CP 602

THE AERMACCHI YAK/AEM-130 AND AT-2000 DESIGN OBJECTIVES: A TOPIC IN THE SUBSONIC VS.SUPERSONIC TRAINING TRADE-OFF

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SUMMARY

A modern trainer should be designed in accordance with the needs imposed by the entry into service of new and more capable operational aircraft. The trainers currently in service were designed, at best, with late 60's generation fighters in mind.
The introduction of a modern trainer into service will allow substantial savings, over their life-cycle, with respect to the existing advanced trainers, even if updated with state-of-the-art avionic systems.
This paper deals with the cost-effectiveness of selecting a subsonic or a supersonic configuration as a baseline.
The result of a quantitative evaluation, carried on a representative training scenario, shows that the higher costs of a supersonic configuration will not be paid by the reduction in training costs, and that the optimal baseline is still a subsonic trainer, designed to be representative as much as possible of the modern combat aircraft.

1. Introduction

Aermacchi, established in 1913, is today one of the oldest aerospace companies. After merging with SIAI Marchetti at the end of 1996, Aermacchi has today 1650 employees and sales near to 200M$. The main activities spread from commercial aerostructures (Do-328, Falcon2000, engine nacelles), to cooperations in military programs (Tornado, EF-2000, AM-X); the company core business is however focused on training aircraft.
Today Aermacchi training products range from the SF-260 screener/initial trainer through the M-290TP Redigo basic turboprop and the S-211 basic jet trainer up to the MB-339FD advanced/lead-in trainer.
These aircraft (and their MB-326 predecessor) have been sold in over 2000 units to 38 worldwide customers.

2. New trainers development in Aermacchi

Since 1985 Aermacchi started planning the introduction in its product range of a new, very advanced training aircraft. The initial studies covered a wide range of requirements, but soon the focus was shifted to a high transonic configuration, with limited supersonic capabilities, able to cover both the primary role of advanced/fighter-lead-in training and a secondary role as a lightweight fighter.
From 1985 to 1995 Aermacchi invested around 500,000 engineering hours studying 20 different configurations (canard, aft-tail, single and twin engine, dry and augmented propulsion), introducing in the design the result of 5000 hours of wind tunnel testing and of 3000 hours of simulation.
The AT-2000 preliminary design envisaged a

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full-authority FBW aircraft featuring a variable camber wing, coupled with a forebody / strakes / empennage design able to provide good transonic characteristics, coupled with a linear and predictable behaviour well over 35 degrees angle of attack.
During these studies Aermacchi was joined initially by Dornier, then by DASA LM.
The work on the AT-2000 ended in late 1995, freezing the final configuration.

In 1992 Aermacchi started evaluating what was then known as the YAK-UTS, a new trainer which was under initial development at the Yakovlev Design Bureau in Moscow. The YAK-UTS design had many common points with the AT-2000, being a very advanced trainer, capable of medium/high angles of attack, featuring a moderate aspect ratio wing with variable camber, large strakes, chined forebody.
Due to a firm requirement from the Russian Air Force, the aircraft was based on a twin-engine configuration, being the engine initially selected the AI-25.
Given the high similarity of technical characteristics between the YAK-UTS and the AT-2000, a cooperation agreement with the YAK Design Buro was signed in 1993, which allowed Aermacchi to take part in the conceptual and preliminary design, in the development and production and in sales of the aircraft.
Up to mid 1997, Aermacchi performed around 280,000 engineering hours, working on redefinition of the configuration, aerodynamics (with 2000 hours of wind tunnel testing), FBW design (with 2000 hours of test rig simulations), and taking part to the flight test activities being performed on a DEM-VAL aircraft build by Yakovlev which flew in April,1996. This demonstrator was based at the Aermacchi facilities during July 1997 for a short test campaign focused on performance validation and FBW assessment.
As a result of these activities the YAK-UTS configuration was widely modified to cope with the general and detailed requirements defined by Aermacchi, becoming the YAK/AEM-130, a sensibly smaller and lighter aircraft powered by two more powerful DV-2S engines.
The current planning envisages that the first YAK/AEM-130 prototype aircraft will fly end 1998/early 1999, with a first batch of ten aircraft in service with the Russian Air Force by year 2000. The prototype of the international version, which will differ from the russian aircraft mainly in the avionic system, will fly in early 2000, with start of deliveries possible from year 2002.

3. New trainer requirements

The AT-2000 before, and the YAK/AEM-130 after, have been designed around requirements derived from the training needs foreseen for the next future.
New combat aircraft types have been introduced into front line service, featuring operational capabilities greatly increased with respect to the previous generation of fighters and attack aircraft.

The new combat vehicles feature large improvements in energy/manoeuvrability, expecially in the transonic arena, with turn rates and specific excess power largely increased when compared to last generation fighters (Fig.1) . High angle of attack capability, meaning the ability to effectively manoeuvre above 30-35 degrees, is now featured by many of the new types, and this capability is brought to its extreme when thrust vectoring is adopted (Fig. 2).

The functional capabilities are multiplied by new, extremely powerful and light processors and sensors, which have allowed the fielding of true multi-role aircraft. New weapons have taken advantage of sensors and processors miniaturization, and new tactics have been developed to exploit them. The appearance of lightweight liquid crystal displays has dramatically changed the cockpit layout, allowing the pilot to concentrate on mission management, instead of looking at his aicraft's round dials.

