ICAS-90-2.10.1

MILITARY TRAINER AIRCRAFT - TURBOPROP OR JET?

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Abstract

This paper makes a summary of the specifications issued by several of the world's air forces for training aircraft. The teaching effectiveness targets of these specifications are assessed by developing a mathematical model based on a highly modified form of Dr. Bazzocchi's analysis (Ref 1).

The paper reviews the different performance and handling characteristics of several modern turbo-prop and jet trainer aircraft and relates these characteristics to the requirements. A separate model is established to estimate the purchase and operating costs of the various types of training equipment. An overall training cost-effectiveness result is then established.

The advantages and disadvantages of each type of training system equipment is discussed in a general manner and conclusions drawn as to the most cost-effective mix.

Special reference is made to the performance of the turbo-prop compared to the jet aircraft in the 'Primary' training phase and their relative cost-effectiveness discusssed.

Introduction

Most of the world's air force fleets of older generation military jet trainers are ready for retirement. Either their fatigue life has expired or they have become far too expensive to operate. With what equipment should they be replaced?

Are the new lightweight jet aircraft the only possibility or could turbo-prop trainers also create graduate pilots capable of handling modern air force equipment? What are the roles of simulators and piston-engined screening aircraft?

Military pilot training is considered, in this paper, to be a 'Black Box', as shown in Fig 1. The input parameters are: "Raw" pilot recruits on the one side, instructors, aircraft, simulators and training aids on the other. The desired output is experienced pilots, selected according to their capabilities for the different roles and ready to enter operational training squadrons. A further output is, of course, the rejection of unsuitable students, preferably at an early stage, when low investments have been made in their training.

This paper proposes a mathematical model to represent this 'Black Box' and analyses the results of introducing various aircraft with different performances into the training system. Of special interest in this paper are the relative merits of a turbo-prop trainer compared to a jet trainer aircraft in the 'Primary' training phase.

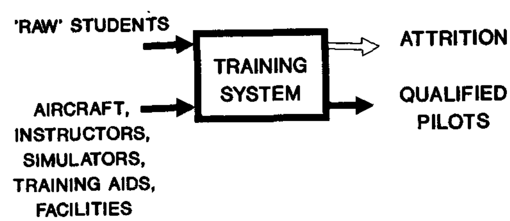


Fig 1 Training System as a 'Black Box'

Turbo-prop versus Jet

The question immediately becomes apparent as to what is the difference between a turbo-prop trainer aircraft and a jet trainer and why this should be a topic of a technical paper! The answer is not simple: The Turbo-prop aircraft has significantly lower fuel consumption for a given manoeuvre performance and therefore can be scaled down to a smaller size. The smaller size requires less power and so allows a "reverse Snowball" effect. The smaller size then results in lower acquisition and operating costs. Being a smaller aircraft with high specific excess power, the volume of sky in which the aircraft operates tends to be smaller and so, more training tasks can be conducted per unit of time. On the negative side, the propeller thrust reduces rapidly with speed whereas in a turbo-fan powered aircraft the thrust will reduce more gradually, affording the jet trainer a higher maximum level speed for the same amount of installed power. Also, the high energy of the slipstream in the Turbo-prop aircraft affects the handling characteristics. There are two distinct schools of thought on this subject: those who believe that it is essential to learn how to use the rudder pedals in primary flight training for future Air-Air combat at high angles of attack and for Transport and Helicopter pilots, and those who consider that 20 years of training on T-37 generation of aircraft shows that this is not essential. We leave this argument open for the time-being, what is relevant in this paper is whether the teaching effectiveness of the turbo-prop is significantly affected by its configuration and outweigh its inherent cost advantages.

