

**Do Modern Tools Utilized in the Design and Development of Modern Aircraft  
Counteract the Impact of Lost Intellectual Capital within the Aerospace Industry**

by

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B.S. Mechanical Engineering, University of Massachusetts, 1981

Submitted to the System Design and Management Program  
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management  
at the  
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## **Abstract**

Prior research has suggested that intellectual capital within the Aerospace Industry has been in decline. The new design aircraft experience base of Post WWIV Aerospace Engineers was approximately 6-12 new design aircraft per career. In contrast, an aerospace engineer starting his career today may experience only one, maybe two new aircraft designs during their career. Anecdotal evidence has been published linking this trend to problems experienced in many recent aircraft programs. Counter arguments cite rapid advances in design, manufacturing and information technologies used in the design and development process of today's new design aircraft have compensated for some or all of declining experience base. This thesis focuses on exploring the validity of this counter argument.

Program performance metrics were established and utilized to draw comparisons between programs. In addition, extensive interviews with personnel who played roles in these programs were conducted to that the root cause in areas of differing performance were understood.

Analysis of the data gathered revealed that the predecessor programs outperformed the more recent programs. Recommendations regarding ways to mitigate intellectual capital performance gap are presented.

Thesis Supervisor: Dr. Eric Rebentisch

Title: Research Associate, Center for Technology, Policy, and Industrial Development

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# 1 Introduction

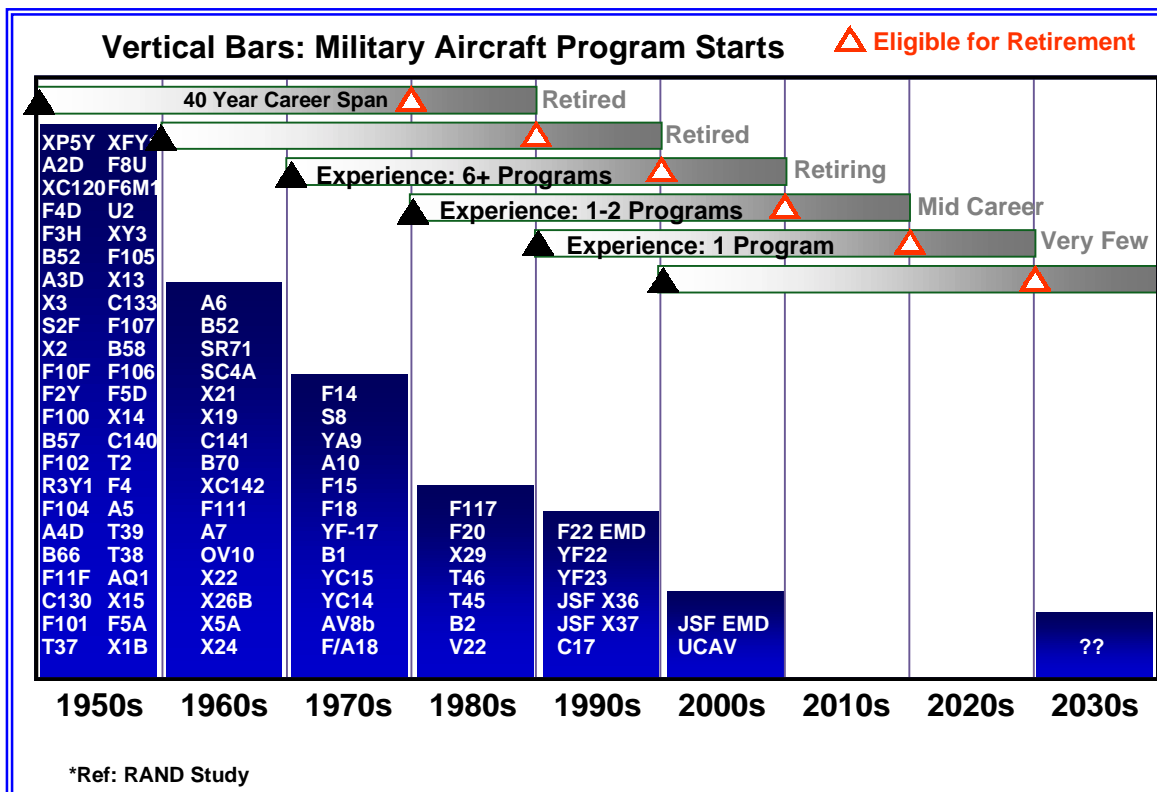
## 1.1 Problem Statement

Prior research has suggested that intellectual capital (IC) within the Aerospace Industry has been in decline. The new design aircraft experience base of Post WWIV Aerospace Engineers was approximately 6-12 new design aircraft per career. In contrast, an aerospace engineer starting his career today may experience only one, maybe two new aircraft designs during their career. Anecdotal evidence has been published linking this trend to problems experienced in many recent aircraft programs. Counter arguments cite rapid advances in design, manufacturing and information technologies used in the design and development process of today's new design aircraft have compensated for some or all of declining experience base. This thesis focuses on providing an explicit link between declining intellectual capital and program performance by extracting quantitative data on the performance of new design civil aircraft programs which have recently with aircraft programs which were executed 20 to 25 years prior. By the nature of the approach taken, the validity of the popular counter argument is explored.

## 2 Literature Review

To a great extent, this research is a response to a RAND study published in 1992 titled; *Maintaining Future Military Design Capability* (ref 1). This report examined historical trends in the aerospace industry and their projected impact on the ability of the United States to design and develop aircraft weapons systems. The most striking trend was the declining rate at which new design aircraft are developed. Figure 2-1 is a modified version of the chart published in this report used to characterize this phenomena. As can be seen, the decline with respect to the 1950's has been dramatic. Overlaid horizontal bars are used to represent the typical career of an aerospace engineer or designer. The point was further made that as the frequency of new aircraft design introductions drops, so does the average number of aircraft programs an aerospace

employee will interact with during their career. Currently, this number is down to one for persons entering this industry within the past decade or in the foreseeable future. The authors further write, "We believe that a declining experience level has been a contributing factor to the problems we observe in many recent aircraft programs." The aircraft programs cited are the T-46, B-1B, P-7 and A-12 programs. It is not stated how this conclusion was arrived at since no details are provided which directly link the performance issues of these programs to this declining experience base. It is however, an easy concept to accept from a common sense standpoint. And, judging by the frequency that this chart and quote is cited in other publications, it has been widely accepted.



**Figure 2-1 RAND Study Depiction of declining intellectual capital in Aerospace Industry**

The RAND study also surfaces the most popular counter argument raised when discussions of declining intellectual capital occur, modern computational tools. In some respects, a form of codified knowledge. "Some have suggested that the application of large-scale computer simulation to the design process will mitigate the need for



experienced designers. While simulation and automation of the design process will certainly help, it cannot substitute for the intuition and inspiration that contribute to successful new and innovative designs. Furthermore, such automation is only marginally effective when dealing with new and untried technologies because the basic information needed for the computational algorithms is missing or of low fidelity." (ref.1)

As with the prior theory, this is a rational conclusion that is easy to swallow, but is not explicitly proven in this work. Several engineering managers from within the aerospace industry which were queried about this conclusion exhibited mixed reactions. One hand they have been spending unprecedented amounts of money each year to secure the latest computational tools. On the other hand, they were not exactly sure of how effective these tools at mitigating lost intellectual capital.

This is not a unique phenomena to aerospace, other industries are wrestling with intellectual capital issues. Shawn Ritchie (ref.2) discusses such issues with regards to the photo processing equipment industry. " Eastman Kodak has seen a slow eroding of the tacit dimension (knowledge) over the past few decades. One reason for this is the aging of the personnel base. In the past, the younger employees would be assigned to work side by side with the more experienced workers, establishing a mentor-protégé relationship. This relationship led to a slow, thorough transfer of tacit and explicit knowledge. In recent years, employees have been let go or encouraged to retire early without any emphasis on tacit knowledge transfer. Managers expect new workers to come in trained or to quickly pick things up on the job after a few shifts and cursory reading of operations manuals. Why? One theory is that companies do not know what they are missing anything and simply have no way to quantify "lost opportunity." They do not know the opportunity cost or value of information not transferred."

As with the RAND study, Ritchie's work does not explicitly demonstrate that knowledge transfer has in fact eroded Kodak's ability to perform faster than other improvements such as computational tools have enhanced it.

Articles published in aerospace industry periodicals discuss "brain drain" and various steps some of the major prime contractors such as Northrup Grumman are taking to attack this problem. Again, no articles or research was discovered which explicitly link declining IC with declining performance. Taking advantage of this lack of prior attention, this thesis is on filling this void.

### **3 Methods**

#### **3.1 New Design Aircraft Case Study**

Case study of four new design civil aircraft programs. New design referring to "clean sheet" designs which do not significantly leverage a predecessor aircraft design in the design, development and certification process. Two of the aircraft programs were executed nearly simultaneously in the late 1970's and will be referred to as the "disco era" programs. The seceding pair were executed during the mid to late 1990's and will be referred to as the "Microsoft (MS) era" programs. Additional details of these programs and their associated aerospace manufacturers will be provided in subsequent sections.

Several criteria utilized in selecting these case studies which can be divided into subsets, similarity criteria and dissimilarity criteria. All of the programs share the following characteristics:

- New design Civil Aircraft certified to the same general Federal Airworthiness Regulations (FAR's).
- Developed Using Company funds
- Developed to meet similar performance and market requirements
- Certified to the same FAR regulations
- Companies have long and rich aviation legacy (didn't start yesterday)
- Have significant US Military business and are to some extent categorized as a "defense contractor"

The "disco era" programs share the following:

- Same period of execution
- Competing head to head in the same market
- High workforce new design aircraft experience base
- Predominantly Paper & Mylar design tools
- Functional Organization with "heavy weight" project managers

The "MS era" programs share the following:

- Overlapping periods of execution
- Overlapping market segments
- Extensive use of computer aided design tools and information technologies
- Use of IPDT's

The subsequent list highlights the dissimilarities between the disco and MS era programs:

- Organic IC significantly lower for MS era programs than preceding disco era programs
- Use of computer aided design tools significantly greater for MS era programs

Various means of comparison, discussed further in subsequent sections, will be utilized to develop an understanding as to the relationship between the performance of these programs and disco/MS set of dissimilarities.

### **3.2 Data collection**

Case study data was collected from a variety of sources, official program documents, industry publications and interviews of participants. These multiple sources of data were used to cross validate the data. While it was desired to have comparable data depth between all programs there are some variables. Identifying and accessing participants

was more difficult for the disco era programs as they occurred twenty plus years ago. The majority of the participants have since retired or worse. Since, most internal documentation is discarded within a few short years of completion, this proved challenging for both the disco and MS era programs. However, in two of the cases, excellent internal documents were obtained from hard core "pack rats".

Aviation Industry publications such as Jane's, All the World's Aircraft, Air & Cosmos, Aviation World as well as many others, were used to gathering information regarding the subject case study aircraft program. In total, hundreds of articles were reviewed for each aircraft program. Jane's, All the World's Aircraft was particularly useful in gathering aircraft performance attribute data.

### **3.3 Metrics**

Four types of metrics were employed , aircraft attribute based metrics, design maturity metrics, program performance metrics and intellectual capital metrics.

#### **3.3.1 Aircraft Attribute Based Metrics**

Traditional aircraft attributes, tracked closely internally, advertised and sometime guaranteed to prospective customers are utilized as metrics. These metrics, summarized below, are referenced the original specification values released at the launch of the program. To aid in direct comparisons of the four programs, the metrics are expressed in terms of percentage with respect to the reference value.

- Empty Weight
- Useful Load / Payload
- Maximum Takeoff Weight
- Range
- Altitude Performance

##### **3.3.1.1 Weight Derived Metrics**

In military and some civil aircraft procurement competitions, often, the ability to retard weight growth during design and development is the discriminator between the winning

and losing team. Further, there are many documented cases of programs cancelled due to burgeoning weight. In the more modest situations, empty weight exceeding the aircraft's specification displaces either payload or fuel. In other words, if the empty weight of an aircraft is 150 lb. over specification, a passenger, 150 lb. of baggage, cargo or fuel (25 gal.) must be left behind. The payload deficit can be closed by increasing the maximum take off gross weight by 150 lb., possibly requiring an updated powerplant which may not exist, or would require the redesign of some aircraft systems, further escalating the weight growth. This is an insidious feed-forward loop that every aircraft manufacturer has experienced at one time or another.

The aircraft will primarily be judged with respect to each other, however for the weight based metrics supplemental manufacturer weight control performance data was compiled for similar type aircraft the Society of Allied Weight Engineers (SAWE) publications.

### **3.3.1.2 Range**

Range is a universal metric for all commercial and military aircraft. For the purposes of these comparisons, the maximum range with a full passenger load and standard reserves is used to reflect the criteria of a commercial customer. In specifying a full passenger load and not a maximum gross weight ensures that adverse weight growth impacts the allowable fuel load and in turn the range. The essential comparison will be the specified range at the outset of the program versus its range upon receiving its type certificate.

### **3.3.1.3 Altitude Performance**

The ability to take off from a field under hot day and/or high altitude conditions (aka: "hot/high") where the air density is low and the power margins lower is also a universal metric. This capability is important to a customer as it is directly related the safety of an aircraft. Normally expressed in terms of standard day altitude in feet or meters, it will be expressed in terms of percent deviation for the initial specification for the purposes of this comparison. For instance, if the initial specification for an aircraft stated that its

takeoff capability at maximum gross weight to be 10,000 ft, and at type certification it was verified to be 12,000 ft. It capability would be + 20%.

### **3.3.2 Design Maturity Metrics**

#### **3.3.2.1 Flight test hours to achieve Type Certification**

For a new design aircraft, the number of flight test hours to achieve flight type certification is a measure as to the maturity of the design going in to flight test. The actual type certification flight testing is not a great variable but the amount of flight testing required to get the aircraft to a certifiable configuration. For example, it could require several hundred flight testing hours to get the handling qualities of an aircraft to the point where it will comply with the airworthiness requirements. A common scenario would be for a set of flight test to be repeated many times with changes to the flight control software, tail planform area, strake configuration etc. until the correct combination is found. In contrast, a new design which has undergone a more effective design and risk reduction process, whether it be attributed to superior tools, personnel of more risk reduction testing, will converge on the certifiable configuration with less flight testing hours. This is compounded by the number of systems that are subject to certification of other functional requirements.

No universal benchmark has been established for this metric. However, since all aircraft are similar in terms of type, complexity and applicable FAR's, the values can be compared directly.

#### **3.3.2.2 Major Specification Changes**

This metric is intended to gauge the quality of the product development process. If perfect, the aircraft configuration which achieve type certification would be identical to the aircraft defined by the initial design trade studies and detail design efforts. This captures inadequacies in a design which are not reflected by the aircraft attributes. For instance; consider an aircraft under development whose range specification is 3000 nm. If during it's the development the engines specific fuel consumption is recognized to be

10% greater than anticipated, the manufacturer is likely in one of two manners. He could reduce the specified range to by 300 nm. if he feels that it would not hurt the salability of the aircraft. Alternatively, he could revise the design to recover the lost range by increasing the fuel capacity or another alternatives. Either scenario would be counted as a specification change. The intent is to pick up high impact changes which cause significant redesign efforts or reduction in the aircraft's advertised capabilities or compliance with airworthiness regulations. Changing the gauge of a skin panel, or altering the seat pitch would not qualify as a major change. This criteria is fairly consistent with the fidelity of information contained in trade publication.

Of the subject aircraft examined only the **nine** spec change categories resulted. These are summarized in Table

**Table 1: Summary of Applicable Major Specification Changes**

1. Maximum Takeoff Gross Weight
2. Useful Load
3. Range
4. Fuel Capacity increases of >5%
5. Significant Reduction or migration of the Center of Gravity Range
6. Key Aircraft configuration dimensions including the fuselage, empennage and lifting surface (including airfoil sections)
7. Propulsion / Drive system rating increase
8. Altitude Take off Performance
9. Any Major Sub-System Redesign

### **3.3.3 Program Performance Based Metrics**

#### **3.3.3.1 Schedule Deviation**

All aircraft development programs have a schedule as to when critical milestones are to be achieved. The aircraft models date of; first flight, type certification and first aircraft delivery will be used as benchmarks. The performance metric will be deviation between the initial dates and the date that they are actually achieved.

### **3.3.4 Intellectual Capital Metrics**

Two very simple the intellectual capital metrics were established for each manufacturer and used for comparison purposes. The first is the frequency of new design aircraft introduction in the decade preceeding the program launch of a aircraft considered. This is a measure of the intellectual capital accrued by the design team functional leads and workforce at task level. The second is nearly the same as the first but considers the number of new design aircraft introduced in the prior two decades. This is an indicator of the experience level of the middle level managers, senior technical staff and program management. These metrics were influenced by the RAND experience decay plot in Figure 2-1

### **3.4 Interviews**

Interviews of key participants of the subject programs were conducted to gain better insight into events and specific performance issues. In all, thirty participants were interviewed. Ten of the interviewees were directly involved with programs from both eras. The interviewees were told that all of the information would be disguised prior to publication.

