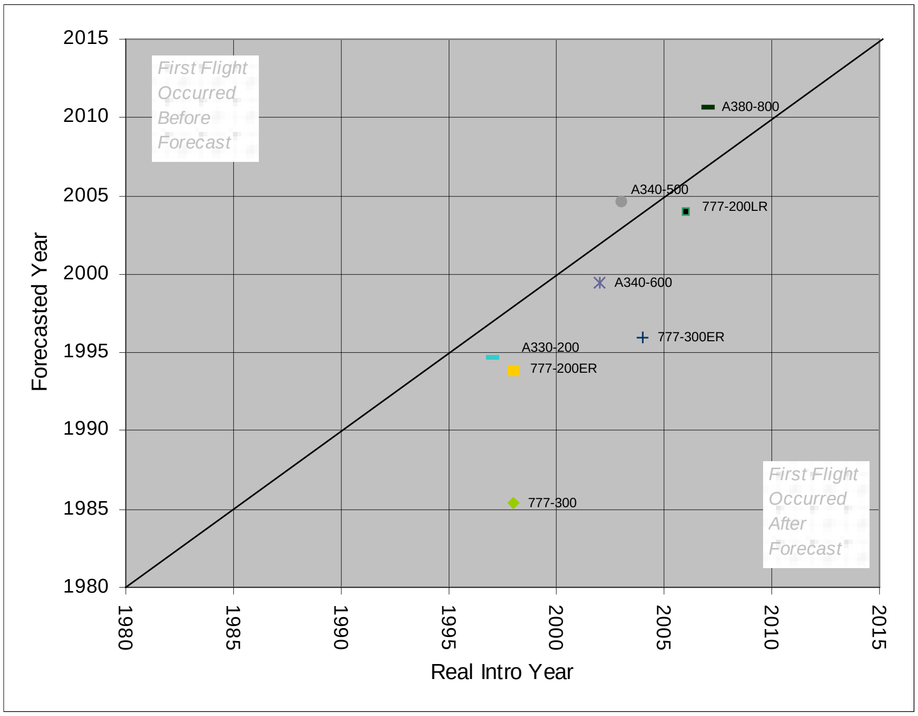

Figure 3: Comparing Real & Forecasted Years of Last 8 Models

As the results show, the Boeing 777-300 and 777-300ER were not initially targeted for very long ranges but were later extended by some technological improvements to increase the range. This is an example of the model predicting earlier technological improvements than what market dynamics would allow for. This is the period in which Airbus was catching up to Boeing's fleet of commercial aircraft capabilities. It is interesting to note Airbus models are a better fit to the multiple regression forecast and this could be due to Airbus' focus on technological innovations; while Boeing may have been more focused on the market and increasing competition. The results of the forecast are below.

Model	Real	Forecast
777-200ER	1997	1995
777-300	1998	1985
A330-200	1998	1994
A340-600	2002	1999
A340-500	2003	2005
777-300ER	2004	1996
777-200LR	2006	2004
A380-800	2007	2011

Figure 4: Forecast of Most Recent 8 Plane Models

Mean Absolute Error (MAE) of the result is 4.6 years. Since the number of data points is <30 and does not follow a normal distribution, the Wilcoxon Signed-Rank test is used. The result provided shows that there is a statistically insignificant difference between the real and forecasted years. Therefore, we can conclude that this forecasting model can be used to forecast future airplane models.

Test Statistics[b]

	MR fcst - MR Real
Z	-1.479[a]
Asymp. Sig. (2-tailed)	.139

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Next, the entire data set of 24 commercial airplane models are used to build the forecasting model for future commercial long-range airplanes—right now defined as the composite material era. The regression results with the two parameters of range and composite material % are shown in Table 5.

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	1944.983	8.173		237.972	.000		
	RNG	2.920	.729	.505	4.006	.001	.592	1.689
	CM	.922	.239	.485	3.852	.001	.592	1.689

a. Dependent Variable: YEAR

Table 5: Result of Regression to Forecast Composite Era Models

Next, the forecasting model for the composite era commercial planes is:

$$Y=(2.92 * X_{Rng}) + (.922 * X_{cm})+ 1944.983$$

Information was gathered on 3 future airplane models which Boeing and Airbus have announced development on. This was gathered by available literature. The table below shows the information that was available (by source) on the expected commercialized year[23-26] as well as on each of the measured predictors of range [24, 25, 27] and composite materials %. [24, 26, 28-31] Additional important technological information is also provided on engine developments[24, 32-34], plane construction and aerodynamics[27-29, 35], and expected use of advanced systems controls[27, 35-37]. This information was used in order to better understand overall technology advancement of each plane being introduced as well as to help with predictor estimates where needed.