This large increase of performance/capabilities in combat types is already posing new demanding requirements to the Air Forces training systems which, for the majority, are still operating trainers which were at best designed for the F-4 class fighters.
This results is an increase of flight hours needed to bring a pilot to the combat readiness in the new types, but due to the trainers lack of capabilities, most of these hours have to be

performed on the combat aircraft itself.
The cost of training up to combat readiness is therefore increased, posing budgettary problems to already strained Air Forces economies.

Any new trainer shall therefore be designed to extend as much as needed the skill of the pupil at the end of his syllabus at the flying school, thereby reducing the number of flight hours required on the new combat aircraft before combat readiness (Fig.3).

The main requirements resulting from the above analysis are:

- Good high end characteristics, in terms of energy, acceleration and speed.
- A significant low altitude speed persistance, both in terms of gust ride and fuel flow.
- Excellent manoeuvrability (sustained load factor/turn rates) at typical manoeuvre altitudes and speeds.
- Fast to climb to training altitude and to accelerate to manoeuvre speeds.
- Representative of the combat aircraft behaviour at medium/high angles of attack (30-40°).

Being however a trainer aircraft, some requirements must be added to allow an easy transition from lower types, such as basic turboprops or even high power piston trainers:

- Low terminal speeds, expecially at final approach.
- Excellent low speed characteristics.
- Forgiving handling.
- Performance and handling should be progressively increased to match the pupil capabilities, up to the point of matching the operational aircraft flying qualities (in-flight simulation).

From the man-machine interface point of view, a new trainer must reproduce the cockpit environment of modern combat aircraft; however also the displayed information must be similar in qualitative and, if possible economically, quantitative terms. Navigation and weapon delivery computing functions shall therefore be as close as possible to those of an operational aircraft, while targeting sensors (RADAR, FLIR; IRST,...), which are still outside the cost range for a trainer, will be simulated, as far as possible (embedded training).

The requirements for a new trainer shall also take into account the need, from many Air Forces, of providing limited fighting capabilities in a secondary role; the new trainer shall thence be capable of carrying at least 6000 lb of weapons, with a limited degradation in performance, and shall be able to operate with the said loads from short runways and in hot/high conditions.
All these requirements can be quantitatively expressed by saying that the the "TRAINING EFFECTIVENESS" of the aircraft should reach a given figure, and that the increase in training effectiveness, with respect to existing trainers, should be proportional to the increase of operational capabilities witnessed in the operational aircraft (Fig.4).

4. Training effectiveness measurement

In the last 20 years, Aermacchi has constantly worked to a quantitative model able to measure the effectiveness of a trainer aircraft. The early models, known as "Bazzocchi method" after the former General Manager of Aermacchi, have been updated to take into account new characteristics, tactics and functional capabilities.
The basis of this method is the quantitative evaluation of the "training effectiveness", which is defined as the pupil skill increase per flight hour (Fig.5).

It is assumed that the training effectiveness is a function of the trainer performance, functional capabilities, flight envelope (in an extended acception), and type of man-machine interface. By giving quantitative values to each parameter (load factors, angle of attack, range, number of flight management functions, number of weapon aiming modes, typical speeds, turn rates ...), a quantitative evaluation of the training effectiveness is obtained.

It can be shown that a good statistical correlation exists between the so defined teaching effectiveness and the number of flight hours flown in a given aircraft before the saturation of its capabilities (Fig. 6), when it is convenient to graduate the pupil to a more capable aircraft; the saturation level for the combat aircraft is the "combat readiness" status for the operational pilot.
Knowing the training effectiveness of a

succession of trainers and of the "target" combat aircraft is therefore possible to define an "optimum" syllabus (in terms of flight hours on each aircraft, including the target), where each trainer is used up to its saturation point and no more.

The model allows also to compute the Life-Cycle Cost per flying hour of all the aircraft involved in the training process.
The life-cycle cost analysis is based on a parametric model which computes separately the development cost, the fly-away cost, the procurement cost and the operation and support costs. The parametric model is constantly trimmed on actual data, whenever these can be found reliable.

It is therefore possible to couple the teaching effectiveness of each aircraft with its life-cycle cost per f.h. (fig. 7), and to compute the cost of the "optimum syllabus" previously defined, up to the final cost of a combat ready pilot on a given operational aircraft (fig.8).
This cost can take into account also the overhead costs and the extra costs due to trainee pilots "washout".
It is now possible to compute the cost of training of a combat ready pilot, with different hypotheses on the advanced trainer used in the syllabus, and to compare the final cost using a subsonic (I.E. the YAK/AEM-130) or supersonic (I.E. the AT-2000) trainer.

5. Trainers design trade-off: subsonic vs. supersonic

The design point characteristics of the YAK/AEM-130 and of the AT-2000 are compared in fig. 9. It can be seen that the take-off mass is roughly the same, but the AT-2000 point performance is higher, providing real supersonic capabilities, even at the expense of a reduction in range and endurance.

The training effectiveness of these new trainers can now be compared to an existing advanced trainer.
For comparison purposes, the MB-339CD has been chosen as the baseline. This model, recently acquired by the italian Air Force, is the newest member of the '39 family: it is fitted with a fully integrated digital avionic system, which includes inertial (RLG) / GPS navigation, HUD with AA/AG weapon aiming modes, three LCD MFD's in each cockpit.
Fig.10 shows that both the subsonic and supersonic configurations provide a significant leap forward in terms of training effectiveness with respect to an existing advanced trainer,even if fitted with a state-of-the-art avionic system. The final skill of the pilot at the end of the training cycle on the advanced trainer can be doubled, by increasing the real number of flown hours by a moderate quantity.

