4/9/80

NASA TECHNICAL MEMORANDUM NASA TM-75793

NASA-TM-75793 19800013819

AERODYNAMICS OF THE NEW GENERATION OF COMBAT AIRCRAFT WITH DELTA WINGS

M. P. Bohn

Translation of "Aerodynamique de la Nouvelle Generation d'Avions de Combat a Aile Delta", IN: AGARD Conference Proceedings No. 241, Fighter Aircraft Design (Presented at the Multi-Panel Symposium on Fighter Aircraft Design, Florence, Italy, Oct. 3-6, 1977), AGARD, Paris, France, June 1978, pp 11-1 to 11-13

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 MARCH 1980

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-75793		

4. Title and Subtitle	5. Report Date
Aerodynamics of the New Generation of Combat Aircraft with Delta Wings.	MARCH 1980
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
M. P. Bohn	10. Work Unit No.
	11. Contract or Grant No. NASw- 3198
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108	13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Aerodynamique de la Nouvelle Generation d'Avions de Combat a Aile Delta", IN: AGARD Conference Proceedings No. 241, Fighter Aircraft Design (Presented at the Multi-Panel Symposium on Fighter Aircraft Design, Florence, Italy, Oct. 3-6, 1977), AGARD, Paris, France, June 1978, pp 11-1 to 11-13.

16. Abstract

This article is a discussion on the use of delta-wing aerodynamic design for modern fighter aircraft.

Various current French fighter airplanes are utilized for comparisons.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

1. This discussion is not a detailed presentation of the Mirage 2000, but rather a reflection on use of the delta-wing aerodynamic design for modern fighter aircraft. /11-1*

2. The first flight of a Marcel Dassault aircraft with a delta wing goes back to 1955. This was the little Mirage 1, powered by two Viper jet engines. It was the first of the line of the 1500 present Mirages.

The first Mirage 3's came off the line in 1961, powered by an Atar 9 engine. After 17 years, this aircraft continues to receive orders, unlike all other planes of its generation (Tiger, F-104, etc.).

Its aerodynamic formula, a delta wing swept back 60° at the leading edge, allowed Mach-2 flight with a single engine of 6 tonnes thrust, while its competitors were equipped with a 7-tonne J79.

The trade-off to this supersonic performance was a large increase in the approach speed, 180 knots instead of 140 kt for the Mystere family. This constraint was accepted for the Mirage III, but later program specifications from the General Staff of the French Air Force required an approach speed below 150 kt.

This explains the birth of the Mirage F1. The development of the 7.2-tonne Atar (Atar 9K) permitted us to accept the increase in drag from the swept wing with rear empennage, with no degradation of supersonic performance. On the other hand, the (configuration of) wing with empennage could be fitted with a high-lift device and one could get back to 150 kt. This aircraft went into production in 1971 and has received many orders.

Plate 1, which shows only approach speed as a parameter, nevertheless shows the relative position of the main fighter aircraft built by Avions Marcel Dassault over a 30-year period.

---

*Numbers in margin indicate pagination of original foreign text.

For a few years one can see flights of the Mirage G and G8 swing-wing aircraft whose approach speed was in the range of 125 kt and thus allowed landing on French aircraft carriers. Swing-wing aircraft were stopped in 1973 for reasons of cost and, especially, because of their inferiority for air-superiority missions.

The Mirage G8 was replaced by the Mirage G8A--fixed-wing geometry and two SNECMA M53 engines--whose prototype was cancelled at the end of 1975 for budgetary reasons.

The year 1975 was a key date for return to the delta wing. It is marked by a big black arrow in Plate 1.

For reasons which will be explained later in this discussion, a delta-wing aircraft was then able to have an approach speed of 150 kt. And since budgetary constraints in France made it possible to build only a single-engine aircraft using the M53 with 9 tonnes thrust instead of a twin-engine aircraft with 18 tonnes thrust, the delta wing was the aerodynamic solution (~~formula~~) which allowed the degradation in the supersonic performance demanded of the Mirage G8A to be minimized.

After the government's decision to replace the twin-engine Mirage G8A by the single-engine Mirage 2000, several prototypes are under construction and the roll-out of the production Mirage 2000 is expected to be in 1982.

3. In the decision taken in France at the end of 1975, several factors we must mention came together at the same time. They are shown in Plate 2.

A Service Technique Aeronautique (Aeronautical Engineering Department) contract comparing formulas for CCV aircraft showed the very great value of rearward centering for a delta wing.

The first flights of the M53 engine in the Mirage F1E prototype showed that approach angles could be increased, thanks to a better reaction time than the Atar.

Finally, AMD-BA (Dassault) had used its own funds for wind-tunnel testing of new delta wings.

4. To go from the Mirage 3 at 180 kt to the Mirage 2000 at 150 kt (in spite of a heavier weapons system), several factors had to be used because no single factor was large enough by itself to produce this advantage.

We shall mention three of them in Plate 3:

1) Rearward centering, permitted by the technology of electric flight controls.
2) Approach angle, increased thanks to the better reaction time of the M53 engine.
3) Decreased wing-loading and thus a larger area. /11-2

This point will be examined in detail below.

5. We have just seen that we need to increase the wing area. This ought to be easy because we have a 9-tonne engine available for the Mirage 3, rather than a 6-tonne.

Nevertheless, the operational requirements for the operational defense mission are very severe. We mustn't forget that this aircraft is replacing a heavy interceptor with 18 tonnes thrust!!

The major operational requirements affecting the supersonic drag appear in the first four points of Plate 4.

6. However, all the supersonic operational requirements together were such that the wing area could not be increased enough to reach 150 kt.

But we have made wind-tunnel tests of several leading-edge cambers (Plate 5). We must remember that the Mirage 3 was not equipped with a movable leading edge; on the other hand, the profile of the Mirage 3 has a strong leading-edge camber, especially at the wing-tip, thus making a compromise between interception and air-superiority missions.

This is why we decided that the profile of the Mirage 2000 would benefit from a slight camber, limited to a value such that the increased supersonic drag would not be very large. However, this choice required installation of movable leading-edge beaks. ?

segments ?

7. In combat, these edge beaks not only allow the performance of the Mirage 3 cambered wing to be equaled, but even exceed it considerably, as the polar plots of Plate 6 show.