	747-8	**787-Dreamliner**	**A350-900**
Starting Year	2011 (*www.boeing.com* , 3/7/09)	2010 (*www.boeing.com* , 3/7/09);	2013(*aerospaceweb.org* , 2009) (*bloomberg.com*)
Range	14,815km (*www.boeing.com* , 3/7/09)	15,200km (*www.boeing.com* , 3/7/09)	15,000 (www.airbus.com. 3/7/09); 13,700km (Wall et al, Miles to Go, 2006)
Composite Material%	2% (Past 747); 밴orrow from 777/787? (*Mecham* , 2006)	50% (*Toensmeier*, 2005); up to 61% (*Read* , 2005); 50% (*www.boeing.com* , 3/7/09)	40% (*Anon, A350 composites* ..., 2006); 52% (*Aerospace.org* , 2009)
Engine	New GEnx (saves fuel consumption, fewer parts, lightweight durable composite materials) (*Mecham* , 2005)	GEnx (Wall, 2005); GEnx or Rolls Royce Trent 1000 (*Mecham* , Range Wars, 2005) (*www.boeing.com* , 3/7/09)	GEnx & Rolls Royce Trent (*Wall, Driving forward* , 2006)
Plane Construction & Aerodynamics	Keeping old fuselage construction; new wing/tail composite (*Mecham* , 2005)	Slight improvement in aerodynamics (*Wall et al* , 2006); Major improvements to composites allowing reduction of fasteners & pieces to fuselage	Fuselage made with composite over metal skeleton to avoid delays; not as revolutionary as 787(*Anon, A350 composites* ..., 2006)
Advanced Systems (Controls)	Partial use of increased electronic control services; otherwise still Federated Avionics Architecture (*Mecham, Noise-Buster,* 2006)	IMA-Integrated Modular Avionics (*Watkins et al* , 2007); Increased electronic control services (*Wall et al* , 2006)	Using classical avionics architecture with improvements(*Adams* , 2005)

Table 6: Suggested Specification of Future Airplane Models

Most of the specifications were fairly clear from the literature except for the estimated percentage of composite material expected to be introduced in the 747-8 model. Note, also, the percentage jump in Boeing's 787-Dreamliner, expected to be introduced with 50% composite material, this is particularly important for Boeing which has previously not introduced a long-range commercial aircraft with more than 10% of its structural weight attributed to composite materials.

Specifications for Forecasting in Composite Material % Era			
	Claimed Intro Year	Range	Composite Material %
747-8	2011	14,815km	12 *
787-Dreamliner	2010	15,200km	50%
A350-900	2013	15,000km	40%
* was less clear than other specifications; so a combination of suggested specifications was used to derive this 12%.			

Table 7: Specifications for Forecasted Airplane Models

The results run on the forecast model compared to stated intentions for the next three airplane models [Figure 5: Model Forecast Compared to Planned Introduction Year] shows the forecast model expects introduction much further out for the Airbus A350-900 and the Boeing 787-8 Dreamliner compared to the planned years for introduction. It is also interesting to note that the forecast model expects the Boeing 747-8 to have been introduced about 10 years ago. As shown previously, our model only explains 68% of the variability in the data. These forecast results could be showing the affect of the unanswered/unexplored predictors and Boeing's 747-8 technological characteristics being not as advanced as the competitive Airbus 380 introduced in 2007. Boeing is introducing some changes to the 747 in order to compete in the market with Airbus. Also, disappointing is that the model seems to have insufficiently captured the level of influence of composite material% growth. As stated previously, advancements in information technology and design tools is enabling rapid improvements in composite material usage in commercial aircraft; one recommendation would be to see if there is any way quantitatively measure this as a predictor.