Training Systems

Reviews have been conducted on past, present and future training aircraft inventories of several Air Forces worldwide. The major difference in the concepts is only in the terminology of the different phases! For the purposes of this paper, the following terminology has been used: Figure 2 shows the typical arrangement of the flight training of an Air Force. It starts with a Screening or 'Basic' phase, usually lasting about 30 hours, followed by a 'Primary' phase of about 90 hours , after which the students are allocated to their separate areas of advanced training, either to Fighter /Bomber /Reconnaissance (here termed 'Advanced') or to Tanker /Transport (here termed 'TTTS'), or to Helicopter training. This paper will deal purely with the fixed-wing element of training.

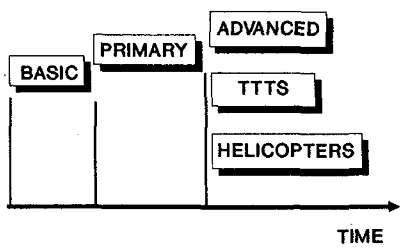


Fig 2 Typical Training Aircraft usage

This figure does not show the usage of simulators in the system, which have the potential to significantly alter the system of training, especially in the early phases and in transition from one aircraft type to another. Unfortunately it was not possible to include this aspect into the model at this stage and will have to be included in the next revision.

TRAINING EQUIPMENT USAGE
IN HOURS

Country	America			U.K.		Australia	Saudi
AirForce	USAF	USAF	USN	RAF	RAF	RAAF	RSAF
Basic	T-41 30	T-41 30	T-34C 66	B'dog 30	B'dog 30	CT-4 35	PC-9 30
Primary	T-37 90	JPATS 89	T-2C 91	JP-V 93	Tuc. 110	PC-9 135	PC-9 90
Advanced	T-38 120	BRATS 119	TA-45 100	JP/HWK 133	Tuc/Hw 112	MB326 35	HAWK N/A
TTTS	-	Beechjet 119	-	J'strm 46	J'strm 45	-	-

Table 1
Air Force training equipment and its usage

Table 1 gives a summary of an investigation of the training material and their utilisation by a variety of different Air Forces. Size limits the inclusion of all the Forces reviewed and the past, present and future structures.

The USAF and USN are in the process of changing almost their entire training equipment within the next two decades, as is Canada. The RAF, RAAF and RSAF are just, or have just changed equipment. The USN has operated Turbo-prop aircraft in the Basic and Primary training phases successfully for almost 15 years. The Royal Saudi Air Force is now successfully operating a high performance turbo-prop to replace their ageing Strikemasters.

Mathematical model

Figure 3 depicts the logic of the mathematical model constructed for the purpose of this training evaluation. It is constructed using a Lotus 1-2-3 spreadsheet for the maximum visibility into its structure and widest utilisation. (see also section on model refinements)

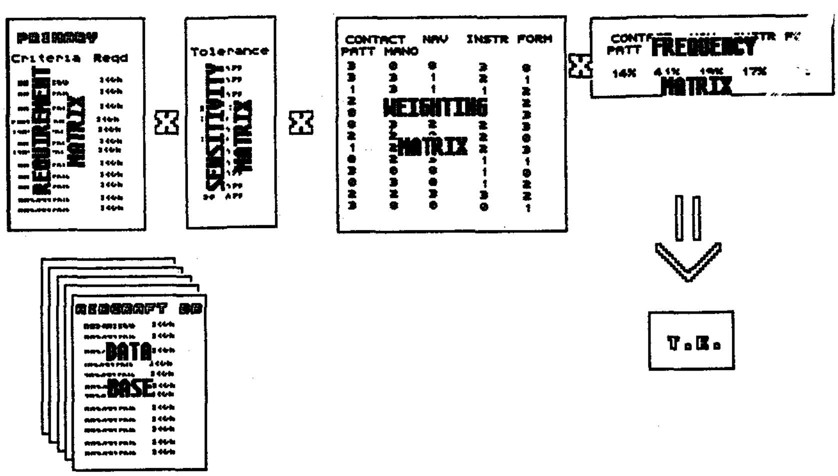


Figure 3 Mathematical model of Teaching Effectiveness

The model is split into five major blocks, each being repeated for the four levels of training:

- The Aircraft Data-Base; containing all information required for the analysis.
- The Requirements Matrix; containing the desired level of performance.
- The Sensitivity Matrix; containing the acceptable tolerances from the requirement and hence defining the performance rating.
- The Weighting Matrix; giving an assessment of the importance of each criteria in each area of training.
- The Frequency Matrix; providing an analysis of the frequency at which each of the training tasks are conducted.