Interviews followed and informal structure, usually opening with a general overview of the thesis problem statement and the case study method selected to study the issues. From there "lay of the land" type questions framed from a historical perspective were used to get the dialogue launched. All of the interviewees were comfortable providing information, and seemed to feel it was important to contribute to an understanding of performance issues. The interviewer took a neutral posture during the interview so as not to lead the interviewee in any particular direction.

Performance metrics, were used to steer the interview to specific areas of discussion. Follow-up questions were used to fill in information voids and for clarification of remarks. When specific documents were referenced during the interview, the interviewer would be "do you still have a copy of that memo, document etc" Often times the interviewee



would dig through their files to find relevant documents without being prompted. About two thirds of the interviews produced copies of original documents with information pertinent to one or more of the case studies.

Cross interview triangulation was used as a method to gain an alternative perspective on a event or to verify information obtained. This was particularly helpful in sorting out old documents with conflicting information.

Interviews were recorded with hand written notes. These notes, being typically somewhat cryptic were reviewed within one hour of the completion of the interview and additional notes added to help improve the post-interview recall. When needed, follow up questions and clarifications were pursued by email. Handfuls of interviews were conducted by email correspondence only due to geographic constraints.

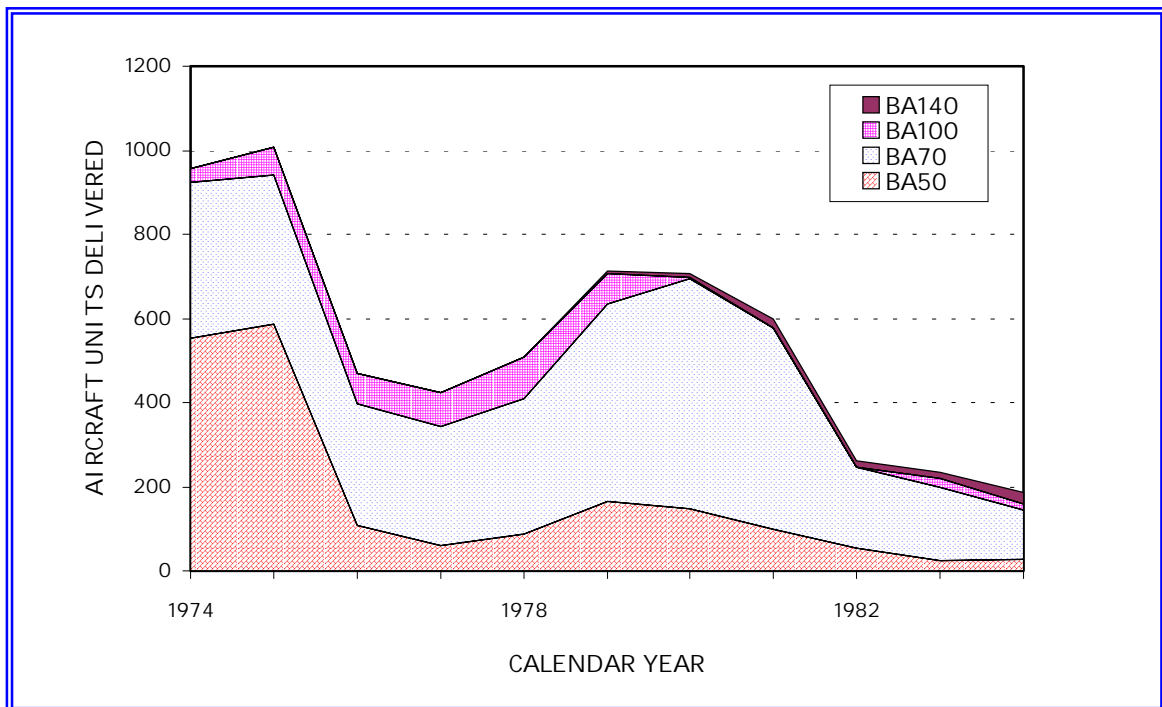
## 4 CASE STUDY DATA

### 4.1 Bush BA140

#### 4.1.1.1 Initial Plan

The Bush BA140 program was officially launched in early 1974. It was preceded by a series of marketing and configuration studies that culminated with the construction of a full scale aircraft mock-up. The mock-up was brought to air shows and industry conventions to get further feedback from potential oil exploration and business customers. The BA140 was aimed at the same market as the SW-24, also featured as a case study program. The aircraft was well received and Bush had no difficulty taking orders for the aircraft.

**Figure 4-1: Annual Aircraft Deliveries / Bush Aircraft**



#### **4.1.1.2 Prelude to BA140**

Prior to embarking on the BA140 program, Bush was delivering over 30 civil aircraft per month and a somewhat higher number of military aircraft per month. About this timeframe, DoD deliveries of the BA50, BA70 and BA100 series models were dropping as DoD was in the process of fostering contracts for the development of a new generation of replacements for the aircraft (ref. Figure 4-1). Bush competed for these new contracts but lion's shares of these contracts were awarded to competitors. Bush did capture a significant military aircraft upgrade program and a NASA X-plane program, which were in progress during this timeframe.

The BA140 would be the first new design aircraft since the B70, 14 years previous. Bush also launched the BA130 and BA150 development and certification programs. These were improved civil version of the BA60/70 models. These announcements succeeded the BA140 model's initial Type Certification. However, according to one of the sources interviewed, there was a significant amount of overlap between these programs.

#### **4.1.1.3 Program Structure**

Heavy weight project team best describes the structure of the BA140 program. The entire team was located in a separate building across town from the main facilities. The engineering leads reported to, and were rated by the program management staff. Reportedly, this was a controversial arrangement at the time, fueling much discussion and concern regarding to use of "best practices" by the engineers, now isolated from the functional organizations.

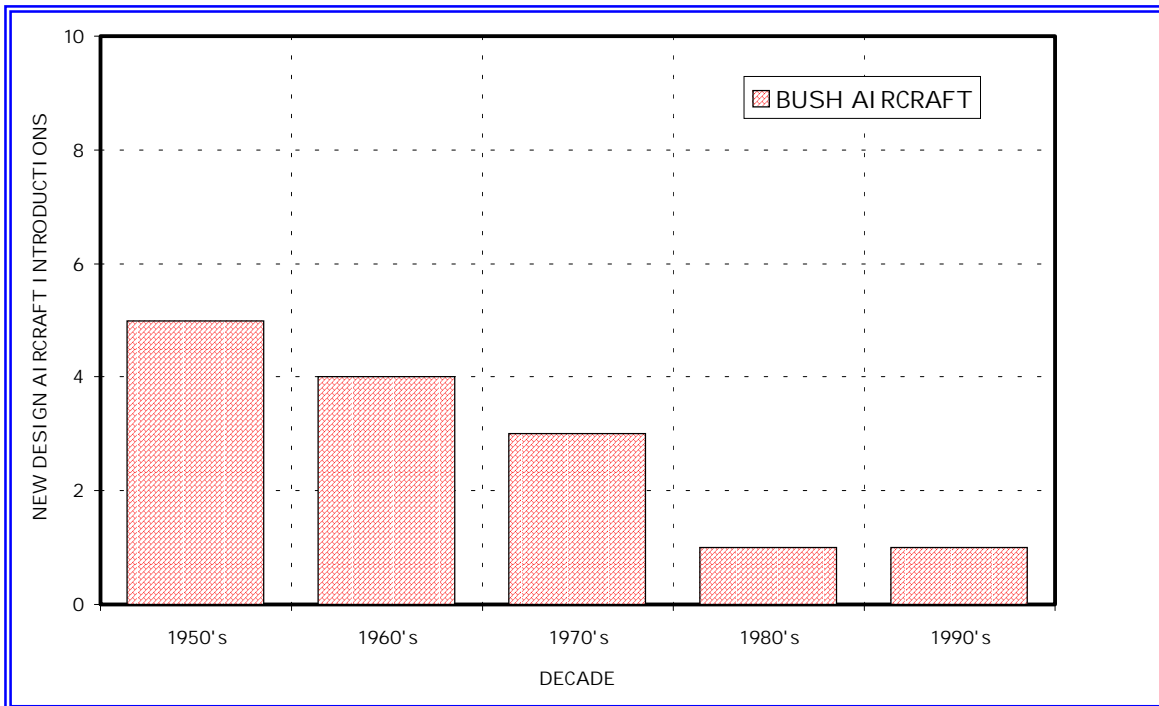
Ex-Bush employees queried, regarded the BA140 team was "top notch". Its program director, project engineers and much of the functional engineering staff highly experienced with aircraft development, having worked on a variety of military and civil programs during their tenures. The number of military and civil models (including

derivatives), developed in the prior decade, Bush's production and R&D activity certainly supports this characterization. This is discussed further in the subsequent section.

#### 4.1.1.4 Intellectual Capital

During the timeframe of the BA140 development, Bush employed 10,000 approximately workers of which 14% were represented by the engineering and design disciplines (ref. 5). For a period of at least ten years prior to the BA140 program, Bush has a steady diet of production contracts and a few research contracts. Its work force was relatively stable during this time period, not experiencing any significant downsizing until 1980's. Many Bush many employees migrated to competitors that had captured the large long-term military contracts that eluded Bush. This was subsequent to the launch and certification of the BA140.

**Figure 4-2: Frequency of New Design Aircraft Introductions / Bush Aircraft**



According to sources interviewed, about 65% percent of its BA140's technical workforce had made significant contribution to experience in the design and development of three or more derivative or and experimental research aircraft prior to the BA140 program. Figure 4-2 presents a summary of the frequency of fielding new aircraft designs for Bush. While not clear from this chart, the last bona fide new design production aircraft, the B70, preceded the BA140 by 10 years. However, during this duration, Bush continued to develop advanced wing, propulsion and material technologies through US government funded research programs as well as self-funded research. New technology was gradually introduced into existing aircraft models as in-line improvements and numerous new / derivative models. In short, there existed ample opportunities for the BA140 team to accrue significant amount of derivative aircraft experience as well as a more modest amount of new aircraft experience.

#### **4.1.1.5 Tools**

This program predated the era of Computer Aided Design (CAD). The majority of the design work was done on the traditional ink on Mylar medium. Mainframe based aero, aeroelastic and flight simulation computer codes were used. Structural analyses relied on early, mainframe versions of NASTRAN, indigenous aircraft loads prediction codes coupled with an equivalent amount of traditional paper and pencil hand analyses. Slide Rules were used commonly but were starting to be displaced with hand held and desk-top calculators. Mainframe computers were also employed for program management functions.

#### **4.1.1.6 Type Certification**

The BA140 received its VFR type certification 11 months later than the original target date. At the time of certification, a backlog of over 100 aircraft had been accrued. This number doubled within the next year.

VFR Type certification experienced further delays and the schedule variance increased to 17 months by the time IFR type certification was achieved.

Table 2 provides a summary of the performance metrics at type certification.

**Table 2: Bush BA140 / Metric Variance Summary**

<u>Metric</u>	<u>Deviation</u>
We	+21%
Useful Load	+14%
Payload	+16%
MTOGW	+18%
Range	-30%
Fuel	+12%
HOGE	-36%
HIGE	-21%
First Flight	+8 mo.
Type Certification (VFR)	+11 mo.
Type Certification (IFR)	+17 mo.
Initial Delivery	+10 mo.
Major Spec Changes	9

#### **4.1.1.7 Post Certification Development Activity**

The BA140 introduced in to service through an official "launch customer", standard procedure for the aircraft industry during this timeframe. The BA140 launch customers experienced its share of new aircraft teething problems. Reliability of the aircraft subsystems and main wing fatigue concerns reduced the availability and increased the operating cost of the aircraft. To address these problems, initially, Bush made sure that sufficient spares and dedicated field representatives were available to the BA140's

launch customers . This was followed up with the introduction of field retrofit kits of redesigned components. While this was not a desirable situation, it is fairly typical situation for a new aircraft's introduction in to service.

More serious was the aircraft's performance shortfalls in payload and range which limited the productivity of the aircraft for many of the operators. In addition, the BA140 experienced delays in achieving its IFR certification, further reducing its productivity for operations that required this capability.

#### **4.1.1.8 IFR BA140 B and B+**

To address the shortcomings of the initial BA140, Bush followed up quickly with an improved and IFR certified BA140B model. The first BA140B was delivered in August 1982. It featured more powerful engines (+8%) and uprated drive system, a 30% increase in fuel capacity and a 5 % increase in maximum take-off gross weight. The majority of the BA140A models were upgraded to the BA140B configuration.

In less than one year, Bush was offering a further improved version, the BA140B+. It featured a further 18% increased fuel capacity, additional seating and a reduced empty weight. It was adopted as the standard production configuration. These changes were aimed at further improving the payload / range performance of the aircraft, which had yet to achieve the original performance claims.

Unfortunately, poor engine reliability and performance continued burden the operators and mar the aircraft's reputation. Aircraft sales of the BA140 at this point in time were well below the early projections.

#### **4.1.1.9 Subsequent Derivatives**

Subsequent to BA140B+, three additional derivative models of the BA140 have been offered by Bush, the BA140SP, B160 and the B190. Each successive version featured increased power takeoff gross weight and range and superceded its predecessor as the

base production model. The B190, Bush's current offering also features a moderate cabin stretch, FADEC equipped engines and a glass cockpit. Despite Bush's support of this model, sales have yet to reach the potential predicted at the outset of the BA140 program.

## **4.1.2 Program Performance Metrics**

### **4.1.2.1 Weight Derived**

The constant growth of the BA140's weight empty and maximum takeoff gross weight during the development program indicate that the program had difficulty with weight control. Four published maximum takeoff gross weights were found in a variety of publications prior to receiving its initial VFR type certification. A fifth followed as the aircraft received IFR certification. Clearly, the increments were aimed at delivering an acceptable payload for its customers. The weight metric data is extracted from Jane's All the Worlds Aircraft (ref.4).

### **4.1.2.2 Range**

The BA140 suffered a continuous decline in range performance throughout its development. Even at the outset of the program, a full fuel load plus full passengers was only possible with the lightweight passengers with no baggage. This could have been a requirements oversight as the spec FAA passenger is 170 lb., much lighter than the typical passenger who would fly in this aircraft is.

As its weight grew, the fuel system was enlarged to recover lost range. Two auxiliary fuel tank arrangements were developed for customers who were willing to trade some payload for range. By the time the aircraft reached certification, its range capability was 30% lower than the initial target specification. This shortfall excluded it from certain markets. The initial two derivative models, the BA140B and BA140B+ featured



increased fuel capacities of 30% and 48% respectively, a validation of the range shortfall conclusion.

#### **4.1.2.3 Altitude**

The altitude performance for the BA140 at Type Certification fell 36% short of the original specification. The aircraft could exceed the original specification at the original spec gross weight though. Again pointing the finger at excess weight gain during design and development.

This capability was improved upon with the BA140B model, which featured increased engine and drive system ratings. As stated in the prior section, most BA140A models were upgraded to this configuration.

#### **4.1.2.4 Frequency of Major Specification Changes**

Ten major specifications changes were gleaned from various aviation industry references. Four of the nine changes are attributed to increases to the maximum takeoff gross weight of the aircraft which occurred in increments of 3%, 7.5%, 6.3%, and 2.6% respectively for a cumulative total of 17.2% over the original design specification. Three are attributed to engine and or drive system takeoff rating increases and one to a fuel tankage redesign which yielded a 15% increase in capacity. Early in the flight test program, the horizontal tail was move forward significantly. And lastly, a redesign of the main wing, increasing it's span by 2% and chord by 8% for an area increase of 10%.

#### **4.1.2.5 Flight Test Hours to Obtain Type Certification**

According to data published in trade publications, three thousand flight hours were accrued on BA140 flight test aircraft in order to gain its VFR Type Certificate. Due to the lack of published data, it was not possible to construct a creditable estimate of the incremental flight testing hours required to achieve its IFR type certification.