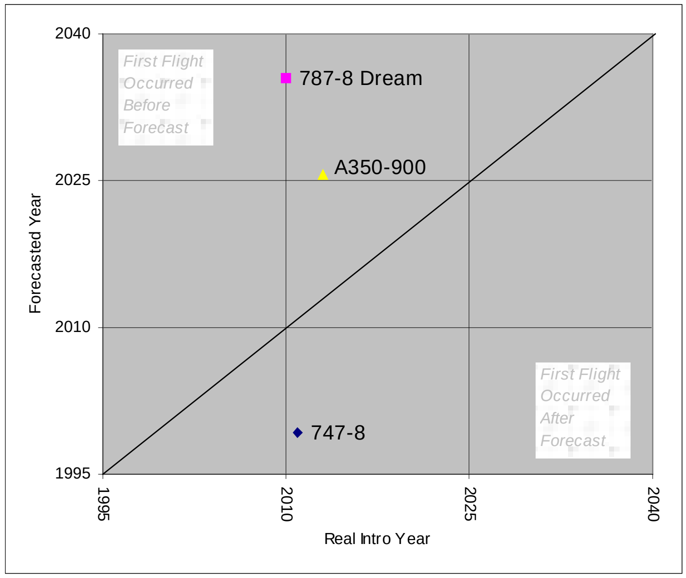

Figure 5: Model Forecast Compared to Planned Introduction Year

Dynamics of these two predictor variables are further explored between two additional forecasting techniques, linear regression and Pearl growth curves, below.

VI. RESULTS OF RANGE AND COMPOSITE MATERIAL % BY LINEAR REGRESSION AND PEARL GROWTH CURVE

Linear regression (y=mx+b) was chosen as a comparative method to growth curve so 1 for 1 comparison could be made with individual predictors. Of the available growth curve techniques, the Pearl curve ($y=L/(1+10^{(-A-Bt)})$) was chosen due to its use for "technology with unexploited potential for further improvement"[38]. With the advancements in avionics, controls, composite materials, and future development occurring in speed with supersonic large and long-range planes, this seems to be a reasonable choice. Comparison of the two methods will be conducted graphically as well as comparing mean absolute errors (MAE). MAE was chosen due to its ability to not overemphasize points with large error—unlike the means square error (MSE). With the market, economic, and technological tradeoffs on this technology, the r^2 is not as high as forecasters would prefer; therefore the MAE approach is used. For some comparative purposes, the same division of dataset used in the multiple regression model (16 data points to test model of 8 data points) was brought forward for this testing as well. The first comparison will be conducted on range.

Below are the model equation definitions for the linear regression method for range as well as the Wilcoxon statistics showing that the linear regression model results in statistically insignificant difference in means.

$Y = (b_1 * X_{year}) + b_0$	
Y: The predicted range of a long range passenger aircraft	
	b_0: Constant
X_{year} : Year	b_1: Regression coefficient of year

Figure 6: Linear Equation Definitions for Range

First, a visual analysis is conducted on comparison of the two methods on range [Figure 7: Visual Comparison of Range Model & Forecast]. The Pearl Curve limit for range is based more on a marketing dynamic than a physical limit; 19,333km, half-way around the world. A quick review shows this to be a relatively sound assumption, for now, as the linear forecast and the Pearl curve forecast show the planned airplane models just below the curve-not pushing the range limit. The forecasted planes show to be fitted more closely with the Pearl curve over the linear forecast. Both forecast graphs show one extremely long range model, Boeing’s 777-200LR, which was introduced for a specific market.

