General Aviation Cost Effectiveness

Richard E. Etherington*
Gates Learjet Corporation, Wichita, Kansas

The general aviation industry has not recovered from the last economic recession. Some studies have indicated a relationship of sales to both model changes and cost effectiveness. This paper examines these key categories and makes some recommendations for future recovery of aircraft sales.

Introduction

THIS paper is an update of AIAA Papers 85-4029[5] presented in October 1985, at the AIAA/AHS/ASEE Aircraft Design Systems and Operations Meeting held in Colorado Springs, Colorado, and 86-2607 presented at the AIAA Aviation Technology Conference Meeting held in September 1986, in Anaheim, California. These papers started with the generally accepted assumption that the general aviation industry's economic health followed the economy, at least since World War II. During the early 1980's, the economy turned down, and general aviation sales also turned down. However, now the economy has recovered and general aviation sales have not. The 1985 paper examined this in a limited way and assessed the cost effectiveness of the general aviation aircraft. A significant drop in general aviation cost effectiveness was identified and some causes examined. Since the economy has been in a state of recovery for at least three years [as shown by both an increase in gross national product (GNP) and the leveling of inflation], if the general aviation industry truly followed the economy, at least some level of sales recovery would have happened by now. Since sales continue to slide, it appears that some factor(s) has taken over. To see if this is the case, several factors have been investigated.

Figure 1 is a plot of total unit sales since 1946. Figure 2 is the same plot with some trend lines added. From about 1947 through 1965, a trend line reflecting a growth rate of 10%/yr has been fitted. This growth rate again shows up in the 1970–1979 time period. Considering the 30-yr span of 1949–1979, a 6% growth rate is more representative. Extending the time frame through 1985 reduces the overall growth trend to 3%. Even a return to the 3% line would obviously be beneficial in the near future.

Figure 3 is the unit sales chart again with the GNP overlaid. The GNP is shown in both "Then Year $" curves and corrected for inflation by dividing by the consumer price index (CPI). Neither GNP curve matches the general aviation (GA) unit curve very well as the "Then Year $" curve shows an 8% growth with no dips. The corrected curve shows a 4% growth rate with only minor dips.

It is probably incorrect to compare GNP in dollars to aircraft unit sales, so Fig. 4 shows total sales in dollars for general aviation. Again, the "Then Year $" curve and inflation-corrected "$" curve are plotted. Figure 5 shows the same plot with trend lines, and the "Then Year $" plot from 1949–1981 showed a spectacular 17% growth rate. Even the corrected curve showed better than 12% growth. In Fig. 6, the GNP and GA sales dollars are overlaid, and it is obvious that general aviation sales do not directly follow the economy.

Another possibility as a measure of the industry has been suggested, and that is that the industry lags the stock market by about six months. Figure 7 overlays the Dow Jones industrial average over the unit sales. Certainly the stock market has its ups and downs but they do not seem to predict GA unit sales. Figure 8 overlays the GA dollar volume vs the stock market, and again there is little correlation. This lack of correlation suggests that there is possibly some other reason for the failure of general aviation sales to recover. The following sections examine two possible contributing factors: 1) GA aircraft cost effectiveness, and 2) model changes.

Cost Effectiveness

The previous paper was used as a measure of cost effectiveness, an index of pounds of payload times range divided by

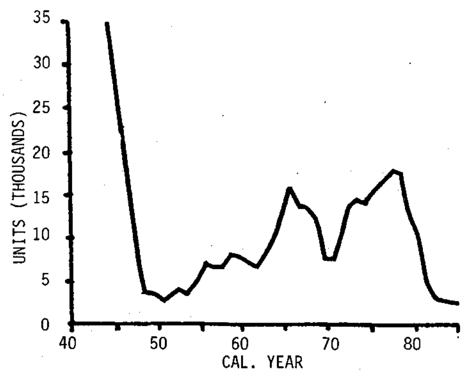

Fig. 1 GA units delivered/year.

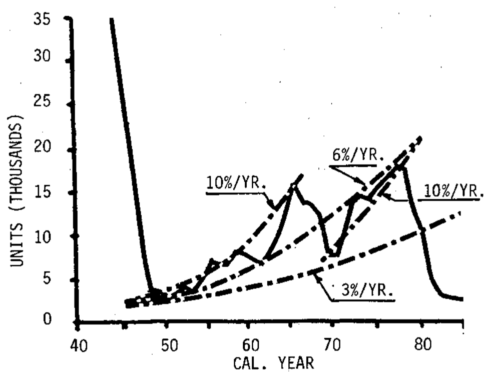

Fig. 2 GA units.

