# SOME CONSIDERATIONS OF OPTIMUM WEIGHT OF FIGHTER AIRCRAFT

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## ABSTRACT

Over the past ten to fifteen years there has been a tendency for fighter aircraft to grow in size, complexity and cost. This tendency became so marked that there has been a reaction towards reduced weight, greater simplicity and design economy intended to keep down the cost. Of late, both military authorities as well as design experts in many countries have paid considerable attention to the philosophy of the light weight strike fighter. Ther is an opposing point of view which maintains that a fighter cannot be made too "Light" if it is to have good combat value.

There are two major factors involved, namely cost and combat effectiveness. How are these factors to be weighed and an optimum design achieved? The problem is extremely difficult since no simple yardstick has been established to measure combat effectiveness. The armament carried, the electronic aids available for combat and precision navigation, the performance of the aircraft, its handling qualities and versatility of the aircraft for use in different roles during unforeseen exigencies are all factors of critical significance. A slight superiority in one respect or other might mean the difference between victory and defeat.

The discussion of the light weight fighter concept has more or less been on a theoretical plane so far. Besides, opinions differ violently as to what exactly is meant when we say that a fighter is of light weight. Should its weight be 6,000 lbs., 12,000 lbs. or 18,000 lbs.? These are all called light weight fighters by different countries in accordance with their own tactical concepts.

The purpose of this paper is to highlight some relevant points and to discuss their technical implications.

## Introduction

The increasing size and complexity of modern fighter aircraft and their mounting costs has been a matter of grave concern to all countries and recently a serious attempt has been made towards achieving greater economy in military spending by the practical application of the light weight fighter concept. Arguments have been advanced for and against light weight fighters and there have been basic differences of opinion between military and technical men.

The problem is essentially one of cost versus combat value and the question has arisen, "Is there any possibility of finding an optimum weight or size for a fighter aircraft? If there is, then what are the considerations affecting this optimum value?"

The major problem is obviously one of specifying the operational requirement which is the prime consideration. And for determination of optimum values in a specification that will fulfil this operational requirement effectively, we have to consider the effects of major inter-related parameters. We have then to find the point of diminishing return when a primary parameter is changed progressively. It is, however, not the intention here to present the results of any analysis made for formulating operational requirements using the methods of operations research but rather to explain the significance of certain design parameters once an operational requirement has been specified.

In the case of a fighter aircraft the two basic parameters determining its ultimate value as a weapon are its "combat value" and cost. The cost factor is determined by size, and the degree of sophistication, which in turn would also affect size. The 'combat value' of the aircraft which may be defined as a measure of its ability to destroy the target and also escape destruction at the same time would depend on many factors such as its performance and handling characteristics, the quantity and quality of its armament, the electronic aids available for navigation, interception etc., and the radius of action. Radar aids for early warning and identification, vectoring, search, tracking and fire control are now invariably vital part of the weapon system for interception and would constitute a very important factor.

In regard to armaments, the type of weapon that is used, *i.e.* guns, rockets or guided missiles, and the method of attack as determined by the radar aids available and the performance of the aircraft, are significant for interception; for the pilot must not only place himself in the most favourable position to destroy the target but must also carry out the attack in such a way that he has a high probability of survival. In the ground attack role, the quantity and variety of external stores that can be carried as well as the mode of delivery are important factors. If the relative influence of the above factors is properly evaluated by detailed analysis using the methods of operations research, in the context of the tactical mission the fighter is expected to perform, and our ideas are clarified as regards the combat load it has to carry (such as guns, rockets, sights, one or more pilots), the electronic aids for navigation, interception etc., the practical radius of action required and its performance and manoeuvrability in the tactical environment contemplated, it should be possible to draw up a specification for a design of optimum weight.

It will be realized that the actual weight of a fighter is a subsidiary issue since its value as a weapon is dependent on a working compromise effected between the two basic parameters namely combat value and cost. The definition of the operational requirement is the crucial consideration. Once it is decided what combat load the aircraft has to carry, and the performance and operating radius needed, the rest is a design problem and here the knowledge and art of the designer have full play.

