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DESIGN OPTIMIZATION FOR A FAMILY OF MULTI-ROLE COMBAT AIRCRAFT

by

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SUMMARY

The future multi-role combat aircraft design process is used as an example throughout this lecture. At the early stage of the design, requirements of the French Air Force and Navy and other potential customers (European and other countries) are studied very closely. Then the main technological improvements - from the existing aircraft - that are needed to meet these requirements are clearly defined. The improvements are achieved by an optimization process carried throughout each and all aircraft design disciplines, involving an intensive use of the very large range of design and test tools available from the aircraft company and state research establishments. Because of the numerous technical innovations which will be introduced in the future combat aircraft, an in-flight demonstration aircraft has been judged necessary. The RAFALE demonstration aircraft, and the evolution into a future family of multi-role specific versions, will be presented.

I - INTRODUCTION

Since its foundation, the AMD-BA company has conceived 92 prototypes, the RAFALE demonstration aircraft being the latest in line (figure 1).

This experimental aircraft is part of the more general RAFALE programme, which concerns the development and industrialization of a family of new generation combat aircraft, designed to equip the French Military Forces in the middle of the next decade.

The following description is intended to illustrate the process which ensures design optimization of this family of multi-role combat aircraft.

2 - REQUIREMENTS

At the early stages of design, it is essential to study very closely the requirements of the staff of the French Air Force and of the French Navy and of other potential customers (European or other countries).

The French Air Force requires a multi-role aircraft able to carry out ground strike missions as well as air superiority missions and even air defence missions. It must cover an extensive flight envelope, have a maneuverability associated with a flying comfort significantly higher than that of present day aircraft, be capable of operating from short runways. Its carrying capacity and its weapons system shall ensure a large operational efficiency, which will also be obtained from its discretion (see figure 2).

The French Navy requires defence and air superiority aircraft to ensure the protection of its aircraft carriers and to carry out strike and reconnaissance missions. The maneuverability characteristics requested are very close to those of the French Air Force ; the same applies to approach speed, the thrust-to-weight ratio, the carrying capacity of external stores...

3 - THE OPTIMIZATION PROCESS

The design of the new family of combat aircraft results from an optimization process, which takes into account, at the utmost, the interaction between the various disciplines involved, such as aerodynamics, structure, propulsion, systems (see figure 3).

The more and more ambitious targets, involved by the previously mentioned requirements, as well as the essential target of the best cost/efficiency ratio, have moreover required extensive progress in the new technologies which have been included in the optimization process.

3.1 - THE AERODYNAMIC CONFIGURATION AND THE AIR INTAKES

Many preliminary studies have been carried out, completed by wind tunnel tests. Several configurations adapted to the low speed targets have been studied (see figure 4). For cost and simplicity reasons, the compromise has been orientated towards a delta-canard configuration. Performance in combat has been studied for various aircraft configurations (see figure 5) so as to determine the influence of the wing area, the aspect ratio, the thrust-to-weight ratio and thrust deflection devices or moving wing control surfaces. Once again, the delta-canard configuration has proved to be superior.

On the basis of this configuration, several other possible solutions could be studied concerning the position of the wings (high, medium, low), the position and number of fins (single fin, fuselage or wing double fin), the position of the air intakes and the type of protection.... (see figure 6).

Finally, the AMD-BA selected the following twin-engine configuration :

- double sweep-back delta-wing with high aspect ratio,
- large area active canard fins,
- semi-ventral "pitot" air intakes,
- single fin with large rudder.

The choice of this new configuration is the fruit of long experience and of the art of using it in the "façon DASSAULT".

In fact this configuration is in line with the family of delta wing aircraft which started with MIRAGE III aircraft and which, later, gave birth to MIRAGE 2000 aircraft then to the "canard + delta wing aircraft" (see figure 7). This latter configuration dates from the "MILAN" aircraft which, in 1969 with its retractable "nose fins", was the first attempt within DASSAULT to decrease the relatively high approach speed of MIRAGE III aircraft (180 kts). Then in 1979 it was the MIRAGE 4000 aircraft and in 1982 the MIRAGE III NG aircraft. The MIRAGE 4000 aircraft is equipped with fixed canard fins, designed to improve its maneuverability, which can be disengaged in case of multiple failure of the flight control system. This gives back stability to the aircraft and enables more traditional flying control.

It is certain that the RAFALE demonstration aircraft and the new family of aircraft which issues from it, will owe very much to the MIRAGE 4000 aircraft. This twin-engine aircraft has enabled experimentation of certain points inherent to the configuration retained for the RAFALE aircraft. For instance, even though they are very different in size, it is important to note that at the level of the shape and sweepback of the canards and of the position of the wing leading edge relative to the canard, RAFALE is a certified true copy of the MIRAGE 4000 aircraft.

For those who wonder why the "delta-wing" family has been momentarily interrupted with the MIRAGE F1 aircraft, I would like to recall briefly that to give a successor to the MIRAGE III aircraft, DASSAULT had chosen to abandon the delta configuration and to adopt the sweptback wing configuration to decrease the approach speed from approximately 180 kts to 140 kts with identical performance. The introduction of fly-by-wire controls, which enable artificial stabilization of an intrinsically unstable aircraft, allowed us to re-use the delta configuration for the MIRAGE 2000 aircraft which, while offering an appreciable maneuverability gain, remained within the 140 kts approach speed.

To come back to the delta moving canard configuration such as it is on the RAFALE demonstration aircraft, the advantages are multiple and we cannot go too far into details. This has already been done within the AGARD during a lecture at Trevise in April 86 by one of our aerodynamics engineers. We simply recall that this configuration enables :

- excellent wing efficiency, especially at high angles-of-attack, due to deflection of the air flow on the wing by the foreplane,
- extensive control of the aircraft's centre of gravity, thanks to the aerodynamic centre effect created by the canard. As you know, it is the mastery of longitudinal balance that guarantees high maneuverability throughout the flight envelope.

  It has been proved in combat simulation that the negative static margin obtained, thanks to the fly-by-wire controls, which was optimum, depends on the optimum limit of maneuver, itself corresponding to the best CL max. The selection of negative static margin thus made, a canard dimension linked to the selection of the aircraft c.g. position is obtained (see figure 8).

- a certain number of new FCS functions, as for instance gust alleviation, decisive for multi-role aircraft. In fact the possibility of delaying the accelerations felt by the pilot at high speed and low altitude (penetration mission) makes possible the selection of larger wings which leads to an improvement of the aircraft qualities in the Air-to-Air dog fight (air superiority mission).

At last, linked to the delta canard configuration, the single fin solution has proved to be the best one.

The semi-ventral pitot air intakes, which are of an entirely new design issuing from many computations and tests, meet specific technological requirements :

- improvement in air intake efficiency at high angle-of-attack thanks to the protection provided by the forward fuselage,
- improvement in the quality of air supplied to the engines by increasing the stationary and unstationary homogeneity of the airflow,
- maintaining a Mach 2 capability, while at the same time achieving simplicity : no moving devices or bleeds,
- finally, complete separation of the right and left air intakes so that misfunctions of one does not affect the other engine, and also to allow sufficient space for installation of a forward retraction nose gear, leaving a large amount of space for carrying long underfuselage stores.

3.2 - SIZE

The selection of size is a decisive step in the fighter design process because then it creates an unavoidable restraint which will affect all other aspects.

From the requirements mentioned in the operational programme sheet which specify a certain number of data, studies of parameters lead to the selection of the optimal size. These studies cover the following main parameters :

- thrust,
- area,
- instantaneous turn rate (or approach speed),
- sustained turn rate,
- rate of climb,
- combat weight.

The effect of these parameters on the result is shown on figure 9.

On the RAFALE demonstration aircraft, this optimization has allowed the design of a twin-engine aircraft which is smaller than the other existing twin-engine aircraft of equivalent installed thrust (TORNADO , F 18) and even much smaller than the other highly motorized twin-engine aircraft (MIRAGE 4000, F15, F14).

At last, it must be recalled that the aircraft size problem has been discussed during the European cooperation feasibility studies with England, Germany, Italy and Spain. Since the size of the aircraft finally retained for the EFA project was too large, France had to withdraw.

Since then, the size of our design has been reconsidered and reduced, the basic version of the future aircraft is smaller than the demonstration aircraft with an empty weight of approximately 1 tonne less ; its dimensions are comparable to the MIRAGE 2000 single-engine aircraft (see figure 10).

3.3 - USE OF NEW MATERIALS

a) Composite materials

Since 1975 approximately, as shown on figure 11, AMD-BA have achieved in this field a progressive and continuous step forward during which it is worth noting that military and commercial fields were complementary to one another.

This has only been possible by the use of a wise and strict methodology , shown on figure 12, consisting in dividing the development of any new solution into three stages :

- experimentation on the ground
- application in flight
- integration on aircraft.

In AMD-BA this methodology is applied for the introduction of any new technology, whatever the field may be, before going to industrialization.

Three main examples will highlight the spectacular character of the technological breakthrough of AMD-BA in the field of composite materials :

- in 1978, the FALCON 50 was the first passenger transport aircraft with a vital component - the outer aileron - made of carbon fibre to be certified by the FAA,
- in 1979, the MIRAGE 4000 was the first aircraft to incorporate a large carbon fibre self-stiffened structure - the fin unit - also used as a fuel tank,
- in 1985, the FALCON V10F was the first transport aircraft to be certified with a one hundred percent carbon fibre wing.

The so-obtained progress have been used in the RAFALE programme and firstly on the demonstration aircraft. Composite materials are used not only for the control surfaces (elevons, rudder, canard), and the wings -for which a new high modulus fibre (IM6-5245C) is used for the very first time -, but also for the fuselage front section (cockpit structure (see figure 13), equipment bay), central section (complete fuel tank) and rear section (below engine area).
All landing gear doors as well as numerous access panels are made from composite material (see figure 14 and 15). The RAFALE demonstration aircraft also incorporates Aramid fibre for numerous elements such as wing-to-fuselage fillets, fairings and the nose radome.