It will be seen that the edge beaks of the Mirage 2000 are all-position and change with angle of attack and Mach number in order to place the aircraft in the minimum-drag position (dashed envelope curve in Plate 6). ?

8. In addition, theoretical methods for three-dimensional aerodynamic calculations available to Avions Marcel Dassault-Breuget Aviation have allowed us to optimize integration of the shapes of the wing and fuselage.

Plate 7 shows a very typical section of the Mirage 3 and of the Mirage 2000. The root shapes have given us a saving in wing weight because of the increased height of the longeron attachment points, without any visible loss for supersonic drag.

Adding this weight saving to the one from carbon-fiber elevons, the Mirage 2000 wing is lighter than the Mirage 3's despite an area about 20% larger and the addition of movable leading-edge beaks (see Plate 8).

9. Now we are going to leave the areas of approach speeds and supersonic speeds to talk about high angles of attack in the transsonic regime manoeuvering limits.

To do this, we are going to use longitudinal-stability (C_m, C_z) curves for several aircraft (French sign conventions).

At the left side of Plate 9, the solid line plots a typical transsonic stability curve for the production Mirage F1. Beyond a certain C_z there is a large increase in stability (pitch-down hyperstability) typical of swept-wing aircraft with low empennage. In a CCV version of the Mirage F1 the static margin would be negative for low C_z but, as before, beyond a certain C_z one would find a hyperstability--i.e., at high angles of attack, a loss of balanced C_z because the empennage must balance this strong couple forcing the nose down. The presence of the strake at the wing root allows C_z to climb back out of that stability hole (right side of Plate 9), which is why strakes are seen on the Mirage G8A or on the F-16. But the problem is fixed, not done away with. For the Mirage 3 there is a different stability curve (solid curve, left side of Plate 10).

A strong hyperstability at practically constant C_z was followed by a slight instability at large C_z's. Still in the same figure, we have drawn the Mirage with edge beaks extended but without lateral fins placed above and ahead of the wing. The negative stability of a CCV aircraft is seen, and also a large increase in hyperstability C_z compared to the Mirage 3. But wind-tunnel studies of various devices have resulted in defining a lateral fin which gives the following compared to the Mirage (right side of Plate 10):

- 70% increase in C_z at the manoeuvering limit;
- a very large reduction in hyperstability.

We won't leave Plate 10 without saying that the aerodynamic role of the lateral fin is very different from that of the ordinary canard. In particular, a canard would have changed the static margin as the small dashed curve at the bottom of the right-hand figure shows.

10. While the longitudinal studies have led to a considerable increase in the C_z range and in the angle of attack of the Mirage 3, as we have just seen, we had to be sure that we were not going to run into other problems at high angles of attack. /11-3

After studying various fins, we confirmed that the angle of attack at which lateral stability has lost was high enough. Even though it is too simple to show the lateral flight qualities of an aircraft with electric flight controls, Plate 11 still shows a transonic gain of 5% to 7% over the Mirage 3.

For the same reason, we have worked the Mirage 2000 air intakes to give enough flow to the engine at high attack angles. At high angles, a ventral air intake would have simplified the work of the aerodynamicist, but carrying large and sophisticated ventral loads would have been limited unacceptably. The Mirage intakes, which have proved their good operation in the hands of many users, have been retained with the addition of devices adapted to flight at high angles. Wind-tunnel test results are shown in Plate 12, and show a gain of 5% to 7% in angle of attack, similar to the gain mentioned above.

11. Although the principle of the Mirage air intakes was retained, the supersonic performance of these air intakes was improved by working from theoretical computer calculations for the forward fuselage shape.

In the same way, we have found that at the same flight Mach number, Mach 2, the local Mach number at the air intakes goes from Mach 2.10 for the Mirage 3 to Mach 1.95 for the Mirage 2000, which is, of course, reflected in increased efficiency at a given Mach number (see Plate 13).

12. We have spoken a lot about the role of theoretical aerodynamics in the development of the aerodynamic design of the Mirage 2000. But it must not be forgotten that all French wind tunnels have made

contributions to the identification or, in some areas, the development of this aircraft.

Because of this aircraft, many changes had to be made to existing wind tunnels, and many devices built. The main reason was the systematic exploration of high angles of attack.

The list of the main new developments at French wind tunnels is shown in Plate 14.

13. We have touched on the main reasons for choosing the Mirage 2000, and have shown the main results obtained. Now we are going to state this choice more clearly by comparing the performance of the Mirage 2000 to what we would have obtained if we had used other aerodynamic designs, especially the swing wing and the swept wing with rear empennage.

Our first criterion for comparison is going to be the manoeuvering limits.

14. First of all, to orient ourselves we are going to compare the Mirage 2000 to its big brother, the Mirage 3, which already has a reputation as an excellent combat machine.

For this comparison and others following, we shall use graphs showing:

- maximum combat C_z;
- wing area.

Now, while all the aircraft in our comparison have about the same weight (of the order of 9 tonnes), their manoeuvering limits will be higher when the product of $C_{z\ max}$ times wing area is itself larger; in each case it will thus be proportional to the area of the cross-hatched rectangle in Plate 15.

In comparing the Mirage 2000 to the Mirage 3 (Plate 15), the wing area is increased by about 20% and $C_{z\ max}$ by 70% as we have seen in Plate 10, so that the manoeuvering limit has been doubled.

15. In view of our own wind-tunnel and, of course, flight test results for swept-wing aircraft with beaks, combat flaps and rear empennage, and also in view of the performances of aircraft of other manufacturers, it can be said that at the present state of the art an aircraft with rear empennage has about a 40% higher $C_{z\ max}$.

This holds true for swing-wing aircraft, which cannot fight in the high transsonic range and at high load factor with the wing forward, but rather put their wing in a position in the range of sweeps for fixed-geometry aircraft.

Although there is a gain in $C_{z\ max}$, there is also a large loss of wing area. All the swing-wing aircraft which have flown in France, the United States and England/Germany have a high wing load.

Since this wing load is approximately three times that of the Mirage 2000, we say that if you yourself--or someone else--would design a swing-wing aircraft around a 9-tonne engine (and not 11 tonnes as for the Mirage G-01) its area would be equal to 35% of the Mirage 2000's.

Taking the product of the $C_{z\ max}$ ratio (1.4) times the area ratio (0.35), we find that a swing-wing fighter with the same engine /11-4 would have a manoeuvering limit of 50% of the Mirage 2000's.