It will be evident from the above that the determination of the optimum weight of a fighter has two aspects: one relates to optimization of the operational requirement to meet a certain tactical situation and the other to the achievement of a design of minimum weight.

In the present paper an attempt has been made to analyse the influence of certain basic design parameters affecting the total weight of fighter/bomber aircraft meant to fulfil specified operational requirements. Brief mention is also made of relative costs and tactical considerations but it has not been the intention to examine these aspects from the standpoint of optimization of an operational requirement although a secondary aim has been to focus attention on these aspects too and to indicate present day trends.

**The N.A.T.O. light strike aircraft concept**

The philosophy of the light weight fighter came into great prominence when the N.A.T.O. was considering the question of the effective defence of Europe against a massive surprise attack. What N.A.T.O. needed was a light weight strike fighter with sufficient fire power to help the ground forces hold out against a numerically superior enemy. The prblem was one of ensuring protection from total annihilation of the combat aircraft stationed in forward areas of about 300 miles in depth during the initial mass attack. If the locations of these aircraft provided stationary targets, they could be easily destroyed by use of tactical atomic weapons. Hence wide dispersion and mobility of the combat squadrons would be necessary. It was found that the light strike fighter offered the best solution for such combat conditions. The problem once stated unambiguously led to the solution that the aircraft must be capable of taking off from small fields or grass runways, should be able to carry a wide range of conventional armament, must be so designed that rearming and refuelling could be done in the shortest time and should also have adequate high speed performance and fighter capability necessary for either quick get away or for fighting at low altitudes. N.A.T.O. found that in view of the special and limited tasks for this type of fighter, their complexity and, therefore, the weight could be reduced considerably. At the same time it was also recognized that the overall N.A.T.O. strategy required two types of strike aircraft, one heavier and the other lighter; the first intended for destroying enemy bases and launching sites and the second for direct support of the ground forces. In the light of the above it will be realized that to base the requirements of fighter/bomber aircraft of any country entirely on the NATO concept which is restricted in scope and has a limited objective only would be a mistake unless the overall strategy is considered the same as that of NATO.

**Current light fighters**

Ever since these ideas have been in the process of crystallization, a question that has been asked is how light should a light fighter be. Today even a fighter of 20,000 lbs. weight may be considered light. We have at one end of the scale ultra-light fighters such as the Gnat and at the other end, fighters such as Draken, which from the American point of view, are also to be considered light; in between, we have the N.A.T.O. light strike aircraft such as the Fiat G-91, the Breguet Taon and the Etendard VI. These fighters more or less fall in the 6,000 lb., 12,000 lb. and 18,000 lb. weight brackets respectively. It is to be determined whether in terms of 'combat value' for their intended roles, they are worth the cost one has to pay for them. The characteristics of these three basic types are summarised in Table I. Figure I indicates graphically the weight breakdown of the major elements.

## TABLE I

*Weight Breakdown of Fighter Aircraft*

| | A | $B_1$ | $B_2$ | $C_{10}$ | $C_{11}$ | D | E | Remarks |
|---|---|---|---|---|---|---|---|---|
| *Air Frame, Accessories and Fixed Eqpt.* (Lbs) | 2768 | 4960 | 5400 | 8452 | 8962 | 10100 | 9193 | |
| *Engine* .. .. .. (Lbs) | 850 | 890 | 890 | 1780 | 2110 | 4070 | 3300 | |
| *Fuel* .. .. .. (Lbs) | 1392 | 3000 | 3500 | 4960 | 4960 | 3800 | 3136 | |
| *Combat Load*— | | | | | | | | |
| Internal Armament .. .. (Lbs) | 994 | 1010 | 1010 | 2000* | 2000* | 2160† | 1563 | |
| Pilot & gear .. .. .. (Lbs) | 220 | 220 | 220 | 220‡ | 220‡ | 220 | 220 | * with rockets<br>† with missiles |
| Radio, Radar & special equipment (Lbs) | 176 | 220 | 220 | 222* | 222* | 850 | 238 | ‡ Capable of seating 2 |
| Total .. | 1390 | 1450 | 1450 | 2442* | 2442* | 3230 | 2021 | |
| *All up Weight*—Clean Aircraft .. | 6400 | 10300 | 11240 | 17640 | 18440 | 21200 | 17650 | |
| *Radius of Action*, (N.M.)— | | | | | | | | |
| (*a*) High Altitude (45000 ft.) .. | 220 | N.A. | N.A. | 470 | .. | N.K. | 275 | |
| (*b*) Low Altitude (3000 ft.) (NATO Mission) with auxiliary tanks. | 120 | 150 | 180 | 240 | .. | N.K. | 140 | |