Altogether, composite materials account for over a fourth of the structure weight.

b) Aluminium-Lithium

To cope with the competition of composite materials, metal workers had to find a solution : the aluminium-lithium alloys incorporate the required improvements. Indeed, with a proportion of 2.7 % of lithium for instance (beyond 3 % the metallurgical balances are broken) the density decrease is 10 % and the rigidity increase is 8 % relative to conventional aluminium alloys.

With a view to an increasing use of these new alloys in our aircraft, studies have been carried out in connection with the metal workers, they have more particularly dealt with :

- forging of ingots,
- thermal treatment,
- mechanical machining,
- chemical machining (development of baths),
- study of chromic anodic protection,
- geometric evolution and redressing of parts during and after machining,
- checking of weight saving and rigidity increase on samples and test parts.

Figure 16 shows the applications studied on the RAFALE demonstration aircraft. The zones retained deal with the fuselage skin panels and the inner panels of the engine tunnel. Furthermore, two fin attachment frames have been entirely machined.
The use of massive parts is under study and particularly depends on the feasibility of large blocks and the improvement of their mechanical properties.

Thus, the use of Aluminium-Lithium alloys could lead to a structural weight saving of 10 to 15 % for the future aircraft, while keeping the means of transformation and manufacture used at the present time for conventional alloys.

c) SPFDB

This revolutionary technology which results from the combination of superplastic forming and diffusion bonding, takes advantage of the property of some types of titanium alloys to stretch by up to 800 % and allows the manufacture, in a single hot forming operation, from thin flat plates, of self-stiffened structural elements of complex shape.

Since 1978, AMD-BA has developed this technique (see figure 17) : it has been incorporated for the first time in production on the strake of MIRAGE 2000 aircraft. It has shown simultaneously, a rare occurence :

- a weight reduction due to the decrease in thickness ensured by titanium,
- a cost price reduction, involved by the fact that the baking cycle also achieves assembly and enables the suppression of most fasteners.

The process has been used for the manufacture of the wing leading edge slats of the RAFALE demonstration aircraft.

We are studying the extension of this process to other components such as : canards, air intakes, canopy framing,...).

Remarks

For technological reasons (limiting thickness of titanium) the weight reduction can be subject to limitations, which leads to the idea of transferring the SPFDB to new aluminium alloys (SPF on aluminium already exists, but not the combination). An interesting example can be seen here in which manufacturing problems lead to new metallurgical research.

d) Conclusion

As a whole, 35 % of RAFALE's structural mass are made from various new materials, which, as far as we know, constitutes a world premier for a combat aircraft.

On the future aircraft, their use will be at least as large but may be different owing to the competition between aluminium-lithium alloys and composites.

3.4 - FLIGHT CONTROL SYSTEM

In this field also, the technological advance made in AMD-BA, marked very soon by the decisive stage which was the creation of the Dassault Equipment Division (see figure 18), has each time given the answer to - and has even often gone beyond-the operational requirements.

Here again, the permanent compromise between the essential innovation and the respect of the traditions tending to use a maximum of proven solutions, has been the main element of the development of the flight control systems used on our aircraft.

Figure 19 shows this evolution in time and how we gradually replaced the simple direct mechanical links by fly-by-wire control systems.

On the RAFALE demonstration aircraft a further step has been made with the generalization of digital systems.

The resulting CCV design, linked to the aerodynamic configuration retained, ensures an optimal utilization of the numerous servo-controls (17 control surfaces and 2 engine servo-controls (see figure 20)) and thus enables the introduction of a certain number of functions (see figure 21).

Some of them have already been tested in flight on the MIRAGE 2000 aircraft. The others, which are new, will be developed on the RAFALE demonstration aircraft to be, if possible, integrated in the future versions.

The use of optical fibre for data transmission will be evaluated.

3.5 - AIRFRAME LAYOUT

It has become traditional within the AMD-BA to manufacture at the beginning of the design process an entire full-scale layout mock-up (see figure 22).

This mock-up becomes essential to fit out an aircraft of reduced size, using for the airframe a large part of new materials where retrofit is difficult and receiving a large number of equipment (operational or ancillary equipment), which are not on the shelf and the overall size of which has not been entirely defined.

Due to this mock-up, we can study and solve more easily and sufficiently soon the problems of location of equipment and the problems of running the numerous related wiring and piping.

But it also enables every one, and in particular the future operational users, to help us all along the design, so as to consider the correct accessibility to the circuits and equipment.

Thus this method enables us to optimize the ease of operation and maintenance of the aircraft. This aspect is of prime importance for the design of a family of multi-role aircraft (possible utilization on runways or on aircraft carriers).

3.6 - INSTALLATION OF THE PILOT AND MAN/MACHINE INTERFACE

Two main criteria, proper to future combat aircraft, had to taken into account, in the design of the cockpit :

- the improvement of maneuverability in the entire flight envelope, which results in an appreciable increase of accelerations (see figure 23) and of their duration,
- the extension of the operational functions of a multi-purpose weapons system.

Very soon, it seemed to us that an optimum answer to these two criteria would necessarily lead to a complete revision of the installation of the pilot in the aircraft and, concurrently, to reconsider entirely the man/machine interface.

The difficulty of the problem has led us to examine all the solutions, including the most advanced ones (inclined ejection seat). This was covered by the OPE study (Organisation du Poste d'Equipage) initiated by the French Official Services.

The OPE study : following on a computer augmented anthropometric study, simple mock-ups have quickly shown that it was possible to work correctly in a highly reclined ejection seat, provided that the upper part of the torso is straightened up by a support at the level of the shoulder blades. With tests made in centrifugal machines we have checked that an angle up to 50° ensures an excellent protection against load factors - the reclined position lowers the blood column between the brain and the heart.

Beyond that, the pilot started to have difficulties in breathing (chest extension). Moreover, as from a certain inclination, the surfaces capable of receiving flying or operational instrumentation were becoming non existent or inacessible.

Application to the RAFALE demonstration aircraft

When defining the demonstration aircraft, it has been decided to experiment in flight the solution studied within the OPE. Several problems, inherent to the reclined installation of the ejection seat, remained to be solved :

- to eject from the aircraft without delay and in good conditions in case of emergency. That is to say to keep a sufficient ejection path,
- to cope with the quasi disappearance of the instrument panel.

Furthermore, we had to check if the performance of existing ejection seats enabled this type of installation since the main problem was the clearance above the fin during ejection. From this point, trajectory computations followed by tests have quickly proved feasibility.

Thorough studies and detailed mocking-up sessions have allowed us to obtain a satisfactory, original and ergonomic compromise solution, shown by figures 24 and 25. This new installation of the pilot and the new related man/machine interface can be briefly described as follows :

- ejection seat inclined at a 32° back angle (possibility 37°)
- flying control according to the HOTAS concept "hands on throttle and stick", with the control stick on the right and a throttle lever on the left (only one control for two engines), both having a low displacement and integrated controls. Their high position, associated with the presence of elbow rests, avoids blood accumulation in the arms under large load factors.
- flight and mission parameters synthesized on displays generated by the latest technologies such as :

  . head-up display with holographic imaging,
  . head-level display collimated to infinity,
  . lateral multichromic head-down display,

  associated with a multi-function keyboard and voice control.

The experiments in progress show, thanks to these improvements, that it is still possible to improve the comfort (reduced workload and physiological restraints) and therefore the operational efficiency of the pilot, and to reject a certain trend of thought according to which man now constitutes a limiting factor in the development of modern combat aircraft.

It must be added to this, due particularly to a bubble canopy and very low position of the canopy arches, that the pilot has an exceptional external visibility, which is in no way obstructed by the canards.

3.7 - GENERALIZED INTEGRATION OF THE AIRCRAFT SYSTEMS

With the RAFALE demonstration aircraft, a large step towards the general integration of the systems has been made.

In addition to the flight controls which have been already mentioned, the aircraft systems and circuits, such as fuel, hydraulics, electricity, air conditioning, engine control, navigation and communications, make wide use of digital technology, with information transit and exchange being made over two centralized digital data bus lines. Thus the pilot does not have to worry about monitoring the systems ; he will only be warned in the event of failure, if this is strictly necessary, and will be provided with the information required to take rapid and efficient action.

Experimentation in flight of this integration concept will enable the optimization of the really necessary integration level in the future operational aircraft.

3.8 - STORES

Designing a multirole combat aircraft means providing a high weapon-carrying capability ; in this respect, the RAFALE is particularly well placed since it has, in addition to its internal gun, twelve hardpoints allowing approximately 7 tonnes of external stores to be carried.

We have already mentioned previously that the architecture of the aircraft air intakes, nose and main undercarriages gives the capability for a large store to be carried under the fuselage, which is essential to achieve certain Air-to-Ground missions (see figure 28).

Certain configurations, such as those with air-to-air missiles conformal to the fuselage, have been designed especially to reduce drag and radar signature. Figure 29 shows the configurations which have been tested in the wind tunnel for under fuselage tandem-mounted missiles. The structural optimization has enabled the installation of the missile ejectors inside the aircraft.

This store carrying capacity, which is exceptional for an aircraft of this size, has been obtained by opting for a mid-fuselage wing location and designing a special linkage system for the nose gear that minimizes the space required under the front section for retraction and extension of the gear.

Here we have (figure 30) an air-to-air configuration showing 8 MICA missiles and 2 MAGIC missiles.