However, the cost of the new trainers is higher than that of the existing ones, and this is expecially true for the AT-2000, whose development costs are nearly four times those of the existing baseline (fig. 11).
The development and procurement costs of the YAK/AEM-130 are further reduced by the cooperative nature of the program.

The final cost-effectiveness of both aircraft is shown in fig. 12: while the YAK/AEM-130 and the AT-2000 are both a substantial leap forward in terms of cost-effectiveness, the first still shows a small advantage.

The cost of training a combat-ready pilot on different types is shown in fig. 13.
The supersonic trainer will allow a significant cost reduction in the training process for EF-2000 and Tornado pilots, but will actually increase the cost of training an attack/close air support AM-X pilot, since it will not be possible to exploit the aircraft up to its full potential (this is partly true also for the Tornado track).
The subsonic trainer will allow significant savings on all types, but more so in the attack/CAS track and in the Tornado track, where its capabilities will be fully exploited at a much lower cost than that of the supersonic aircraft.

If we take into account a representative distribution of "fighter track" pilots between the types, we can compute the yearly training costs of an Air Force: it can be seen that the introduction of a modern trainer can allow significant savings, but more so for the more economic subsonic advanced trainer (fig.14).

6. Conclusions

A modern trainer should be designed in accordance with the needs imposed by the entry into service of new and more capable operational aircraft. The trainers currently in service were designed, at best, with the late 60's fighters in mind.
The introduction of a modern trainer into service will allow substantial savings, over their life-cycle, with respect to the existing advanced trainers, even if updated with state-of-the-art avionic systems.
A modern supersonic trainer will allow a substantial reduction of the cost of training a combat-ready pilot for the front-line aircraft (EF2000, Rafale, F-22A, F/A-18E class),but training costs for all the other pilots which need advanced/lead-in training (attack, strike, recce, ECR, ...) will be less favourably affected.
A modern subsonic/transonic trainer will achieve less substantial cost reduction for the training of front-line fighter pilots, but will allow greater savings in the other tracks.
Both configuration must however be designed for high AoAs, to be representative of the behaviour of modern combat aircraft even during unusual manoeuvres.
The need for real supersonic training is therefore limited and, in and by itself, is not enough to pay for the vastly higher development costs required. Also the procurement and O&S costs of the supersonic trainer will be higher.
The requirement for a secondary role capability for the advanced trainer can push towards a supersonic configuration, expecially if "point defence" roles would be envisaged. It must however be recognized that these capabilities will be limited by the aircraft maximum economical size as a trainer: in particular the number and kind of weapons that can be integrated on a small aircraft will be reduced, as will be the payload/range characteristics of any advanced trainer, when compared with those of an F-16C class fighter.
In the last years the aerospace industry has often pursued the T-38/F-5 legacy dream, but the expected market success has still to materialize.

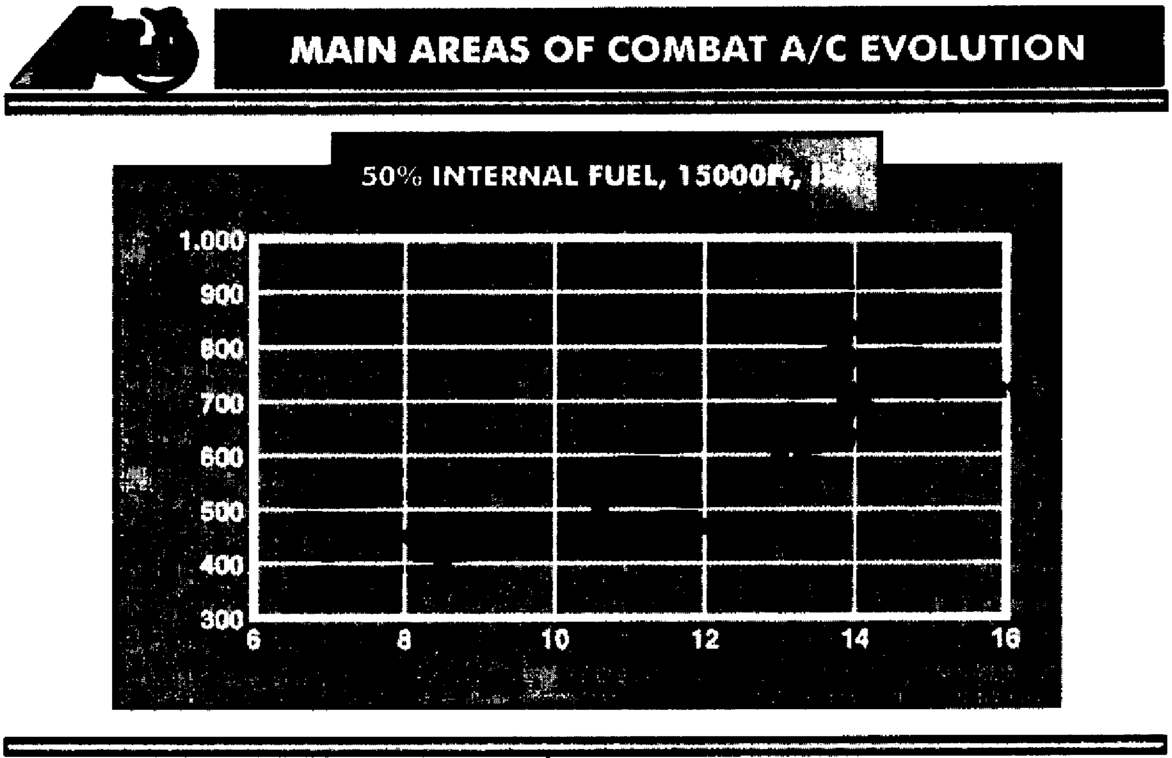
MAIN AREAS OF COMBAT A/C EVOLUTION
50% INTERNAL FUEL, 15000Ft,
1.000
900
800
700
600
500
400
300
6
8
10
12
14
16