## **4.2 Swamp SW-24**

### **4.2.1 Overview**

#### **4.2.1.1 Initial Plan**

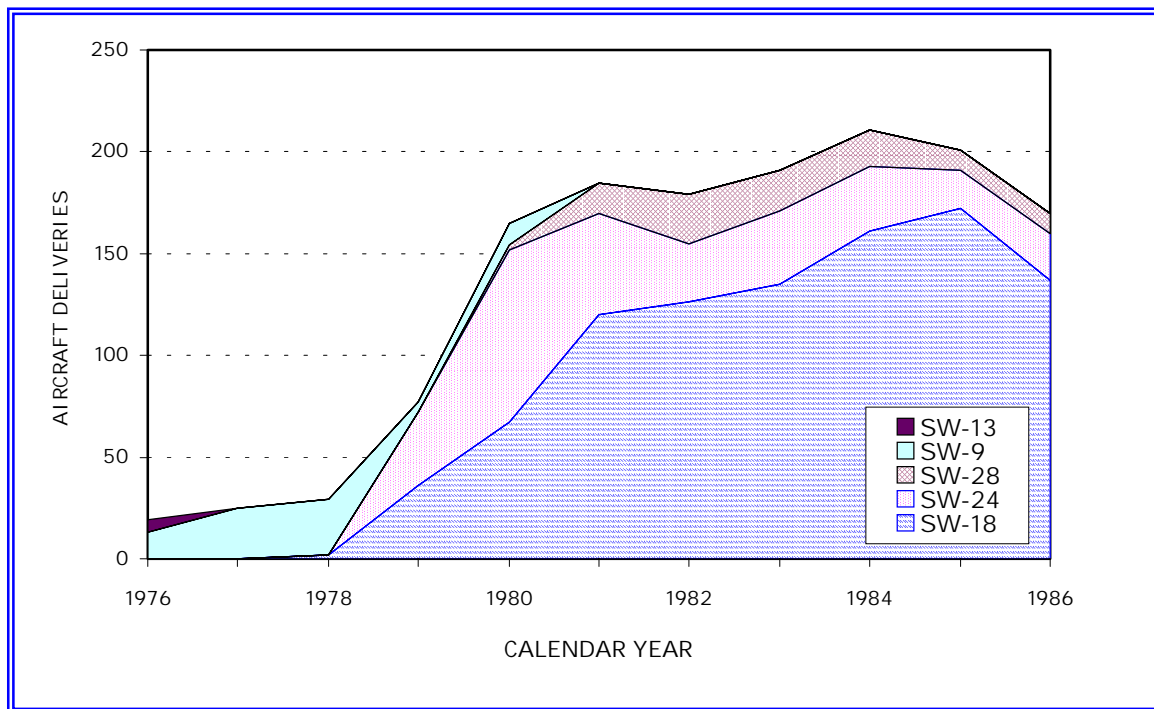
Swamp announcement of SW-24 program occurred early in the year 1975. This was followed by a study phase during which time market research, competitive benchmarking and launch customers were sought. The SW-24 featured the latest technology used in the SW-18 to achieve maximum performance and to reduce risk. Program launch with the backing of Swamp's parent corporation occurred about one year after the program was announced. The initial press releases at this time cited mid 1976 for with FAA certification and initial deliveries in late 1977 followed by rate production in 1978 (ref. 4). A launch customer was signed on for the initial ten aircraft shortly after to the launch announcement.

#### **4.2.1.2 Prelude to SW-24**

During the mid-1970's, Swamp was delivering new SW-9, SW-12 and the SW-13 model aircraft at rates of 20-40 per year along with 10-20 upgraded SW-9's. An all time low point in Swamp's history according to those interviewed. Figure 4-3 provides a summary of Swamp's production deliveries from this low point forward, compiled from internal records.

Prior to embarking on the SW-24 program, Swamp was fully involved in the later phases of the NUAC (New Utility Aircraft) program competition with Big Valley Aircraft. The SW-18 prototype's first flight had preceded the SW-24 program announcement by 3 months. Although Swamp would be awarded this contract twenty-three months later, uphill battles to solve design problems, and a "winner takes all" fly-off competition lay ahead. In short, there was much uncertainty in Swamp's future.

**Figure 4-3: Annual Aircraft Deliveries / Swamp Aircraft**



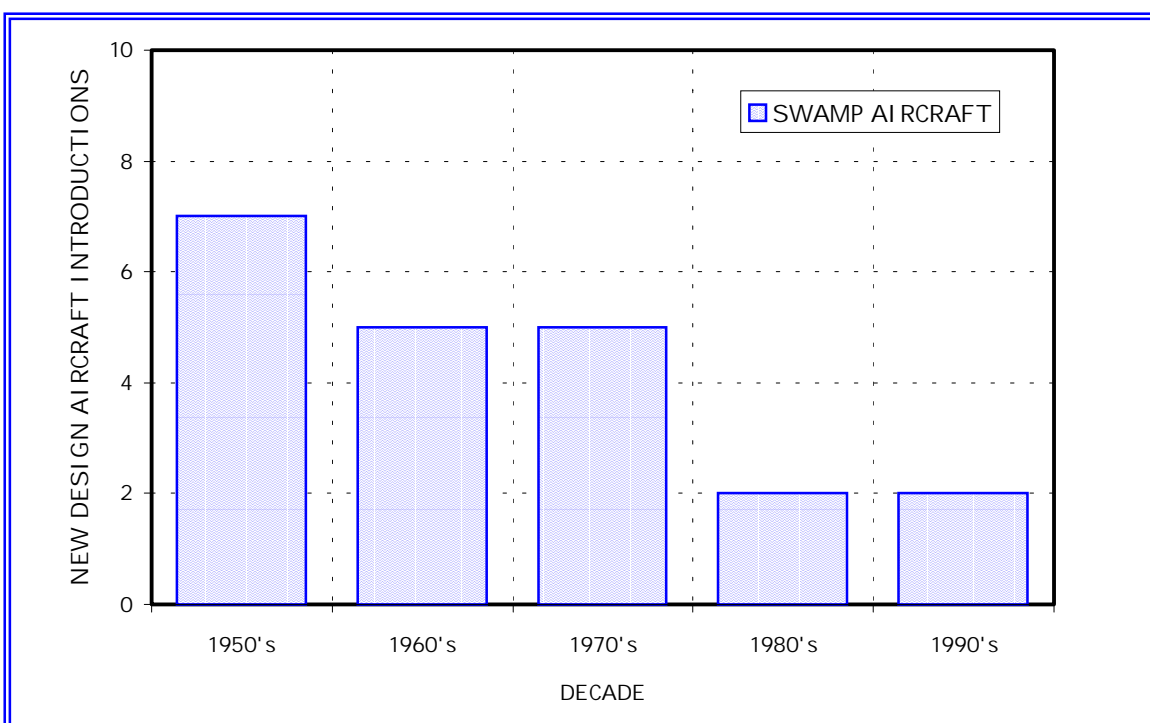
#### **4.2.1.3 Program Structure**

A heavy weight project team, staffed with functional engineering organization leads best describes the structure of the SW-24 program. The functional leads were responsible for making sure that the project tasks were supported by the functional organizations. The program manager and chief of design were highly experienced and previously held equivalent positions on the NUAC program. The functional organization leads, were hand picked by the chief of design according to their experience. The majorities were fresh off the NUAC program.

The program was also staffed with dedicated administrators and finance personnel to help with project management tasks.

In order to segregate the SW-24 activities from that of other government funded activities, the majority of the SW-24 team was located in a separate facility in an adjacent town. According to interviews, this was vital to the programs success as the main facility was experiencing many difficulties in their effort to prepare for SW-18 rate production. Production rates not experienced for many years and a ten fold increase over the current aircraft production rate.

**Figure 4-4: Frequency of New Aircraft Introductions / Swamp**



This is captured in part by Figure 4-3 which chronicles aircraft deliveries for the period just subsequent to the awarded of the NUAC contract and type certification of the SW-24. To the left side of this chart, one can see the rapid rate of increase for deliveries of both the NUAC and SW-24. According to one of the sources interviewed, "The main plant was in turmoil trying to ramp up for NUAC production. Any available body in main plant ended to be commandeered to work on the NUAC program. Therefore, it was recognized in the early phases of the program that an off site facility was imperative for the programs success."

#### **4.2.1.4 Intellectual Capital**

The program manager and chief of design were highly experienced and previously held equivalent positions on the NUAC program. In addition, the majority of the functional organization leads had 15-20 years experience and had contributed to design and development of three to six other "clean sheet of paper" aircraft according to sources interviewed. . This information seems realistic when compared the number of new designs fielded by Swamp in the preceding decades, presented in **Figure 4-4**. The functional organization leads, according to one of the participants interviewed, were hand picked by the "chief of design" "as a prerequisite to his acceptance of this position. accepting the assignment as chief of design, Al Albert insisted that he must be able to hand pick his team." As such, the team of functional engineering leads consisted of the most experienced engineers, many of that were fresh off the NUAC program or one of the other development programs.

#### **4.2.1.5 Tools**

This program predated the era of Computer Aided Design (CAD). The majority of the design work was done on the traditional ink on Mylar medium. Mainframe based aero, aero-elastic and flight simulation computer codes were used extensively, and complimented with 1/10 scale, 1/5 scale, and full scale subsystem wind tunnel testing. Structural analyses relied on early, mainframe versions of NASTRAN, indigenous aircraft loads prediction codes coupled with an equivalent amount of traditional paper and pencil hand analyses. Slide Rules were used commonly but were starting to be displaced with hand held and desk-top calculators. Mainframe computers were also employed to track the program budgets.

#### **4.2.1.6 Type Certification**

The SW-24 program was swiftly executed with type certification occurring within 6 months of the original target date. At the time of certification, a backlog of over 200 aircraft had been accrued. This number doubled within the next year. Table 3 provides a

summary of the performance metrics at type certification. These metrics are discussed further in subsequent sections.

**Table 3: SW-24 Metric Variance Summary**

<u>Metric</u>	<u>Deviation</u>
We (lb)	+7%
MTOGW (lb)	+3.1%
We/MTOGW	+3.6%
Useful Load (lb)	+2%
Range (nm)	+4 %
HIGE (ft)	+22%
HOGE (ft)	-15%
First Flight	+9 mo.
Type Certification	+6 mo.
Initial Delivery	+8 mo.
Major Specification Changes	3

#### **4.2.1.7 Post Certification Activity**

While the program had been executed successfully from a many technical and business perspectives, the initial SW-24 production models its share of teething problems. In the initial two years many reliability issues arose, of which some had Airworthiness Directives (AD) issued against, often requiring inconvenient special inspections and unscheduled maintenance. The engines were experiencing a high rate of in-flight shutdowns and were not providing adequate power margins for some operations.

In addition, the UK SW-24 operators had range issues due to additional equipment required by the CAA for over-water operations. This required them to reduce their passenger counts.

Customers exerted pressure on Swamp to resolve these issues. Swamp responded by putting together a special task force comprised of engineering and customer service personnel. The team's charter was to identify the root cause of the field problems and to implement corrective actions swiftly. Initially, the availability was dramatically improved by providing stocks of critical spare parts to operators on consignment and dedicated on-site field representatives. Introduction of field retrofit kits, which included redesigned components, followed. The weights of the aircraft escalated as these changes were incorporated.

This team stayed in place for two years before it was disbanded. At least one of the sources interviewed was of the opinion that this effort demonstrated the companies commitment to the customers and likely saved the program from an early demise.

#### **4.2.1.8 SW-24 MkIV**

The introduction of the SW-24A Mark IV, a mature and more reliable SW-24 occurred in early 1982. It incorporating 44 improvements over its predecessors including a 5% increase in engine power, and increased payload achieved by increasing the maximum gross weight 3%. Mark IV retrofit kits and made available to operators at no cost. Nearly all early SW-24A's are retrofitted to the Mark IV configuration.

Despite this progress, the aircraft's reputation continued to be marred by engine problems including engine bursts. The resolution of this issue eventually spawned the other SW-24 models discussed in the subsequent section.

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<sup>1</sup> An Airworthiness Directive or AD is an order issued by the Federal Aviation Administration which mandates that operators take some kind of action to address a potential safety issue with regards to a particular aircraft model..

#### **4.2.1.9 Other Descendants**

Engine problems experienced with the SW-24 force renewed interest in a re-engined version of the SW-24 designated the SW-24B. It featured 50% greater engine power margins for hot climates and high altitude operations as well as 15% in the drive system power rating. The SW-24B program was announced in 1984 and the received its Type Certification in 1987. The aircraft gained popularity with the Emergency Medical Services (EMS) and executive transport market segments.

Several other SW-24 derivatives, also characterized as re-engined versions followed the SW-24B. The SW-24A+ was a re-engined version of the SW-24A. This engine retrofit was conducted by an enterprising third party to took advantage of the many SW-24A models in service. Eventually, this led to a new model the SW-24C, an SW-24B airframe and drivetrain fitted with more capable versions of the engine initially introduced in the A+ as a retrofit.

#### **4.2.2 Program Performance Metrics**

##### **4.2.2.1 Weight Derived**

Based on data compiled from Jane's (ref. 4), the SW-24's empty weight was **7 %** over the initial specification value upon receiving its initial Type Certification. Initially, there was some confusion regarding what weight empty value to use as a baseline. Jane's (ref. 4) published several lower empty weights up to the point in time that the aircraft was actually certified. The earliest reference came from the study phase of the program and was likely established by simple preliminary design methods and revised. The second value published seems more creditable since it appears consistently for several years in Jane's and other publications. Interviews with the lead mass properties engineer on the program also veirified this value and provided an explanation for some of the numbers confusion. Equipped weight empty<sup>2</sup> values for specific aircraft

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<sup>2</sup> Equipped weight empty refers to an aircraft configured with mission specific equipment such as avionics, safety equipment.



configurations corresponding to target markets were tracked internally and sometimes released. These values were commonly published without noting the specific configuration they represented. Nearer to the conclusion of this research effort, a copy of an early internal aircraft specification was discovered, eliminating any final doubts about the baseline value chosen.

Another observation was noted, the SW-24 spec empty weight represents a more austere configuration than any of the "launch" customers would operate. This is not an unusual marketing practice in the aerospace industry and will not impact any conclusions regarding weight control performance as long as the empty weight definition remained consistent throughout the program. This issue was discussed with several of the interviewees, none were aware of mid-stream change in the definition of empty weight for the SW-24. Their explanation for the situation was that a large market for a stripped down, single pilot VRF, "no-frills" aircraft was anticipated. However, to their knowledge, no customer ever purchased such a configuration due to the surplus of inexpensive used aircraft. They also verified that a payload shortfall did exist with UK customers who conducted over-water operations. For these operations, the aircraft required additional avionics and safety equipment as compared with its US counterpart. This was the primary reason given for the 3.1 % increase in gross weight late in the development program.

Due to the relatively small magnitude of the increase, this change was accomplished with minimum program and aircraft impact. Structural analyses were revised, a major effort, but no redesign of the airframe or landing gear of significance was warranted. Some tests, including landing gear drop tests were repeated at the higher weights.

Over the course of the model's life, this card was played on three additional occasions with regard to -A models and once with the -B model. In all cases, the motivation was to recover payload capacity lost to weight growth. Two of the post certification weight increases with the SW-24A were executed within five years of receiving Type

certification, and were also accomplished with minimal impact to the airframe and landing gear.

In closing out this discussion, the useful load of the SW-24 upon Type Certification was exactly on target, due primarily to the increase in the maximum takeoff gross weight late in the program.

#### **4.2.2.2 Range**

The SW-24 spec design range was intended to be a realistic capability for its operators. It was based on carrying a full passenger load and fuel with a thirty-minute fuel reserve. During development this range status value dipped as low as 7.5% below the spec value, However, it was 1% over specification upon type certification. No specific range recovery actions could be identified other than a fuel capacity increase of 3%. Queries regarding this increase attributed it to latent capacity discovered during fuel system testing and not attributed to a specific redesign.

As discussed in a prior section, some customers could not achieve the spec, range due to the additional they were required to carry and the heavier than average passenger loading.

#### **4.2.2.3 Altitude**

The SW-24 exceeded its spec altitude performance by 10% upon receipt of its Type Certification. There were no specific recollections regarding the program history of this attribute. However, copies of original attribute tracking charts show that the aircraft's power margins was tracked to a value 5% higher than the spec value during development.

#### **4.2.2.4 Frequency of Major Specification Changes**

Three major changes to the design of the SW-24 were detected from the examination of records and publications. An increase in maximum takeoff gross weight, discussed in

prior section, a reduction in vertical tail area and the change from a variable to a fixed incidence horizontal tail. In actuality, the initial design had a fixed incidence tail. This was changed to a variable incidence tail after configuration risk reduction wind tunnel tests and flight simulation. According to reference 1, this decision was made in part to reduce the schedule risk associated with such a change introduced mid stream in to a certification flight test program. If the added capability was not needed the incidence could be simply fixed. As it turns out, the fixed incidence provided satisfactory handling qualities to obtain both VFR and IFR type certificates.

#### **4.2.2.5 Program Schedule**

First flight of the SW-24 occurred in early months of 1977, nine months later projected at the program launch. Its initial VFR Type Certification was obtained late in 1979 followed a month later with its IFR certification. Both dates are six months later than the original plan. Lastly, the first customer aircraft was delivered in February of 1979, reflecting an eight month slippage.

#### **4.2.2.6 Flight Test Hours to Obtain Type Certification**

Accurate documentation of the number of flight test hours was obtained through a Swamp Aircraft source. To obtain VRF type certification, four prototype aircraft accrued 1500 flight test hours. To gain IFR certification, an additional 700 hours were flown.