At last, its multitarget capability stems also from its aptitude to carry out long range missions : to achieve this, it has a high internal fuel capacity. In fact the internal fuel-to-empty weight ratio is the highest for fighter aircraft in this category, which reflects the efforts made to optimize the use of the aircraft's internal space.

Figure 31 gives the envelope of the Air-to-Ground configurations, with in particular the 2000 l drop tanks at wing station 1.

4 - MEANS FOR COMPUTER AIDED DESIGN

The generalized optimization process which we have just described, could only be attained thanks to the considerable and continuous increase of the design and development means. We now propose to consider shortly the main means available.

4.1 - IN CAD-CAM : CATIA (Conception Assistée Tridimensionnelle InterActive)

We started more than fifteen years ago a policy of development and operational utilization of CAD-CAM.

In this view, the decision of developing the firm's software "CATIA" has been a decisive step.

Within our design offices, the basic tool remains the traditional drawing board, the latter is henceforth completed by CATIA work stations (figure 32). Progressively, we encounter the same type of work station in an increasing number of specialized departments taking part in the design of the project : aerodynamics, structure, systems...

The role of CATIA does not stop at the design phase but as any modern CAD-CAM tool, and probably more than others, it is present all along the continuous line which goes from design to manufacture, maintenance and documentation.

Thus the generalized and multidisciplinary utilization of CATIA (figure 33) enables an increase of efficiency and coherence of the complete process of development, and thus improves the quality of the product, which in particular profits from better accuracy.

The RAFALE demonstration aircraft is, also in this respect, an eloquent example.

As is the penetration of the CATIA system all over the world : nowadays more than 500 companies use the CATIA tool in more than 7000 work stations.

4.2 - IN AERODYNAMICS

Computational aerodynamics, which is in fact at the origin of the CATIA development (since the shape drawing is initially a by-product of the system designed by the aerodynamics engineers for computation) is a rapidly evolving discipline benefiting largely from advances in computer technology and on the other hand it constitutes a primary driving force for computer technology development by its outstanding computation performance requirements.

The codes used, which are of varied complexity and adapted to the various stages of the project, have been and will be obviously widely used within the RAFALE programme. As their contents are the subject of regular correspondance in AGARD, we limit ourselves here to an illustration of their application on the RAFALE demonstration aircraft (figure 34).

Often opposed in the past to computational aerodynamics, wind tunnel tests still constitute an essential element of the aerodynamic design of the aircraft, but in this respect we note a significant change.

Computational aerodynamics now enable configuration screening and optimization at the very preliminary design stage. Thus, from the retained configurations we immediately come to a relatively reduced number of models, whose design and manufacture delays are greatly reduced thanks to the utilization of CATIA (within a ratio from 4 to 1) and whose wind tunnel tests, enable us to cover quickly the whole flight envelope.

From this, the accurate check and the validation of various solutions as well as the final selection become possible within acceptable delays.

This proves that more than ever experimental and computational aerodynamics must not be competitive but complementary disciplines at every stage of design.

Anyway wind-tunnel testing remains important for identification of vehicle characteristics after configuration freeze and to generate data required by flying quality simulations, performace evaluation, structural analysis, etc...

There are three particularly important areas in combat aircraft development where wind-tunnel testing plays a unique role :

- high angle-of-attack behaviour characterization,
- air intake performance and flow distortion,
- tests related to external store installations, release, ejection and firing.

RAFALE models installed in various wind-tunnels, to carry out the tests required by the above topics, are shown on the figure 35.

4.3 - IN STRUCTURE

In this field the finite elements computer code, called "ELFINI", has become an essential tool.

The development of this code, operational in the AMD-BA stress division for nearly twenty years and continually enriched since, has also been made possible thanks to the increase of computer performance, the advent of intelligent terminals and high resolution colour screens and to progress made in numerical analysis and programming.

It is now possible to solve very large scale structural problems (close to 200 000 degrees of freedom) and to carry out the iteration cycles required by structural optimization or by non-linear computation within an acceptable time and cost schedule.

Without lingering on the numerous possibilities of the ELFINI code, which has also been the subject of AGARD correspondance, we show its application on the RAFALE demonstration aircraft on figure 36.

Additional advances are predicted in the near future in the following areas :

. integration of the ELFINI code in the CATIA CAD/CAM system,

. improvements in damage tolerance analysis,

. prediction of buckling and postbuckling,

. transonic unsteady aeroelasticity,

. active control,

. multidisciplinary optimization,

. structural behaviour in high temperature environment.

Most of them will be used for the first time operationally in the continuation of the RAFALE programme. It is notably the case for the prediction of buckling and postbuckling, which will enable the optimization of the rear fuselage skin panels.

4.4 - SIMULATION

In the area of simulation, which has become an important development and evaluation tool, recent activities were orientated in three directions :

a) Update and enhancement of the AMD-BA engineering simulator capabilities for advanced flight control design and flying qualities studies.
At the beginning we can study in a dome the behaviour of the "entirely simulated" aircraft, then once the servo-controls and the computers have been manufactured by Dassault Equipment Division, the connection with the simulator is made thus enabling perfect simulation of the aircraft.

b) Development of a multi-aircraft combat computer programme to synthesize and validate combat tactics.

c) Development of a flexible display tool for the design of cockpit symbology. It is the OASIS system (Outil d'Aide aux Spécifications Informatiques des Systèmes).

These tools - particularly the engineering simulator and the OASIS system - have enabled the ultra rapid design and development of the numerical fly-by-wire controls and the entirely new man/machine interface of the RAFALE demonstration aircraft. In addition, they have enabled the pilots to get used to and to grow familiar with these new systems as soon as possible, which is a true break with the past.

Finally one must add to these simulators, those which exist in Government Test Centres and which are widely used for the development of the cockpit, the integration of the weapons system and combat training : these are mainly the CEV (Centre d'Essais en Vol) and the CELAR (Centre Electronique de l'Armement) simulators.

Figure 39 shows the main means of simulation used. They will be obviously used all along the development of the new aircraft.

4.5 - CONCLUSION ON THE GROUND MEANS

To conclude this chapter, without going any further, we shall merely say that equivalent means are set into operation in all the other disciplines implicated in the development of the future aircraft, i.e. :

- New materials,
- Mechanical and acoustic vibrations,
- Propulsion,
- Circuits and equipment,
- Weapons systems including countermeasures,
- Electrostatic environment,
- Equivalent radar surface and infra-red signature.

The means concerning this last item are to be developped particularly due to the increasing importance assumed by discretion and stealth aspects, in the design of new generation combat aircraft.

In all these disciplines, the internal AMD-BA means and the means available either in the Government Test Centres or in private companies, are harmoniously complementary to one another.

Thus, they form a solid basis to establish the Dassault validation methodology, which judiciously puts together computation and ground experiments before going to the ultimate step : flight tests.

5 - FLIGHT TESTS

In this area, the RAFALE programme will be able to profit from 50 years of experience, which, thanks again to a well considered step-by-step policy, nowadays gives rise to an homogeneous entity which is certainly unique in the world.

This entity, based on an original organization, uses particularly efficient means.

The organization is characterized by an integration of flight tests in the previsions - partial tests - ground tests contrary to other companies or countries which differentiate clearly the flight tests from others even if they have to be integrated in specialized test centres. Figure 40 illustrates our integration of the flight tests.

The means used are essentially made of :

- a recording/analyzing system of parameters collected on board based on telemetry, which, as far as we know, has no equivalent in technology and performance. The architecture of this system is shown on figure 41.
- an airborne numerical data acquisition system using leading technologies such as hybrid circuits with LSI components as required. This system called "DANIEL 90" and supplied by Electronique Serge Dassault has a capacity of analysis of 32 000 pts/sec.

  As far as we know, this system is one of the most efficient flying in Europe at the present time, well adapted to the acquisition of data on all types of digibus (GINA, MIL-SDT-1553, COLLINS, PROLOG).

All this has already been used on the RAFALE demonstration aircraft, which has encountered an unprecedented rate of flight in our company.

The related test facility enables, all along the flight, a follow-up in real time of nearly 1200 parameters and enables the modification, if needs be, of the flight instructions and/or warning the pilot of a degradation of a parameter or an unexpected variation in flight conditions.

6 - EXPERIMENTAL SYSTEMS

In order to prepare the future combat aircraft, a set of experimental systems have been launched in the main fields concerned by the RAFALE programme. Figure 42 shows this set.

As concerns the aircraft, it is the RAFALE demonstration aircraft, which we have widely discussed all along this report. Its role was, let us recall it once again, to integrate in flight a maximum of new technologies (see figure 43) and thus enable through its experimentation the orientation of the technical decisions for the future aircraft.

It is also used as a reference to judge the ability to carry out various missions, notably those of the Navy, as well as to establish the provisional development cost file.

A brief schedule of the flight tests made is shown on figure 44. We can state positively that this aircraft has here and now proved the validity of the concepts considered for the future aircraft and confirmed the computed performance.

As concerns the engine, SNECMA has manufactured an M88 experimental engine which has been running on the test bench for more than one year and which has up to this day proved the thrust performance. The HP portion of this engine has been retained to be used as a basis for the definition of the production engine, the total thrust will result from the choice of the LP portion with which it is fitted.

It is anticipated that the RAFALE experimental aircraft will be used as a flying test rig for the M 88 engine in order to ensure as soon as possible its integration in the future aircraft.

As concerns the radar, an exploratory development has been launched to study the multitarget function, as well as an experimental radar RACAAS at TH-CSF, whilst ESD leads the work in the ANTILOPE family (a functional mock-up is launched).

As concerns the MICA missile, various designs were launched several years ago, concerning propulsion, seeker, launching system as well as its association with the multitarget fire controls.

By adding to these experimental systems other work relative to other components of the system and important steps in the discretion area, a large assembly of data has been established to enable the selection of the final configuration for the operational aircraft.