This amounts to a swing-wing aircraft at the Mirage-3 level, which isn't too bad, but isn't good enough to fight against new-generation aircraft.

We have just illustrated the main reason for stopping work on swing-wing aircraft in France.

16. Likewise, we have considered a fixed-wing aircraft with rear empennage designed around the same 9-tonne engine. We have called it the Super F-1 in Plate 17. Its design and its characteristics are very similar to an American aircraft recently chosen by several European countries.

We can see the 40% increase in $C_{z\ max}$ mentioned in the preceding section. But there, too, the presence of the empennage reduces the wing area which can be designed around a given fuselage.

This Super F-1 would have a wing area about 35% smaller than the Mirage 2000's.

One would get a manoeuvering limit for the Super F-1 equal to $1.4 \times 0.65 = 0.91$ times the Mirage 2000's, just a little smaller.

But considering that a few per cent difference is not significant because of the refinements possible for any aerodynamic design, let us look at their supersonic performances to decide between the two formulas.

17. Plate 18 shows the $S \cdot C_{z\ max}$ product, important in combat, and the $S \cdot C_x$ product, important for total drag of the aircraft in supersonic flight, for these two aircraft, the Mirage 2000 and the Super F-1.

It can be seen that while the combat performances are similar, as we have just seen, the supersonic drag of the Super F-1 is about 35% higher than the Mirage 2000's at equal engine thrust, as we recall.

Penalization of supersonic performance is thus large, and has not been accepted in France since 1975, the date when it could be shown that the Mirage 2000 design would allow an approach speed of about 150 kt.

18. The previous plates are very diagrammatic: Problems such as

stability or performance in aerial combat are, of course, more complicated and have required long studies in the wind tunnel or with computers or simulators. But it is often quite pleasant and heartening when results of complicated studies can be presented by simple lines of argument.

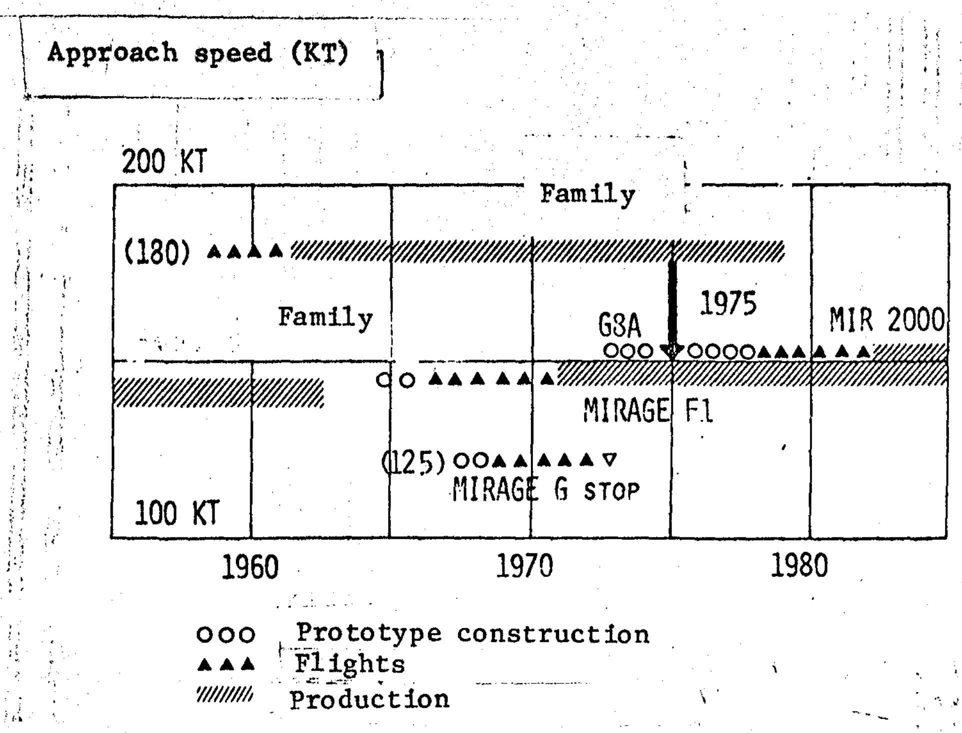
Another lecturer has presented a triangular diagram showing the three roles of a fighter aircraft (Plate 19):

1) Air defense or interception
2) Air superiority
3) Ground strikes

Thus, with a given engine, the M53 at 9 tonnes, we think we have optimized the aerodynamic design around the missions of interception and air superiority by again abandoning the rear empennage.

As for the third vertex of the triangle, the Mirage 2000 will also be an excellent ground-strike aircraft, as the Mirage 3 was.

PLATE 1



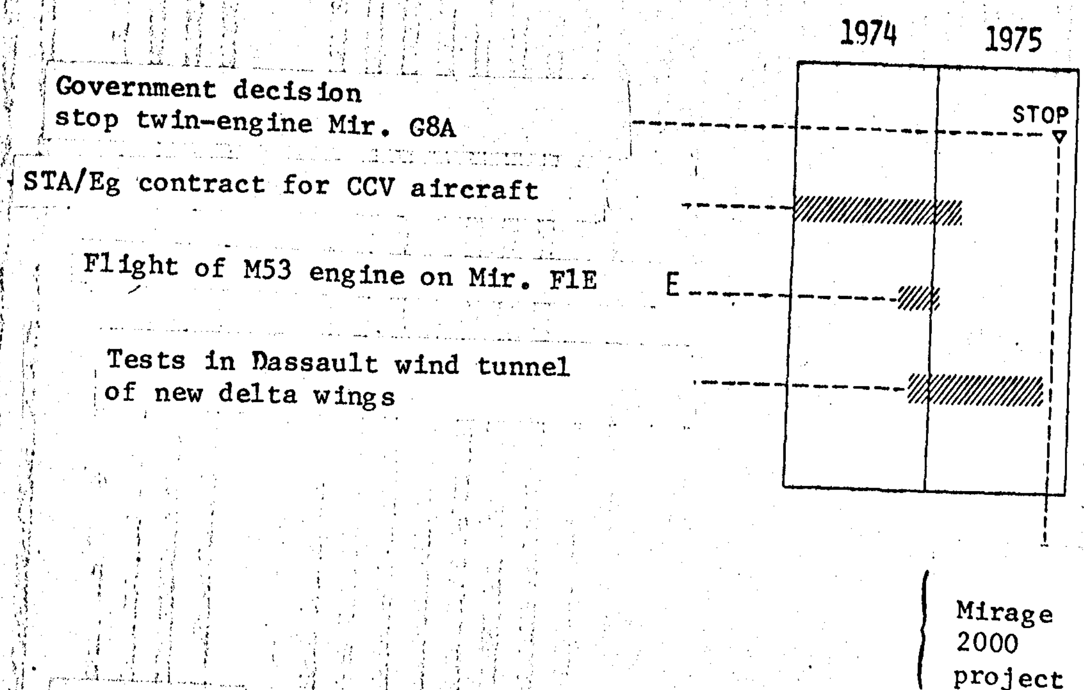


PLATE 2:

