

Cost Estimating Software for General Aviation Aircraft Design

Charles N. Eastlake, Harry W. Blackwell
Embry-Riddle Aeronautical University/Lockheed Martin Corporation

Abstract

The widely used DAPCA IV cost model for estimating aircraft acquisition cost is based on Department of Defense data and thus, not surprisingly, overpredicts the cost of general aviation (GA) aircraft. These equations were modified by the author for use as a tool for aircraft design classes at Embry-Riddle Aeronautical University in 1986. The first phase of modification was an intuitive adjustment based upon personal experience with the differences between designing military and civilian aircraft. Then a second phase of adjustment was made to force the equations to predict the correct current price of a Cessna 172. The equations were programmed in Basic and named LiteCost. The DAPCA equations were programmed almost "as is" to use for executive jet type projects and were named ExecCost. Then companion programs called LiteOps and ExecOps were written from scratch to estimate operations costs in dollars per flight hour. These were fairly fundamental book keeping type calculations based on inputs of flight hours per year, cost of fuel, amount of money borrowed to purchase the aircraft, and specification of design features which are more complex to maintain. This set of four programs has been in continuous use since then, and has been provided to several other universities.

In 1999 the co-author acquired the programs for use in a graduate school project. To enhance usability, he ported the existing code for the four programs into a newly created Windows-based graphical interface application using Microsoft Visual Basic. The convenience and user-friendliness of the programs are dramatically increased.

1. Introduction

The senior aircraft design course sequence at Embry-Riddle Aeronautical University has a long history of using general aviation aircraft as the assigned design specification. The incorporation of cost analysis into the design process has always been viewed as an important segment of the learning process. In the last two decades the concepts of Life Cycle Cost and Design to Cost have evolved from merely important to absolutely essential. The quandary provided by this situation is that the accepted cost models are based heavily on military acquisition data. Specifically, the DAPCA IV cost model (Reference 1) for aircraft acquisition cost is derived from military aircraft data. And as one would expect it predicts costs that are unrealistically high when applied to the relatively small and simple general aviation aircraft typified by civilian flight trainers and personal aircraft. In the case of the Cessna 172, the aircraft of this type which has been produced in the greatest numbers, the DAPCA IV model predicted a cost over three times the actual sale price. Coupled with this consistent overprediction of acquisition cost, there is not a commonly accepted model for the operational support cost portion of life cycle cost which is well suited for use with the limited amount of data available in student projects.

2. Acquisition cost

The author undertook the task of remedying this design education tool deficit in 1986. The initial set of equations were taken as listed in Nicolai (Reference 2) which was the text being used by the author at ERAU at the time. Raymer (Reference 3) is now used in the same courses and is more familiar to current students. It presents essentially the same equations. The process of adjusting this set of Cost Estimating Relationship (CER) equations was begun by calculating and tabulating the magnitude of various segments of the design and manufacturing process as given by the cost model. The equations break up the cost into eight major contributors: engineering hours, tooling hours, manufacturing hours, quality control hours, development support cost, flight test cost, cost of manufacturing materials, and engine production cost. Each segment is estimated by an equation generated by regression analysis of Department of Defense database information. The equation for engineering labor hours is typical:

$$\text{Engineering labor hours, } E = .0396 A^{.791} S^{1.526} Q^{.183}$$

where A = airframe weight in pounds

S = maximum speed in knots

Q = total number of aircraft produced

Then a subjective judgment was made on the question of how time consuming or difficult each segment is when done on a general aviation aircraft as opposed to being done on a military aircraft. The results of this weight factor decision are summarized in Table 1. The values selected are indeed subjective but they are logical, being based on the author's own experience as a light aircraft owner and as an engineer working on both military and GA aircraft and military jet engines. The initial list of weighting comments like "a little too big", "way too big", and "probably about the same" was converted into numerical form as multiplying factors. "Way too big" resulted in that segment being multiplied by 1/3 or 1/4, "a little too big" was multiplied by 2/3 or 3/4, "about the same" was left alone, and so on. This modified set of equations produced a cost which was only about 12 percent higher than the actual cost of the 1986 Cessna 172, ironically the year Cessna temporarily stopped producing single engine aircraft. This was dramatically more credible than the 239 percent high which the original model calculated.