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*Director, Experimental and Technical Engineering. Associate Fellow AIAA.

acquisition cost. Although many other factors determine the marketability of an aircraft, this index is a consistent measure for a given aircraft vs time. Factors such as speed, cabin volume, number and types of engines, etc., certainly affect the relationship of effectiveness for one aircraft vs another in the same class; and this can affect the percent of sales within the class that each aircraft obtains. For the purpose of measuring cost effectiveness vs time for a single aircraft, however, the simple index works very well. From the previous paper, six categories of aircraft were examined. Samples of individual aircraft models were selected from each of the following categories: 1) four-place single engine, 2) light twin, 3) turboprop twin, 4) light turbofan, 5) medium turbofan, and 6) large turbofan. Data for deriving the index were obtained from the yearly charts published by Business and Commercial Aviation Magazine (BCA). The parameters selected were payload with full fuel, range with full fuel, and BCA-equipped price.

The index was plotted using "Then Year $" curves and also adjusted for inflation by mutliplying the index by CPI. The general conclusion was that cost effectiveness fell off significantly. The source of BCA data available only went back to 1974, and so in terms of general aviation history, these plots

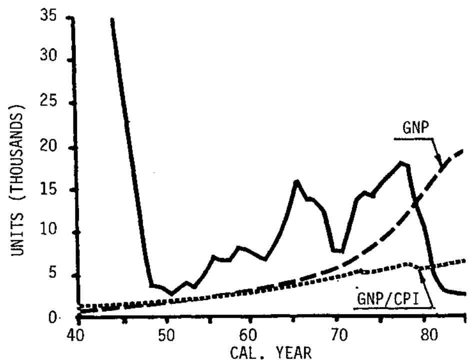

Fig. 3 GA units vs GNP.

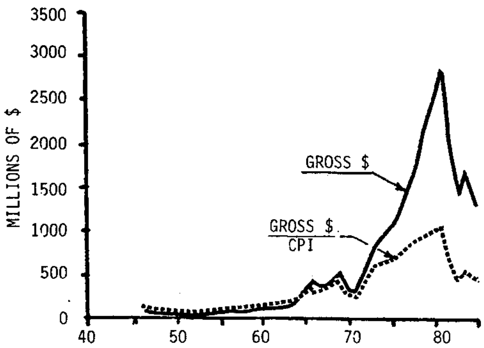

Fig. 4 GA gross sales.

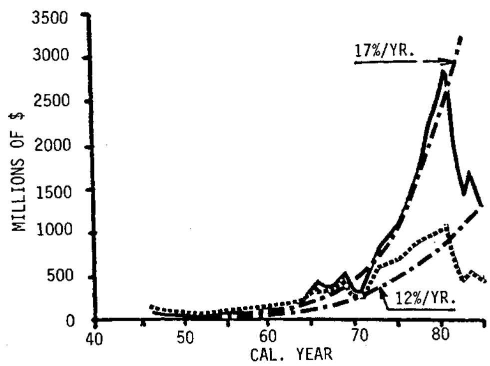

Fig. 5 GA gross sales.

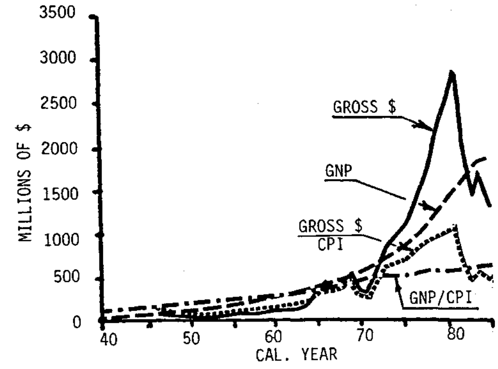

Fig. 6 GA gross sales vs GNP.

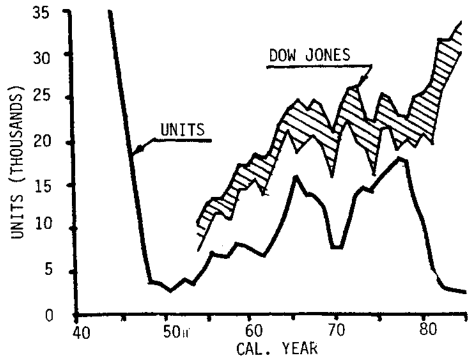

Fig. 7 Units vs Dow Jones.