## 4.3 M700

### 4.3.1 General Overview

#### 4.3.1.1 Prelude to M700

Prior to the M700 program launch, Marsh was delivering 150 new aircraft per year on average, with a peak production rate of 194 for 1987. Figure 4-5 chronicles the actual deliveries by model for Marsh from 1984 to 2000. Production was split roughly 60% / 40% between the two model lines, with deliveries split 80% / 20% military and civil customers. In the late 1980's, these numbers were anticipated to fall dramatically in the coming years as several military contracts were settling. These contracts were the primary source of revenue for Marsh, and, although potential follow-on upgrade and life extension US and foreign military contracts were likely, an overall downturn in revenues was projected.

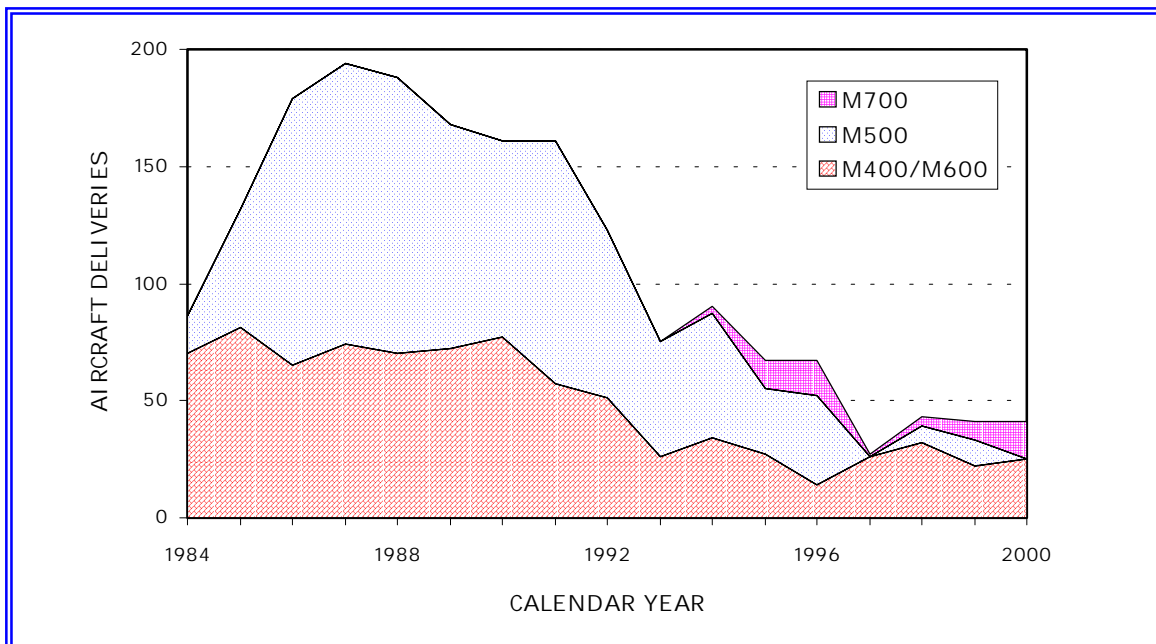


Figure 4-5: Aircraft Deliveries / Marsh Aircraft

To address this, upgraded versions of two existing models were under development and early marketing and configuration studies of an aircraft, which led to the Marsh M700 program, were underway. Due to the post Cold War defense decline, these initiatives were focused on increasing the civil aircraft business.

Marsh's last foray into developing a new design aircraft occurred in the 1970's. It was a major military contract that was competed for by two other manufacturers. The contract award led to a protracted and controversial development program for this aircraft, the M500. There were many challenges in the areas of handling qualities, systems integration and reliability. Eventually, the aircraft entered service bringing with it impressive capabilities not seen in predecessor weapons systems. However, it has never been able to erase its reputation for being temperamental and unreliable.

The remainder of Marsh's product line traces their origin to a military aircraft developed in the 1960's. Over the years, this aircraft and its many derivatives became highly popular with both military and civil users.

#### **4.3.1.2 Initial Plan**

The Marsh M700 program was launched early in 1989 with the full support of Marsh's parent corporation. It was preceded by a year of configuration and market studies. First flight of the new aircraft was anticipated in 1992 with initial deliveries following within a year.

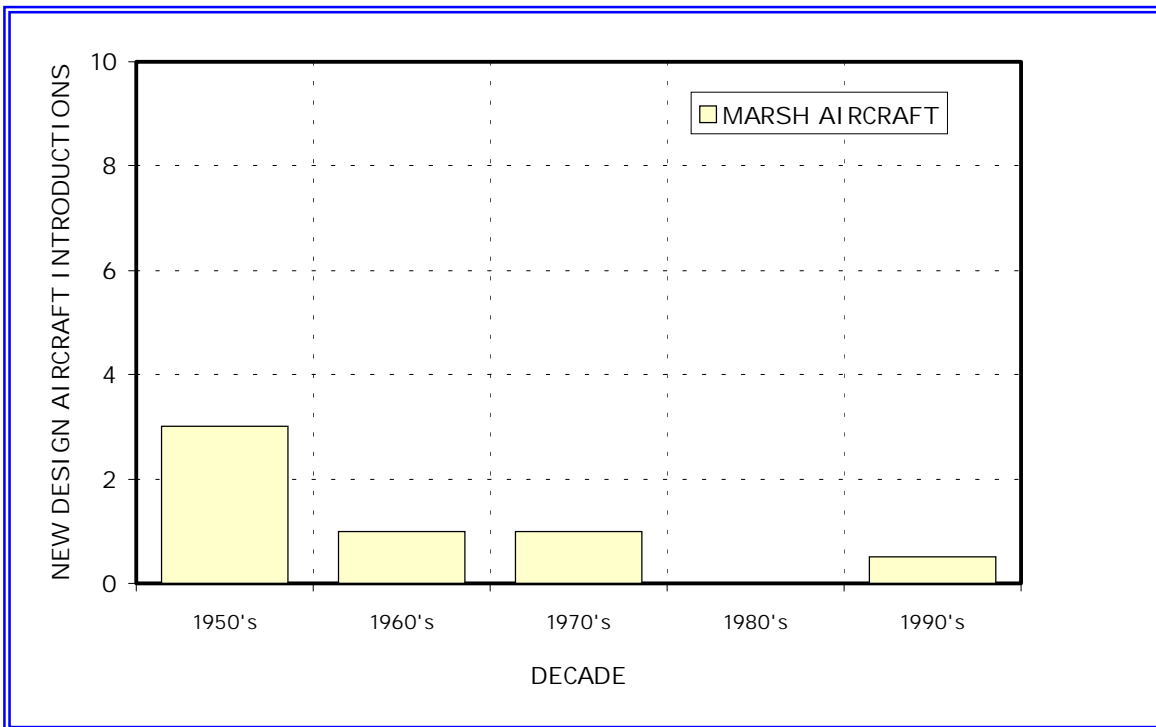
The launch announcement was well received, with over one hundred certificates of interest accrued in the course of one week.

### 4.3.1.3 Program Structure

Integrated Product Development Team (IPDT) best describes the configuration of the M700 program. A customer focus group comprised of potential launch customers from various market segments also supported the IPDT's during the early definition stages and at various design reviews.

To reduce the capital outlay for development, risk-sharing partners from North America, Europe, the Middle East and Asia were recruited to share in the development cost. In return, these partners would receive a share of the profits from each aircraft sale. Marsh retained the design of the primary flight systems, systems integration, final assembly and the delivery of the aircraft. The development of major modules including; the engines, fuel system, drive systems, main fuselage structure, landing gear, avionics, interior and furnishing were delegated to these partners.

**Figure 4-6: Frequency of New Design Aircraft Introductions / Marsh Aircraft**



#### **4.3.1.4 Intellectual Capital**

As previously stated, the last bona fide new design Marsh aircraft was the M500 which was designed during the mid-1970's. In fact, as depicted in Figure 4-6, the frequency at which new design aircraft introductions in the prior two decades was less than one. The lowest of the four case study manufacturers. Marsh did however have a knack for getting the most out of each new design by spawning many derivative models of each.

The sale of Marsh to another concern in 1984, impacted its indigenous intellectual capital when its engineering and manufacturing operations were moved several hundred miles inland to an adjacent state. The climate of the new location differed greatly and many longtime Marsh employees elected not to relocate. Most of the manufacturing talent was available local to the new site. To fill the voids in the technical ranks, aggressive recruiting of Marsh competitor workforces was employed.

At the time of the relocation, Marsh's priorities were (1) move it's existing manufacturing operations (2) bring the M500 in to rate production and (3) to secure the NGAC (Next Generation Aircraft) contract. The M700 was still a few years down the road.

When it came time for the M700 program, Marsh again turned to recruiting of Marsh competitor workforces. Ex-Marsh employees assigned to the M700 program estimated that 50% of the technical personnel on the program were recruited from outside companies, including themselves.

#### **4.3.1.5 Tools**

The Marsh M700 utilized all of the state of the art design and development tools including sophisticated a 3D digital CAD/CAM system. Using this system, machined parts are fabricated by numerical controlled machines directly from the digital data.

Another feature enabled a three dimensional virtual representation of the aircraft design to be assembled in whole or in part from a database of CAD files for components and sub-assemblies. This was utilized to evaluate inferences as well as maintenance access and vision obstruction. A host of contemporary finite element tools for stress analysis (NASTRAN) and fluid dynamics codes was utilized as well. An information exchange network was established so that this digital design and analysis data could be shared between partners with a minimum of difficulty.

Wind tunnels testing, a more traditional aircraft design tool, were used extensively. A 1/5 scale model tested in the Texas A&M wind tunnel was used to do configuration validation and development and drag reduction. A full-scale test of the main wing was conducted in one of the NASA wind tunnels.

The MARSH M700 features a unique directional control system that was first introduced on another model just prior to the M700 launch. The development of this system on this aircraft led the M700 by several years and contributed greatly to the M700.

#### **4.3.1.6 Type Certification**

The MARSH M700 program suffered some delays during its execution, completing initial VFR certification 12 months later than the original target date. Type Certification for IFR operations experienced a considerably longer delay of 33 months. This will be discussed further in a subsequent section.

On a more positive note, one reference claimed that the M700 achieved certification in a mere 23 months after its maiden flight, the shortest on record for an aircraft of its type.

#### **4.3.1.7 Post Certification Development**

The majority of post TC development activity was focused on obtaining IFR type certification and enhancing the range and single engine capability of the aircraft. This



work eventually led to an improved -200 version of the aircraft which is discussed briefly in the subsequent section.

#### **4.3.1.8 MARSH M700 -200**

The -200 version of the M700 features an updated engine and transmissions, improvements to the air inlets and a gross weight increase. A 7% increase in range and a 16% increase in payload resulted from these improvements. This model replaced its predecessor as the standard production configuration. Operators wishing to upgrade their aircraft to this configuration could buy these kits.

### **4.3.2 Metrics**

#### **4.3.2.1 Weight Derived**

The weight metrics baselines were extracted from a technical publication authored by an MARSH employee early in the development program. They seem quite optimistic, and yield high weight metric variances (ref Table \_). Putting the variance magnitudes aside, the constant creep of MARSH M700's weight empty and maximum takeoff gross weight indicate that the program had difficulty with weight control. Four published maximum takeoff gross weights were found in a variety of publications prior to receiving its initial VFR type certification. A fifth followed as the aircraft received IFR certification. Clearly, the increments were aimed at delivering an acceptable useful load for its customers.

#### **4.3.2.2 Range**

The MARSH M700 suffered a continuous decline in range performance throughout its development. As envisioned, the aircraft maximum takeoff gross weight would be reached with a full tank of fuel and the advertised payload. However, as its weight escalated, the full payload and fuel could not be carried simultaneously. Due to geometric constraints imposed by its configuration, enlarging the fuel system of the

M700 proved difficult and only increased slightly over the duration of the development program.

The shortfall of its range performance led to its demise in one of its primary markets. In fact, the launch customer for the aircraft cancelled its option for further aircraft due to the range shortfall.

#### **4.3.2.3 Altitude**

The altitude performance for the MARSH M700 exceeded the original specification by 10%. An increase in engine and gearbox ratings was effective in countering detrimental impact of the aircraft's weight escalation during development.

#### **4.3.2.4 Frequency of Major Specification Changes**

Twelve major specification changes were identified for the M700 by examining published documents. As previously discussed, the maximum takeoff gross weight of the Marsh M700 was increased five times. The actual impact to the development cost and schedule could not be quantified, although it is known that no changes were required to the aircraft for the last increase.

Other major changes allocated to this case include increases in both the engine and transmission ratings, a redesign of the electrical system, widening the fuselage 4" and the shortfalls in range and payload performance.

#### **4.3.2.5 Schedule**

As noted in Table 4 the schedule variance to achieve initial type certification was 12 months. Not entirely too bad for this industry. However, a much more serious delay of 33 months was encountered in obtaining IFR certification.

It is typical for aircraft in this class to obtain VFR certification first, deliver a few aircraft to customers to start the process of training its pilots and mechanics. Within three to six months the IFR certification is expected with little difficulty.

In the case of the M700, the basic electrical system did not meet the certification criteria for redundancy and had to be redesigned. In addition, the unique directional control system of the M700 was not architecturally compatible with existing automatic flight control systems offered by the chosen vendor. Thus, it required a significant redesign and several iterations to arrive at a certifiable solution. This clearly reflects on the lack of prior experience with IFR certification of civil aircraft.

Also of note, the M700's IFR type certification was sub-contracted to the automatic flight controls system manufacturer. This is a unique situation with respect to the other case studies.

#### **4.3.2.6 Flight Test Hours to Obtain Type Certification**

Three development M700's shared the type certification duties. Initial VFR Type Certification was achieved within 23 months after its maiden flight. It is estimated from literature that these aircraft collectively logged approximately 3,000 flight in reaching this milestone.

As mentioned in the prior section, a third party conducted the IFR certification of the M700. No published data or other sources could be found to establish the flight test hours required for the M700 to obtain an IFR type certification.

#### 4.3.2.7 Summary

Table Table 4 provides a summary of the performance metrics at the M700s initial VFR type certification.

**Table 4: MARSH M700 Metric Variance Summary**

<u>Metric</u>	<u>Deviation</u>
We	+36 %
Useful Load	-18 %
Payload	-28 %
MTOGW	+11 %
Range	-22 %
Fuel	+8 %
HOGE	+10 %
First Flight	+9 mo.
Type Certification (VFR)	+12 mo.
Type Certification (IFR)	+33 mo.
Initial Delivery	+12 mo.
Flight Test hours to TC	3,000 hrs.
Major Specification Changes	12

Further discussion regarding the metric values assigned are contained in the prior sections.

## **4.4 SWAMP SW-40**

### **4.4.1 Overview**

#### **4.4.1.1 Early History**

The SW-40 first appears in publications in the early 1990's. Initially the emphasis of the program and corresponding aircraft design was to capture a DoD contract for a multi-mission aircraft. At this early stage in the program, the aircraft was a direct derivative of the SW-18, an aircraft already in widespread service with the US and foreign militaries. This strategy was adopted to capitalize on cost effectiveness of procuring a high commonality derivative of an incumbent DoD aircraft as opposed to a new design model<sup>3</sup>. A civil variant was to be derived from the military model, which bode well with the "dual use" philosophy emerging at the time.<sup>4</sup> While a compelling case, the DoD procurement program was cancelled amidst a myriad of political turmoil.

After this, there was a period of internal deliberation as to the viability of such a program without the support of the US DoD. During this interval, the program was throttled back while the program direction vacillated back and forth from a DoD spec. aircraft to a pure Civil/FAA certified aircraft. Eventually, a new vision of the SW-40 program and aircraft emerged. It was externally similar to its predecessor, but based on significantly different assumptions.

This new vision was based on certification of the aircraft to the latest FAA/JAA airworthiness regulations. To enhance the aircraft's appeal to potential military customers, selected systems would be designed to meet more stringent military requirements.<sup>5</sup> The low cost argument, previously based on commonality with the SW-

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<sup>3</sup> The basis of this argument revolved around network externalities such as pilot and maintenance training, and an established logistics system and procurement efficiency.

<sup>4</sup> The term "dual use" describes the philosophy where military technology is used for civil applications and vice versa.

<sup>5</sup> A large percentage of the projected international market for this class of aircraft was projected to be foreign militaries who were in need of replacing their older obsolete fleets.

18, shifted to achieving the lowest operating cost in its class. When the preliminary design studies for the aircraft were repeated to these criteria, it was recognized that these objectives could only be accomplished with a new design aircraft. Hence, the derivative aircraft approach was quietly abandoned. With ambitions of capturing future predecessor aircraft upgrades, certain aspects of the SW-40's subsystem architectures was constrained to enhance their future retrofit-ability to the large fleet of SW-18 aircraft and its derivative.

The revised program business plan for the SW-40 was now based on an internally funded program which, in the worst case scenario, would sell several hundred aircraft, the optimistic scenario, an order of magnitude more. To reduce its own development cash outlays, five international risk-sharing partners were solicited to share in the development cost of major aircraft modules. In return, the profit from aircraft sales is shared with these partners.