This variation could have been used as is, but it was close enough that it seemed feasible to go through a second cycle of weight factor modification to make the equations hit the calibration point almost exactly. The right hand column in Table 1 shows what modifications made that happen. Design and manufacturing of tooling was cut to 1/4 of the DAPCA value, manufacturing labor was cut to 1/3, quality control and inspection was cut to 1/3, and manufacturing materials and equipment (particularly equipment) was cut to 1/8. Other cost segments were left unchanged. One exception was the engine production cost equation which was replaced by a simpler set of equations generated from the bits and pieces of cost data the author could acquire on small piston and turbine engines. They are:

$$\text{Piston engine cost} = \$83 / \text{HP}$$

$$\text{Turboprop engine cost} = \$180 / \text{HP}$$

$$\text{Turbojet engine cost} = 414 (\text{Rated thrust})^{.8356}$$

$$\text{Turbofan engine cost} = 494 (\text{Rated thrust})^{.8356}$$

It is worth mention that such data are surprisingly hard to find. All too typically, one prominent manufacturer would not offer cost information on its two engines which are well suited to student projects. The reasoning was that one does not buy an engine. One negotiates a package of engines, spare parts, and training for service personnel. While this may be valid thought, it is

not much help to students trying to estimate cost of their engine. So the new equations were used to estimate the cost of the engines and the manufacturer was asked to confirm that the answers were in the right ballpark. The company was even hesitant to answer that request, but eventually did agree.

CER Category	Original set of calculations	First stage modification	Second stage modification
Airframe engineering hours	As is	As is	As is
Tooling hours	As is	x 50%	x 25%
Manufacturing hours	As is	x 33%	x 33%
Quality control hours	As is	x 33%	x 33%
Flight test cost	As is	As is	As is
Production support cost	As is	As is	As is
Manuf. materials & equipment cost	As is	x 25%	x 12.5%
Engine cost	New equations	New equations	New equations
Avionics cost	User input (0)	User input (0)	User input (0)
Fixed landing gear	Not an option	- \$10,000	- \$7500
Profit	User input (10%)	User input (10%)	User input (15%)
Calculated cost of Cessna 172 (\$86)	\$168,248	\$55,544	\$49,582
Actual cost of Cessna 172 (\$86)	\$49,600	\$49,600	\$49,600

Table 1. Modification to DAPCA CER's

Several other adaptations were also made. Probably the most important is that a multiplying factor was included to allow the user to adjust costs for the changes in the consumer price index relative to the base year represented by the equations. A bar chart illustrating CPI trends over the last several decades are presented in class so that students can get a feel for the unpredictability of this trend out into the planned lifetime of their design. Another change was a deviation from standard wisdom in Air Force Systems Command handbooks in applying the "learning curve" or quantity discount factor to account for the effect of production quantity on the price of each unit. An 80% learning curve is widely used. This means that each time the total number of units produced is doubled, the price per unit drops to 80% of the previous unit price. This value was originally applied in the equations but produced incredibly low prices at production quantities in the thousands. Based simply on what produced realistic answers, a 95% learning curve was finally adopted.

In addition, several additional modification increments to selected cost segments were instituted to account for design choices. They include choosing a tapered wing planform, using composite materials, and pressurizing the fuselage. The increments are listed in Table 2. These are again subjective, based on the author's personal experience, and there is no argument if someone

would prefer to use other numbers. The manner in which they are implemented, however, is logical and makes a trend statement to design students.

CER Category	Primary Category Certification	100% composites	Untapered wing	Complex flaps	Fuselage pressurized
Airframe engineering hours	x 66.7%	x 200%	----	+ 3%	+ 3%
Tooling hours	----	x 200%	- 5%	+ 2%	+ 1%
Manufacturing hours	x 75%	x 125%	----	+ 1%	----
Quality control hours	x 50%	x 150%	----	----	----
Flight test cost	x 50%	----	----	----	----
Production support cost	x 50%	x 150%	----	+ 1%	+ 5%
Manuf. materials & equipment cost	x 75%	----	----	+2%	+ 1%

Table 2. Modification of CER's for design choices

One final calculation modification is an attempt to estimate what product liability cost does to the sale price of an aircraft. This is currently a manual step accomplished after the cost model has done its work. It is done manually to force students to think about this reality of being in business in the US, but incorporating it into the automated equations would be easy. The calculation instruction is accompanied by a strongly worded caution that this is not a reliable estimate and is there simply to illustrate a point of information. Based primarily on widely-quoted testimony of Cessna's CEO before a congressional committee, the estimate is that product liability increases the purchase cost by 50% for unit costs up to \$100,000, and above that the cost increment is simply a constant \$50,000 per unit. There is no apparent way to verify how realistic this estimate is. But it is noteworthy that using it with the above equations gives an estimated price for a 1999 Cessna 172 as \$144,000, which is definitely in the right ballpark.