N.A. Not applicable.

N.K. Not known.

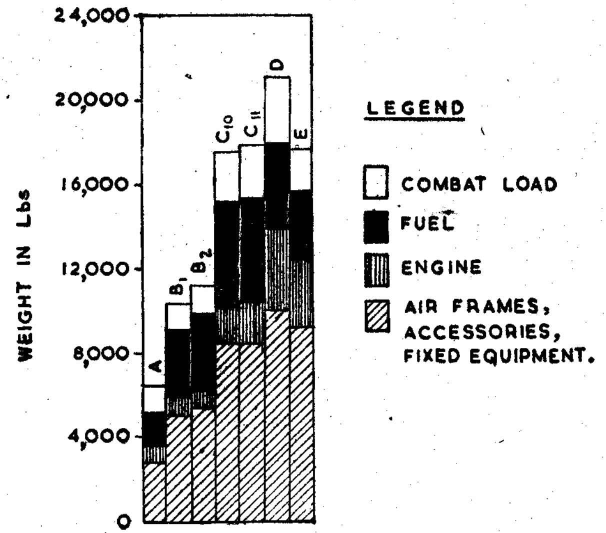


FIG. 1. WEIGHT BREAKDOWN OF FIGHTER AIRCRAFT.

It will be generally agreed that the 'combat value' of a fighter aircraft in a weapon system is not easy to assess by analytical or statistical methods in view of certain intangible factors. Among the factors whose influence can be known to a greater or lesser extent are the performance and manoeuvrability of the aircraft, the radar aids available, its armament, method of attack, the electronic aids for ensuring accuracy of hit and finally its radius of action and endurance. In a modern design, the performance is dependent on thrust loading of the aircraft *i.e.* W/T which whould be as near to unity as possible and should not in any case exceed 1.5. Together with performance, adequate manoeuvrability is implied but this is more a matter of good design than one of cost and weight. The armament and the electronic aids needed for acquiring the target and delivering the attack are of critical importance. These along with the pilot would constitute the essential "combat load" of the aircraft and, therefore, a crucial factor in the total cost. The "useful load" will be the combat load plus the fuel.

The next consideration is the range and endurance, which would determine the radius of action and ability to deliver repeated attacks. This is dependent on the amount of fuel carried as well as the s.f.c. of the engine.

**Analysis of weight breakdown**

Before examining the merits and demerits of the current types of fighter mentioned earlier it will be worthwhile to appreciate the significance of the various elements that go to make up the total weight of an aircraft.

Let W be the total weight of aircraft,

$W_s$ = Wt. of airframe, accessories and fixed equipment.

$W_e$ = Wt. of engine.

$W_f$ = Wt. of fuel.

$W_p$ = Wt. of armament, airborne electronic equipment, pilot, sights etc. *i.e.* "Combat load."



Then $W = W_s + W_e + W_f + W_p$.