Each of the elements of the model will be described in more detail below.

The Overall Teaching Effectiveness is obtained by working through the spreadsheet: The aircraft to be analysed is compared with the specified level of performance and sensitivity. The results of this analysis are multiplied by a weighting scale for each of the training tasks to give the importance of the criteria. The Frequency Matrix is used to factor the results to represent how often each task is conducted. Finally, the summation of the results for each training task will give the Training Effectiveness. The resulting number has no absolute meaning. To obtain a meaning for the quantity, it is necessary to relate the training effectiveness of the aircraft being analysed to that of a known (baseline) aircraft. The resulting factor gives a direct measure of the time a student will take to achieve the same level of training as in the baseline aircraft.

The model is used for each phase of training, from Basic through Primary to Advanced or Transport /Tanker. Each element of the model is described in more detail below:

Figure 4 shows the Requirements and Sensitivity Matrices. The layout of the matrices is identical for all phases of training, but the values change as the learning process is advanced, allowing the student to have a steadily increasing challenge as he (or she) becomes more familiar with the environment of flight.

The criteria have been selected to include measures of flight performance, handling characteristics and systems to try to give an overall assessment of the 'goodness' of an aircraft in the training role. Care has been taken to try to include criteria which can be assessed correctly so as to give a valid comparison. A duplication is avoided, so that no aircraft is penalised or favoured doubly for one single characteristic.

The effect of the tolerance inputs is to define the sensitivity of the requirement on a scale from 1 (worst) to 10 (best): The defined limits of the tolerances will provide the analysed aircraft with a rating of 3 out of 10. If the result fall outside this value they will reduce in proportion to the minimum value of 1.

In the area of flight performance, the following criteria have been selected:

- Approach speed: a very important criteria for the early phases of training in the terminal area. Both too fast and too slow are not beneficial to training, hence the equal tolerance requirements.

- Rate of climb at sea level & at cruise altitude: the criteria are used separately depending on the area of training. The criteria gives a good measure of the 'liveliness' of the aircraft. A rate of climb lower than the requirement is less desirable than higher rates.

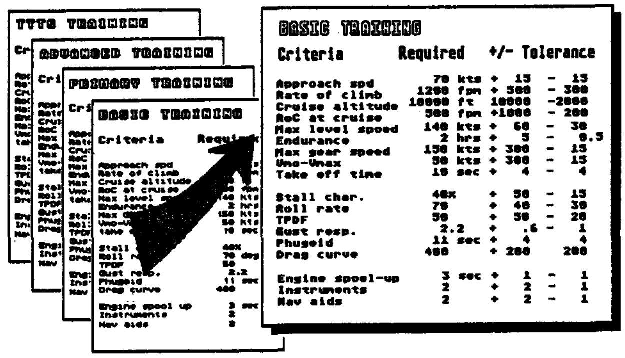


Fig 4 Requirements & Sensitivity Matrices

- Cruising altitude is important for navigation and general handling ('Contact Manoeuvre') exercises. Higher cruise altitudes are preferred to altitudes below the specified value to allow flexibility in the training area to have 'stacked' operations.

- Maximum level speed at sea level is important in a similar manner as approach speed, but assessed in different areas of flight. Likewise, the upper tolerance is more relaxed than the lower one.

- A minimum value of endurance at normal training fuel flows is necessary to fulfil a training mission with sufficient reserves. A much more lenient upper tolerance is given than the lower one.

- The maximum speed at which the aircraft may be flown with landing gear extended gives a measure of the time used in the circuit. Again, low values are penalised severely.