PLATE 3

MIRAGE 3 180 KT

1. REAR CENTERING

2. INCREASED APPROACH ANGLE

3. REDUCED WING LOADING

MIRAGE 2000 150 KT

PLATE 4

COMPARISON OF MIRAGE 2000 AND MIRAGE 3 PROGRAMS

M53 THRUST = 9 TONNES (instead of 6 to 7 for the Atar)

<u>BUT</u> (operational demands)

1 • LARGER AIR-AIR ENGINE

2 • TWO ENGINES INSTEAD OF ONE

3 • NEARLY DOUBLED RADAR ANTENNA DIAMETER

4 • PERMANENT COUNTER-MEASURES DEVICES

5 • TIME TO MACH 2 AND BACK

PLATE 5

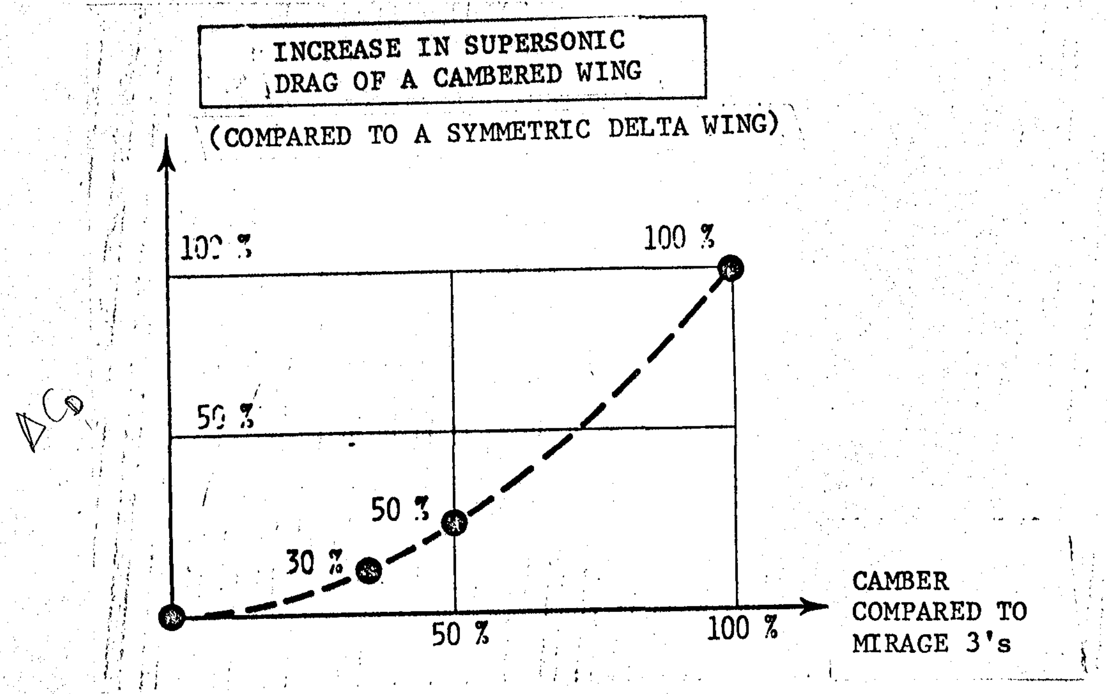


PLATE 6

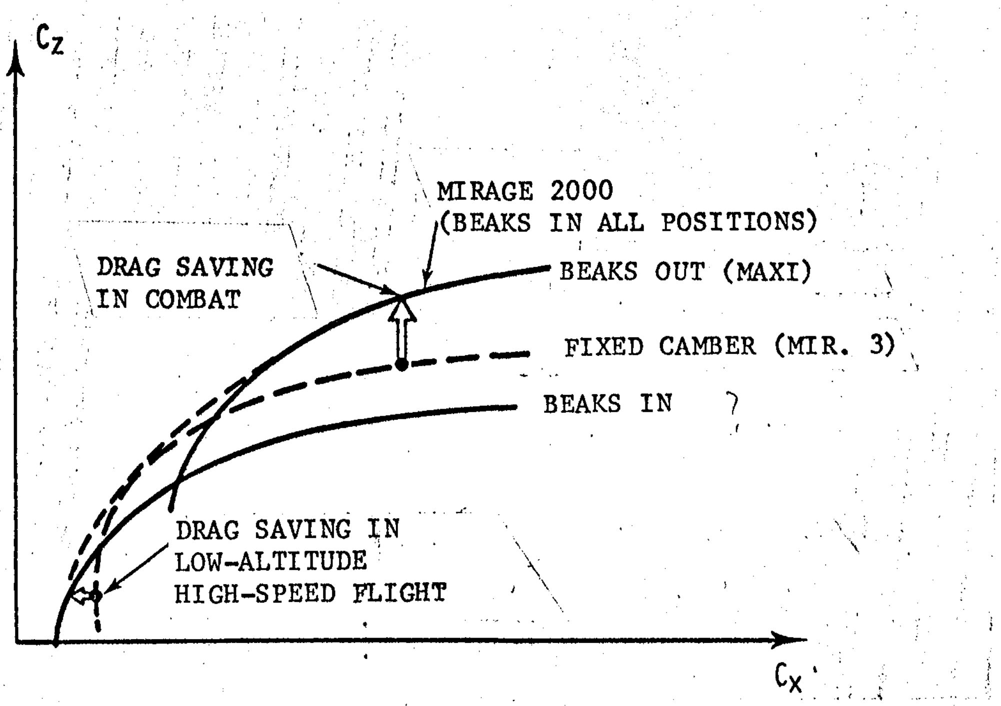
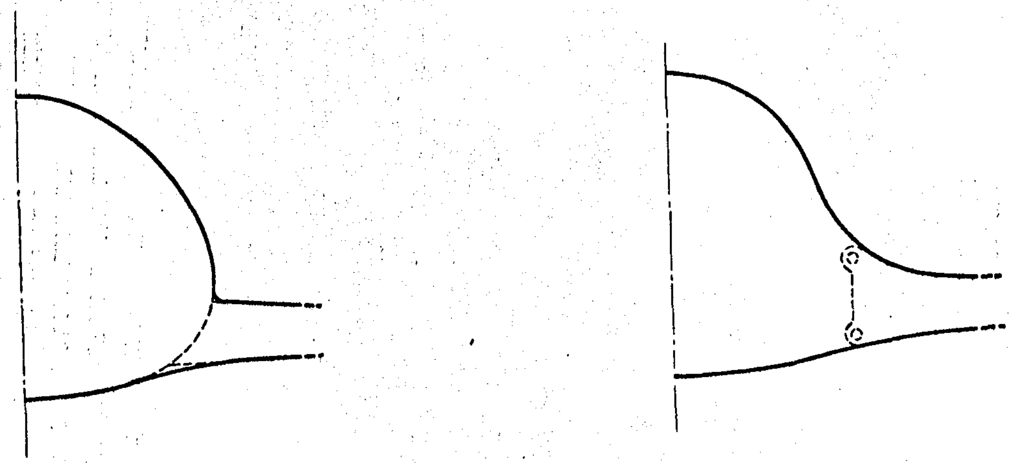