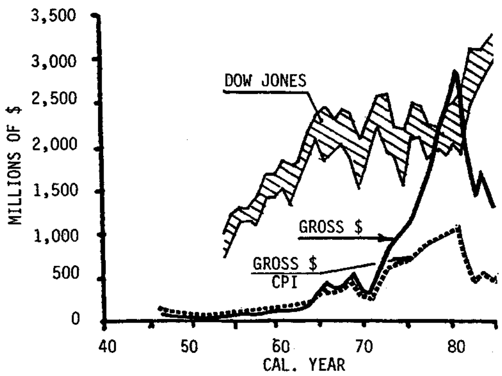

Fig. 8 Dow Jones vs gross sales.

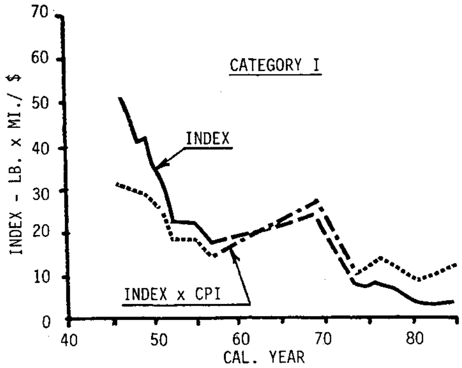

Fig. 9 Single-engine aircraft.

only reflected a small section of the product's life. Some limited data on earlier years of production of these aircraft were obtained and adjusted as best as possible to a similar data base, and the cost of effectiveness plots extended.

In category I, the four-plate single-engine aircraft data were available intermittently on one aircraft back to 1947. Figure 9 reflects this aircraft's cost effectiveness index. It can be seen that cost effectiveness of this aircraft has fallen steadily over the entire production life. It may be significant that moderate improvement is cost effectiveness in the late 1960's corresponded to an area of peak unit sales.

In the light-twin category, data were not available until the early 1960's. Figure 10 is a plot of the selected light-twin index. Here, it appears that the cost effectiveness held relatively consistent through the sales drip in the late 1960's. Subsequently, cost effectiveness declined in both "Then Year %" and "Adjusted $" curves.

In the turboprop category, again, early data were not as readily available. Figure 11 is a plot of the turboprop index. Following the late 1960's, cost effectiveness increased significantly and then started to again decline. This segment of general aviation was the fastest growing segment in the late 1970's time frame.

The small turbofan shown in Fig. 12 follows a slightly different format. Data here reflect a model progression that shows increasing cost effectiveness up to 1975. Even with improved models, cost effectiveness again declines markedly in the late 1970's and early 1980's.

The medium jet is shown in Fig. 13. The format also includes the effect of relatively large model changes.

The large-jet class is shown in Fig. 14. This is the same plot that was in the 1985 paper. As noted in the previous paper, the initial drop in cost effectiveness is due to the typical start-up cycle of a new model. The initial optimism in the design parameters is reflected in a high index. As the development progresses, the true weight/range/payload picture emerges, and the true index develops. Following initial deliveries, the index of this aircraft has been maintained in "Then

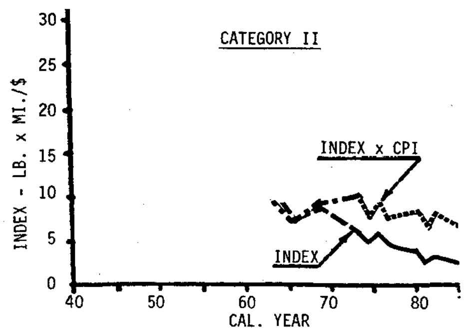

Fig. 10 Light-twin aircraft.

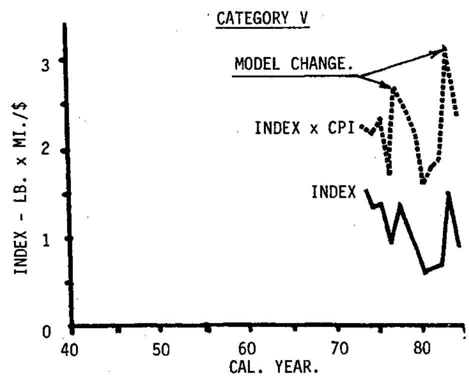

Fig. 13 Medium turbofan aircraft.

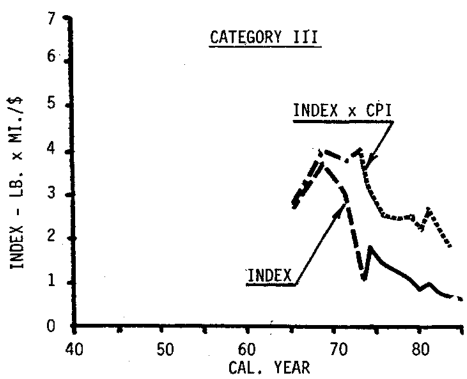

Fig. 11 Turboprop aircraft.