3. Operation cost

A model was generated from scratch to estimate operations costs in dollars per flight hour. This used fairly fundamental book keeping type calculations drawing heavily on the author's efforts at tracking several years of costs associated with his own aircraft. Essential inputs are flight hours per year, cost of fuel, amount of money borrowed to purchase the aircraft (to include loan payments in the model), and amount of insurance coverage. The model begins with an assumption of 0.3 maintenance manhours per flight hour (MMH/FH) for a single engine, fixed gear, fixed pitch prop aircraft. It is assumed that the owner is the pilot and thus does not use any cost for flight crew. Increments are made to the MMH/FH number for specification of design features which are time consuming to maintain. These include difficult engine access, retractable landing gear, complexity of avionics equipment installed, wet wings, and complex high lift devices. Negative increments are given for the cost savings realizable from the owner doing his/her own maintenance to the extent it is allowed by FAA regulations and for the simpler craft intended to be certified under the Primary Category which was recently established.

Storage cost, annual inspections, and contributing to an engine overhaul bank are also included. The cost is ultimately presented in dollars per flight hour, which is convenient in terms of comparison with rental cost for a similar aircraft. This set of equations was named Liteops.

A second model was created for corporate or executive aircraft type operations. It is similar to Liteops except that it assumes that paid flight crew are being used and that all maintenance is professionally accomplished. This model was called Execops.

4. Computerization of the models

As mentioned above, the acquisition cost model modified for GA aircraft was programmed in Basic and was named Litecost. The related operations cost program was named Liteops. For acquisition cost of corporate or executive type aircraft at the high end of the GA spectrum the DAPCA IV equations were programmed almost unchanged and were named Execcost. The main change was that the author's own equations for estimating engine cost were retained in place of the DAPCA equation. Again, the operational support cost model for executive type operations was named Execops.

All four of these programs were originally written in Microsoft Basic and run on a DOS-based PC within the Basic application environment in a traditional command line mode. This seemed the most practical approach to widespread usability because at that time Basic was provided as a no-cost addendum to the DOS operating system on virtually all PC's. As Windows became widespread, PC sellers stopped providing Basic. So the programs were compiled into executable files using Quick Basic 4.5 so that they could run in the DOS mode on virtually any machine. The programs were listed in University of Virginia's compendium of design software for education (Reference 4) and were provided by the author to several universities and aircraft companies.

Early in 1999 a Lockheed engineer, the co-author, acquired the programs for use in a graduate school project. To make the programs more accessible in the Windows environment that is now so prevalent, and to enhance usability, he combined the four separate programs into a single 32-bit Windows (Win 9x, Win NT) based application having a point and click graphical user interface. The Microsoft Visual Basic 5.0 development environment was used for this. The application currently allows analyses to be conveniently run and modified, and the results observed on-screen, by toggling between input and output screens. Hardcopy output reports can also be generated. A representative input screen is illustrated in Figure 1 and the corresponding output screen is shown in Figure 2.

5. Conclusion

The convenience and user-friendliness of the cost model has been dramatically increased by this recent effort, particularly for current undergraduate students who generally have little familiarity with Basic and almost none with DOS. These modernized programs are now available to the education community. The authors make no claim as to the absolute accuracy of the calculations but important trends in how design decisions affect cost are illustrated clearly and logically. They should serve as a useful tool for design classes in particular.