7 - THE FAMILY OF MULTIROLE COMBAT AIRCRAFT

All the work entered into within the RAFALE programme, and already concretized by the previously stated experimental systems, shall open out on a new family of multimission and multirole combat aircraft.

The optimized process described all along this report ensures the design of a basic version for the French Air Force, adapted to its various operational missions - ground strike - air superiority or air defence.

From this basic version, it will be possible to derive a version designed for the Navy thanks to the fact that we have taken into account, from the beginning of the process, the requirements proper to this version, namely :

- low approach speed and increased visibility,
- installation of an undercarriage capable of receiving a specific Navy landing gear with catapulting by the nose gear,
- space available for the attachment of an arrester hook at the rear,
- large ground clearance.

For certain European countries, RAFALE is an alternative aircraft, lighter and cheaper than the Eurofighter.

For export, RAFALE should be in the range of 7 to 10 tonnes aircraft, beyond MIRAGE 2000 aircraft.

8 - CONCLUSIONS

In a report established in 1973 by the Rand Corporation on AVIONS MARCEL DASSAULT, we read :

"Dassault's fundamental development policy is to minimize the extent of technical risk that is incurred at any single point in time. A given aircraft design, although it may appear to be novel, usually incorporates no more than one or two unique major design features...

Adoption of some of the forms of the Dassault process could well change American aircraft, and the industry that makes them, for the better..."

The 92 nd prototype of a long line, the RAFALE experimental aircraft is the achievement of this continuous and regular process of technical innovations which opens the way for a new generation of multirole combat aircraft (see figure 45).

FIG. 1 - RAFALE DEMONSTRATOR IN FLIGHT

- NEW GENERATION AIRCRAFT TO OPPOSE TO THE VARSOW PACT FORCES
- REPLACEMENT OF MIRAGE III E AND JAGUAR AT LOW COST TO HAVE AVAILABLE AIRCRAFT IN SUFFICIENT NUMBER
- THREE MISSIONS OF EQUAL IMPORTANCES
  - AIR SUPERIORITY ABOVE NATIONAL TERRITORY AND BATTLE DISPOSITION
  - LONG RANGE AIR TO GROUND AND INTERDICTOR STRIKE
  - LONG LOITER WITH FLIGHT REFUELLING
- GREAT AGILITY AND MANEUVERABILITY
- USE OF SHORT OR DAMAGED RUNWAYS
- LOW OBSERVABLE CHARACTERISTICS

FIG. 2 - FRENCH AIR STAFF REQUIREMENTS

FIG. 3 - THE AIRCRAFT PROCESS DESIGN

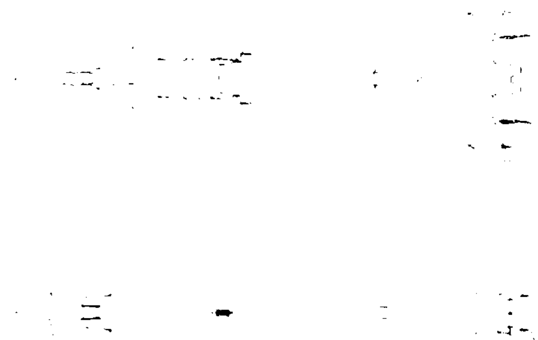


FIG. 4 - EXAMPLE OF LOW SPEED CONFIGURATIONS STUDIED

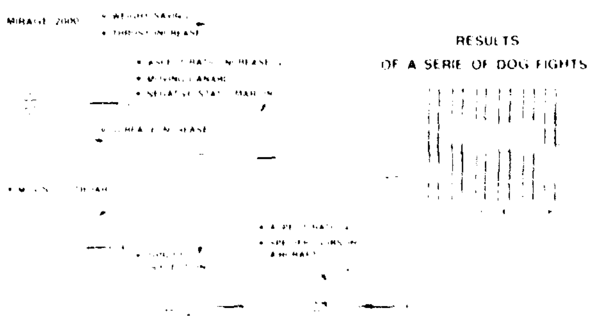


FIG. 5 COMBAT PERFORMANCE OF NEW AIRCRAFT FORMULA

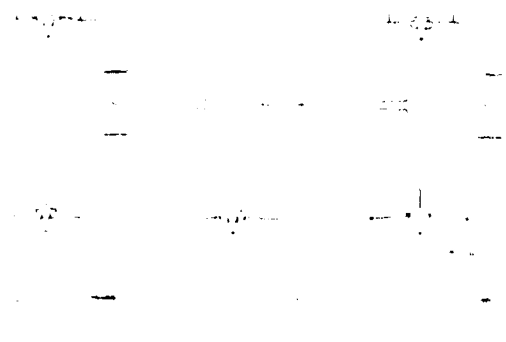


FIG. 6 - EXAMPLE OF DELTA-CANARD CONFIGURATIONS STUDIED

FIG. 7 - FILIATION OF DELTA WING AIRCRAFT AND CREATION OF DELTA-CANARD AIRCRAFT

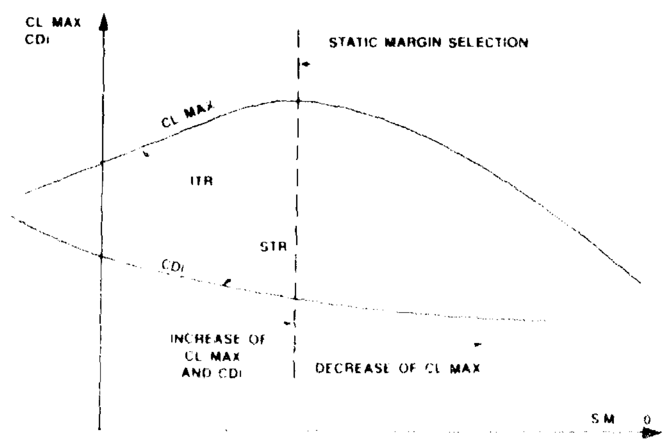


FIG. 8 - NEGATIVE STATIC MARGIN SELECTION

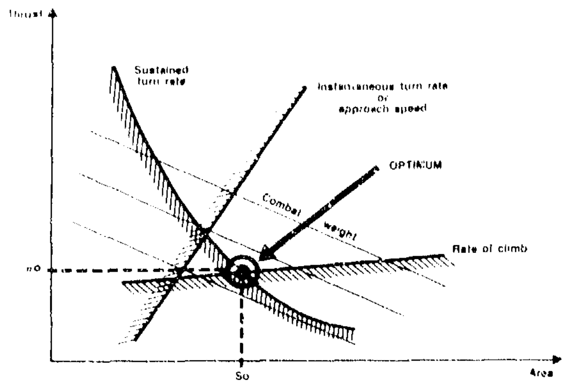


FIG. 9 - PARAMETER STUDY : AN EXAMPLE OF OPTIMIZATION

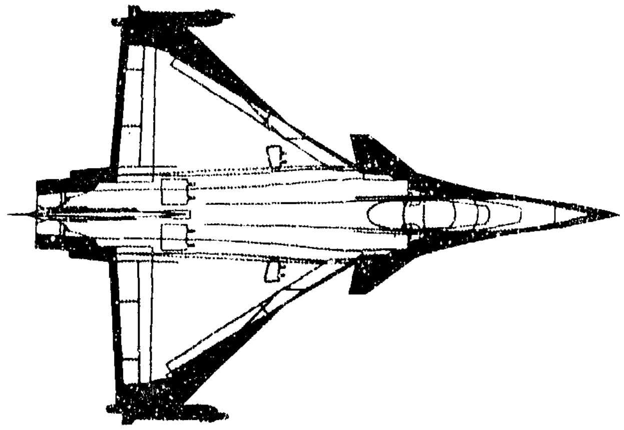


FIG. 10 - SIZE COMPARISON BETWEEN RAFALE AND MIRAGE 2000

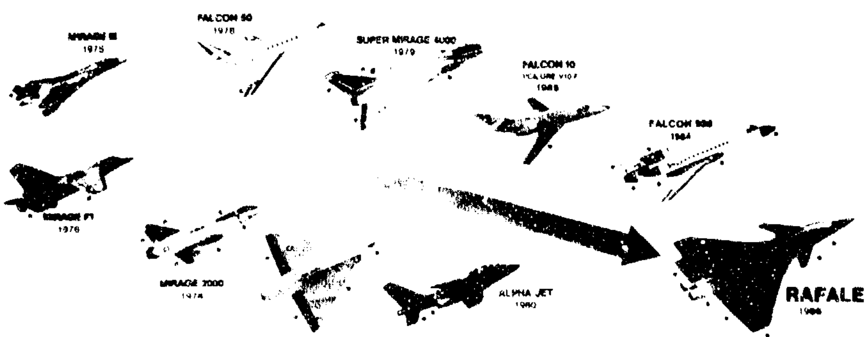


FIG. 11 - COMPOSITE MATERIAL IN DASSAULT-BREGUET AIRCRAFT FROM MIRAGE III TO RAFALE

FIG. 12 - THE DEVELOPMENT STAGES OF A NEW TECHNOLOGY

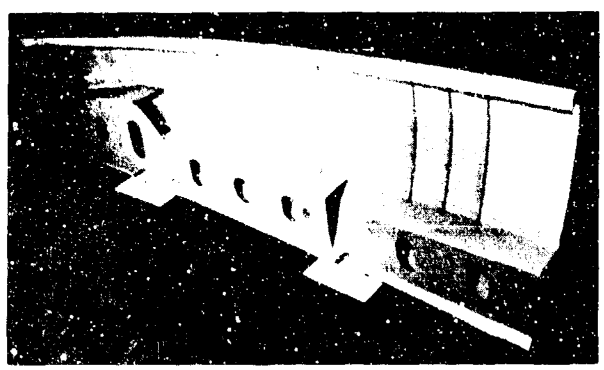


FIG. 13 - RAFALE FRONT FUSELAGE CARBON FIBER ELEMENT

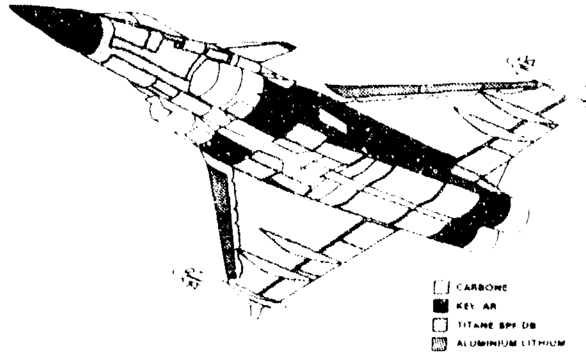


FIG. 14 - NEW MATERIALS IN RAFALE (BOTTOM VIEW)