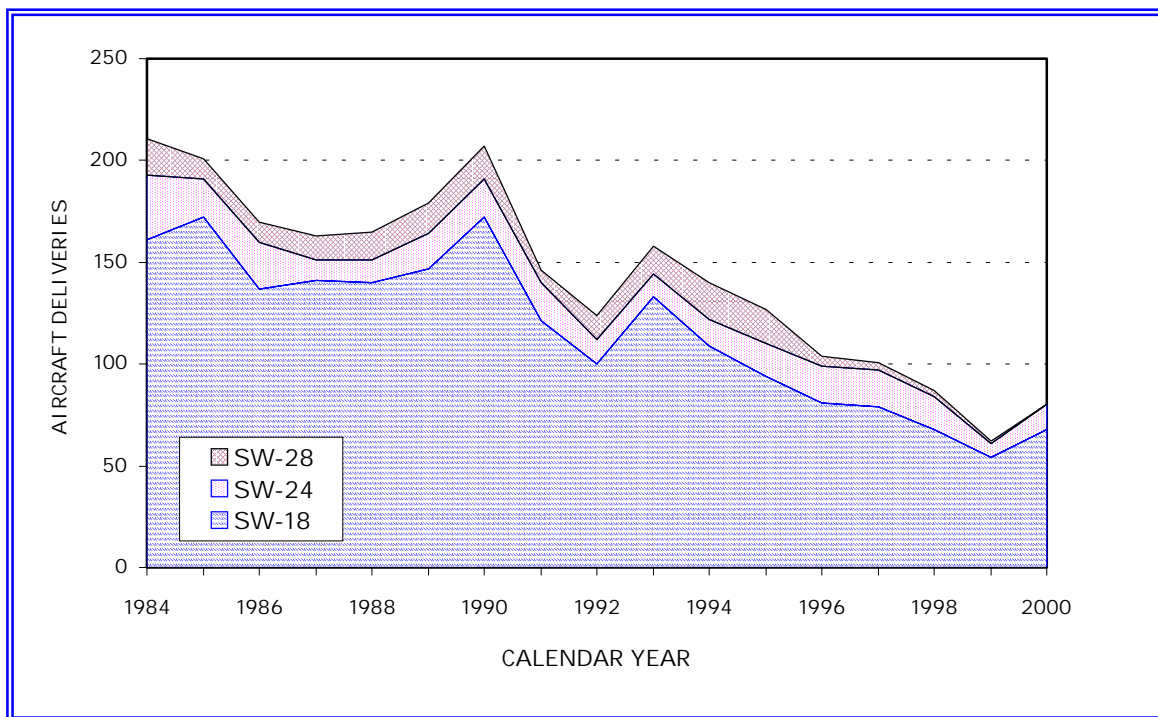
The official launch of the SW-40 program was announced at a major international air show in the mid-1990's. At that time the expected date of first flight was mid-1998 with Type Certification and aircraft deliveries by early 2000. For the purposes of this research, the performance of the SW-40 is benchmarked against this "Second Coming" as it meets the criteria new design aircraft criteria. Documentation which preceded this period was not utilized to establishing performance metrics.

#### **4.4.1.2 Business Climate**

Since starting production, SW-18 and derivatives thereof have been the primary revenue-generating product for Swamp. As depicted in Figure 2-1, SW-18 deliveries to US and foreign militaries during the 1980's averaged 120 to 150 aircraft per year with peaks as high as 172. In the early 1990's, DoD deliveries of these aircraft as well as the SW-28 started to fall as contracts were fulfilled and defense funding dropped due to the demise of the "Cold War". The SW-24 also contributed 10 to 12 aircraft per year.

In the near term, DoD deliveries of the advanced SW-38 were scheduled to commence in 1996. This combined with SW-40 sales and increased foreign sales of SW-18 models were anticipated to offset the declining DoD sales of the SW-18 and -28. However, lacking adequate budget and political support, the SW-38 program slipped continuously during the 1990's, delaying expected revenues from this program. This in turn impacted the funding available for SW-40 development since a large percentage of the development funding was derived from US government IR&D funds.<sup>6</sup>

**Figure 4-7: Annual Aircraft Deliveries / Swamp Aircraft**



#### 4.4.1.3 Program Structure

The SW-40 Program structure conforms to the Integrated Product Development Team (IPDT) model which became popular in the 1990's. The program staff and IPDT's were

<sup>6</sup> IR&D is an acronym for Independent Research and Development. The funds are provided to US government contractors based on a fixed percentage of contract valuation.

collocated in one area of Swamp's engineering department. The IPDT's were organized according to the partner aircraft modules; which in this context includes modules to be designed and manufactured by Swamp and the aircraft assembly. There was also System Integration IPDT that coordinated communication with the partners and Attributes IPDT responsible for ensuring that the aircraft performance objectives were met. The IPDT leads were typically engineers with at least ten years of design and development experience with derivatives of in production legacy models. The IPDT's were staffed from the various functional engineering groups. The majority of the IPDT leads and their staff had no prior experience with the design and development of a "clean sheet" aircraft. Initially, all of the IPDT leads severed ties with their respective functional organizations and became direct reports to the program. This relationship proved undesirable over time and was replaced by a temporary assignment status. This avoided putting experienced and valued personnel at risk during periods of "downsizing". Reportedly, some managers did not fully cooperated with the collocation decree in order to maintain control over their staff. According to some of the sources interviewed, these situations weakened IPDT philosophy.

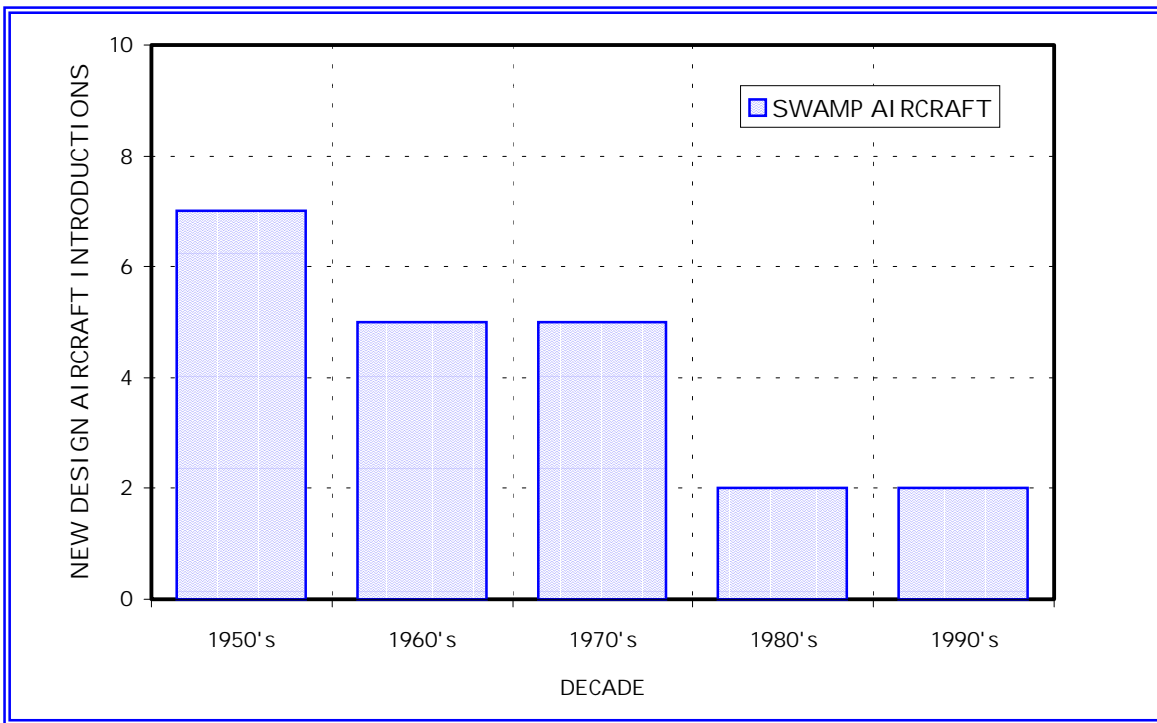
The program staff consisted of a Program Vice President, Program Manager, Chief of Design, Business Manager, Partner Manager as well as few other staff positions. The SW-40 Program VP reported directly to the CEO. The program did not have the traditional Program Engineering Manager or a strong Engineering oversight function. Similarly, there was no official marketing representation until the later stages of the program. The Program VP, company CEO and deputy VP's shared in the marketing duties to fill this void.

#### **4.4.1.4 Intellectual Capital**

Figure 4-8 presents Swamp's frequency of new aircraft introduction. Of all of the case study manufacturers featured in this research, Swamp has rate of new aircraft introductions in every decade. However, in the decade preceding the S-40, new aircraft introductions were just 2. For the 1990's, the only other new aircraft introduced other



than the SW-40 was the SW-38. According to sources, due to several factors, the SW-38 experience has not been a great benefit to the SW-40 program in terms of intellectual capital. The aircraft designs being quite different in terms of configuration, level of technology and intended use. The SW-38 program is housed in a separate, autonomous facility in an adjacent town. Migration of personnel between these two programs was minimal due to the scarcity of resources and the resulting protectionist attitudes of both programs. And lastly, as quasi-concurrent programs, their program schedules were not favorable to any significant migration or resource sharing.



**Figure 4-8: Frequency of New Design Aircraft Introductions**

At the program level, the SW-24 leadership all had distinguished records of service within Swamp. Though, it was heavily weighted towards legacy programs with little or no prior experience with new design aircraft development. In addition, none had backgrounds with any significant flight science exposure..

Staffing levels during the development experienced peaks and valleys but were generally characterized by persons interviewed as "under staffed". This is corroborated by consecutive years where the program under spent their budgets and the frequent schedule slippage.

Many former NUAC / SW-24 "key players" were still employed at Swamp when the SW-40 was launched and the earlier program years. Most of these personnel held middle/upper level manager positions, including the CEO, several VP's and functional engineering directors or were prominent engineering technical specialists. Many of these individuals were offered early retirement incentive packages during the mid to later 1990's to help achieve the company's downsizing plan. Few, if any were still employed at Swamp by the time the aircraft embarked on its maiden flight.

#### **4.4.1.5 Tools**

The SW-40 utilized all of the state of the art design and development tools including a sophisticated 3D digital CAD/CAM system called CATIA. This system was first introduced on a large scale with great success on the SW-38 program. Using this system, machined parts are fabricated by numerical controlled machines directly from the digital data. Another feature enabled a three dimensional virtual representation of the aircraft design to be assembled in whole or in part from a database of CAD files of components and sub-assemblies. This was utilized to evaluate interferences as well as maintenance access and vision obstruction. This referred to as the DMU, or digital mock-up. A host of finite element tools for modal analysis, stress analysis (NASTRAN) and fluid dynamics codes were utilized as well. An International Wide Area network (IWAN) was established to enable the exchange of this digital design and analysis data with the risk-sharing partners over satellite links.

One fifth and one sixth wind tunnel tests were conducted to validate the early configuration and develop the basic data used to construct a flight simulation models.

The relative use of wind tunnels was described as less than the SW-24 program and about equivalent to the SW-18 program.

Many hours of full-scale test development flight test data were accrued on the SW-40 main wing using an SW-18 flight test aircraft as a surrogate SW-40. The flight test version of the wing of the wing was shorter in span with respect to the actual SW-40 wing.

#### **4.4.1.6 Flight Testing and Development**

The first flight of the SW-40 occurred near the close of 1998 calendar year, twenty-one months later than the original scheduled date. While the maiden flight went well, the aircraft flew significantly more nose up than was predicted or would be acceptable for achieve type certification. Subsequent flights also revealed the aircraft to have marginal longitudinal stability at some CG's and excessive control system actuator and horizontal tail loads during some flight regimes.

Over the next year and one half, the SW-40 team focused on resolving these issues. This entailed many diagnostic flights with the baseline configuration eventually leading to the fabrication and flight testing of many development-only empennage configurations. These tail configurations were crudely fabricated and attached to expedite the completion of the evaluation of the candidate configurations. A total of 8 iterations were accounted for from research. Changes to the main wing and vertical tail were also evaluated.

Eventually a series of configurations changes were agreed upon which satisfactorily addressed the certification issues at hand. These included; a fuselage stretch, relocation of the horizontal tail from the top of the vertical tail to its base, shortening of the vertical tail and a migration and narrowing of the CG range. Parts were redesigned for increased strength where excessive loads were experienced.

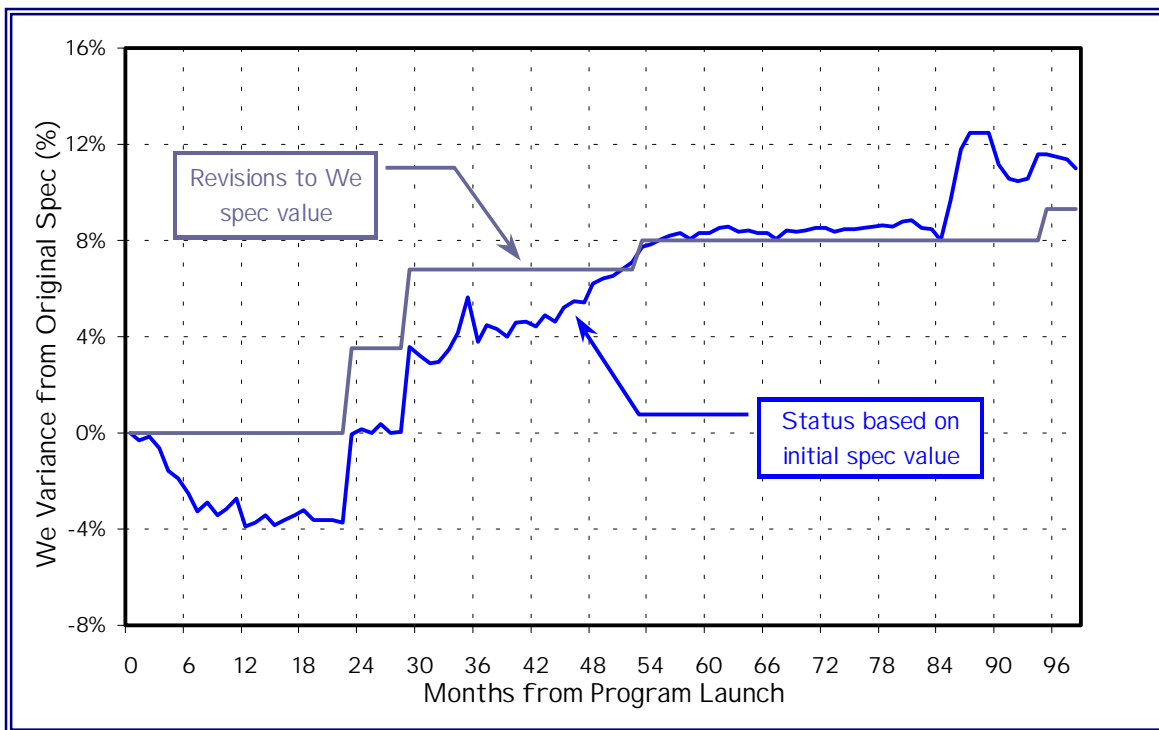
Due to the extensive changes required to update two of the five development aircraft to this configuration, certification flight-testing was further delayed until early 2001, when the first flight of SW-40, aircraft number 5 took place.

## 4.4.2 Metrics

### 4.4.2.1 Weight Data

As with the SW-24, Swamp employed the use of a PVP (ref. Appendix A) to counter weight growth on the SW-40 during design and development. Figure 4-9 presents a summary of the programs weight history from program launch through type certification. As can be seen from this chart, the weight control for the first 20 months was initially successful with the status weight below the spec weight value. However, beyond this point the aircraft status weight and the spec value escalates and never fully quite recovers. At the right side of the chart, where the data terminates, the We spec deviation is 11 %.

**Figure 4-9: SW-40 / We Status During Design and Development**



To offset the steady weight escalation and preserve useful load, the maximum takeoff gross weight was increased 4 times during the design and development phase. This was an effective strategy for recovering useful load at the expense of the budget and schedule required to reanalyze the design at the increased weight and to redesign low margin parts. A maximum takeoff weight variance of +10.3% and a useful load variance of +7.9% are calculated from published data which was closest to the SW-40's TC date.

#### **4.4.2.2 Range Performance**

The initial range specification for the SW-40 is identical to its predecessor, the SW-24. It is derived from the same basic civil version operating with a full passenger load with adequate fuel for two alternate landing locations. As an important customer and design attribute, the range status was reported is on a weekly basis. On several occasions during the program development, the range status declined below the spec target. The most prevalent range countermeasure applied during the program to recover the range was to increase the fuel system capacity, which was implemented on three occasions. Driven primarily by weight escalation, the first redesign, which occurred within about one year after T0, increased the fuel capacity 7%. Since the fuel tanks are not carried in a wing structure, the supporting airframe structure required reanalysis and redesign to comply with certification criteria for flight and crashworthiness.<sup>7</sup> Software for the Aircraft Systems Computer and a few other more trivial areas were impacted also. At this time, no hard tooling had been fabricated or any fuel system qualification testing conducted and as such there was no impact to these areas. Personnel interviewed, who were knowledgeable of these events, agreed that these changes caused adverse impact to the program schedule and budget. However, due to the simultaneous interaction other issues, which also impacted the program schedule and budget, none were comfortable in estimating the impact of these changes.