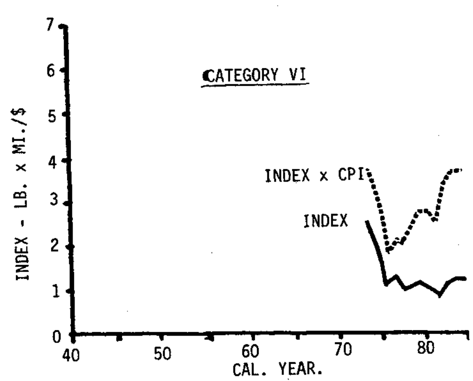

Fig. 14 Large turbofan aircraft.

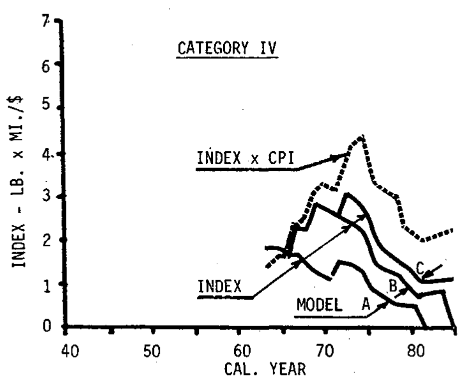

Fig. 12 Small turbofan aircraft.

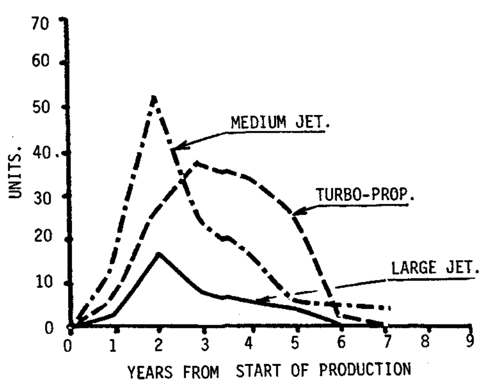

Fig. 15 Life cycle.

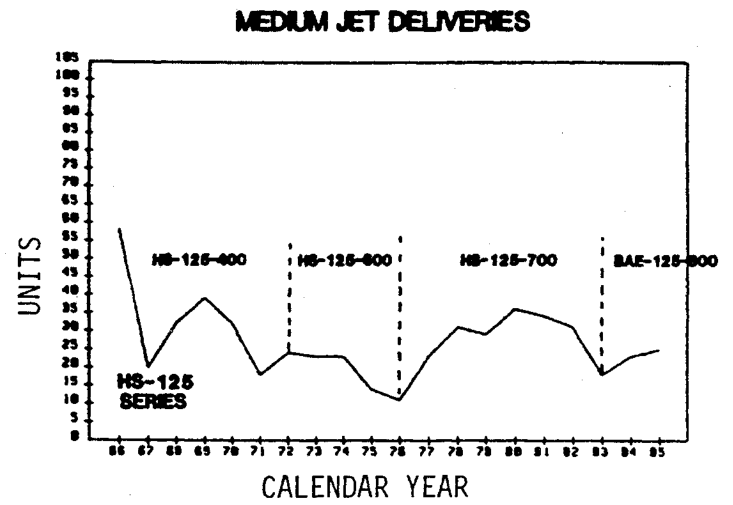

Fig. 16 Life cycle with model changes.

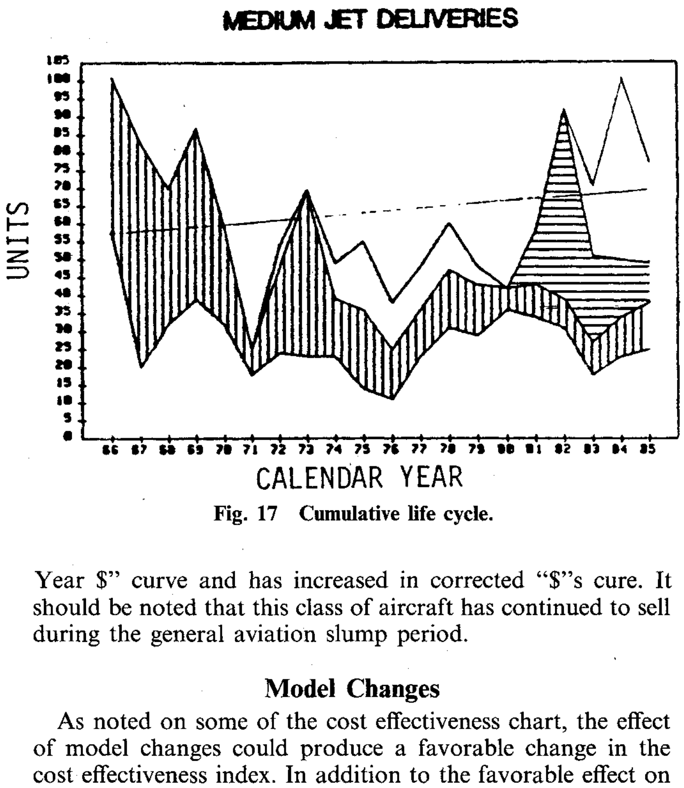

Fig. 17 Cumulative life cycle.