PLATE 7

MIRAGE 3 MIRAGE 2000



NEW ROOT SHAPES (from three-dimensional theoretical aerodynamic calculations) = { • weight saving • no drag loss

PLATE 8

150 KT ⇨ INCREASED WING AREA (~20 %) ⇨

2 SUPERSONIC CONDITIONS ⇨ CAMBER REDUCTION ⇨ BEAKS ⇨

→ WEIGHT LOSS

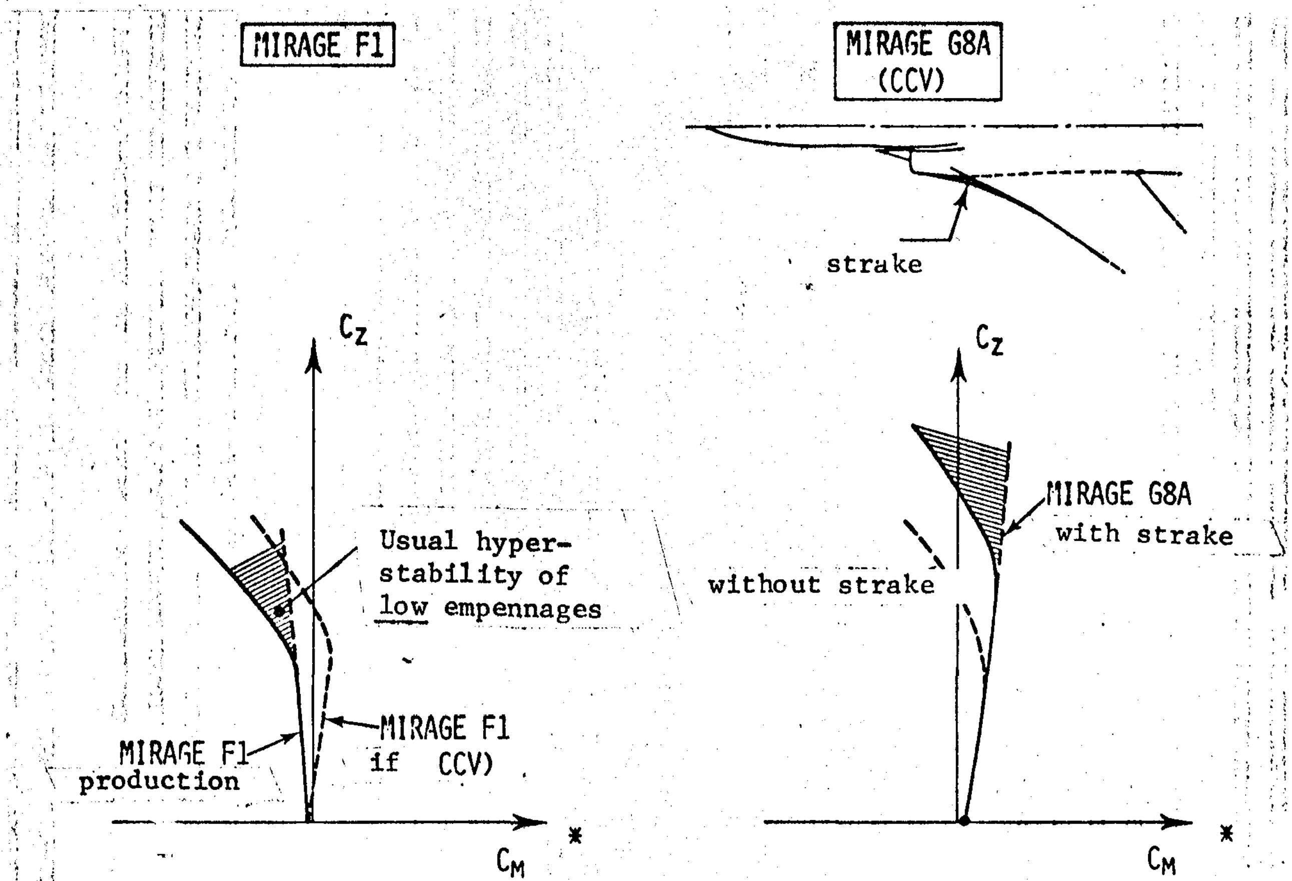
NEW ROOT SHAPES ⇨

CARBON-FIBER ELEVONS ⇨

→ WEIGHT SAVING

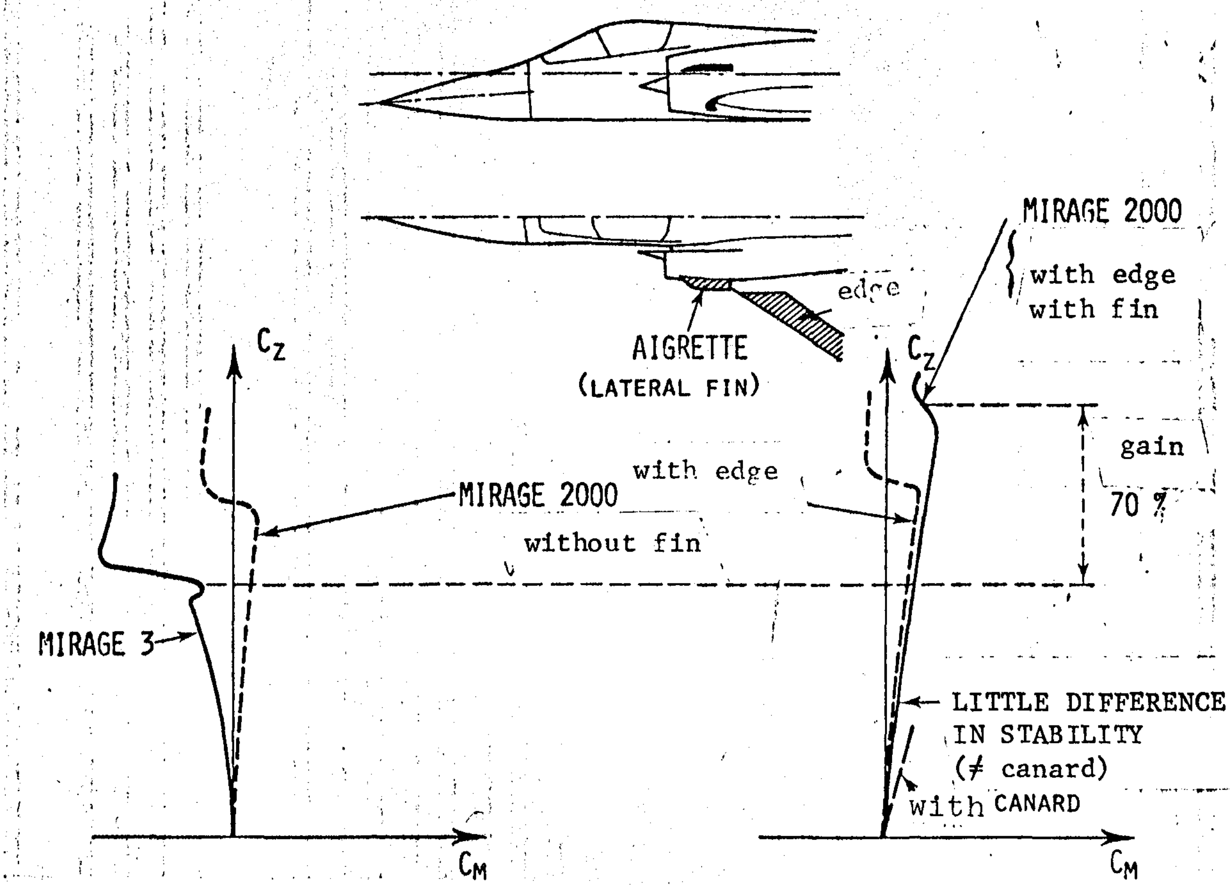
→ MIRAGE 2000 WING LIGHTER THAN MIRAGE 3's