Let $\frac{W_s}{W} = a_s$

The ratio $W_e/W$ may be equated to

$\frac{e_2}{e_1} = e$ where

$e_1$ = Thrust loading = $\frac{W}{T}$ and

$e_2$ = Specific wt. of engine = $\frac{W_e}{T}$

If $f = \frac{W_f}{W}$

and $p = \frac{W_p}{W}$

Then $W = W.a_s + W.e + W.f + W.p$ .. .. (2)

Hence $p = (1 - a_s - e - f)$ .. .. .. .. (3)

and $p + f = (1 - a_s - e)$

Table II shows the values of these parameters for different types of fighters. Fig. 2 indicates graphically the distribution of these weight ratios for current types of fighters.

TABLE II

*Weight Ratio Distribution in Fighter Aircraft*

| | A | $B_1$ | $B_2$ | $C_{10}$ | $C_{11}$ | D | E |
|---|---|---|---|---|---|---|---|
| $W_s/W = a_s$ .. .. | ·43 | ·48 | ·48 | ·48 | ·48 | ·48 | ·52 |
| $W/T = e_1$ (Thrust Loading) | 1·4 | 2·1 | 2·3 | 1·8 | 1·32 | 1·35 | 1·7 |
| $W_e/T = e_2$ (Specific Weight of Engine). | ·19 | ·18 | ·18 | ·18 | ·14 | ·27 | ·33 |
| $W_e/W = e_2/e_1 = e$ .. | ·13 | ·09 | ·09 | ·10 | ·11 | ·19 | ·19 |
| $W_f/W = f$ .. .. | ·22 | ·29 | ·30 | ·28 | ·27 | ·19 | ·18 |
| $W_p/W = p$ .. .. | ·22 | ·14 | ·13 | ·14 | ·14† | ·14 | ·11 |
| f+p .. .. | ·44 | ·43 | ·43 | ·42 | ·41† | ·33 | ·29 |

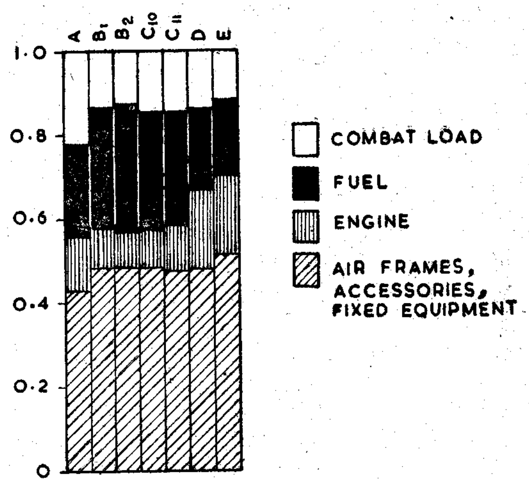


FIG. 2. WEIGHT RATIO DISTRIBUTION IN FIGHTER AIRCRAFT.

In general, the following values have been found to hold good for modern fighter aircraft:—

TABLE III

| | Range of Values | Representative value |
|---|---|---|
| $a_s$ | 0·5—0·45 | 0·5 |
| $e_1$ | 2 —1·5 | 1·5 |
| $e_2$ | 0·33—0·15 | 0·15 |
| | 0·20—0·30 | 0·25 |

Using the above value we get in the case of a typical design having an engine of low specific thrust, the following relation:—

$$W_p = 0{\cdot}15 \text{ Wt.} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

The most significant point to note is that in the case of current Orpheus powered aircraft, f+p happens to be more or less the same. In other words the total useful load of the aircraft works out at about 42 to 44 per cent of the all-up-weight of the clean aircraft. This remarkably high figure for Orpheus powered aircraft may be compared with a value of the order of 30 per cent only for Avon powered aircraft. The improvement is basically due to the low specific weight of the Orpheus of less than 0·2. It will also be evident that with the Orpheus it will be comparatively easier to achieve supersonic capability. With the Avon, after-burning would be essential in supersonic designs.

It should again be noted that a higher weight ratio in armament and electronic equipment is only possible by cutting down on fuel, thereby reducing range and endurance. In fact owing to the low all-up-weight of Type A and the necessity to carry the minimum combat load consisting of internal armament of two 30 mm guns, ammunition, the minimum electronic equipment, gunsight and the pilot, the whole weighing about 22 per cent of the all-up-weight, the fuel load has to be limited to about 22 per cent only, as against nearly 30 per cent in the case of other Orpheus powered aircraft with greater endurance.