fig 1

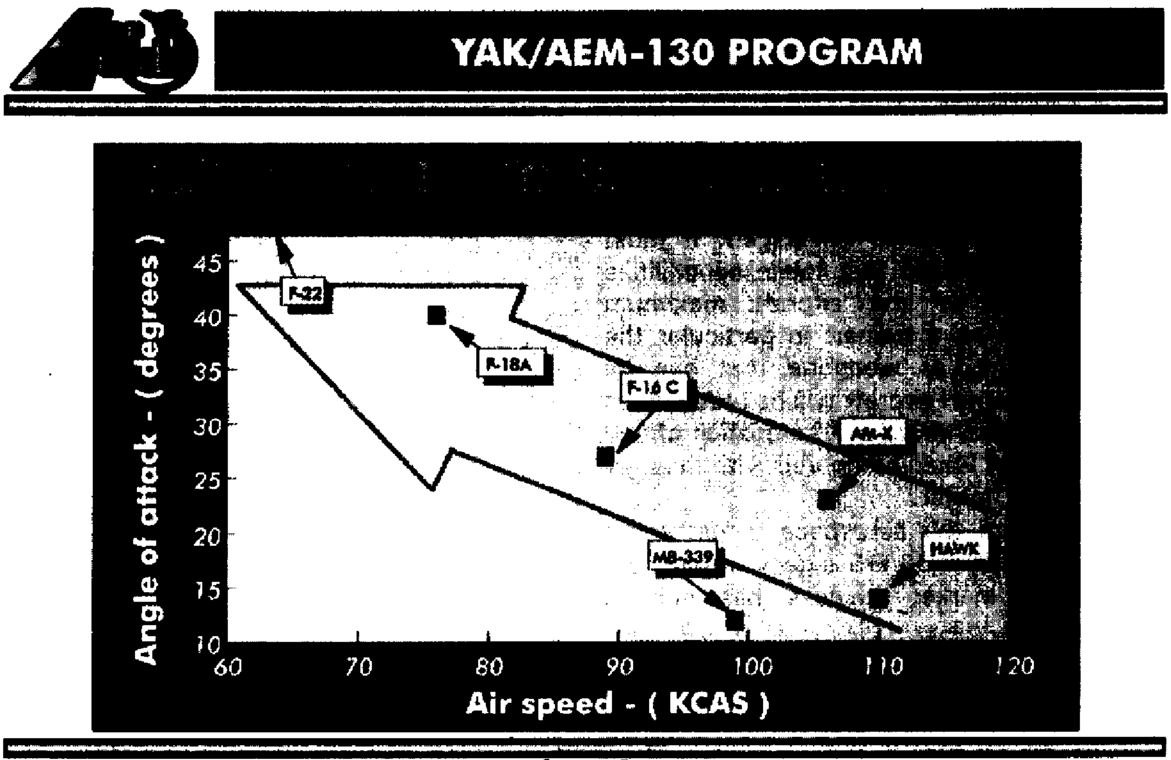
YAK/AEM-130 PROGRAM
Angle of attack - (degrees)
45
40
35
30
25
20
15
10
60
70
80
90
100
110
120
Air speed - (KCAS)
F-22
F-18A
F-16 C
AM-X
MB-339
HAWK

fig 2

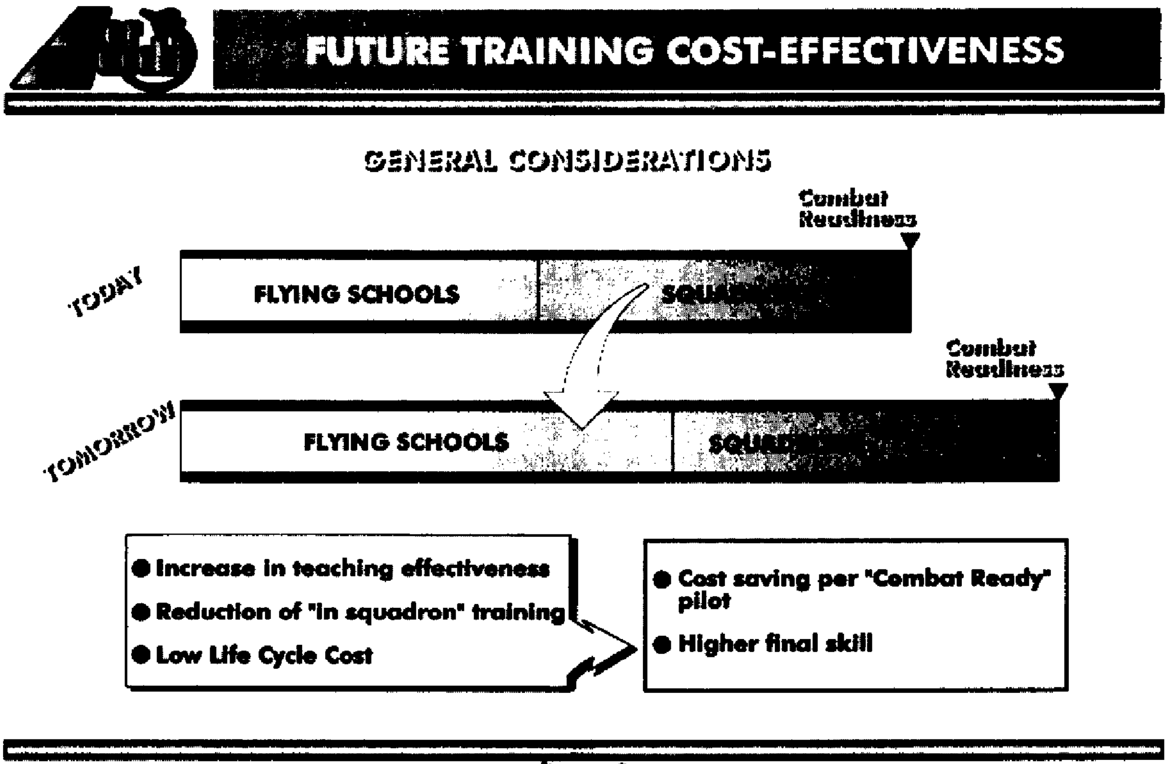
FUTURE TRAINING COST-EFFECTIVENESS
GENERAL CONSIDERATIONS
Combat Readiness
TODAY
FLYING SCHOOLS
Combat Readiness
TOMORROW
FLYING SCHOOLS
● Increase in teaching effectiveness
● Reduction of "in squadron" training
● Low Life Cycle Cost
● Cost saving per "Combat Ready" pilot
● Higher final skill