PLATE 9



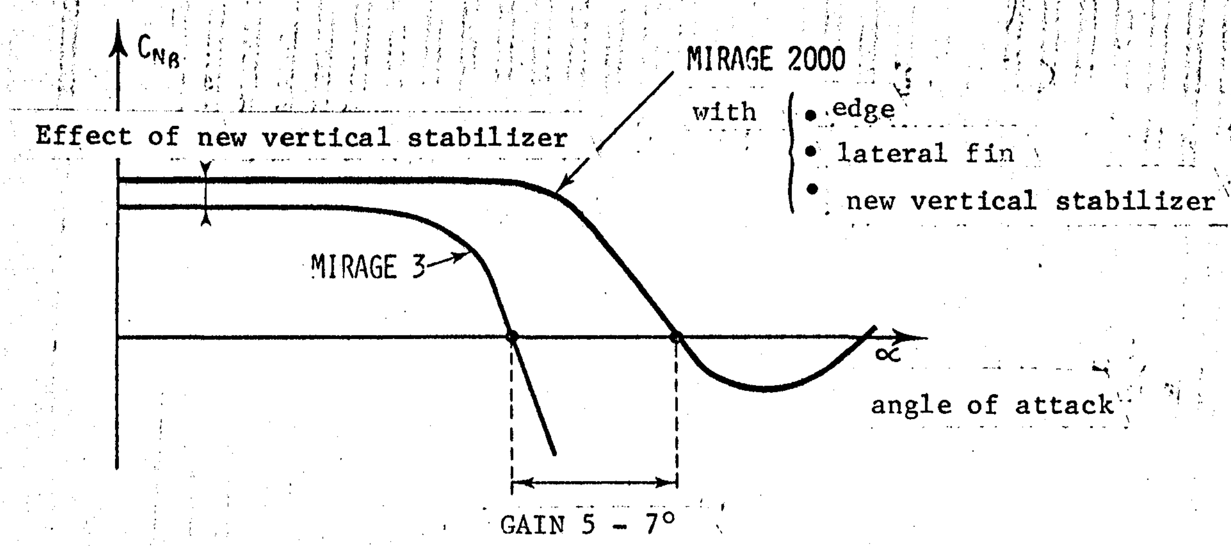
~~* Sign convention opposite U.S.~~

PLATE 10



edge
AIGRETTE
(LATERAL FIN)
MIRAGE 2000
with edge
with fin
C_Z
C_Z
gain
70 %
MIRAGE 2000
with edge
without fin
MIRAGE 3
LITTLE DIFFERENCE
IN STABILITY
(≠ canard)
with CANARD
C_M
C_M

LATERAL STABILITY AT HIGH ATTACK ANGLES



+ CCV

(1) NEW VERTICAL STABILIZER

- less sweep, greater aspect ratio
- built of carbon fiber (cloth: mixed boron/carbon)