Since 45 per cent of the all-up-weight may be assumed as the design limit for the total useful load, it will be obvious that if the combat load in the weapon system plan including the electronic aids, sight etc. is already specified, the only way to increase the fuel load for achieving greater radius of action would be to increase the all-up-weight of the design. But if this were done without a corresponding increase of the engine thrust, the thrust loading increases and hence to get the same performance, the engine thrust should also be put up. This may be done by using an improved engine or by the use of after-burning. The specific weight of the engine remaining more or less the same, we have in turn to cater for an increase in the engine weight which will be reflected in a further addition to the all-up-weight. Hence in an optimum design a compromise has to be reached taking into account all these interdependent factors. But in all cases the starting point of the design has to be the total useful load. Inevitably these considerations are to a large extent determined by the availability of a suitable engine. Hence, in general, it will be realised that a critical consideration in the design of a successful fighter is the availability of the right type of engine, having a low specific weight and a low specific fuel consumption. Another consideration is the ability to improve the thrust output of the engine without radically affecting its size or weight, either by suitadle modifications or by using after-burning.

**Cost Considerations**

Cost and size are directly related. In the estimation of cost we have to consider three factors namely,

(*a*) the cost of the airframe, accessories and fixed equipment,

(*b*) the cost of the engine and

(*c*) the cost of the armament and electronic equipment.

The cost of the fuel is not particularly relevant and it is obviously difficult to estimate the cost of a pilot. Today cost estimation is further complicated by the introduction of guided missiles and special electronic equipment.

The following approximate unit costs may be assumed for purposes of analysis:—

| | |
|---|---|
| Airframe, accessories and equipment .. | $r_a$ —Rs. 125 per lb. |
| Engines .. .. .. .. | $r_e$ —Rs. 200 per lb. |
| Guns & ammunition .. .. .. | $r_{p_1}$ —Rs. 50 per lb. |
| Conventional electronic equipment for aircraft .. .. .. .. | $r_{p_2}$ —Rs. 400 per lb. |
| Guided missiles and their special equipment | $r_{p_3}$ —Rs. 750 per lb. |

On the above basis, the average unit cost of an aircraft equipped with conventional weapons works out to be of the order of Rs. 100 per lb. of the all-up weight. Based on the combat load carried, the total cost $C_t$ of the fighter may be expressed in terms of the combat load by the approximate formula,

$$C_t = 750\ W_p, \text{ where } W_p \text{ is in lbs and } C_t \text{ is in rupees} \quad \quad (7)$$

In case guided weapons along with their special equipment are partly substituted for conventional armament, the total cost of the aircraft would probably be given by:

$$C_t = 1250\ W_p \quad \quad (8)$$

In this case the greater sophistication and the corresponding higher cost has to be justified by the augmented destructive power of the fighter.

The above formulae are only approximations, useful for making quick estimates and are not to be used for any detailed cost analysis. Two things are clear namely : (*a*) the cost goes up with all-up-weight and (*b*) the increase in cost would be very considerable if sophisticated armament and electronic aids are used.

In the next section, it will be shown how the unit costs and weights have been combined to give approximate relations between cost and combat value.

**Some tactical considerations**

The military value of an aircraft is extremely difficult to assess. It has been indicated that the combat value depends on many factors. An over-simplification of the problem towards which there may be a strong tendency in order to find mathematical solutions may lead to pitfalls. In fact in such evaluations we should always keep the practical aspects in view and not lose sight of the factors that are difficult to define quantitatively as for instance, the inability of the pilot to distinguish targets visually at high altitude and the difficulty experienced by the pilot to manoeuvre himself into the most favourable position in relation to the target in order to destroy it with the weapon he is using and also accomplish this in such a manner that the probability of survival is maximum. There are many other psychological factors also which do not easily lend themselves to mathematical expression; but to neglect them would be erroneous.