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<sup>7</sup> Aircraft with wing mounted fuel tanks generally can increase their fuel capacity with minimal impact to airframe structure provided the added tankage is in the wing also.

Two years later in the program, further weight and drag increases reduced single engine performance and range to just below the spec value again. A change to a more powerful, but less fuel efficient engine was an effective remedy for the single engine performance but hurt range performance further, prompting another redesign of the fuel tanks to increase their capacity another 8 %. The impact was broader than the first redesign since it impacted the supplier subcontracted to supply the fuel tanks. The detail design tank as well as some risk reduction testing of the crashworthy bladder had previously been started. Some renegotiations with the supplier were required to cover these changes.

The last redesign to increase the fuel capacity was driven weight and drag increases, this time resulting from changes to the aircraft fuselage length and empennage configuration. This iteration increased the fuel capacity another 8.5% requiring the redesign of the fuel bladder, fuel gauging and venting system. Reanalysis fuel tank support structure and the potential requirement to conduct another round of fuel bladder and tank drop testing. As with the prior changes, there was clearly budget and schedule impacts resulting from this redesign effort, but no reliable means of estimating them.

In summary, the SW-40 team was effective at meeting their range specification through a series of fuel capacity increases, which accrued to a 26% increase in its capacity over the baseline spec value. However, these changes adversely impacted the program's and subcontractors schedule and budget.

#### **4.4.2.3 Altitude Performance**

The altitude specification set forth at the outset of the program was based on performance with full fuel and passengers. The most current projection of this capability at Type Certification is a shortfall of 26.5%. As with the single engine performance, some of the lost performance was recovered by the 5% increase available power made possible with a switch to a more powerful engine. These changes were accomplished with relatively little impact to the design, schedule and budget. The more powerful

engine was a planned option for introduction later in the program and the transmission rating increase was a previously established contingency plan. Some schedule impact resulted from the engine development schedule which did not coincide with the first flight, type Certification and production start up dates. In fact, the first two test aircraft did not receive these engines but the less powerful version.

#### **4.4.2.4 Schedule**

Based on the was the date established when the program was officially launched with the blessing of Swamp's corporate parent in mid 1995. The Type Certification schedule deviation is projected to be 48 months. Some lost schedule is expected to be recovered between TC and the first aircraft delivery, with the schedule deviation of +44 months.

#### **4.4.2.5 Major Specification Changes**

Fourteen major specifications changes were gleaned from various aviation industry references as well as internal sources. The majority of these changes have been introduced in prior sections. Four of the fourteen changes are attributed to increases to the maximum takeoff gross weight of the aircraft, cumulatively totaling 10.3% over the original design specification. Another four to design changes identified as a result of issues identified during early flight testing; empennage design changes, fuselage stretch and wing relocation. Three are attributed to fuel tankage redesigns that yielded a 26% increase in capacity. And, two by performance requirements; a change to a more powerful engine and a drive system rating increase.

The last change is not discussed in the prior sections, a complete redesign of the aircraft's avionics system. This is a somewhat gray item, especially in context to the disco era programs, which were equipped primarily with non-integrated mix of electro-mechanical systems. The MS era aircraft are both equipped with "glass cockpits" based on integrated digital based systems. For these aircraft, abandoning a relatively complete and mature avionics system design is costly.



Reportedly, there were several issues, which contributed to this late change with two emerging as the primary drivers. Business issues related to industry consolidation and downsizing within the aerospace industry can characterize the secondary issues. The first of the primary issues was negative customer feedback of initial SW-40 avionics system. Simply stated, the majority of the potential SW-40 customers had pre-existing relationships with another major avionics manufacturer and had, to a large degree standardized their aircraft fleet on this manufacturer's systems. While not well understood at the outset of the program, this loyalty was based on more than preference, having business and safety dimensions. Standardization reduces the amount of training required for both the pilots and maintainers and the amount of spares required in context to having a multitude of systems. Safety is enhanced by reducing the probability of a pilot reacting incorrectly in a critical situation due to a misinterpretation of information rooted in a differing display convention used by another manufacturer.

The second major issue was the lack of system modularity, which would made it difficulty to upgrading or add popular features and/or options not present within the basic system.

While this discussion certainly has some strong technology dimensions, it is fundamentally a case where the manufacturer had a weak understanding of its customer. The fact that the disco era aircraft did not have systems of such complexity is a moot point, thus I have I am including in the total. It also meets the visibility criteria, as it is a change that is detectable to the industry press. Some of the changes that are discussed in prior text did not meet this criteria and therefore are not included in this tally.

#### 4.4.2.6 SW-40 Performance At Type Certification <sup>8</sup>

**Table 5: SW-40 Metric Variance Summary**

Initial Specs:	Deviation
We	+12%
Useful Load	+7.9
MTOGW	+10.3%
We/MTOGW	+1.44%
Range	+7.5%
HOGE	-26.5%
First Flight	+21mo.
Type Certification (projected)	+48 mo.
Initial Delivery	+44 mo.
Major Specification Changes	14

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<sup>8</sup> The SW-40 had not obtained Type Certification. These metrics are based on the latest available data at that just prior to the publication of this research.

#### 4.5 Case Study Metric Summary

Table 6: Case Study Metric Variance Summary

Design Attribute Metrics:	B140	SW-24	M700	SW40
We	21%	7%	36%	12%
Useful Load	14%	2%	6%	10%
payload	16%	3%	-18%	7%
MIOGW	18%	3%	11%	10%
Range	-30%	1%	-22%	8%
Altitude	-36%	22%	9%	-27%
Program Performance Metrics:				
First Flight	8	9	9	21
Type Certification (VFR)	11	6	12	48
Type Certification (IFR)	17	8	33	48
Initial Delivery	10	8	12	44
Design Maturity Metrics:				
Specification Changes	9	2	12	15
Flight Test Hours	3000	1500		1800
Intellectual Capital Metrics:				
New Design Introductions, prior 10 yrs.	3	5	1	2
New Design Introductions, prior 20 yrs.	9	11	5	8

## **5 RESULTS AND DISCUSSION**

### **5.1 Program Ranking**

#### **5.1.1 Metrics**

To make the relative performances of the subject programs clearer, a simple ranking technique based scale of 0 to 100 was applied. For each metric category, the high score of 100 was assigned to the "best in class" performance and a zero to the "worst in class". The intermediate scores were determined by linear interpolation these extremes. Table 6 presents the summarized results of this ranking.

The tallied score for each program, provided at the base of each column, is simply the arithmetic sum of the metric scores. These scores are not intended to be the end of this story but a means of providing direction to useful in understanding the relative performance of these programs but not the end of the story. A more "balanced scorecard" could be attained by eliminating some of the overlapping metrics.

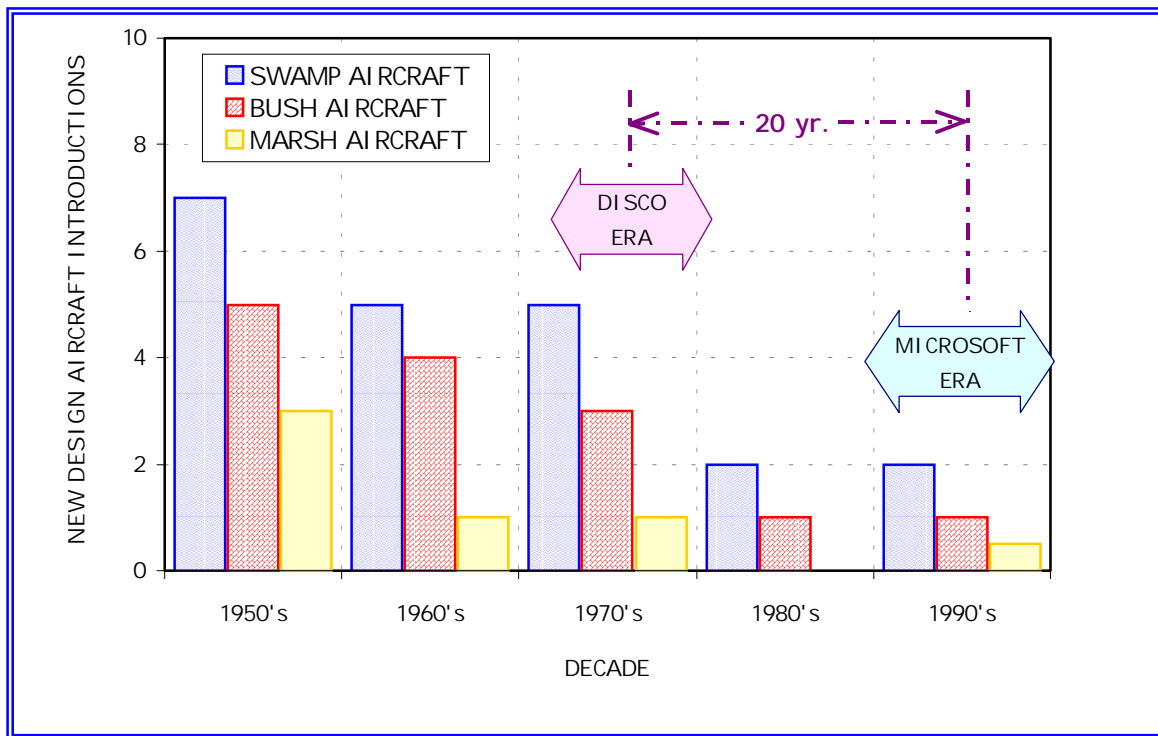
**Table 7: Scored Case Study Metric Comparisons**

	<b>B140</b>	<b>SW24</b>	<b>M700</b>	<b>SW40</b>	<b>DISCO</b>	<b>MS</b>
<b>Design Attribute Metrics:</b>						
Weight	52	100	0	83	76	41
Useful Load payload	100	0	33	69	50	51
MIOGW	100	62	0	74	81	37
Range	0	100	47	51	50	49
Altitude	0	83	21	100	41	61
Altitude	0	100	78	16	50	47
Subtotal Scores:	<b>252</b>	<b>444</b>	<b>179</b>	<b>393</b>	<b>348</b>	<b>286</b>
<b>Program Performance Metrics:</b>						
First Flight	100	92	92	0	96	46
TC (VFR)	88	100	86	0	94	43
TC (IFR)	78	100	38	0	89	19
Initial Delivery	94	100	89	0	97	44
Subtotal Scores:	<b>360</b>	<b>392</b>	<b>304</b>	<b>0</b>	<b>376</b>	<b>152</b>
<b>Design Maturity Metrics:</b>						
Specification Changes	46	100	23	0	73	12
Flight Test Hours						
Subtotal Scores:	<b>46</b>	<b>100</b>	<b>23</b>	<b>0</b>	<b>73</b>	<b>12</b>
<b>Aggregate Score Totals =&gt;&gt;</b>						
	<b>658</b>	<b>937</b>	<b>506</b>	<b>393</b>	<b>797</b>	<b>450</b>
<b>Intellectual Capital Metrics:</b>						
New Design Aircraft, Prior 10 years	50	100	0	25	75	13
New Design Aircraft, Prior 20 years	67	100	0	50	83	25
Subtotal Scores:	<b>117</b>	<b>200</b>	<b>0</b>	<b>75</b>	<b>158</b>	<b>38</b>

### 5.1.2 Intellectual Capital

Figure 5-1 presents a summary of the frequency of new aircraft introductions for all three case study manufacturers. Each individual set of data has been previously presented along with each of the respective case studies in section 4. The Intellectual Capital metrics presented in Table 7 and Figure 5-1 have been derived from the same set of data. However, predecessor decades in Table 7 are referenced to the program launch dates and not calendar decades.

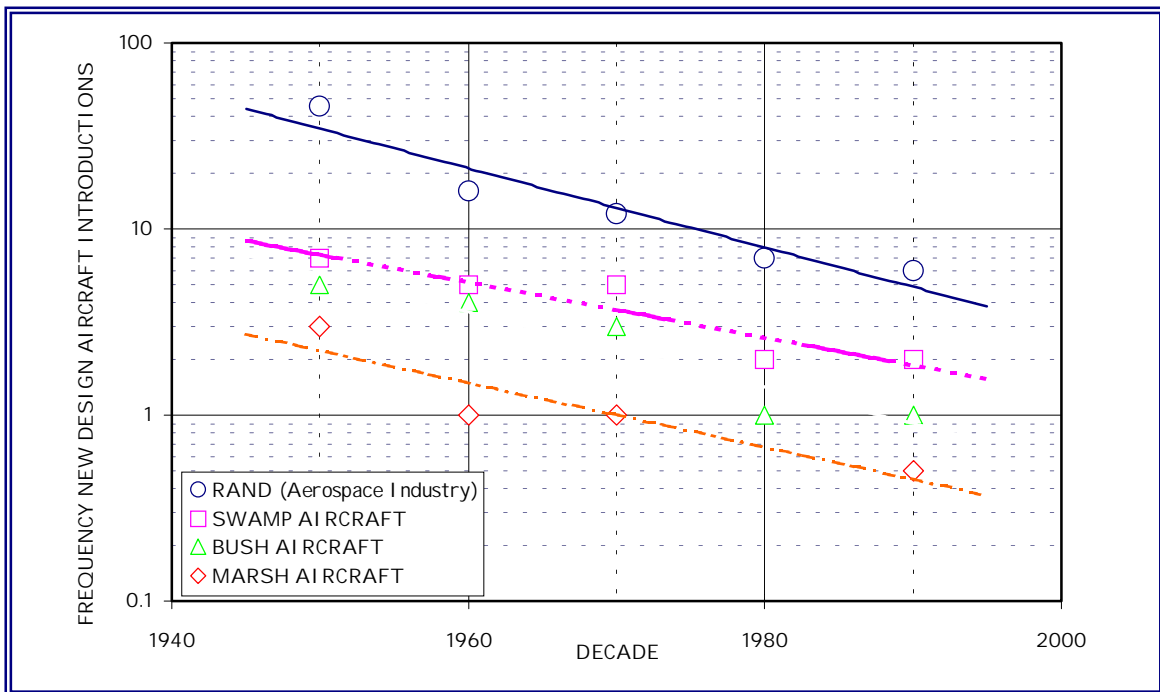
**Figure 5-1: Frequency of New Aircraft Introductions / All**



The calendar reference employed in Figure 5-1 and its predecessors were derived from the RAND study (ref 1) in order to facilitate comparisons with industry wide data presented in this research. Such a comparison is presented in Figure 5-2. In order to accommodate the differing order of magnitudes of the manufacturer and industry level

data, the data is presented with semi-logarithmic format. Conveniently, this technique also exposes the exponential nature of these trends and again illustrates the similarity of the decay rates of the case study manufacturers and aerospace industry as a whole.

**Figure 5-2: Comparison / New Design Aircraft Introduction Decay Rates**



## 5.2 Intra-Era Comparisons

### 5.2.1 Disco Era; SW-24 and BA140

The two disco era aircraft are somewhat linked in history, even aside from the comparisons made in this study. Both aircraft were designed to capture the same customer base and in some respects influenced each other in terms of their aggressive design/development schedules and their introductions in to service. Both aircraft represented firsts for their respective manufacturers, as they were the first aircraft produced exclusively for a commercial market using only corporate financing. Put

another way, they were the first aircraft that were not spawned from major US military DoD contract.

With regards to this work and the metrics established for comparison, the disco era programs are most similar in the areas of intellectual capital, program performance and specification changes with both aircraft bettering their disco era counterparts. In terms of design attribute metrics, the SW-24 program, as well as one of the MS era programs performed significantly better than the BA140 program. However, the intra-era ranking correlates with the IC metrics, with the better performance going to the SW-24 program with more IC depth in terms of new design aircraft introduction in the prior decades.

Looking in to this issue further, there were three new design aircraft Bush introduced in the prior decade. For two of these programs, the BA70 and BA100 the development activity is on the far side of the prior decade. The remaining aircraft, the XBA135, a prototype aircraft of which three were produced, did not progress beyond the prototype phase, as the contract was awarded to a competitor. It is certain that these prototype aircraft did not attain the same level of maturity as a production aircraft. Often in the case of prototype aircraft competing for a major DoD contract, some latitude is given to the prime contractor(s) in terms of "bookkeeping" a level of performance that cannot be demonstrated by the actual prototype aircraft. This is to account for compromises in materials and technology made to expedite the construction of the prototype aircraft. The prime contractor must have a convincing story as to how this capability will be achieved on the production version of the aircraft.

A simplistic example of this would be the substitution of plate steel for the prototype aircraft in lieu forged titanium for the production wing attachment fittings. This expedites the development and reduces the cost by avoiding a wait for long lead-time titanium forgings. The deviations incurred by these compromises and their impact on various performance parameters are tracked so that the performance of the actual production aircraft can be derived from the prototype aircraft performance. In a highly competitive



DoD contract, these corrections can be significant and with the rationale often bordering on "smoke and mirrors".