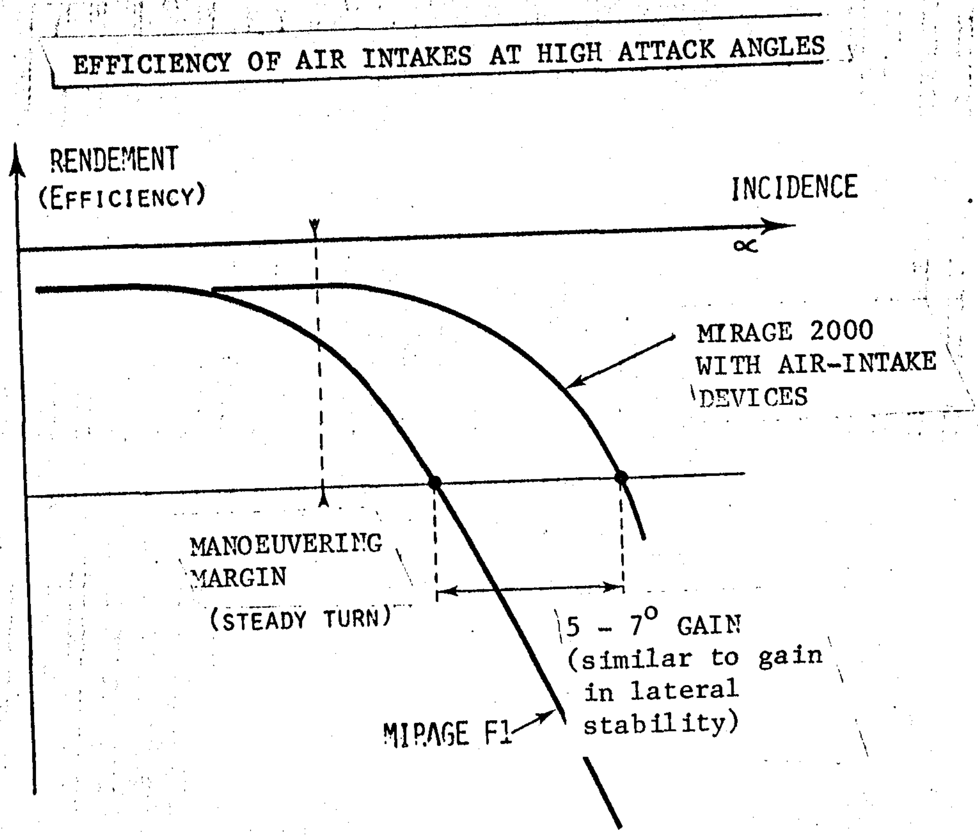

EFFICIENCY OF AIR INTAKES AT HIGH ATTACK ANGLES
RENDEMENT
(EFFICIENCY)
INCIDENCE
∝
MIRAGE 2000
WITH AIR-INTAKE
DEVICES
MANOEUVERING
MARGIN
(STEADY TURN)
5 - 7° GAIN
(similar to gain
in lateral
stability)
MIRAGE F1

PLATE 13

AERODYNAMICS OF NOSE CONE

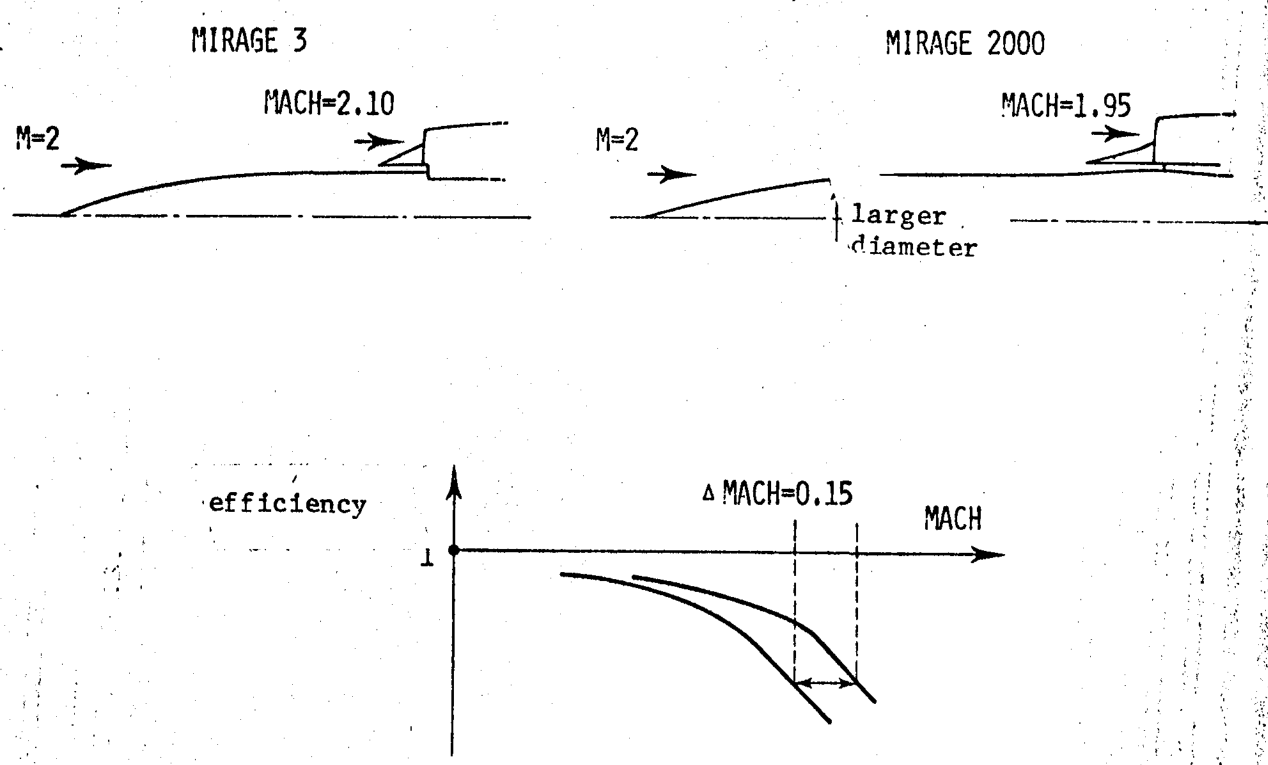


PLATE 14

MIRAGE 2000

EXPERIMENTAL AERODYNAMICS

USUAL TESTS ⟶ EXTENDED TO 35–40^{o} (ALL FRENCH WIND TUNNELS)