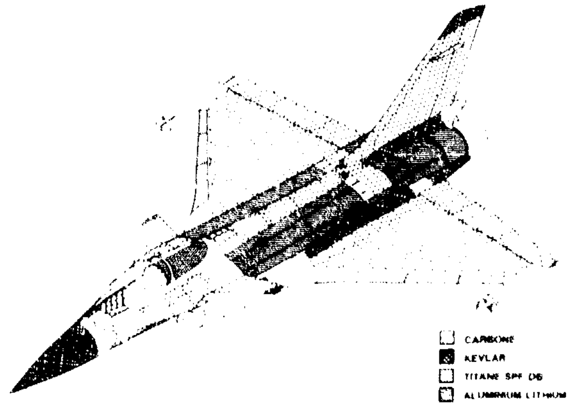


FIG. 15 - NEW MATERIALS IN RAFALE (TOP VIEW)

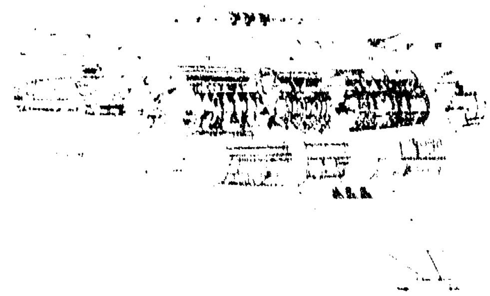
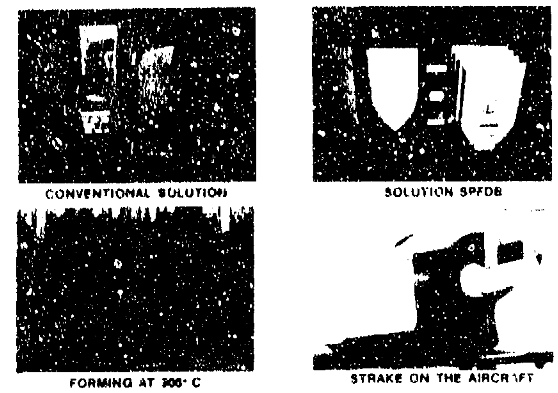


FIG. 16 - INTRODUCTION OF ALUMINIUM-LITHIUM STUDIED ON THE RAFALE

SUPERPLASTIC FORMING - DIFFUSION BONDING
MIRAGE 2000 STRAKE



CONVENTIONAL LIGHT ALLOY		SPFDB TITANIUM ALLOY
[illegible]	WEIGHT	[illegible]
[illegible]	PIECES	4
[illegible]	ATTACHMENTS	[illegible]

SPFDB STRAKE

RAFALE LEADING EDGE SLAT
TA6V SPFDB

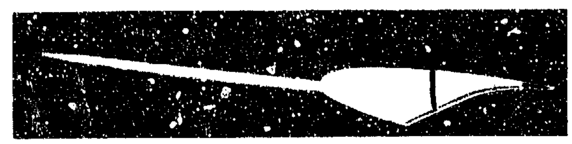


FIG. 17 - SUPERPLASTIC FORMING - DIFFUSION BONDING APPLICATIONS

In the fifties the penetration of aircraft in the sonic field required a new generation of flight controls resorting to servocontrols.

DASSAULT-BREGUET decided to built its flight systems on its own and to use the mechanical experience acquired in the field of propellers and engines. The Dassault Equipment Division (DED) was born.

The close and internal cooperation between the airframe designer and the manufacturer of flight control systems has been continued ever since. Associating the advances in aircraft performance with the advances in flight systems, this cooperation has led today to making aircraft fly at instable configurations thanks to electric flight controls.

The DED masters such technical fields as mechanical skill, high pressure hydraulics, servomechanisms and modern analogical and digital electronics. With a solid experience in design as well as in production, DED carries out specific high performance flight controls devoted for the aircraft and the weapons for DASSAULT-BREGUET and for other aerospatial Companies worldwide.

FIG. 18 - DASSAULT EQUIPMENT DIVISION

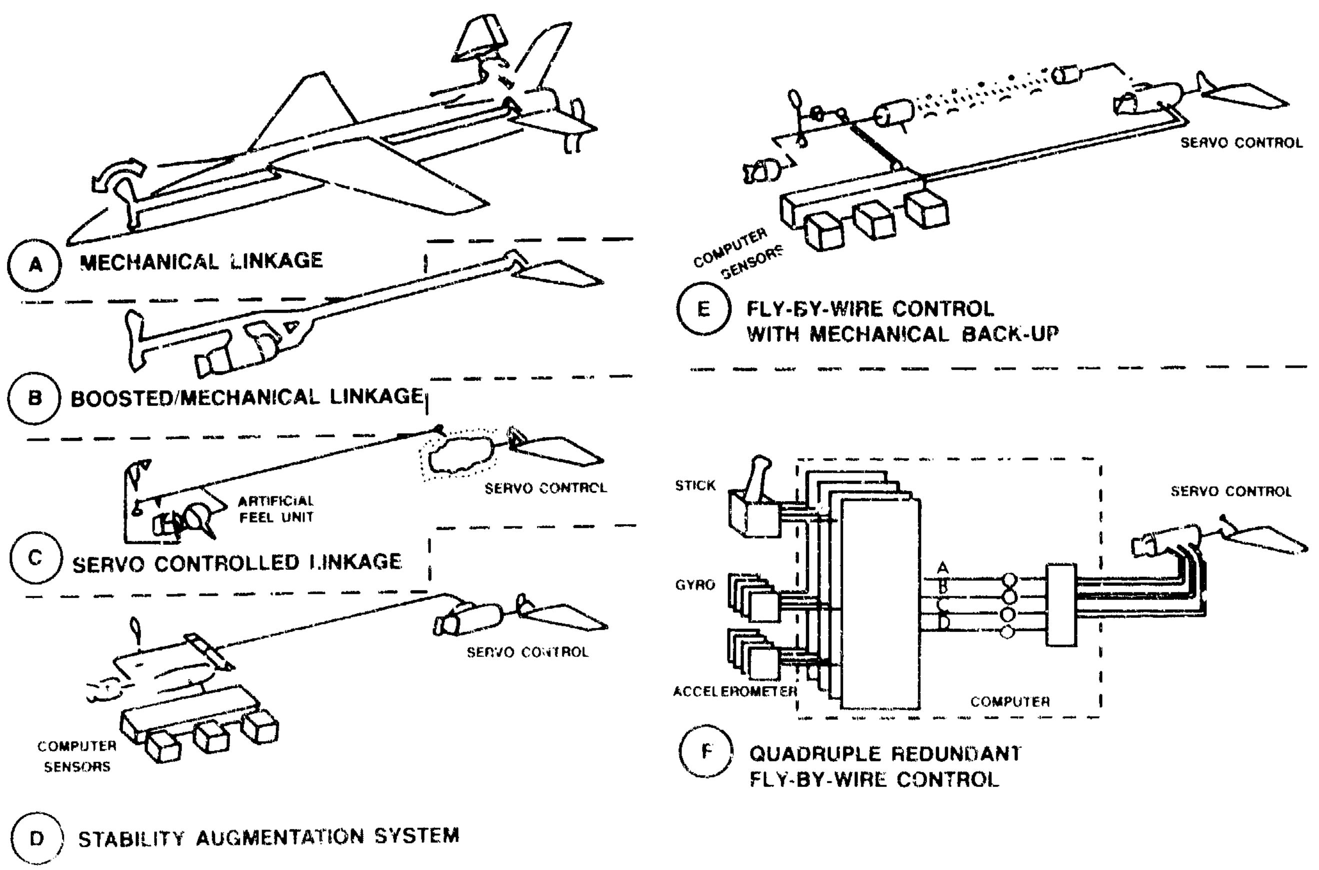


FIG. 19 - FLIGHT CONTROL SYSTEM DEVELOPMENT

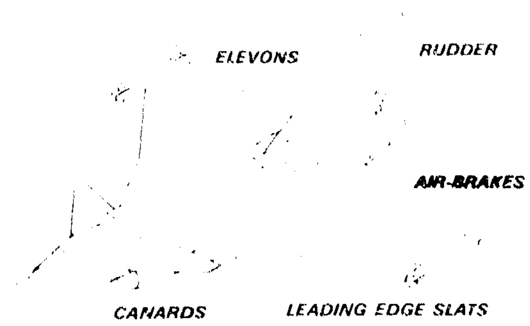


FIG. 20 - RAFALE - CONTROL SURFACES

- CLASSICAL FUNCTIONS (MIRAGE 2000)
  - STABILITY CONTROL ON THE THREE AXES
  - AUTOMATIC FLIGHT LIMITATION
  - CONFIGURATION CONTROL
- NEW FUNCTIONS
  - GUST ALLEVIATION
  - APPROACH MODE
  - HIGH ANGLE OF ATTACK CONTROL
  - STRUCTURAL LOAD MINIMIZATION
  - DIRECT LIFT CONTROL
  - ACTIVE FLUTTER SUPPRESSION
  - SECONDARY FUNCTIONS (ANTI-G SUIT...)
- CONNECTION FUNCTIONS WITH AUTOPILOT