- The difference between the maximum level speed and the maximum operational speed the aircraft is allowed to fly, is a measure of the manoeuverability of the aircraft and the flexibility in the training syllabus to allow full power descents (aerobatics).

- The time taken to take-off is a good indicator as to how fast a student has to react in this heavy workload area. The tolerances are applied symmetrically here, as both variances away from the requirement are detrimental to training.

The criteria which can be applied to flight characteristics are more difficult to assess and required separate mathematical models for their analysis, feeding into the main model:

- Stalling characteristics are very important in the early phases of training, but are not easy to predict. The shape of the lift break has been used based on wing profile camber analysis. The further forward the position of maximum camber, the more likely a leading edge stall will be seen and the sharper the lift break.

- Roll rate is a measure of the sensitivity of the aircraft around the X-axis. Sluggishness is penalised slightly harder than high sensitivities.

- The spin recovery is an important criteria and is assessed in this model by the analysis of Tail Power Damping Factor. Low values (slow recovery) are penalised harder than high values.

- The gust response of a training aircraft can affect a student considerably throughout his (her) flight training; as air sickness in early phases and to hamper target acquisition in later phases. Low responses are favoured.

- To find a measure of the longitudinal response of the aircraft, the phugoid time was selected. The tolerance on this criteria are fairly wide to accommodate aircraft which are considered to be satisfactory.

- In high wing loading aircraft it is usual to approach for landing in an area of the power curve where the drag is increasing with speed reduction ('wrong side of drag curve'). The shape of this curve is important during the final stages of approach. In the early part of training the student should not be allowed to enter this situation.

Even more difficult to assess are the effects that the systems have on the training of student pilots and to quantify the results.

- Engine acceleration time from idle to 85% power (thrust) is a quantity which can both be measured and assessed well. In the early phases of training the student should be given rapid power response, whereas later he (she) should be required to exercise anticipation.

- Instruments and Navigation aids are assessed as a digital value in a range from 1 to 10. The sophistication of the equipment required leads to the rating. An assessment is made of the equipment available. The students should not be overburdened at first, but more demands may be placed on them as their experience increases.

The weighting matrix is achieved by examining the criteria for each phase of training and training task and assessing its importance. A weighting from 0 to 3 is given, where 0 indicates irrelevant and 3 highly important criteria.

Thus, for the Primary training phase, in the terminal area, the criteria with the most importance are: Approach speed, stalling characteristics, maximum gear speed, engine acceleration and the characteristic of the 'Drag curve'. Other factors become more important in other training tasks. The weighting matrix is very similar for all phases of training, but does have a variation in some areas, where the accent has shifted due to the higher competency of the student.

The final matrix in the model is the Frequency Matrix. This identifies what proportion of the training tasks are conducted in each phase of training. Figure 5 shows the frequency of the different training tasks as a percentage of the whole in each of the training phases. In the Primary phase of training 14% of the time will be spent conducting Contact Pattern training, 41% during Contact Manoeuvres, 19% Navigation, 17% Instruments and 9% Formation.

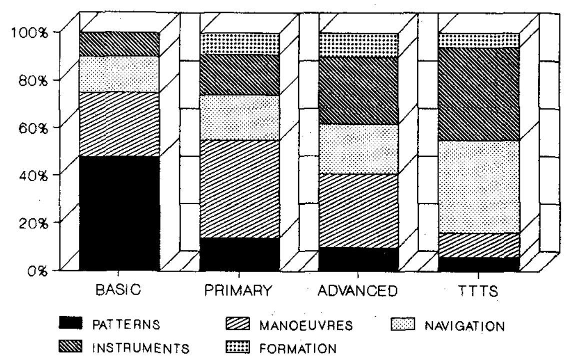


Figure 5 Frequency Matrix

In the Basic phase, the accent is more on the basic flying skills, whereas in the more advanced phases more time is spent in training techniques which will be used later in operational squadrons.