AIR INTAKE TESTS MACH=0.9 $\alpha = 30°$
ONERA (MODANE) (S1 - diameter, 8 m)

DYNAMIC ROTATION COEFFICIENTS AT HIGH 4a
IMFL (LILLE)

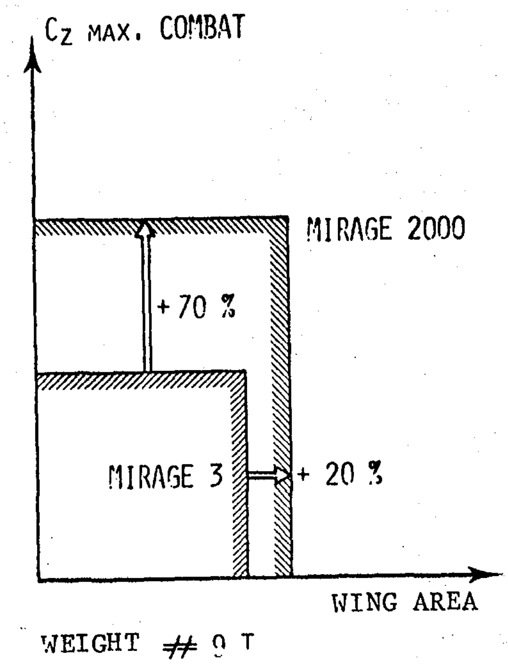
FREE-FLIGHT MODEL (CATAPULT)

IMFL (LILLE)

UNDERCARRIAGE IN
GROUND EFFECT
HYDRAULIC TANK CEAT (TOULOUSE)

PLATE 15

MANOEUVERING LIMITS (1)

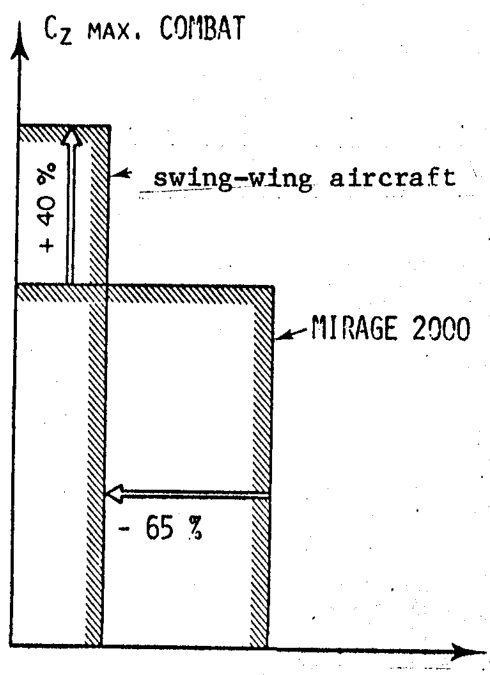


$$1.7 \times 1.2 = 2.0$$

$$\frac{\text{MIRAGE 2000}}{\text{MIRAGE 3}} = 2.0$$

PLATE 16

MANOEUVERING LIMITS 2)



COMBAT WEIGHT #9 T

$1.4 \times 0.35 = 0.5$

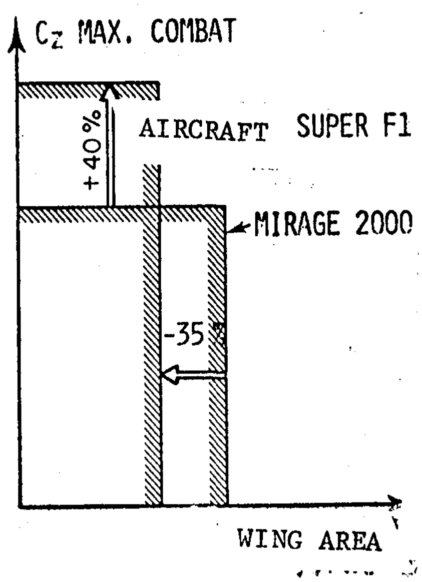
$\frac{\text{MIRAGE 2000}}{\text{swing-wing aircraft}} = 2.0$

SWING-WING AIRCRAFT
INCAPABLE OF AIR SUPERIORITY

STOP SWING-WING AIRCRAFT
IN FRANCE

PLATE 17

MANOEUVERING LIMITS (3)



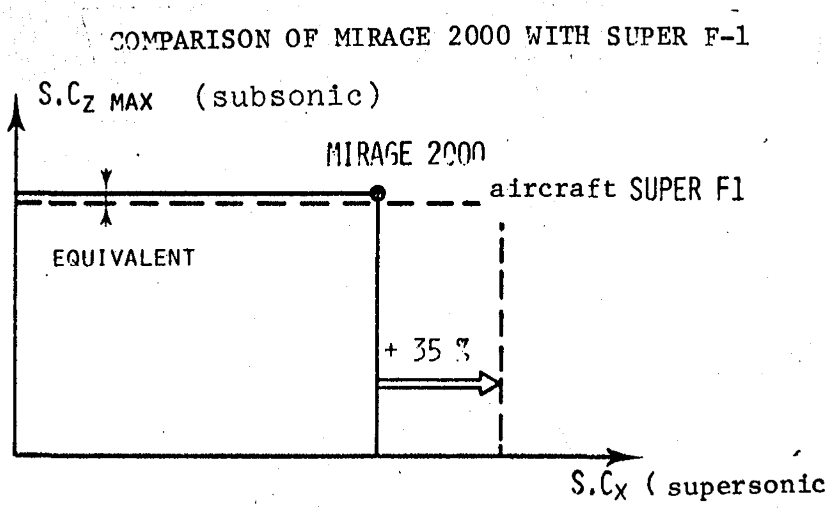
COMBAT WEIGHT # 9 T

$$1.4 \times 0.65 = 0.91$$

$$\text{AIRCRAFT } \frac{\text{MIRAGE 2000}}{\text{SUPER F1}} = 1 + \epsilon$$

EXAMINE SUPERSONIC
TO CHOOSE BETWEEN
2 FORMULAS

PLATE 18



AND SO ⇨ IN FRANCE, THE REAR-EMPENNAGE AIRCRAFT DESIGN WAS ABANDONED AT THE END OF 1975 FOR FIGHTERS

PLATE 19