FIG. 21 - RAFALE - FLIGHT CONTROL SYSTEM FUNCTIONS

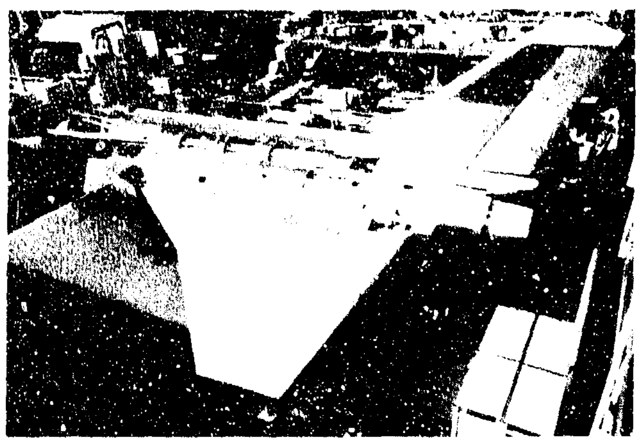


FIG. 22 - RAFALE - FULL SCALE LAYOUT MOCK-UP

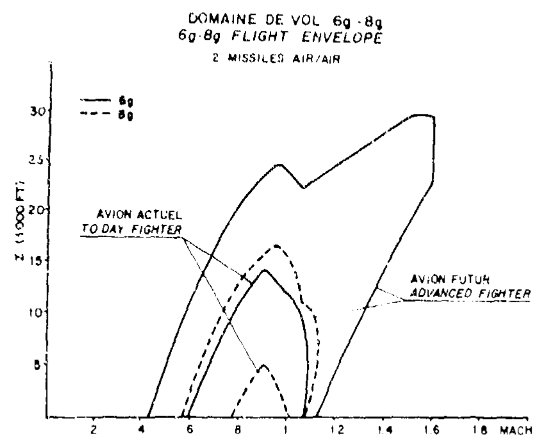


FIG. 23 - FLIGHT ENVELOPE COMPARISON BETWEEN TODAY'S AND ADVANCED FIGHTERS

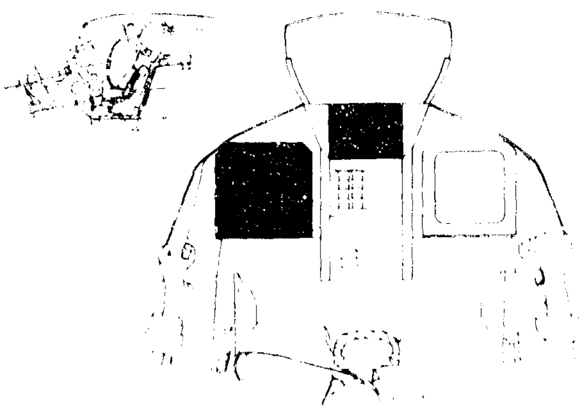


FIG. 24 - RAFALE - PILOT INSTALLATION AND COCKPIT

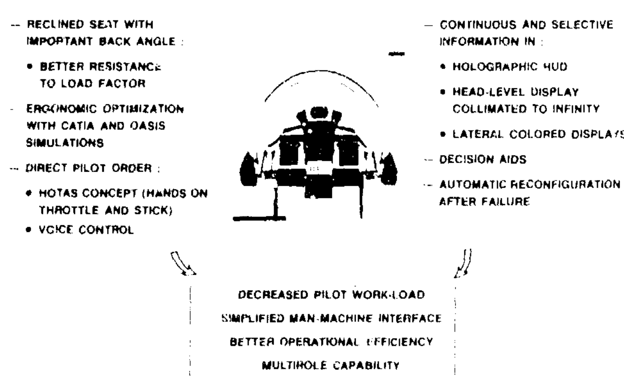


FIG. 25 - PILOT'S ENVIRONMENT

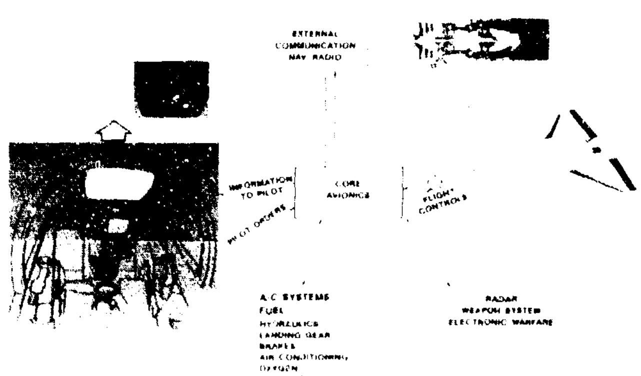


FIG. 26 - OVERALL SYSTEMS INTEGRATION

Fuselage : 1 station capable of two missiles in tandem arrangement

4 side stations

Wings : 1 station capable of one 2000 l extra fuel tank

1 station capable of one 1000 kg load

1 wing-tip station (self-defence missile)