The results of the previous analysis, summed for the different training tasks, are each multiplied by their frequency of usage. This provides a further weighting of importance in the particular phase of training which is being examined.

Results

Figure 6 shows the results of applying the Teaching Effectiveness model to numerous training aircraft in the four different areas of training examined.

The model outputs a Teaching Effectiveness (T.E) rating. The number itself has little absolute meaning and so is presented as a ratio to a selected Baseline aircraft in that phase of training. This is shown as a relative index (in %) in the figure. The aircraft currently in the USAF inventory are taken as the Baselines for the different training phases: The Cessna T-41 for Basic, Cessna T-37 for Primary and the Northrop T-38 for Advanced. The newly selected Beechjet 400 is used as a baseline for the TTTS training. It is interesting to observe the difference between its

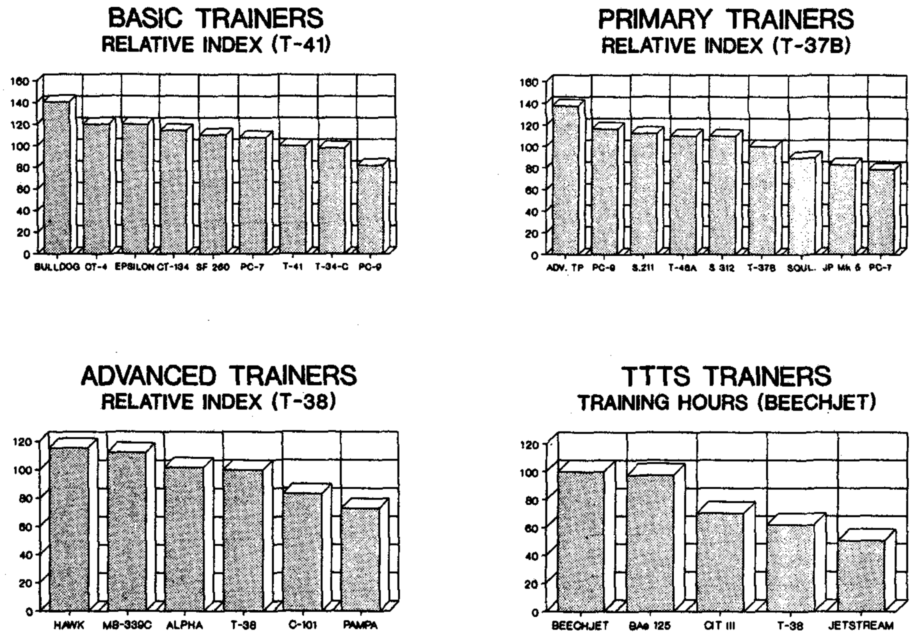


Figure 6 Relative Teaching Effectiveness: Results from model

assessed T.E and that of the T-38, which has conducted the task for almost two decades. In all areas of training substantial improvements of Teaching Effectiveness can be achieved.

It is postulated that the time taken for a student to learn a certain task is directly dependent upon the inverse of the Teaching Effectiveness. This can be confirmed to a certain degree by assessing the T.E of old and new training aircraft in a particular Air Force and comparing the number of hours used in their previous and actual syllabii. For instance, the Shorts Tucano, when assessed against the JP-5 gives a predicted syllabus of 119 hrs (using Table 1 and fig 6) against a quoted foreseen syllabus of 110 hrs.

The same exercise can only be accomplished with caution between different Air Forces, without assessing the different combat aircraft, the Operational Conversion Unit courses and equipment structures.

At the end of this model we therefore have a good assesment of the relative training capabilties of different training aircraft.

Operating Cost model

The second part of this paper is concerned with the costing side of the analysis. A cost model has been derived so as to assess the different aircraft in a similar manner as T.E model above.

The operating cost are made up of several different factors. These are:

- Ammortisation of Purchase Cost
- Fuel costs
- Airframe and Avionics maintenance
- Engine overhaul and maintenance
- Spare parts

Costs of facilities, insurances instructor's costs, etc are not usually considered in the assessment of military training costs and have been ommitted from this model.