fig 3

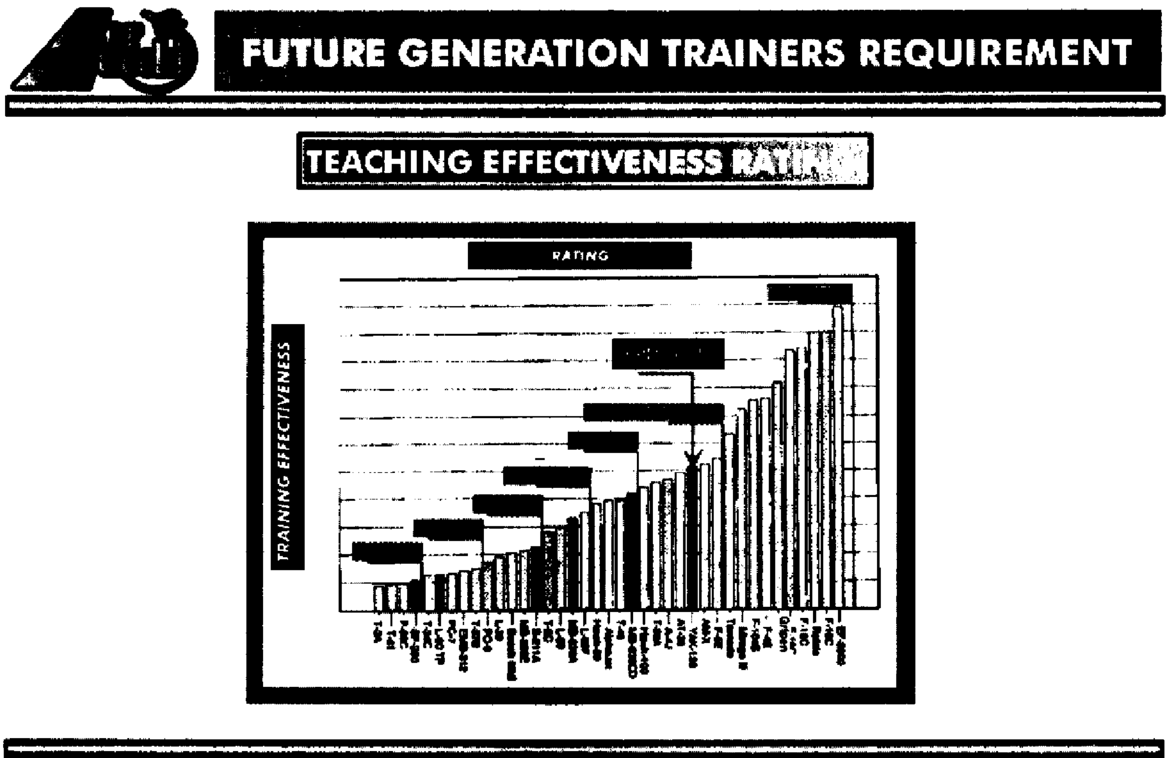
FUTURE GENERATION TRAINERS REQUIREMENT
TEACHING EFFECTIVENESS
RATING
TRAINING EFFECTIVENESS