Total : **12 carrying stations**

or **3 more carrying stations than on the Mirage 2000.**

FIG. 27 - RAFALE - CARRYING CAPABILITY

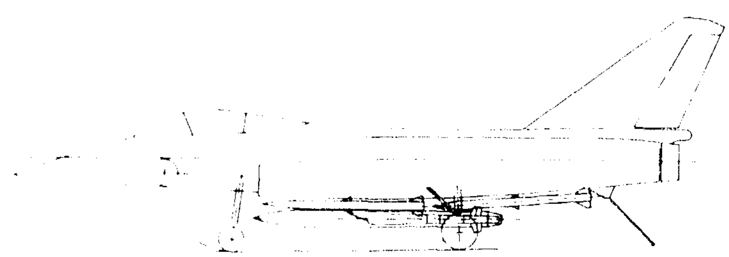


FIG. 28 - RAFALE - IMPORTANT CARRYING CAPACITY UNDER FUSELAGE

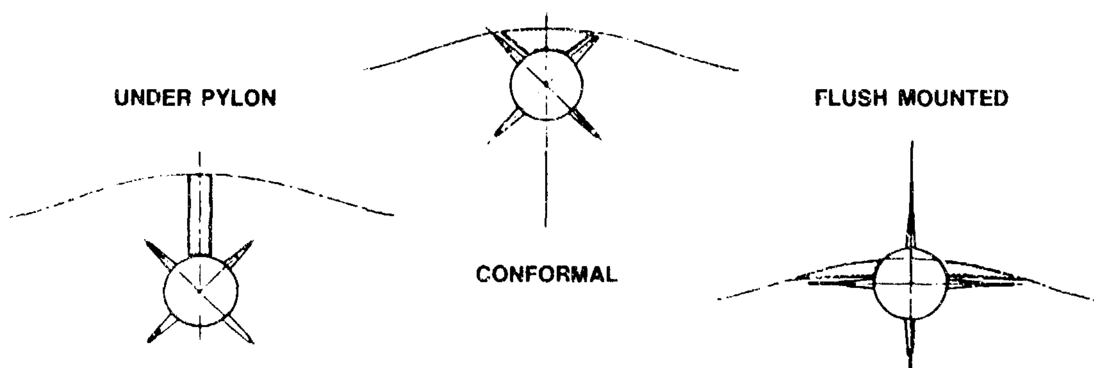


FIG. 29 - RESEARCH OF MINIMUM DRAG FOR UNDERFUSELAGE TANDEM MOUNTED MISSILES

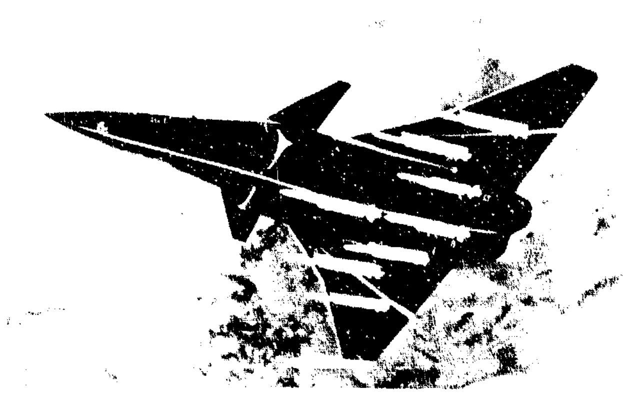


FIG. 30 - RAFALE - 8 MICA - 2 MAGIC CONFIGURATION

FIG. 31 - RAFALE - CARRYING CAPABILITY

FIG. 32 - CATIA WORK STATION