$Y=(.121 * X_{year}) + -228.056$ model validation

$Y=(.141 * X_{year}) + -267.408$ fcst

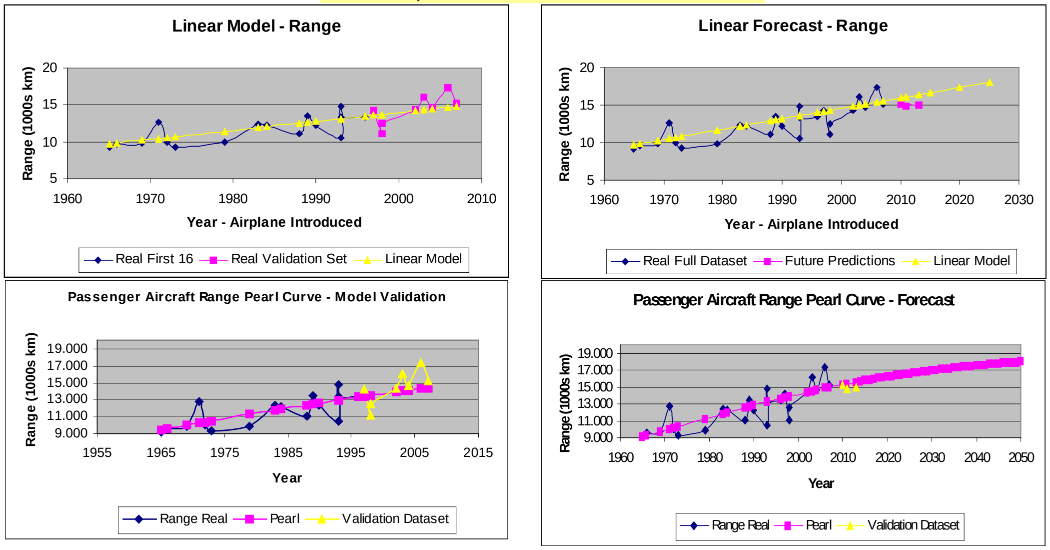

Figure 7: Visual Comparison of Range Model & Forecast

Next, the linear regression and Pearl curve are compared for composite material % [Figure 8]. The limit on the total percent possible for composite materials to make up the airplane structure is 90% which is an average taken from a research paper.[39] The linear model does not appear to fit well with the last data points. The general shape of the Pearl growth curve appears to follow the trend more closely particularly on the forecast. The growth of composite material % is best defined by the Pearl growth curve visually.

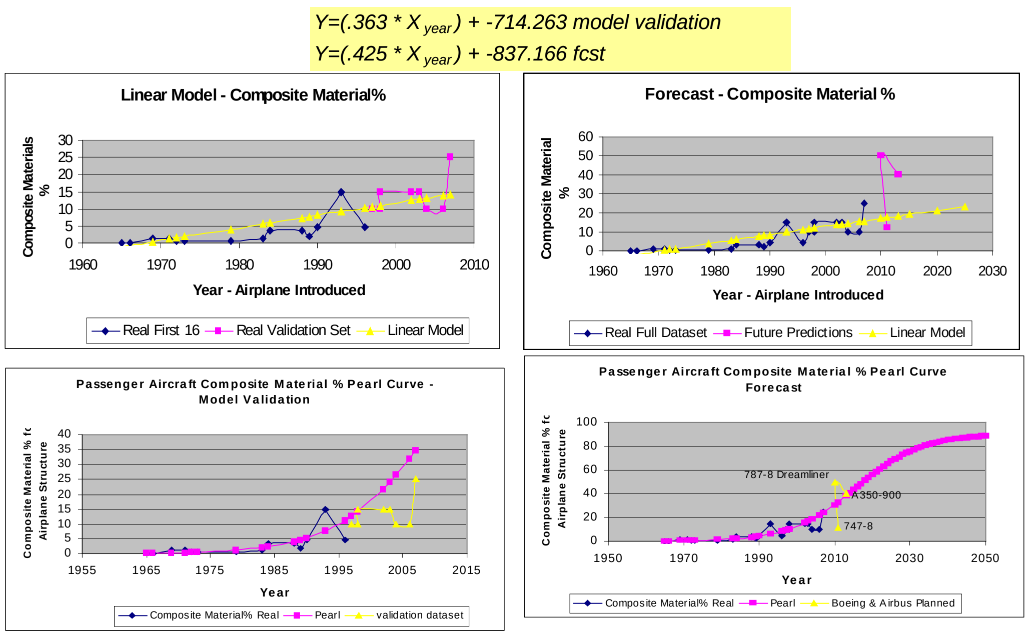

Figure 8: Visual of Composite Material Model & Forecast

A comparative MAE table [Table 8: MAE Comparison Table] is shown below with the Wilcoxon test results included. A picture printout of Wilcoxon results can be seen in [Appendix 2: Wilcoxon Results for Linear & Growth Curves]. Whereas the range MAE (model) show fairly close to one another, the composite material % MAE for the Pearl growth curve differs quite a bit from the linear regression; however, similar to the visual graph of the Pearl curve, the MAE for the forecasted items is better than the same for the linear. The Wilcoxon test shows that the composite material does not pass statistical validity testing as its P<.05.

		r2 model	r2 all	MAE (initial dataset)	MAE (validation)	MAE (fcst)	z	Wilcoxon sig
Range	Regression	0.531	0.663	0.93(1000s km)	1.22	1.18 (1000s km)	-0.84	0.401
	Growth Curve (Pearl)			0.892	1.392	0.429	-0.84	0.401
Composite Material %	Regression	0.5	0.652	3.22	3.52	20.02	0.56	0.575
	Growth Curve (Pearl)			2.32	8.94	14.17	-2.38	0.017

Table 8: MAE Comparison Table

One conclusion that can be drawn is that growth curves and linear regression can be utilized for forecasting in airplane technology, but with caution as the process of airplane introduction allows for high variance. A focus with growth curves and linear regression could perhaps be put to use better on a non-time series basis in studying airplane technology.