Without the experience of transitioning the XBA135 prototypes into rate production deliveries of 10 compliant BA135 aircraft per month, a segment of the Bush workforce is left with an experience void with respect to the winning prime contractor.

Not included in the IC metrics was the XBA120 aircraft, which succeeded the BA140 program by a slight margin. According to interviews, the design and development activity period for this experimental research aircraft overlapped that of the BA140. However, in addition to the issues discussed in the context of the XBA135 program, XBA120's research focus, and physical and technological separation prevented it from providing any significant benefit to the BA140 program.

Swamp's predecessor aircraft are also weighted towards experimental aircraft program with 3 of the 5 aircraft being experimental research aircraft. However, two of the programs were aircraft that achieved rate production with the S-24 following closely on the coat tails of one of those programs. The freshness of the lessons learned from this predecessor program was cited as a vital element in the success of the SW-24 program on multiple occasions during interviews. This is discussed further in subsequent sections.

In summary, the implications introduced by these observations are that; the design, development and manufacture a limited build prototype aircraft may exclude or de-emphasize important experiences necessary to ensure a successful transition a new aircraft design in to rate production. And, the more recent the experience is, the more likely it is to benefit the successor program.

### **5.2.2 MS Era; M700 and SW-40**

As with their disco era counterparts, both the MS era aircraft programs were developed with corporate financing on speculation that there was sufficient demand for these aircraft within the worldwide civil aviation market. This was a first such endeavor for Marsh aircraft and the second for Swamp aircraft. However, based on articles published in the aviation press, both manufacturers were very hopeful of landing some kind of DoD contract award.

With regards to this work and the metrics established for comparison, the MS era programs are most similar in the areas of intellectual capital, program performance and specification changes as both aircraft rank third and fourth in these categories. In terms of design attribute metrics, the SW-40 program rank is much closer to the SW-24 than it is to the M700, which has the lowest ranking in this arena. However, as with the disco era programs, the intra-era ranking correlates with the IC metrics, with the better performance going to the SW-40 program with more IC depth in terms of new design aircraft introduction in the prior decades.

The intra-era ranking for frequency of specification changes is consistent with the IC metrics from a simple 1-4 ranking perspective. However, the SW-40 is really in a class by itself, capturing the lowest rank by a considerable margin. As described in section 4, this program has the most ambiguous program start date as it experienced at least one clear "false start" and arguably a couple of "quasi false starts".

### **5.2.3 Disco Era vs. MS Era**

Based on the averaged Disco and MS era scores tabulated in the far right columns of Table 7, there is a consistent pattern of ranking, with the Disco era programs scoring the highest all metric categories, design attribute, program performance and design maturity. At the subcategory levels, the disco era outscore the MS era with exception of

range. Arguably, the scores for useful load, MTOGW and altitude could be considered a tie.

The program with the highest frequency of "best in class" scores is the SW-24 program. Ironically, the program with the highest frequency of "worst in class" scores is the SW-40 program. This issue is explored further in the subsequent section.

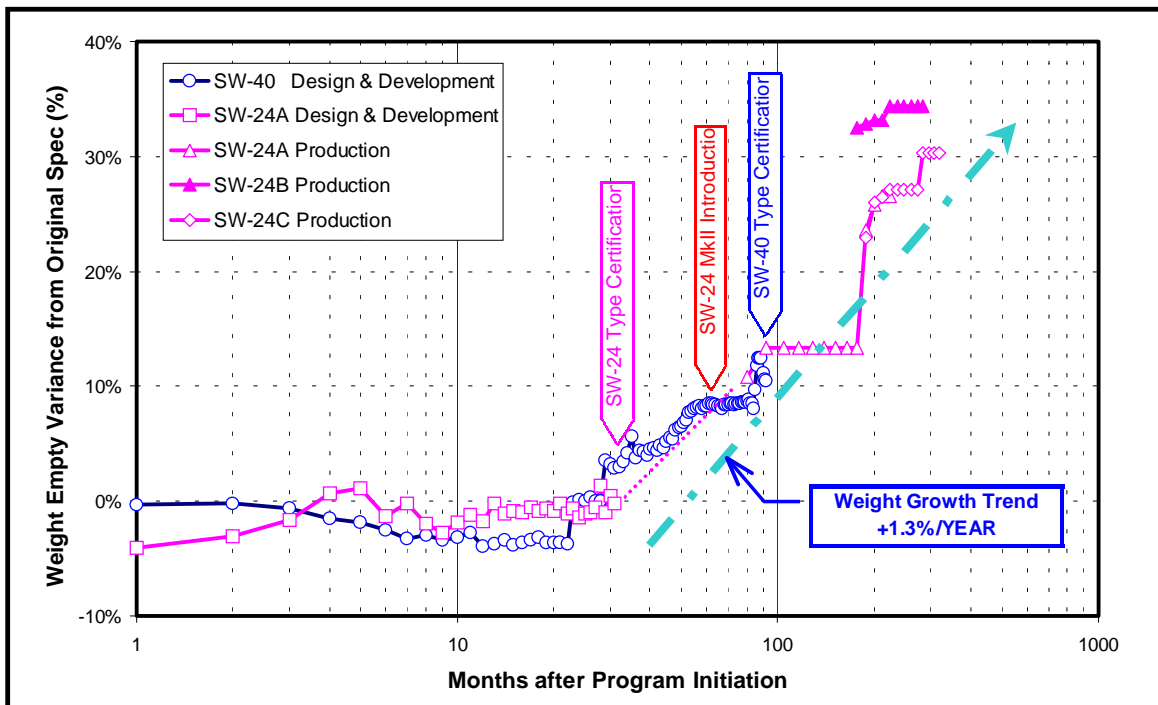
#### **5.2.4 Comparison of SW-24 and SW-40**

In nearly all categories, the SW-24 performance exceeds that of the SW-40. Interviews of current and former Swamp employees who contributed to both of these programs provided valuable insight into understanding this performance differential. Consistently, the NUAC program, which preceded the SW-24 played an important role of the interviewee's explanation of this performance differential. In short, during the later phases of the NUAC program, Swamp Aircraft and Big Valley Aircraft were competing against each other for the aircraft that would replace the thousands Bush B50 aircraft in US DoD service. For the first year and a half of flight testing Swamp's XSW-18 prototypes were performing far below expectation. They were overweight, and did not meet the speed, payload and performance objectives. In addition, severe vibration and low speed handling qualities problems limited the amount of useful flight testing that could be conducted. Little progress was made until a shift in program management towards individuals with stronger flight sciences and aircraft technologies backgrounds. As the story goes, within six months the severe vibration problem was solved by changes in the wing and the low speed handling problem were solved by replacing the fixed horizontal tail with a stabilator. These changes alone also improved of the performance attributes which were in turn further improved by focused weight and drag reduction activities. In the end, Swamp's XSW-18 outperformed its Big Valley counterpart, the XBV-179, by a significant weight and performance margin and was awarded the NUAC contract. The dramatic end of this story is standard Swamp Aircraft

lore. However, the details of the SW-18X's poor performance in the early phases and the steps taken to resolve the technical issues is relatively unknown.

Despite this great victory, some within Swamp realized that many of the problems encountered with the initial NUAC prototypes could have been avoided and that steps should be taken to preempt such problem in the future. Local "Lessons Learned" data bases were created to capture this knowledge. The database included not only NUAC lessons but from other programs as well. The effort was championed by Swamp's engineering management team.

**Figure 5-3: Swamp SW-24 and SW-40 Weight Growth Profiles**



The SW-24 program, following on the coat tails of NUAC was the greatest benefactor of this period of reflection and freshly Xeroxed documents resulting from it. While it is not the intent to expand the scope to include all the the NUAC lessons learned, ones that which potentially impacted the performance metrics are discussed.

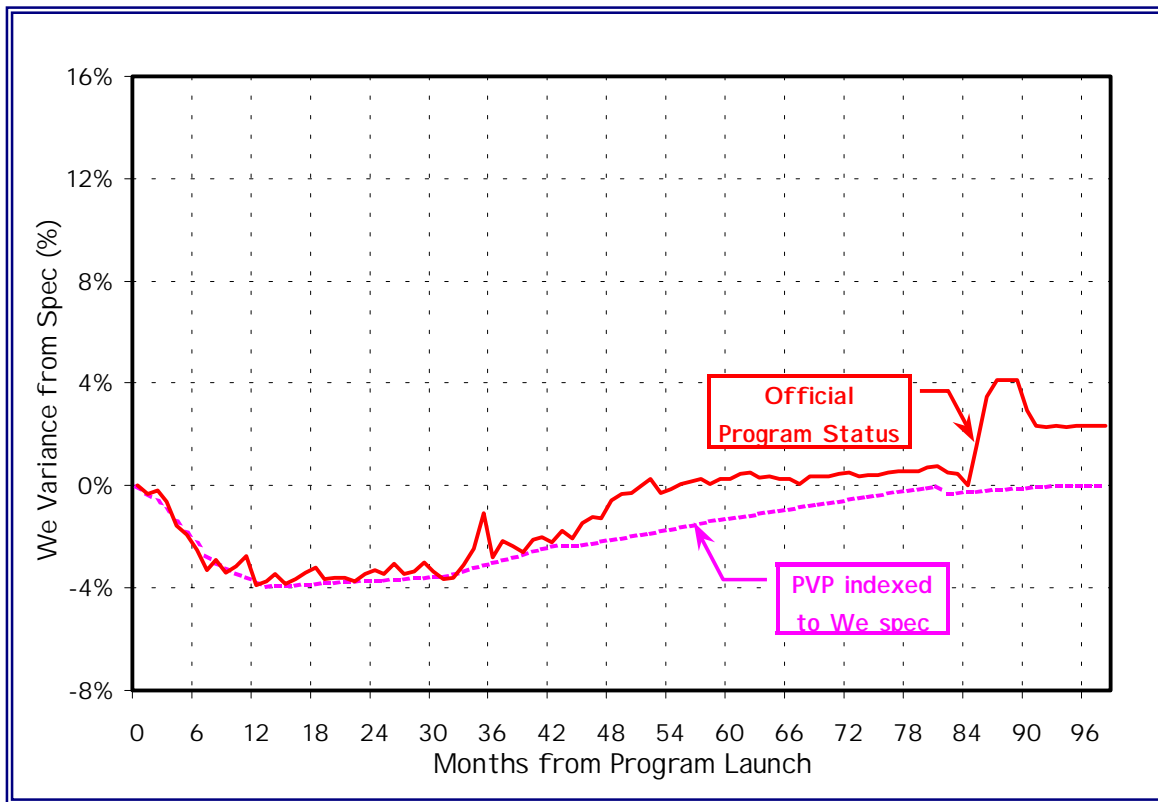
As presented in their respective sections, both the SW-24 and SW-40 utilized the same PVP methodology to control aircraft weight growth. As evident from Table 7, the SW-24 weight control was quite good through its initial type certification and "best in class" among its case study counterparts. One of the subjects interviewed stated that the program manager, and later the VP of Engineering, enforced a "pound in pound out mandate." He further explained that, if it was concluded that one pound needed to be added to a particular system or component on the aircraft, a pound which can be removed must be found somewhere else in the aircraft. He also recollected that this program manager strongly believed that the overall health of an aircraft development program was reflected in weight status charts. Historically, this view is shared by military procurement agencies which universally use weight as a primary program help metric.

For comparison purposes, the lifetime weight growth of these two aircraft is presented in Figure 5-3. Included is the design and development weight status for both models and the specification weight for production SW-24 and subsequent derivative models. The time lines are baselined to their respective program launch dates.

Initial impressions of this comparison by colleagues has consistently generated similar responses, "they look about the same." The status weights of both aircraft fluctuate at or below the spec weight for 30 months or so and then begins to climb. For the SW-24, the weight gain starts a few months prior to type certification, continues steadily in response to design is modified to eliminate aircraft problems identified during field use. The weight stabilizes with the introduction of the MkIV model and stair steps with each successive derivative model. This, according to one of the Swamp weight engineers interviewed, is a "classic" lifetime weight growth history.

The major discriminator between the SW-24 and the SW-40 weight growth trends is that the SW-24's achieved type certification within the left hand portion of the weight trend where there exists strong weight control and the weight is relatively stable. Its weight does not start to climb until the aircraft enters production when the weight control effort is significantly reduced or non-existent. In contrast, the SW-40, with the same alleged weight control methodology, is quite good for the initial 20-30 months, when it steadily climbs at a rate of a production aircraft.

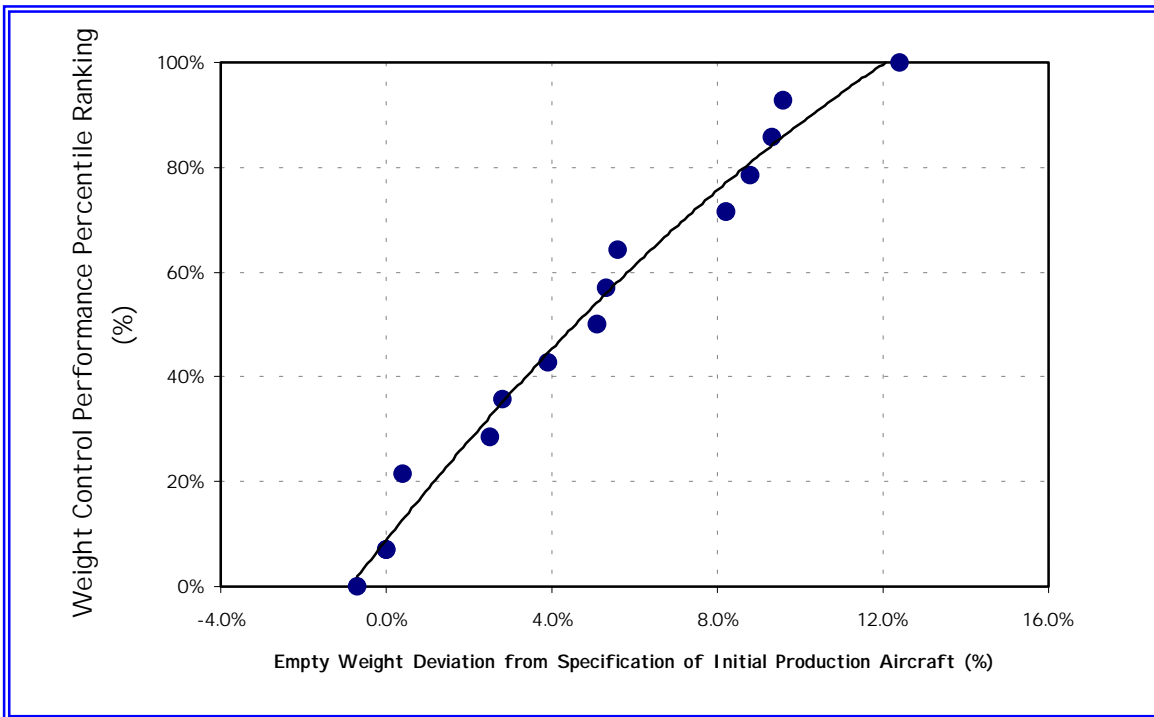
**Figure 5-4: SW-40 / Official Program Empty Weight History During Design & Development**



The SW-40 empty weight status, also plotted in Figure 5-3, starts off well but starts to falter in the 20-30 month range. Beyond that its weight growth is similar to that of the post TC SW-24. When queried about the general effectiveness of the SW-40 weight

control , weight engineers consistently complained that program management would not support an aggressive weight control program early in the program when it would be most effective. This reluctance, in their opinion, was rooted in program staffing/funding constraints. It should be noted that these responses were referenced to their own internal weight status charts which are not presented in terms of percent and are referenced to spec empty weight. Figure 5-4, although still presented in terms of percent, represents Swamp's internal accounting of the SW-40's weight variance through the program. In reviewing this chart, one would agree that the weight control was not perfect, but reasonably good by industry standards. In fact, a +3% weight variance at type certification would be ranked in the top 30<sup>th</sup> percentile with respect to weight control compared with Army aircraft programs of the same type over the past 30 years (ref. Figure 5-5).