The assessment of the purchase price of the various aircraft is made using the following factors:

- Airframe man-hours
- Engine price
- Systems price
- Materials
- Ammortisation of R & D costs
- General & Administration overheads
- Profit

All elements of the cost model have been taken from statistics from the literature or in-house experience. The results have been compared to published prices and 'tuned' as required.

The ammortisation of the purchase cost is accounted for over a 20-year life at an estimated 720 flying hours per year. The purchase cost of the aircraft can be well predicted, as there is considerable transparency into the purchase prices of the competing aircraft.

Fuel costs are estimated knowing the specific fuel consumption of the engines. For several of the competitors, a detailed mission analysis has been conducted, which allows correction factors to be applied to the others. Kerosene has been assumed at a price of US$ 1.65 per US Gallon.

Airframe and Avionics maintenance is one of the most difficult of the factors to assess. It depends on the complexity of the equipment, accessability to components and other factors which are difficult to evaluate. Statistics are readily available from civilian operations and have to have factors applied to them for a military environment.

Engine overhaul and maintenance can be accurately predicted using statistics from civilian operations, factored for the lower overhaul times of the military operations and different pricing structure. Times between overhaul are typically 2'500 to 3'500 hours compared to up to 8'000 hours for some commuter operations.

Spare parts are considered to be proportional to max. take-off weight. The factor has been taken from civilian operations, with military levels of pricing.

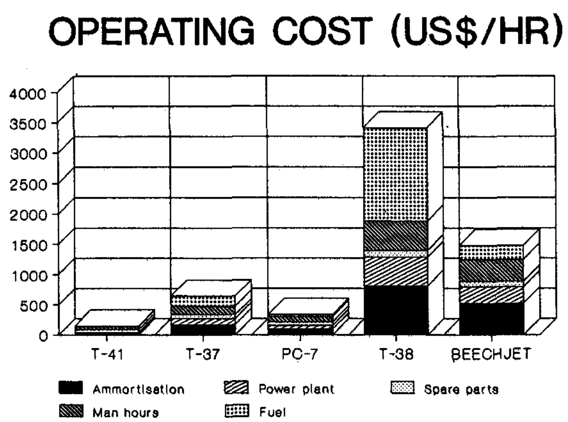


Figure 7 Typical Operating cost breakdown

Figure 7 shows the results of applying the operating cost model to representative aircraft in each of the training categories. The present USAF inventory has been taken. For the 'Primary' category an existing medium performance turbo-prop aircraft is also shown, for comparison purposes. In all areas except maximum level speed, it has performance not far below those of the T-37 jet aircraft.

The 'Basic' training phase will typically utilise an aircraft with very low operating costs. The comparison between the T-37 and the PC-7 operating costs show that there is a potential to achieve considerable savings in costs for the 'Primary' training phase. According to the model, the T-38 operating costs are in excess of 3'000 US$ per hour, of which almost half is the cost of fuel. There is a potential to reduce these costs significantly by utilising an aircraft with a modern high by-pass engine. The savings which can be achieved by training pilots in future on the Beechjet, instead of on the T-38 for the TTTS role, is clearly apparent. However, all these savings can only be achieved with enormous investments in new aircraft and ground equipment. Here the Turbo-prop scores well once again with its low acquisition costs.

Conclusions

Figures 8a and 8b show the conclusions of this clearly. The vertical axis shows the cost expended to train a pilot in the phases considered. The horizontal axis shows the time taken to conduct the training. The time is a variable, depending on the teaching effectiveness of the aircraft.

The existing USAF training structure is visible in the figure depicting 'Basic through to Squadron'.