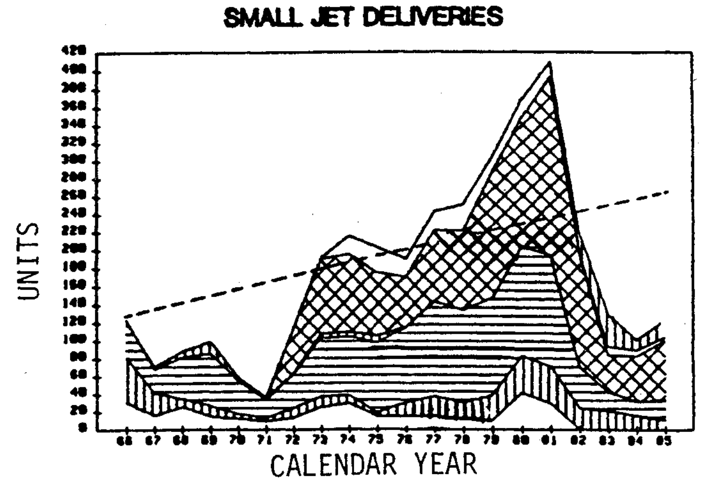

Fig. 18 Cumulative life cycle.

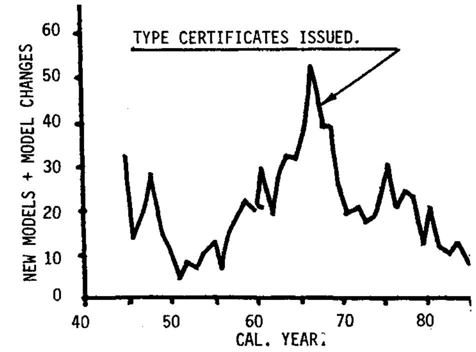

Fig. 19 Certifications

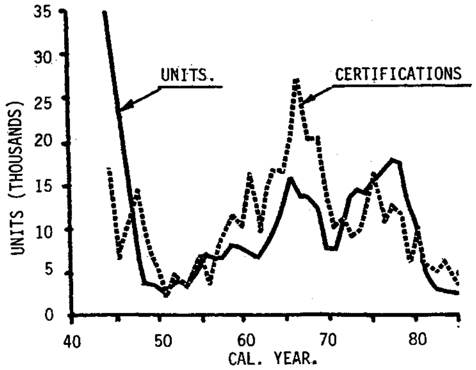

Fig. 20 Units vs certifications.

Year $" curve and has increased in corrected "$"s cure. It should be noted that this class of aircraft has continued to sell during the general aviation slump period.

Model Changes

As noted on some of the cost effectiveness chart, the effect of model changes could produce a favorable change in the cost effectiveness index. In addition to the favorable effect on cost effectiveness, there appears to be a direct correlation of the life cycle of a specific model with model changes. Unlike the automotive industry, where the life of a given product is one year with a nominal wear-out in 5–7 years, the aircraft never wears out. A study of several aircraft that have entered the marketplace without model changes shows a life cycle of 5–8 years with peak sales in years 2–4. Figure 15 shows a typical plot of three of these types of aircraft.

In order to sustain a model past its nominal life cycle, model changes can be used effectively to achieve continued sales past the 5–8-yr life cycle. Figure 16 shows this model change effect. Figure 17 is a plot of unit sales with several different aircraft models stacked to show the total market. From this chart, the introduction of a new aircraft into the field does not appear to significantly reduce the unit sales of other aircraft in the category; however, it does drive the total unit sales up. This can also be seen in Fig. 18, which is a similar plot of a different category of aircraft.

Since these changes show a strong dependence on model changes within a category, it seems reasonable that model changes and new models might be a predictor of general aviation sales. The best measure of model change and new model introduction appears to be Federal Aviation Administration (FAA) certification. Figure 19 is a plot by year of number of certifications of new aircraft and model changes. Figure 20 is an overlay of certification and unit sales by year. Certainly there is a match of the hills and valleys, at least more than that of the GNP and stock market comparisons. From these charts, it appears that new models are a key to increased sales. It should be noted, however, that the time of peak certification also corresponded to a peak in the cost effectiveness curves.