fig 4

TRAINING EFFECTIVENESS

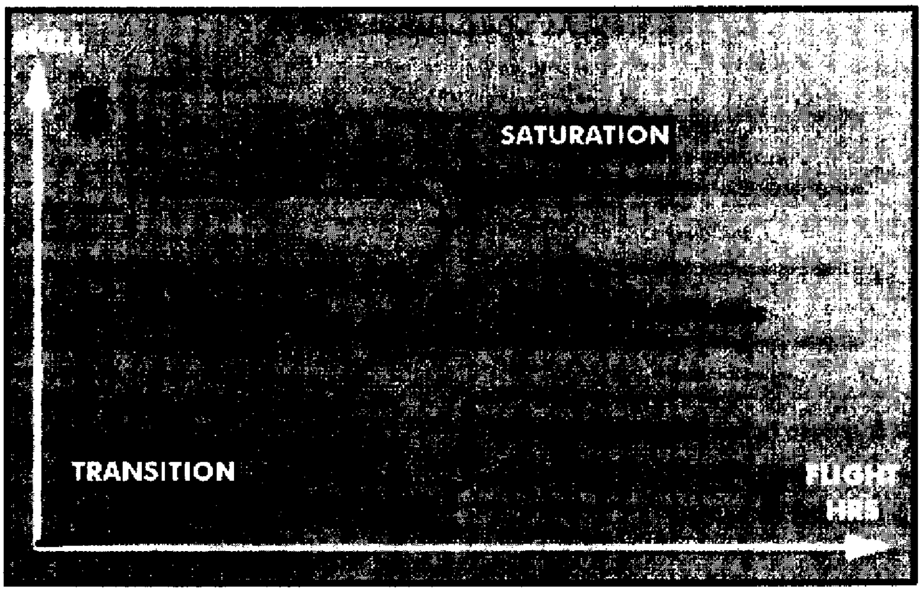

fig 5

TIME TO SATURATION

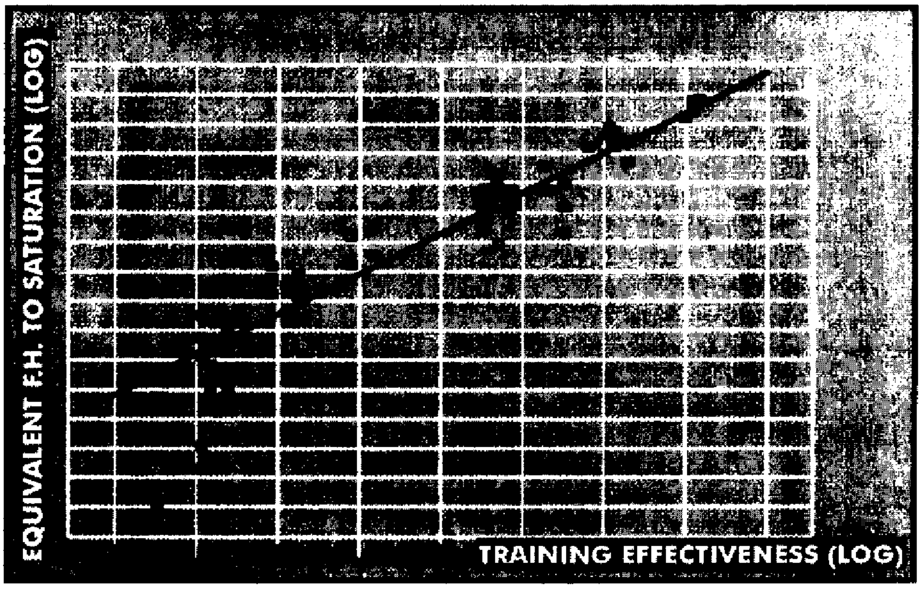

fig 6

TRAINING EFFECTIVENESS AND COST

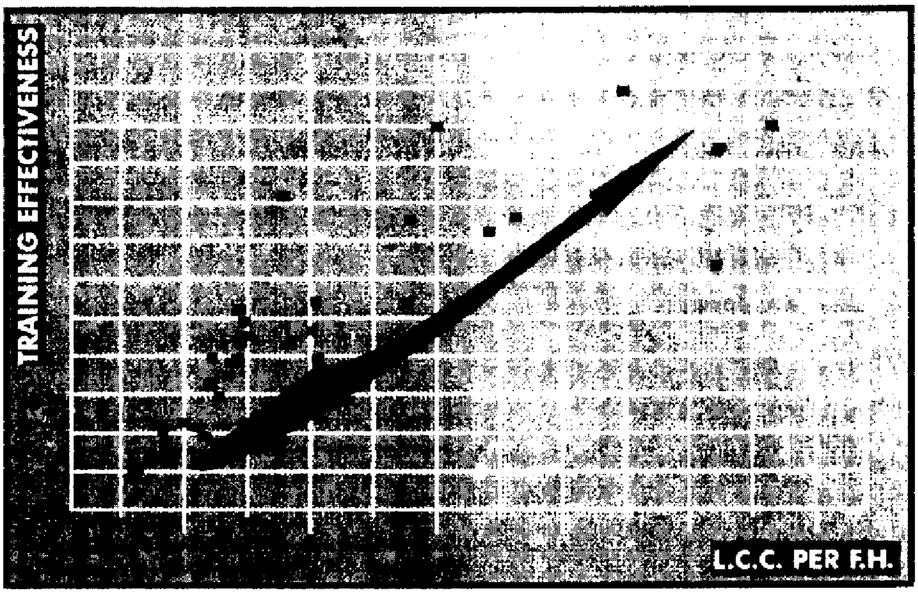

fig 7

TRAINING SYSTEM CAPABILITY

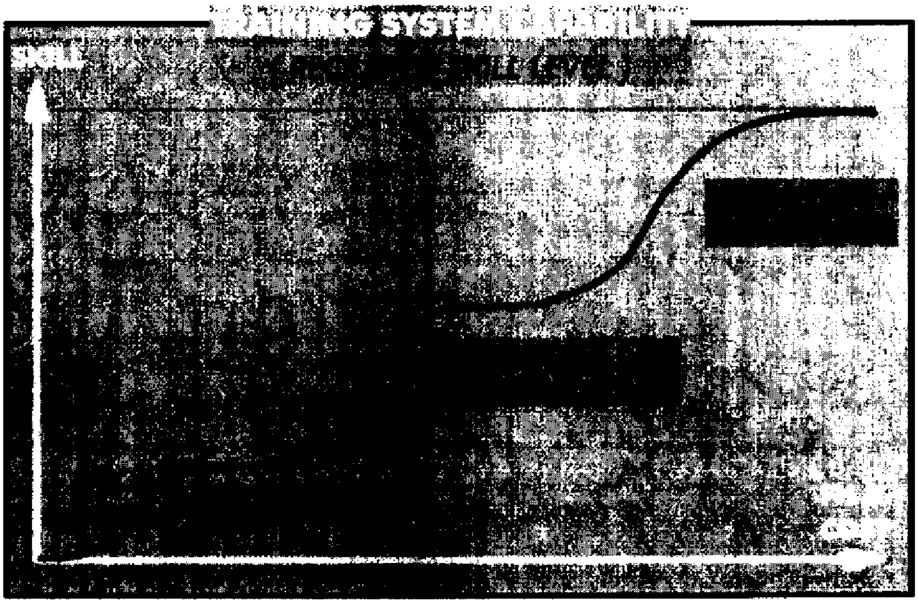

fig 8

DESIGN POINT COMPARISON

	YAK/AEM-130	AT-2000
MAX LEVEL SPEED, SL	540Kts	650Kts
SUST. LOAD FACTOR, 15KFt	5g(@M=.8)	7g(@M=.85)
MAX S.E.P., 15KFt	250 Ft/s	550 Ft/s
MAX MACH	0,92	1,45
TRANSONIC ACCELERATION	-	[illegible]
APPROACH SPEED	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