The problem being one of effecting a practical compromise between cost and combat value it is necessary to establish certain basic relationships. A simplified approach to the problem has been attempted by Gullstrand and Palme[1]. Taking a typical case where a large number of bombers distribtued in space and time are attacking an area and fighters are sent up in sorties to intercept them, if $P_1$ is the probability of destroying a bomber and $P_2$ is the probability of being shot down, they get in the first place

$$n = \frac{1}{P_1} \quad \quad (9)$$

where n is the number of planes required to destroy one bomber.

The cost of these will be

$$S = \frac{C_t}{P_1} \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad (10)$$

The probable loss would be;

$$R = \frac{P_2}{P_1} C_t, \qquad \cdots \qquad \cdots \qquad \cdots \qquad (11)$$

Which must be counted against the destruction of a single bomber.

S would be important in a blitz-krieg whereas R would be important in a war of attrition: and this latter case is of special interest. But the determination of $P_1$ and $P_2$ is by no means easy unless operational data valid for the actual tactical situation considered are available. There are normally logarithmic functions but for the sake of simplicity a linear relationship is stated to be sufficiently valid.

Now equation (11) may be expressed as

$$R = \frac{P_2}{P_1} W_P (1.r_a + m.r_e + r_p) \qquad \cdots \qquad (12)$$

Where $r_a$, $r_e$ and $r_p$ are unit costs of the airframe and accessories, engine and combat load respectively and 1 and m, multiplying factors given by the relations,

$$1 = \frac{W}{W_P} \qquad \cdots \quad a_s,$$

$$\text{and } m = \frac{W}{W_P} \qquad \cdots \quad e.$$

The fuel cost may be neglected in these considerations.

The Swedish authors have obtained the following relations:

$$\frac{\triangle P_1}{P_1} \geqslant \frac{\triangle W_P}{W_P} \qquad \cdots \qquad \cdots \qquad \cdots \qquad (13)$$

This would indicate that any increase in the combat load will not be worthwhile unless it increases the shooting down probability very considerably in relation to the weight increase by the use of suitable devices of minimum weight.

The weakness of such analysis may also be seen from the following consideration:

Putting $1.r_a + m.r_e = r_x$ in equation (12) and differentiating the following relation has been obtained:—

$$\frac{\triangle P_1}{P_1} \geqslant \left(\frac{\triangle r_p}{r_p}\right) \left(1 \Big/ \frac{r_x + r_p}{r_p}\right) \qquad \cdots \qquad (14)$$

Substituting average values for these from the available data one may get values ranging from 2 to 8 for $\frac{r_x + r_p}{r_p}$ depending on what value is assumed for $r_p$. This introduces an element of arbitrariness. The Swedish authors assume a unit cost of nearly Rs. 375 per lb. for the combat load. But if we include only conventional armament and electronic aids, the unit cost hardly comes to more than Rs. 80 per lb. But if the conventional armament is replaced by guided

Very often owing to lack of statistical data and actual experience, the methods of operations research may not be adequate to indicate an operational requirement. In such cases, the rquirements have to be based on a military appreciation of the tactical situation and good judgement. Then, an answer to the question of finding the optimum weight for a fighter/bomber aircraft which should fulfil the specified operational requirements may be found from *a priori* considerations.

For example let the following hypothetical requirements be assumed:

(*a*) The aircraft should primarily be a day fighter and ground attack aircraft. But it should be capable of being adapted as all-weather fighter, photo reconnaissance aircraft and 2-seater trainer.

(*b*) It should have adequate endurance to fulfil its many roles. The high altitude operating radius should not be less than 400n. miles and the low altitude radius of action, not less than 200n. miles.

(*c*) The aircraft should have adequate internal armament; both guns and air-to-air rockets.

(*d*) It should be capable of carrying a variety of external war stores in sufficient quantity for its strike role.

(*e*) It should, when fully developed, have supersonic capability.