In order to keep the results of the figure readable, only the Basic and Primary phases are considered in the other figure. The uppermost point shows the cost to train a pilot to progress to the Advanced or TTTs phase of training using the current USAF system. Only small advantages would have resulted, according to this model, if the T-46 had been selected as the New Generation Trainer. Further reductions can be obtained by using a tubo-fan aircraft with higher performance. However, according to this model, real savings can only be achieved when a high performance turbo-prop with its associated lower operating costs and high T.E is included.

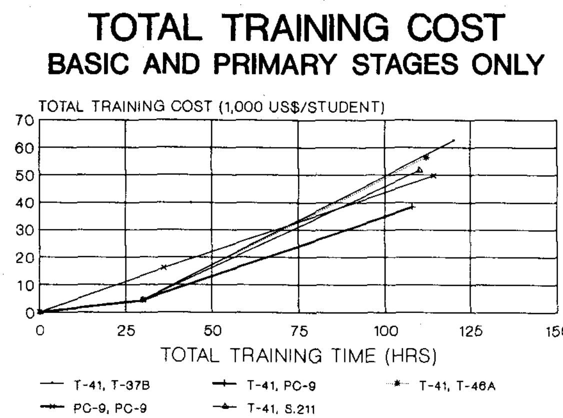
It can be concluded that the high performance Turbo-prop trainer has a firm future in the training of military pilots in the 'Primary' phase of training.

One can go further: Analysis of the high performance turbo-prop in both the 'Basic' and 'Primary' phases of training show that, in spite of the higher cost of operation in the 'Basic' phase than is necessary, the pilot is ready to step up into an 'Advanced' or 'TTTS' training system has been produced even cheaper than going through a piston-engined 'Basic' trainer and a modern jet 'Primary' trainer. This, in spite of the simplistic nature of the model which does not include the costs of transition from one trainer to another.

Model refinements

The Teaching Effectiveness model and cost models exist in their basic forms, but cannot be considered as complete. Further refinements can be made to improve them.

The model can be considered to be a significant improvement on the original ideas of Dott Bazzocchi in the area of assessment of training aircraft. Nevertheless, the authors would recommend some further refinements in the areas of handling qualities and the addition of a criteria which assesses the cockpit environment, to include visibility and presentation of information, as well as an inclusion of an assessment of the transition phase.



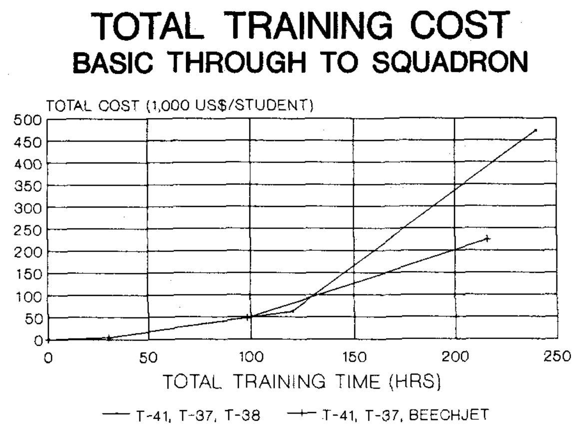


Figure 8. Total Cost to Teach Students: Results from Models

A major omission in the present model is the exclusion of simulators in the training system. Their function and usage is currently under review and will be included in the next issue of the model.

It is hoped that the model can be used by various Air Forces to establish the most effective aircraft for their own purposes. The model has sufficient flexibility incorporated that the user can define his own criteria, if his accent in training is different from those established for the model. This could be because the training environment is geographically different, because of different front line aircraft or because he prefers to conduct some of his tactical training at an earlier stage of the student's flying career.

The latest status of the model will be described at the ICAS congress in Stockholm. It is hoped to describe the modified version in an edition of the AIAA publication, the 'Journal of Aircraft', late in 1990.

The authors would like to express their thanks to members of the organisations of Pilatus Aircraft Ltd, Northrop Aircraft Division, British Aerospace and McDonnel Douglas, who have made comments on the model based on the wealth of their experience in the training and analyses of military training, available in discussions with the authors

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