fig 9

TRAINING EFFECTIVENESS COMPARISON

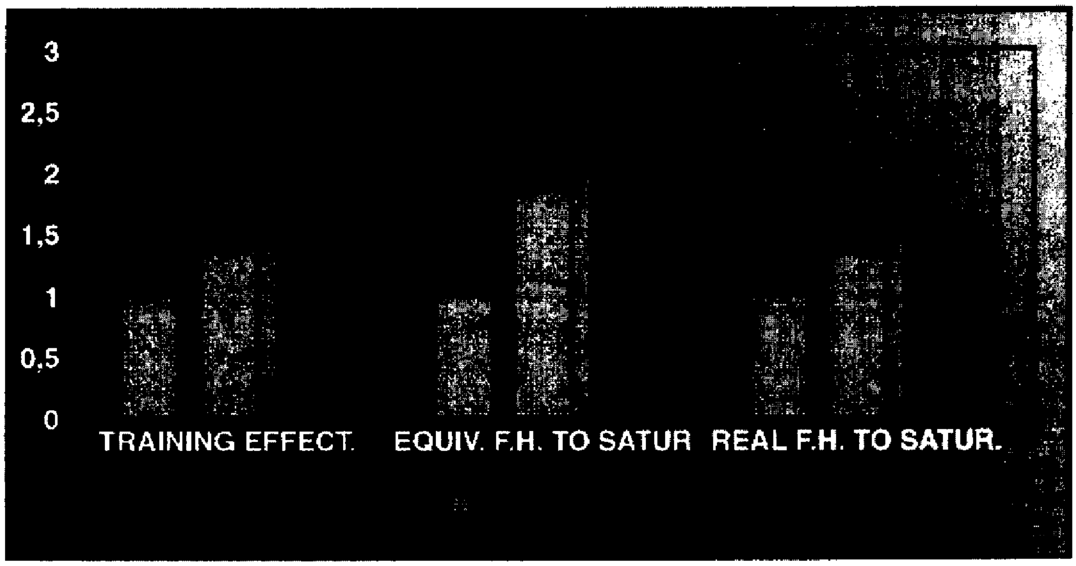

fig 10

COST COMPARISON

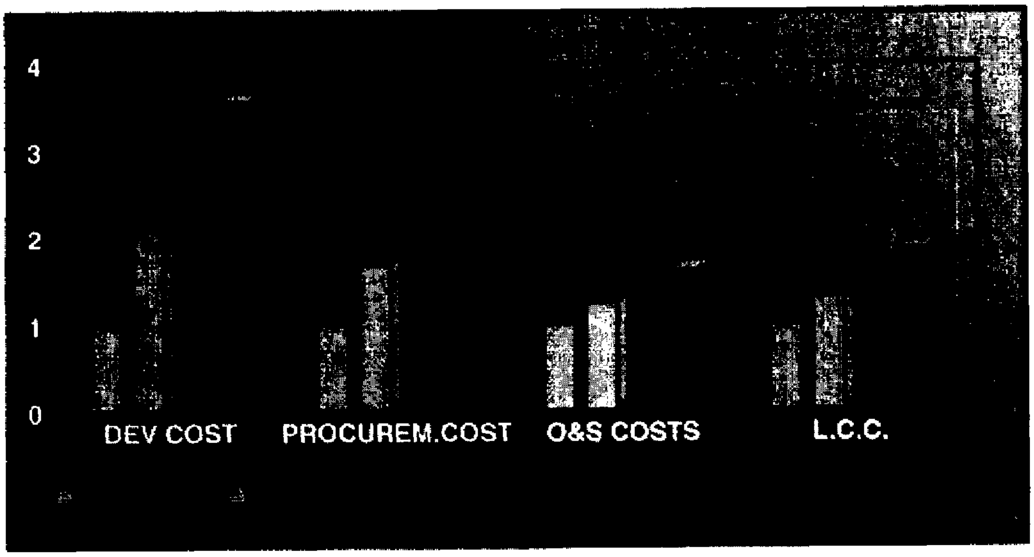

fig 11

TRAINING EFFECTIVENESS AND COST