(*f*) It should be able to carry a complete range of modern radio and radar aids for navigation and interception and should have adequate capacity to take in additional equipment in future.

(*g*) It should be capable of accommodating the latest type of A.I. radar equipment and also carry guided missiles at a future date if the necessity should arise.

(*h*) It should have the capacity to accomodate higher thrust models of the original engine type used as and when they are further developed, and also to use reheat.

It will be evident from a consideration of the data in tables I and II, that type $C_{II}$ is likely to be suitable design to meet the above requirements particularly since the strike capability of the aircraft is a primary consideration. In fact a twin Orpheus (B. Or. 12) configuration will have, *prima facie*, good potentiality for future development. A type such as $C_{II}$ (with twin seater capability) can also be a very versatile aircraft since there will be adequate scope for combat load increase in future. Another important consideration is that even if such an aircraft should fail to come up to specification as an intercepter, it can be very effective in its strike role which is less critical. It has considerable war load capacity and operating radius.

In no case can performance be sacrificed, for whatever may be the deficiencies of a fighter in other respects, the possession of adequate performance and manoeuvrability will give it a great advantage once target acquisition has been effected. The low thrust loading of type $C_{11}$ ensures good performance.

In conclusion, it may be emphasised that once the operational requirements are laid down and the combat loads, operating radius, and the minimum performance specified, the designer has a straight forward task set out for him, since normally the choice of engine is also restricted and invariably one has to build around existing engines having favourable specific weight and s.f.c. characteristics.

The general trend today in view of the advent of the high speed jet bomber is towards greater sophistication in intercepter capability and practically all advanced countries are attempting to keep down the overall cost by reducing the number of fighter aircraft and not by over-simplication of aircraft, restricting their operating radius and equipment. The tendency is not only towards better performance but also towards greater versatility; for a country with limited resources cannot afford to multiply special types. The aim is to have a basic type which can be adapted for more than one role. A standard type should also have potentiality for development. There is at present not sufficient evidence to show that any country with a large area to defend can reasonably adopt a radically different tactical pattern for Air Defence and accept very light weight fighters with limited armament, operating radius and flexibility as standard types unless the results of future studies based on authentic statistics should indicate otherwise. The combat value of a fighter is extremely difficult to assess and the use of war games and training exercises are not considered adequate particularly since there are many unknown factors. Therefore, in the final analysis, the decision has to be based on practical operational experience and sound judgement.

**Reference**

1. Gullstrand and Palme, "*Saab Sonics*" No. 25, 2 (1957).

**Discussion**

Dr. Dhawan mentioned that the analysis of weight breakdown presented by the lecturer would undoubtedly serve as a useful guide in arriving at the optimum design, but he enquired from the lecturer whether, apart from the weight of the bare engine, it was not desirable to introduce a factor to take into account the specific fuel consumption. It could well be that an engine of high weight thrust ratio had also a high specific fuel consumption making it necessary to carry considerably more fuel in the aircraft. Under these circumstances the weight analysis presented by the lecturer would require some modification.

Dr. Nilakantan replied that all the performance parameters are normally included in a specification on the basis of which any weight optimization has to be effected. The major consideration was weapon effectiveness, that is, cost vs combat value, and the war load necessary to fulfil an operational requirement. He had already indicated in the paper that in no case should performance and manoeuvrability be sacrificed to effect weight saving.

Dr. Ghatage also pointed out that besides the weight breakdown it was also important to introduce additional parameters in arriving at the optimum design. For example, it was necessary to take into account various performance features such as rate of climb, maximum speed, radius of action, endurance etc.

This was further pointed out by A/Cdr Goyal who mentioned that additional parameter to be considered when comparing the relative merits of the design was versatility. He gave some examples of versatility which would greatly improve the usefulness of the aircraft in operation. For instance it was desirable to arrange for interchangable packs of war load and fuel. Again a high performance aircraft suitably modified to have short take off and landing had a very important application in operational use. Such factors which improve the versatility should also be considered in comparing different designs.