VII. LIMITATIONS OF STUDY

There are limitations to this study. A conservative approach to collinearity diagnostics was utilized in the multiple regression method and this could affect the model. Also, there are many subsets within airplane introduction strategy which could be explored quite successfully, particularly with a more-focused scope than this study performed originally. It would be helpful to have expert input into airplane technology as this may shed more light on what appears to be plenty of tacit knowledge about airplanes from many enthusiastic followers of the technology.

VIII. CONCLUSIONS

The multiple regression model passed statistical validity testing, but with the result that it too fell into a study on limited number of predictors. In reviewing approach to technological forecasting techniques [40], it is recommended that if a researcher is wanting to perform a larger context forecast with multiple variables for airplane technology projections, they may want to consider simulation as a good fit. Airplane technology is undergoing rapid technological change so the more technology forecasting researchers can provide insights into the complexities involved, more value can be provided to the industry.

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Letter Corresponds to Illustration on Commercial Aircraft NPI Strategy			
A	Gillett & Stekler, 1995	L	Wall, “Positive projection”, 2006
B	Kumar & Hefner, 2000	M	Butterworth-Hayes, 2001
C	Ruffles, 2003	N	Ashford, 1985
D	Fraser, 1985	O	Anon, “Salt Lake …”, 2007
E	Masson, et al, 2007	P	Goehler, 1990
G	Mavris, et al, 1999	Q	Sprague, 1988
H	Wilhite, 2008	R	Bruekner, 2009
I	Esposito, 2004		

Appendix 1

NPar Tests

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Pearl Wil CM Fcst - Pearl Wil CM Real	Negative Ranks	1[a]	1.00	1.00
	Positive Ranks	7[b]	5.00	35.00
	Ties	0[c]		
	Total	8		

a. Pearl Wil CM Fcst < Pearl Wil CM Real

b. Pearl Wil CM Fcst > Pearl Wil CM Real

c. Pearl Wil CM Fcst = Pearl Wil CM Real

Test Statistics[b]

	Pearl Wil CM Fcst - Pearl Wil CM Real
Z	-2.380[a]
Asymp. Sig. (2-tailed)	.017

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

NPar Tests

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Pearl Wil Range Fcst - Pearl Wil Range Real	Negative Ranks	6[a]	4.00	24.00
	Positive Ranks	2[b]	6.00	12.00
	Ties	0[c]		
	Total	8		

a. Pearl Wil Range Fcst < Pearl Wil Range Real

b. Pearl Wil Range Fcst > Pearl Wil Range Real

c. Pearl Wil Range Fcst = Pearl Wil Range Real

Test Statistics[b]

	Pearl Wil Range Fcst - Pearl Wil Range Real
Z	-.840[a]
Asymp. Sig. (2-tailed)	.401

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

NPar Tests

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
LR Wil (CM) Fcst - LR Wil (CM) Real	Negative Ranks	4[a]	5.50	22.00
	Positive Ranks	4[b]	3.50	14.00
	Ties	0[c]		
	Total	8		

a. LR Wil (CM) Fcst < LR Wil (CM) Real

b. LR Wil (CM) Fcst > LR Wil (CM) Real

c. LR Wil (CM) Fcst = LR Wil (CM) Real

Test Statistics[b]

	LR Wil (CM) Fcst - LR Wil (CM) Real
Z	-.560[a]
Asymp. Sig. (2-tailed)	.575

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

NPar Tests

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
LR Wil (Range) Fcst - LR Wil (Range) Real	Negative Ranks	6[a]	4.00	24.00
	Positive Ranks	2[b]	6.00	12.00
	Ties	0[c]		
	Total	8		

a. LR Wil (Range) Fcst < LR Wil (Range) Real

b. LR Wil (Range) Fcst > LR Wil (Range) Real

c. LR Wil (Range) Fcst = LR Wil (Range) Real

Test Statistics[b]

	LR Wil (Range) Fcst - LR Wil (Range) Real
Z	-.840[a]
Asymp. Sig. (2-tailed)	.401

a. Based on positive ranks.

b. Wilcoxon Signed Ranks Test

Appendix 2: Wilcoxon Results for Linear & Growth Curves