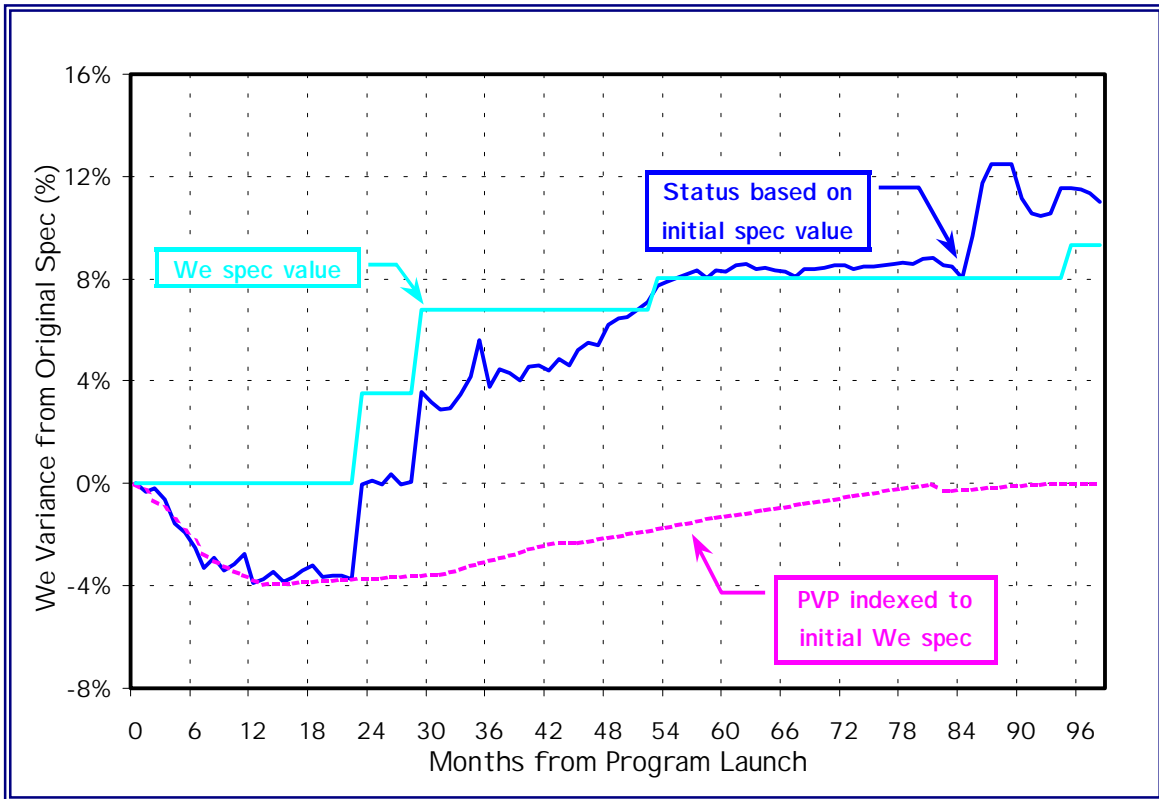
**Figure 5-5: Weight Empty Variance from Initial Specification versus Percentile Ranking for DoD Aircraft of the Same Type**



In contrast, Figure 5-6 is constructed from the same set of weight status data, re-referenced to the SW-40 initial specification weight empty as are the We variance metrics described in Section 3 and summarized in Table 6. The weight deviation peaks at 12.5% and closes out at 11.6%. at the 100 month mark. Again, referencing Figure 5-5 this is a relatively poor, lower 2 percentile performance. Also depicted is the We spec value which has increased four times for a total of 8%.

In electing to status the weight empty PVP in terms of weight empty delta instead of actual weight empty, the cumulative impact of spec revisions to the weight empty are lost to an audience of managers viewing the chart. Considering program managers come and go during the duration of such a project, it is unlikely that today's program manager can possibly grasp the full context of situation.

**Figure 5-6: SW-40 Empty Weight History Referenced to Initial Spec Value**





An aerodynamacist who participated in both the SW-24 and SW-40 programs pointed out that the use of PVP's was not limited to weight, but were also developed and utilized to improve the probability of meeting other important SW-24 aircraft attributes such as range, cruise speed, and rate of climb. This is supported by markings on some of performance attribute tracking charts obtained from other sources. This approach was not adopted for the SW-40 and the interviewee felt that the program could have benefited from this approach.

This person also recited specific NUAC lessons learned that were adopted a design rules and employed on the SW-24 program to ensure performance goals were met. They were:

- The final aircraft fuselage outer mold lines (OML) or fuselage shape must be windtunnel and hover stand tested to ensure that drag assessments are correct and wake interactions are understood.
- Analytical models used to predict performance must take advantage of the most up to date codes and be properly correlated utilizing windtunnel data.
- Any new design wing system must be undergo a full scale wind tunnel testing.

The SW-24 programs compliance with these three NUAC lessons Learned is well documented in several technical papers presented at industry conferences and published in several industry technical journals The extensive analysis and wind tunnel testing efforts required significantly greater front end staffing than NUAC. This was described by the interviewee in the following manner, "the SW-24 had half an aero department working on it." In contrast, the NUAC staffing was described as "one aero guy who was "thrown off" the program for not being success oriented."

In comparison, the SW-40 program conducted more windtunnel testing than NUAC, but less than the SW-24 program. On fifth and one sixth wind tunnel models representing a very early SW-40 configuration was tested. The sortened version of the wing on a SW-18 flight test vehicle.

According to interviews, a risk reduction program of scale model testing and analysis was proposed for the SW-40 but was nixed due to budget constraints. The staffing level for the SW-40 rarely exceeded that of one man which meant that the aerodynamacist was consistently overwhelmed by the amount of work at any given point in time. As such , work is done to a shallow level and rarely checked due to time constraints. At least one substantial performance prediction error was attributed to this situation. It was particularly embarrassing because it was a very simple error which could have been easily been caught with a very high level checking process. Instead, the error lingered undetected for several years before being identified and corrected. The interviewee also mentioned felt that he felt a "standard work" approach could help avoid this situation.

It is interesting to note that the lessons learned regarding risk reduction wind tunnel testing were not adhered to on the SW-24B which received its TC in 1985, 7 years after the initial TC of the SW-24A. This later impacted the certification schedule as the aircraft alternative empennage configuration iterations were designed, manufactured and evaluated on the development flight test aircraft. This was quite a surprise at the time as this was considered a straight forward "re-engine" program.

The SW-24B performance on weight control at TC was also quite poor with respect to the SW-24A. The aircraft was overweight by approximately 6 % based on weight empty, 20% based on the perecentage of the aircraft weight which represents new and/or redesigned systems.<sup>9</sup>

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<sup>9</sup> About 2/3'd of the SW-24B weight empty is represented by legacy SW-24A systems with which there is no uncertainty in its weight.

Two explanations as to this phenomena were offered by interviewees. The first is based on how vivid the organizations recollection of the pain of the prior traumatic experience. The SW-24B followed the NUAC difficulties by about ten years, enough time to forget the pain of the events. The second explanation was presented differently but may be essentially the same. It focused on career paths of the experienced personnel who had lived through the NUAC and SW-24A experiences. The efforts and the talent of many of these were people and their contribution to the companies success was recognized and they were promoted to higher level management positions within Swamp and United Technologies. As their careers ascended, the availability of their experience to the larger engineering workforce is reduced or eliminated and their former positions are filled with lesser experienced personnel. Not to say that these personnel lack experience in the broader context, but they are lacking the key experiences which allows them to recognize the key technical and strategic decisions which differentiate between success of failure in developing a new aircraft.

Over time, the recollections and protests the few remaining knowledgeable technocrats are progressively less persuasive and subject to overriding rationalizations regarding a new analysis, budget constraints or other which makes not prudent to do the prudent thing.

In most cases, an employee who has made his point clear on an issue will not pursue it to the point of jeopardizing his job. If he or she is convinced they communicated their message clearly to the group at large, they are willing to drop the issue, commonly documenting their position and the program and or managements decision not to heed to their warnings.

The disparity between the SW-24 and SW-40 approach with regards to risk reduction testing and early staffing had the most adverse impact in the area of handling qualities. As detailed in reference (1), the series of windtunnel and hover stand tests and flight simulation conducted during its design proved effective in minimizing empennage

configuration changes during flight testing. Most notable was the fact that the SW-24 team was prepared to evaluate several tail configurations going in to flight testing. The SW-24 entered its flight test development program with a horizontal stabilator with incidence actuated as a function of speed to provide good low speed pitch characteristics and positive stick gradients throughout its operating speed range. It was hoped that this system would not be necessary and that a fixed incidence stabilizer would prove to be an adequate solution. The introduction of a fly by wire tail was not considered desirable from a safety standpoint so long as the fixed tail performance proved adequate. In addition, the team was prepared to evaluate other contingencies, including a pitch bias actuator (a device that is used enhance the stick gradients) and horizontal endplate and planform configurations. This preparation proved effective at quickly solidifying the final configuration, a fixed horizontal tail with a pitch bias actuator. The ability to change the horizontal tail pitch in flight proved valuable in reducing flight testing time as high confidence A to B comparisons could be made quickly.

The approach to empennage development and handling qualities risk reduction for the SW-40 also involved wind tunnel testing and flight simulation. However, as previously stated, the amount of testing conducted was considerably less. Also, in all testing, a single balance was used whereas the majority of the 1/5 scale tests conducted with the SW-24 utilized independent fuselage, wing and tail balances. This provided a much higher fidelity information which was particularly important to the development of the empennage configuration. Hot wire velocity probes were also utilized to map the wake velocities about the empennage.

The majority of empennage configuration development for the SW-40 was conducted on the first two flight test vehicles. Steel mounting provisions which would accommodate a variety of tail configurations was developed. Eight horizontal tail and two vertical tail configurations and were evaluated. In addition, some configurations were evaluated at varying incidence and with modified airfoil contours to alter the lift slope characteristics.

### **5.2.5 Discussion of Key Findings**

Examination of these case studies showed a strong correlation between intellectual capital metrics and the performance metrics for programs. The correlation was found at both the intra-era and inter-era comparisons and within all metric categories. Deeper investigation into the root causes of the correlation consistently validated them to be true IC issues and not some confounding outside phenomena.

Although no numerical technology / tool metrics were assigned, it is clear that the MS era programs, with superior tools across the board, achieved lower scores in all areas. This is not to say that these tools did not provide benefit to these programs. In fact, both the disco era programs likely could not have been executed with international partners as they both were. In addition, the manufacturing quality of both MS era aircraft far exceed their disco era counterparts.

Some negative impact was found to be associated with today's computational tools. Not so much the tools themselves, but with regard to the tacit knowledge derived when interacting with them. Two engineering managers interviewed, separately and without any solicitation, expressed the concept that today's tools, are much less effective at developing the tacit knowledge of the users.

Sophisticated simulation models of all types, some with realistic graphic presentations seem to command a greater level of creditability than they deserve in many cases. The handling quality problems encountered by the SW-40 fit this description. The simulation model used in the design of the aircraft configuration and its automatic flight control system (AFCS) had many flaws, leading to significant design changes very late in the program and program slippage. In digging for a root cause, it is clear that there were significant shortcuts were taken with respect to supporting wind tunnel testing and modelling effort needed to develop a model worthy of the level of confidence with which it was being applied.

It is appropriate to reinforce that there were highly experienced and senior aerodynamicists and handling qualities engineers who brought these same critical issues to the table at the appropriate time, early on in the development program. They lobbied for more resources and wind tunnel testing and in their words, ignored. Intellectual capital is not just about having the knowledge within the boundaries of the company facilities. There must be enough "critical mass" of intellectual capital to overcome making decisions that are counterproductive. In short, there must be enough experienced personnel at key meetings to recognize the cost avoidance value of, in this example, doing more wind tunnel testing. In addition, they have to feel confident that supporting this position will have positive rather than negative consequences. This is difficult to do without some prior experience base and some confidence that other participants in the meeting, like yourself will also lend their support.

The experience of SW-24B, encountering handling qualities issues avoided by its parent aircraft the SW-24A sheds some light on the limitations of knowledge capture and codification. A variety of internal "lessons learned" documents covering broad ranges of issues and models had been published prior to the SW-24 program. Some were codified as new design rules which would eliminate a recurrence. The lessons were adhered to during design and development of the SW-24A and are directly linked to many of the SW-24A's "best in class" program performance metric scores. As noted in section 4, The success achieved with the SW-24 handling qualities and performance development were also documented in industry technical papers.

However, just seven years subsequent to the SW-24 type certification, these same codified rules were circumvented, causing significant program delays as the flight test aircraft underwent many iterations of empennage modifications and months of unplanned development flight testing. Essentially repeating one of the important lessons learned during the development of the XSW-18. A decade later, the SW-40 followed suit in also circumventing these same rules.

Does this imply that knowledge capture and codification is not an effective approach to mitigate the decay of intellectual capital. For Swamp aircraft yes, with the key to understanding being provided by a story presented in section 4. The story describes a latent error which went undetected for several years. The error would never have escaped this organization if there was even a cursory check process in place. While the error was eventually corrected leaving no residual damage to the program, it was extremely embarrassing to this organization. The punch line to the story is the interviewee's statement that, " I think that a "standard work" approach could help avoid this situation."

In essence, he was telling me that really there was no standard work process within his group. The path taken to accomplish a task was largely left up to the individual's discretion. This was also determined to be the predominant approach in other engineering organizations. Publishing "lessons learned" documents and/or incorporating them as process revisions will not be effective at mitigating errors or retaining knowledge so long as they are not part of a process which has been adopted by an organization. These will stay buried in the back of an old grey filing cabinet if not process mandates their incorporation. In the case of the SW-24A, the personnel who lived through and wrote these "lessons Learned" were still directly involved in the day to day processes. There was no need for them to check this filing cabinet to review these lessons learned. "the pain could still be felt" as one interviewee put it. Incorporating the process of checking the filing cabinet is for the engineers that will be hired five and ten years later.

## 6 Summary

- 6.1 Strong Linkage between IC metrics and Program Performance Metrics was established
- 6.2 No instances could be identified where of the use of modern / MS era computational tools offset reductions in program performance linked with reductions in intellectual capital. Note: This is not to suggest that it is prudent or even possible to stop using these types of tools.
- 6.3 Ignorance regarding the process and commitment required to ensure that computational tools live up to their expectations was cited as causing major delays in one of the case study programs
- 6.4 Engineering managers interviewed consistently presented the opinion that many of the modern computational tools are much less effective at developing the users tacit knowledge when compared with predecessor analysis methods.
- 6.5 There must be adequate "critical mass" of intellectual capital. Having one employee who has worked on every single aircraft and knows absolutely everything there is to know will not get you where you need to go.
- 6.6 Knowledge capture and/or knowledge codification methods will not be effective if they are implemented in non-process oriented environments.
- 6.7 A design and development team with experience weighted towards prototype and experimental aircraft is likely to lack the disciplines required to bring a new



aircraft design through certification and rate production within its specified performance and schedule targets.

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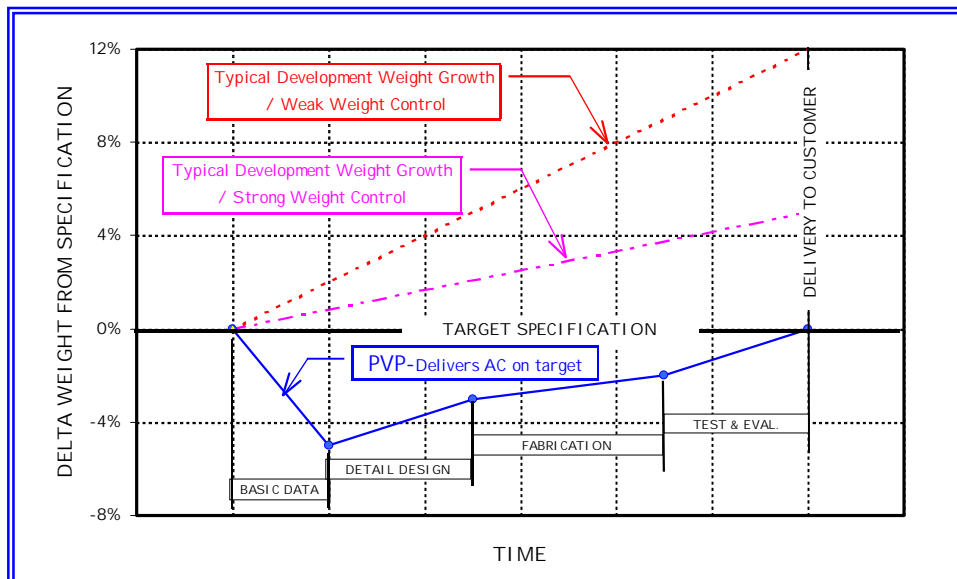
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Note: The vast majority of reference material used to support this research could not be disclosed due to agreements made to disguise the aircraft program identities.

## Appendix A - Swamp Aircraft's PVP

Swamp employed the use of a weight PVP (Planned Value Profile) to counter weight growth on the SW-24 during design and development. Simply stated, the weight target is lowered by 5% during the early basic data phase and is allowed to grow 2% during detail design, 1% during manufacturing and 2% during the test phase. If all goes according to plan, the aircraft is delivered at the empty weight target. This methodology was first implemented on the DemVal (Demonstration and Validation) phase of the NUAC program after experiencing overweight problems during the prototype phase. It was a great success, with the production SW-18 being delivered under weight by 3%. The concept was developed from a study weight growth study of many aircraft during development. Figure 6-1 presents an generic illustration of Swamp's weight PVP methodology<sup>10</sup>.

**Figure 6-1: PVP Illustration**



<sup>10</sup> Swamp's use of PVP's is not limited to weight control. The concept has been applied to many key aircraft attributes such as, range, rate of climb, Vmax etc, on the SW-24 and other programs.