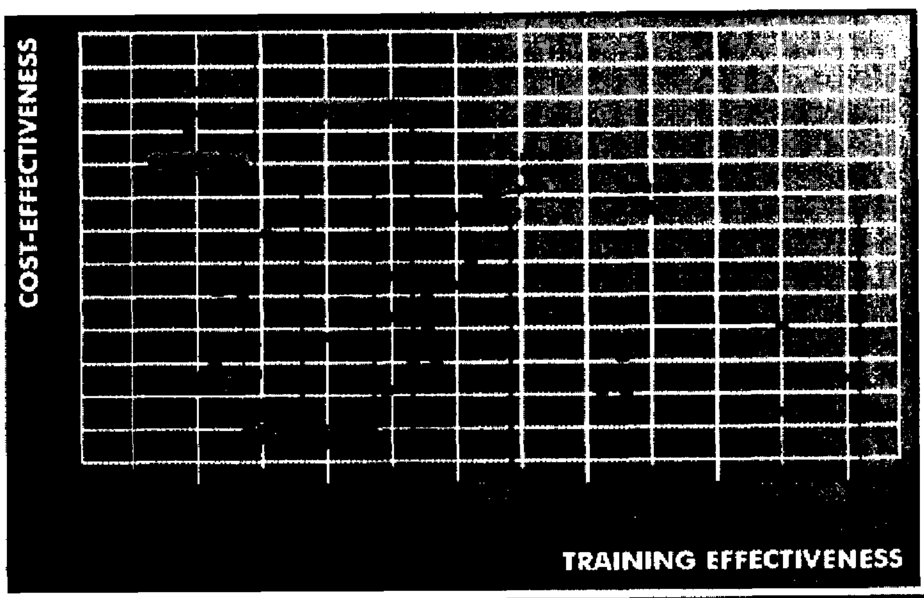

fig 12

TRAINING COSTS

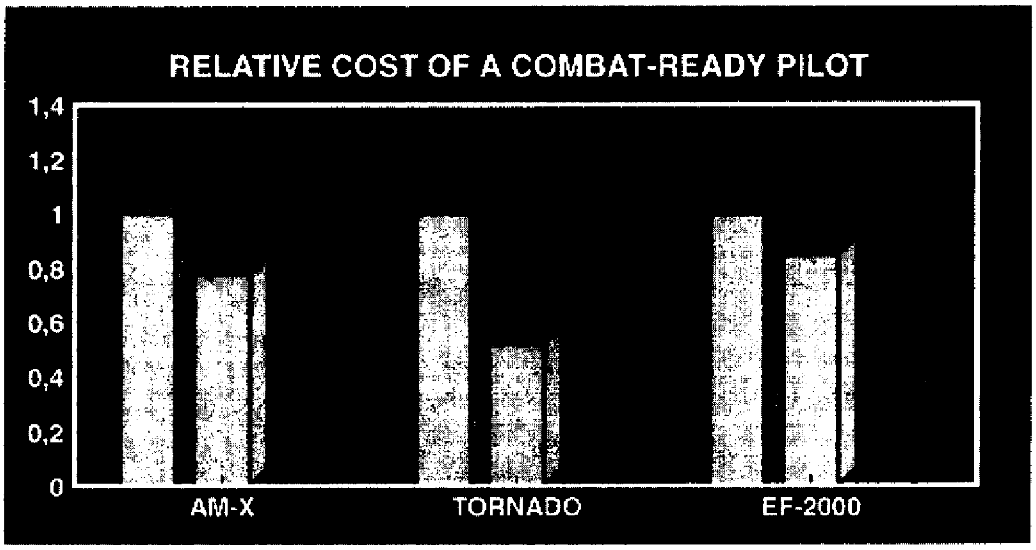

fig 13

OVERALL TRAINING COSTS

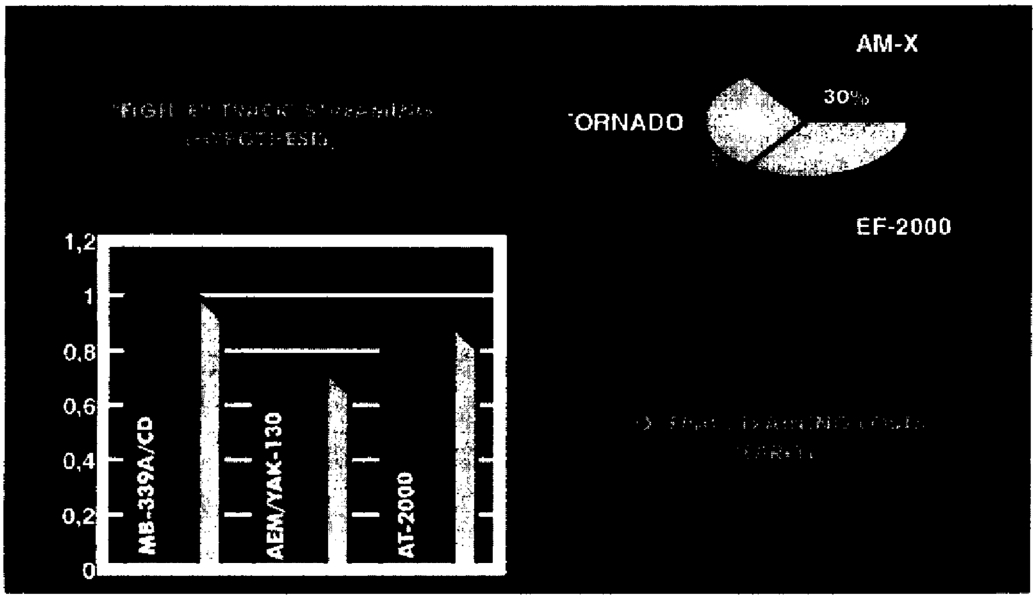

fig 14