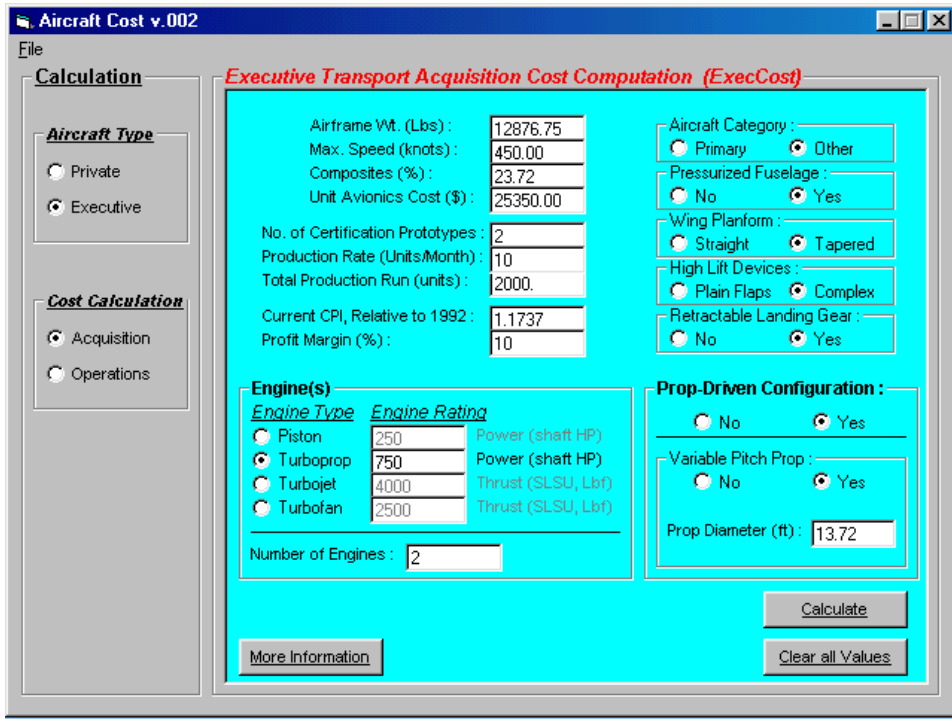


Figure 1. Bitmap image of the input screen

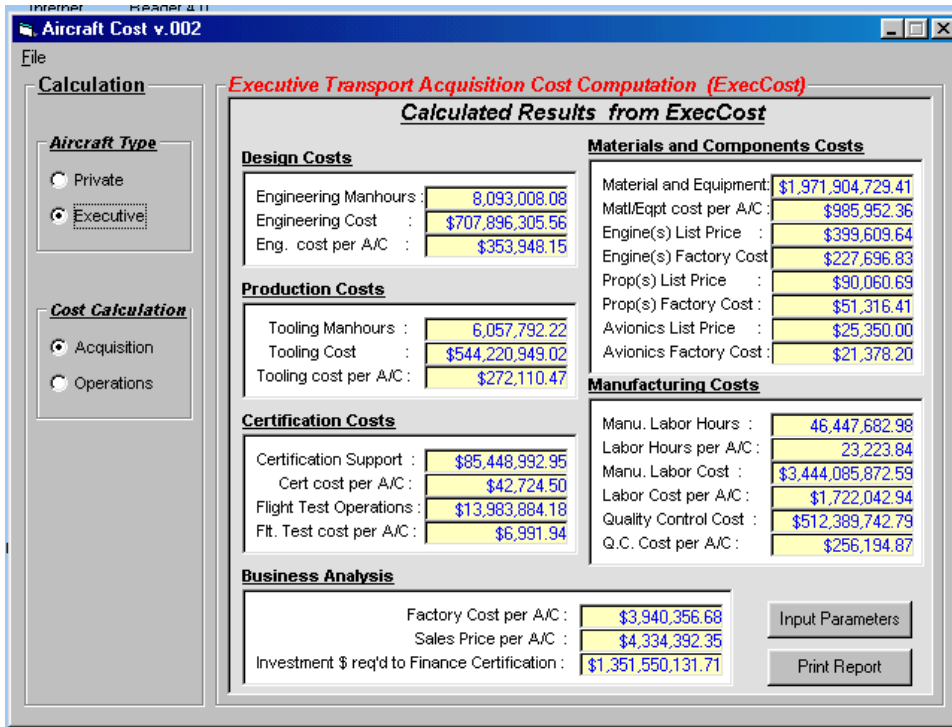


Figure 2. Bitmap image of output screen

Bibliography

1. Hess and Romanoff, "Aircraft Airframe Cost Estimating Relationships," Rand Corp. Report R-3255-AF, 1987.
2. Nicloai, Leland, "Fundamentals of Aircraft Design," 1975.
3. Raymer, Daniel, "Aircraft Design: A Conceptual Approach, 3rd Edition" AIAA Education Series, 1999.
4. Mason, William, "Aircraft Design Information Sources," Virginia Polytechnic Institute Report VPI-AOE-208, 1994.

CHARLES N. EASTLAKE

Charles Eastlake is a Professor of Aerospace Engineering at Embry-Riddle Aeronautical University in Daytona Beach, FL. He has taught aircraft design and wind tunnel testing for 21 years. He did propulsion research and was a structural designer with the USAF 4950th Flight Test Wing during the 13 years prior to taking up teaching. His design class won the 1999 NASA/FAA National General Aviation Design Competition. Email contact at: eastlkc@db.erau.edu.

HARRY W. BLACKWELL

Harry Blackwell is an aeronautical engineer in the Advanced Design Department at Lockheed Martin Aeronautical Systems Company in Marietta, GA. He has 18 years of experience in the aircraft design industry, serving in functional groups such as Aerodynamics, Flight Mechanics, Wind Tunnel Test, and Configuration Design. He is currently pursuing a Masters Degree in Computer Science. Email contact at: hblackwe@spsu.edu.