In support of this, note Fig. 21, which is simply Fig. 2 with the last two years of used turbine power sales added. Note that with only these units added, the sales come back at least

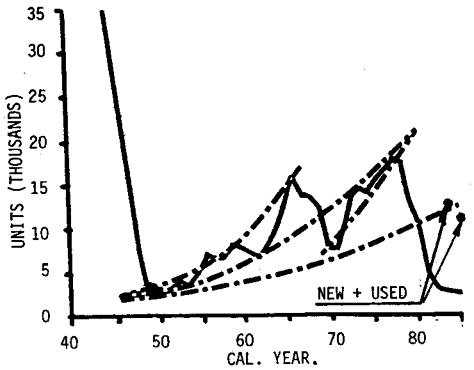

Fig. 21 Effect of used unit sales.

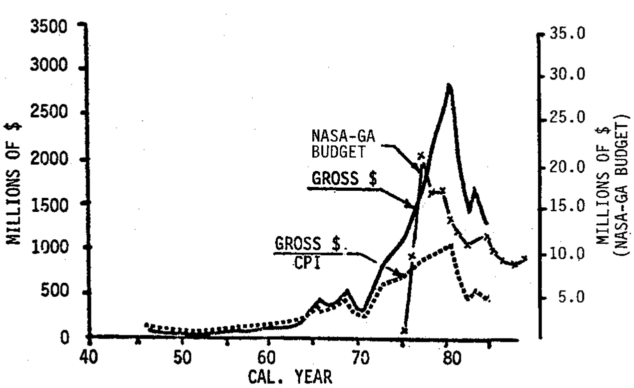

Fig. 22 GA gross sales.

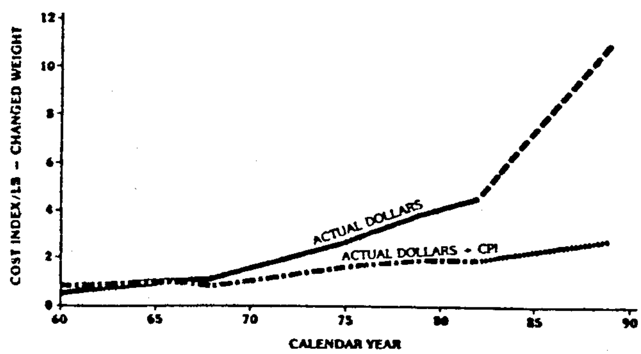

Fig. 23 Total program costs per pound.

to the cumulative growth trend. Since these used units are most effective, they tend to support the cost effectiveness argument.

The model change and cost effectiveness are not mutually exclusive but, in fact, in many cases are complementary. Model changes and new model derivatives upgrade the product and can increase the cost effectiveness of the aircraft. This continual upgrade requires constant recertification effort. The recovery of these certification costs and the added manufacturing costs due to the changes cause prices to rise. If performance is enhanced significantly, then, of course, the cost effectiveness can be maintained. Some model changes do not accomplish this. Unfortunately, the cost of certification is contributory to the falling cost effectiveness. The rising cost of certification will be addressed in the next section.

Finally, it should be noted that the basis for model changes and derivatives requires some technology input. The best measures of possible new technology development is probably

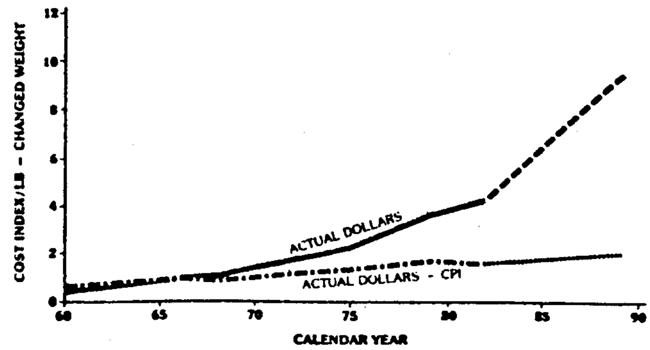

Fig. 24 Engineering cost per pound.

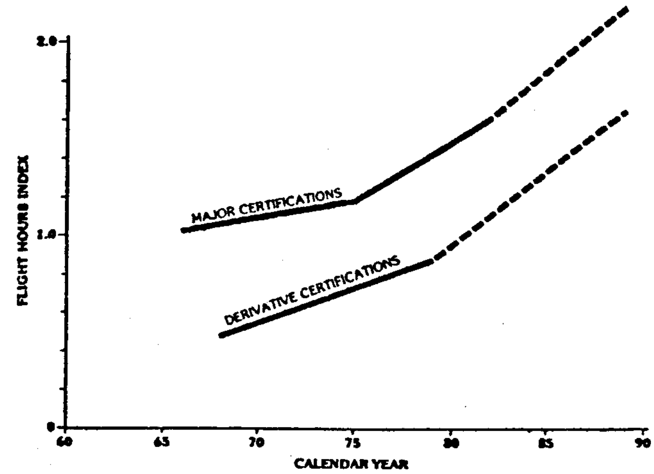

Fig. 25 Flight hours.

the NASA budget. The NASA GA budget directly in support of GA was not available back to 1946; however, NASA has provided that data back to 1975. Prior to that time, NASA was primarily space-oriented, and little applicable GA-specific technology was addressed. Figure 22 is an overlay of NASA GA budget vs aircraft sales. As can be seen, the NASA budget trends did closely follow the GA sales trends, indicating that NASA technology possibly contributes directly to stimulation of model changes and derivative aircraft.

Certification Costs

The data base for this section reflects that of a single aircraft manufacturer; however, through various discussions with cognizant employees of other general aviation companies, it appears to be representative.

In order to compare programs of significant size and over significantly different time spans, a method of reducing the data to a common denominator was essential. The most representative unit would be a pound of new or changed weight. Each program was, consequently, evaluated for the pounds of a new or changed weight affected for that certification. This was further divided into two categories. One category represented major certification effort for a new model program, and the other represented major product improvement that resulted in a model letter change.

The results of this study are shown in Figs. 23–25. Figures 23 and 24 are the cost/lb plotted vs calendar years, divided by the CPI. Figure 23 reflects total program cost, while Fig. 24 addresses only engineering costs. There are many reasons why this line could be expected to show lower cost/lb. These are:

1) Engineering, manufacturing, and tooling departments are mature and experienced.

2) Facilities and equipment are much advanced, allowing more rapid and economical fabrication of test parts.

3) Computer capacity provides much faster and more comprehensive technical data.

4) Computer-aided design and manufacturing (CAD/CAM) provides drawings quicker, more accurately, and more readily transferable to tooling and manufacturing.

5) Ground-test instrumentation is computerized and automated.

6) Flight-test data system can handle hundreds of channels of data vs tens of channels 20 years ago.

7) Data reduction via computer in real time is now available with final plots in engineering units.

8) Telemetry allows on-line analysis during flight.

9) More vendor support is available for design, test, and hardware support.

10) Computational techniques are available to solve problems not previously possible.

11) Increased data base of wind-tunnel and flight-test data are directly applicable to our products.

There are many other significant items that could contribute to lower certification costs; nevertheless, the costs as shown in Figs. 23 and 24 have increased, not dropped. Since 1967, these costs, after correcting for inflation by dividing by the CPI, have doubled. Another indication of increased costs is shown in Fig. 25. This plot represents flight hours required for certification, and shows almost double the flight hours required today over those required for 1967.

Manufacturing Costs

It appears vital that significant improvement to the general aviation aircraft cost effectiveness is required to regain the sales growth of the 1970's. In view of the escalation in certification costs, this is a most difficult task. Furthermore, in reviewing the costs of fabrication, labor, and material, it is evident that material costs are also an important driver. Approximately 60–70% of most aircraft "out-factory-door" cost involves purchased parts and raw materials. Of this, 40–50% is the engine cost. Engine costs from the mid-1970's to now have escalated at 175–200% of the inflation rate. Other materials have also followed this trend. Some of this cost escalation may well be the result of fine tuning of the individual components for increased performance. This fine tuning, of course, requires FAA recertification, and the net result may cause costs to increase faster than the improvement in effectiveness. Manufacturers, in order to control certification costs, have resorted to more usage of technical standard order (TSO) certification hardware. This of course, drives the component costs up, as these certification costs at the vendor level must be recovered. Much of this certification testing and documentation is repeated in the aircraft certification and helps contribute to the final aircraft cost. Since certification cost appears to be a major driver in two areas directly involved in deriving a customer cost, some further looks at certification requirements are warranted.

Certification Requirements

Over the past several years, certification requirements have become more and more detailed. In the past, many regulations depended upon good judgment of the FAA representative to assess compliance. In recent years, pages and pages of regulations have been written to detail exactly how a test must be run and what constitutes pass or fail. A simple check showing satisfactory operation does not suffice. In many cases, repeated testing is required to demonstrate compliance throughout the flight envelope where it is obvious that one area is clearly critical. This, of course, causes repeated flights, increases the volume of data, and adds to the complexity of the certification report. In many cases, the aircraft is required to be tested with dual and latent system failures and demonstrated to be nonhazardous. By regulations, these failures must be proven to be not possible within a probability of 10^{-9}.

A second increase in flight-test activity is caused by increased requirements by the FAA for function and reliability testing. In most cases, the FAA requires 75–150 h of flight on the first production article to prove functional and reliability of the aircraft, in addition to hundreds of hours on two or more prototype certification articles.

Because of the more detailed FAA requirements, the manufacturer must do additional developmental testing to insure that FAA requirements are met and to provide the data base for FAA to review prior to their agreement to start the certification flight testing.

Product liability cannot be ignored in the picture. Both the FAA and the manufacturer are confronted daily with liability litigation, and this potential results in increased testing requirements as both the manufacturer and the FAA strive to avoid future losses.

Not all certification cost increases can be laid at the feet of the FAA. The new technology in computers and instrumentation encourages engineers to perform tests and conduct studies because they have the tools to do so. They sometimes let this capability drive up cost and extend schedules, when a simple rule of thumb or past experience would provide a high level of confidence of success. Most static tests and flight tests today utilize sophisticated multichannel instrumentation. Much of the data is requested in the event of the test failing so that diagnostic information is available. Unless most tests are expected to fail, the cost and time required for this extensive instrumentation may be wasted.

Another cause of increased flight hours is the result of retesting for minor configuration changes. Some changes obviously have no effect on the results of previous tests. Many times long lists of satisfactory tests are repeated because the conformity status changed slightly. Good judgment and possibly some minor analysis could in many cases replace costly retest.

The last factor considered in this analysis is the use of multiple prototypes. Because testing requirements have gone up, in order to hold or shorten schedules, more than one flight article is usually used. This requires multiple instrumentation and usually causes the cost of more than one flight to be charged to the certification cost.

Conclusion

As an industry, general aviation is in a real dilemma. With the loss of sales, it is hard to justify new programs. Yet, without new programs, cost effectiveness goes down, and sales are going to used aircraft. In reviewing GA history, new models were generated by new technology, as shown in the following:

Mid-1940's	Four-place retractables
Mid-1950's	Light twins
Mid-1960's	Turbojets/turboprops
Mid-1970's	Turbofans

These technological advances allowed general aviation manufacturers to produce more cost effective transportation, and generated an environment that allowed the manufacturer to justify the expense of new development.

A key question now is whether there is enough new technology to justify expenditures for another round of growth. There certainly is not the technology generated by new power plants like the turbine engine of the late 1950's and early 1960's, or the turbofans of the 1970's. There have been new developments that can be combined to improve our products, although not revolutionize them as the past has done. Natural laminar flow airfoils, turbulent drag reduction, composites, and new configurations can be combined to give significant performance improvements. Unlike the past, a simple derivative of an existing aircraft will not produce the cost effective change of the past. In order to produce a saleable new aircraft, they must be cost effective. To accomplish this, cost of manufacture must be reduced. This can only be achieved

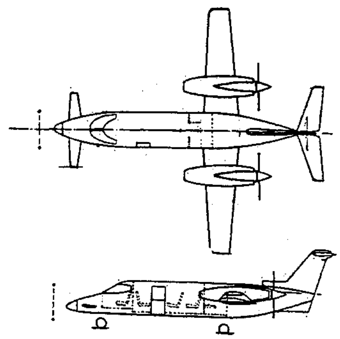

Fig. 26 Turboprop aircraft.

by building smaller aircraft (less pounds of airframe to build) that require less power (smaller engines to drive down purchased parts costs) and still perform better than current models. To see if this is feasible, several aircraft were designed using a quick preliminary design method for performance and cost. The results show that such aircraft are indeed feasible. Innovative techniques may be required to achieve the cost targets.

Figure 26 shows one of these aircraft. By using composites weight is reduced, allowing a smaller wing to be utilized. With the reduced size and an NLF airfoil, drag is reduced, allowing a smaller engine to be used. The lighter airframe reduces manufacturing cost, and the smaller engine reduces the bill of materials. This aircraft could be 50–100% more cost effective than aircraft currently available.

Although this example was typical of all of the categories of aircraft, each category had some different problems. The single engine will be most challenging to achieve restored cost effectiveness.

In general, it appears GA manufacturers have been so involved in building the ultimate airplane, they have forgotten that they are selling transportation. With airline deregulation, travel costs have come down, while general aviation costs have gone up. The key to increasing new aircraft sales requires the manufacturers to reaffirm their faith in the industry, and actively develop new and cost effective aircraft.

The solution is not that simple, of course. Aircraft maintenance costs must also be brought down, the product liability problem solved, and certification costs must be reduced. Each of these areas must be addressed by the manufacturers and by appropriate governmental agencies for general aviation to recover.

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