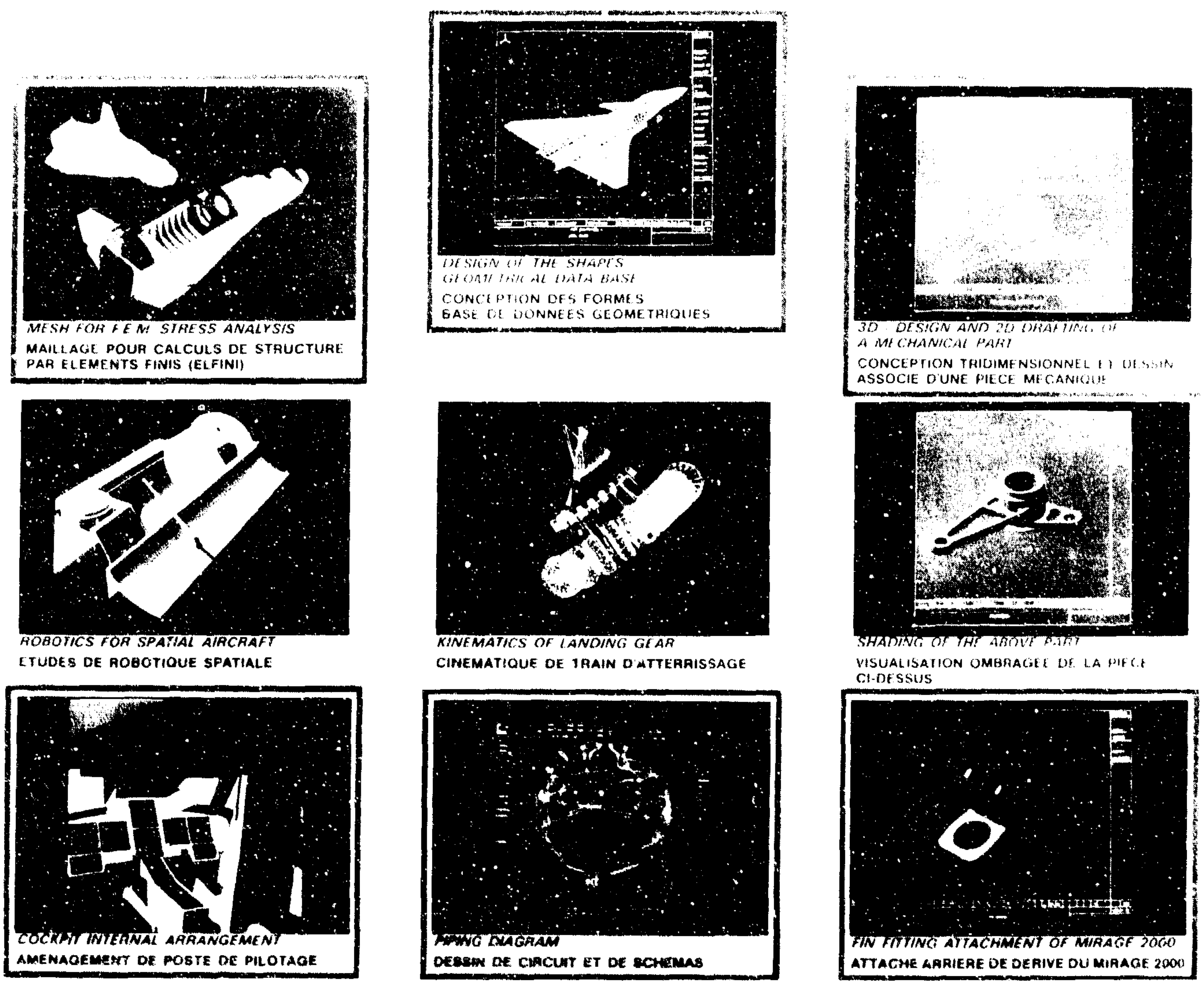


FIG. 33 - CATIA : CAD CAM SOFTWARE IN AMD-BA

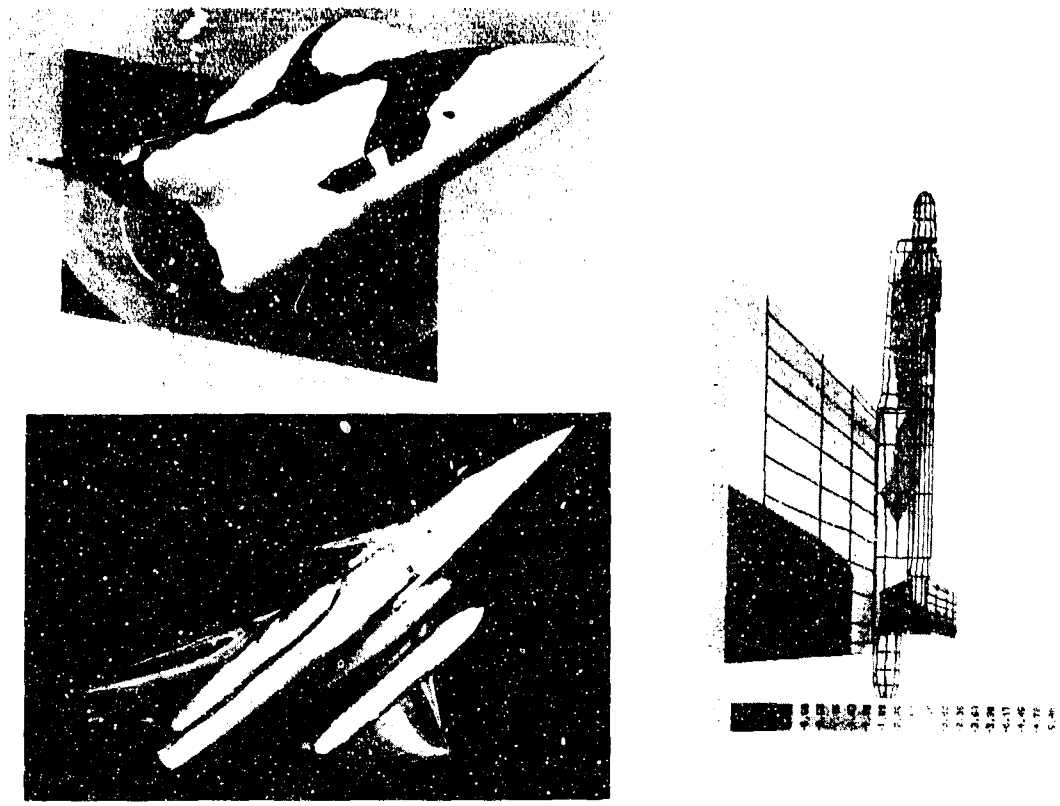


FIG. 34 - USE OF COMPUTATIONAL AERODYNAMICS CODES ON RAFALE

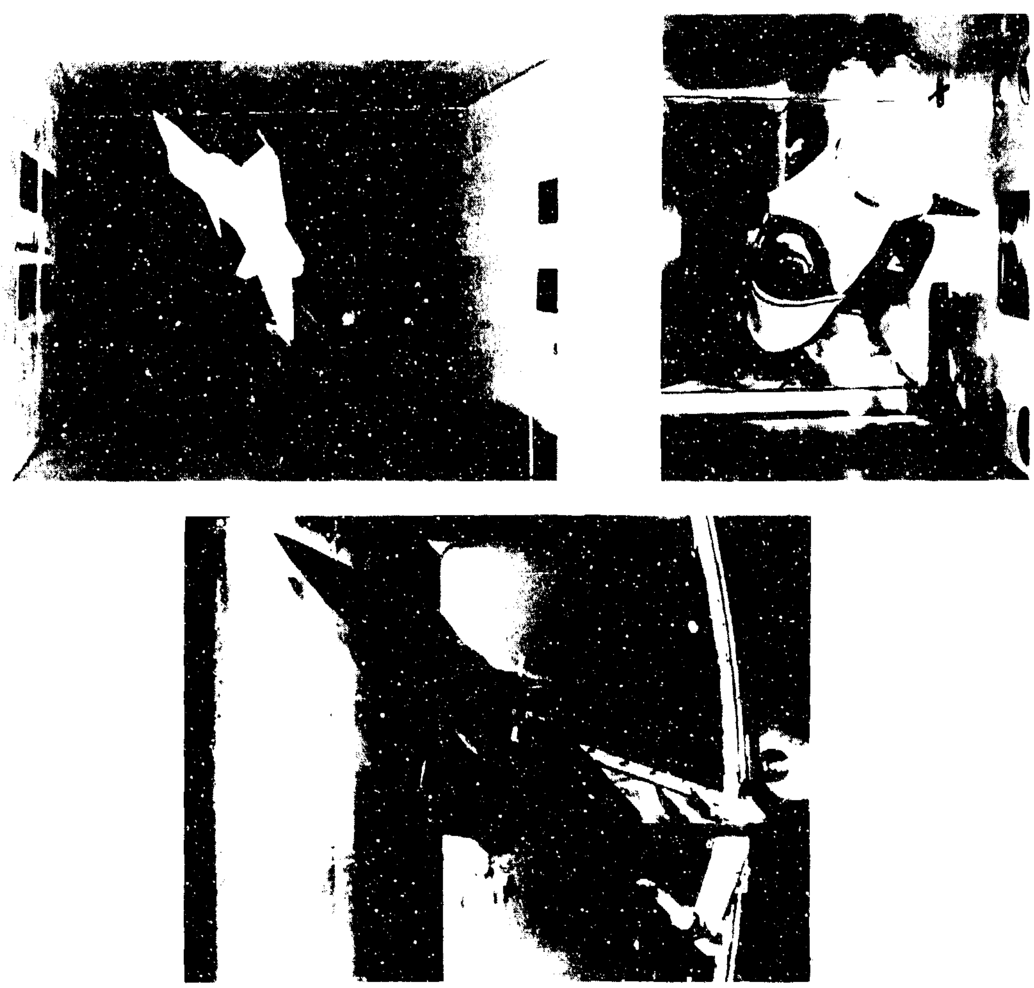


FIG. 35 - WIND TUNNEL TESTING OF RAFALE MODELS

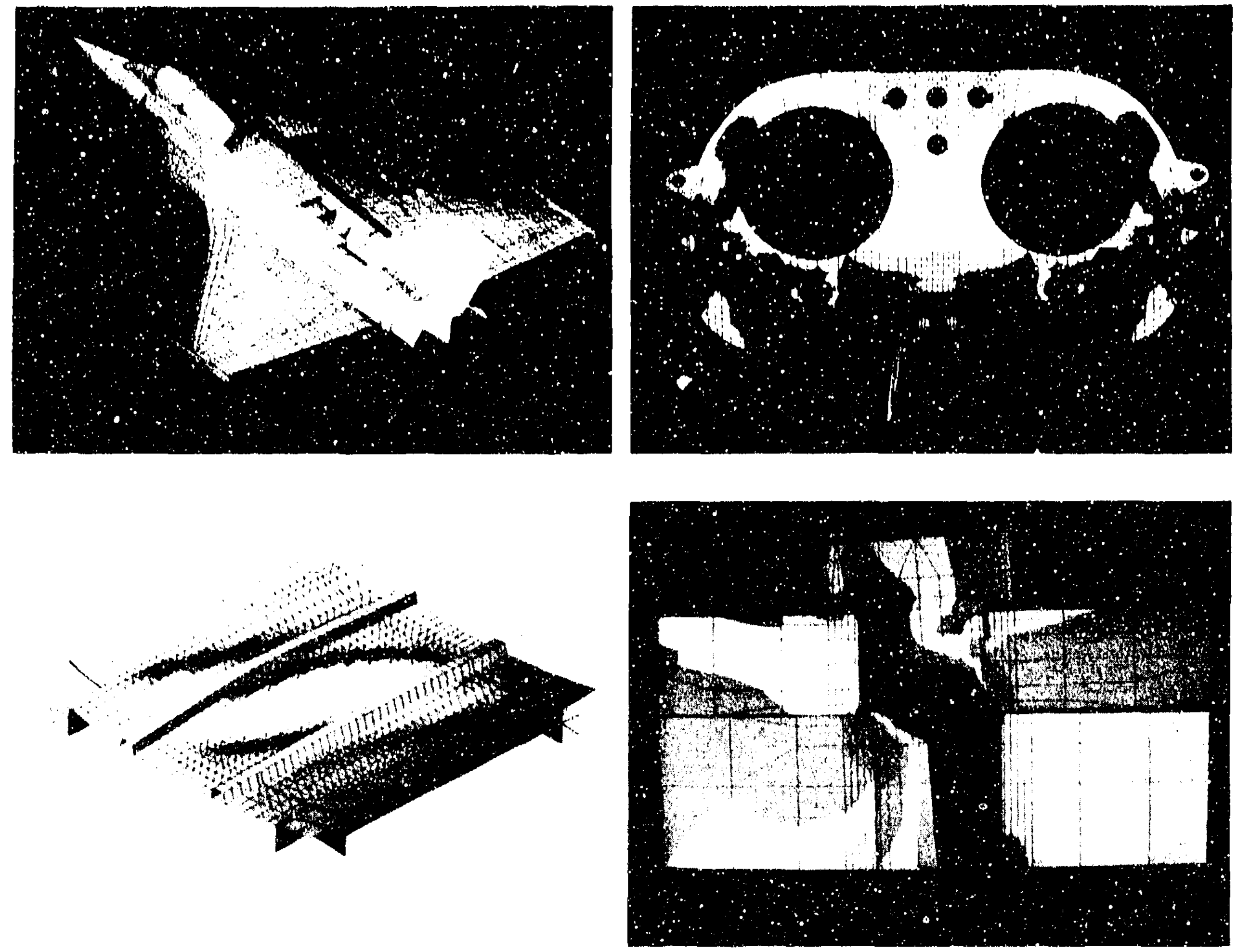


FIG. 36 - USE OF FINITE ELEMENT CODE "ELFINI" ON RAFALE

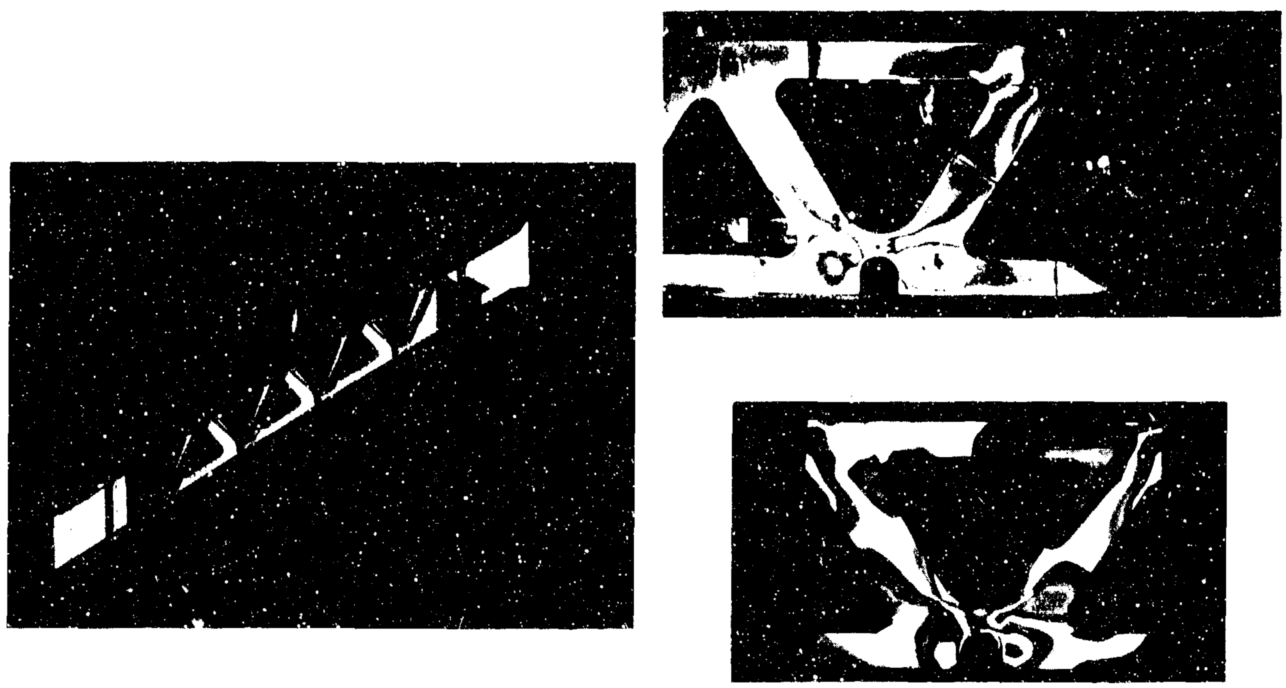


FIG. 37 - STRUCTURE - COMPARISON BETWEEN TEST AND COMPUTATION

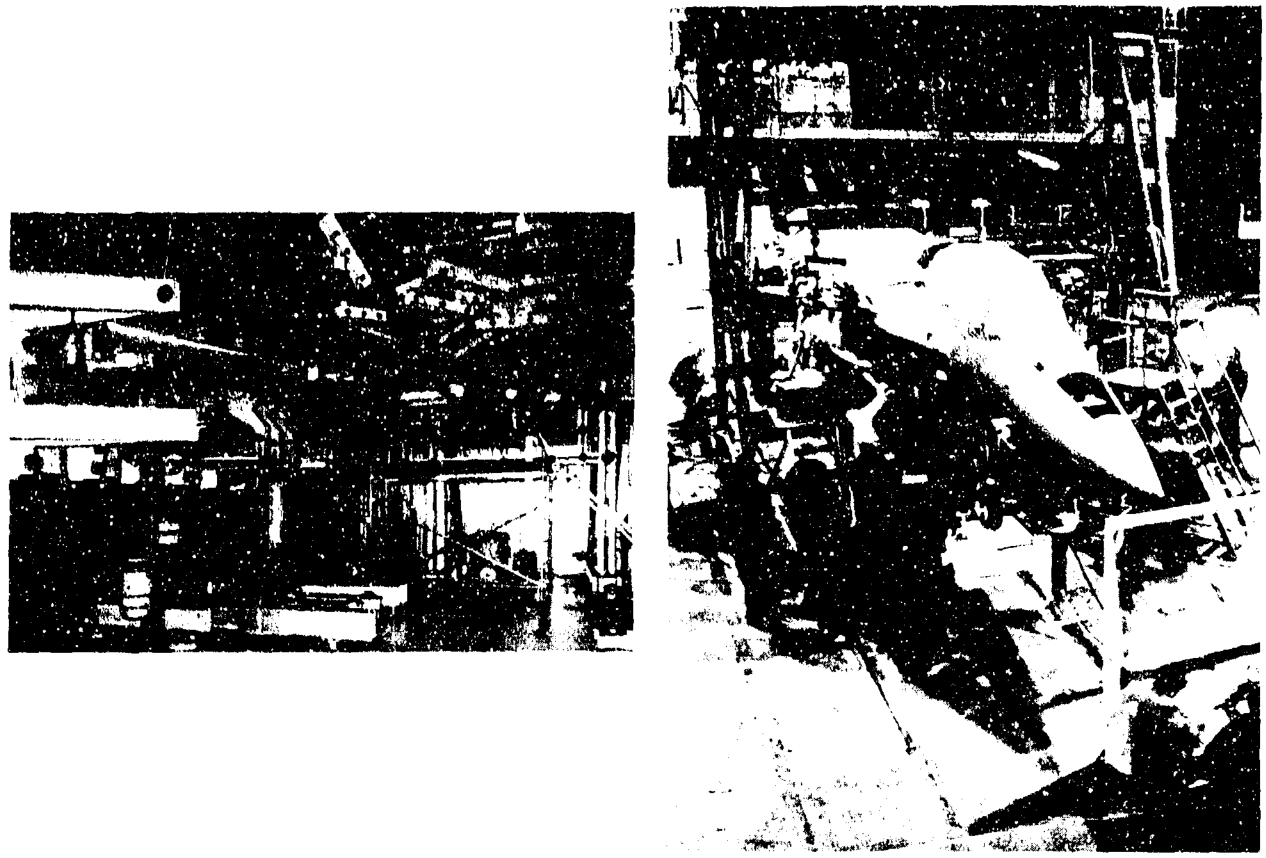


FIG. 38 - STRUCTURAL TESTS

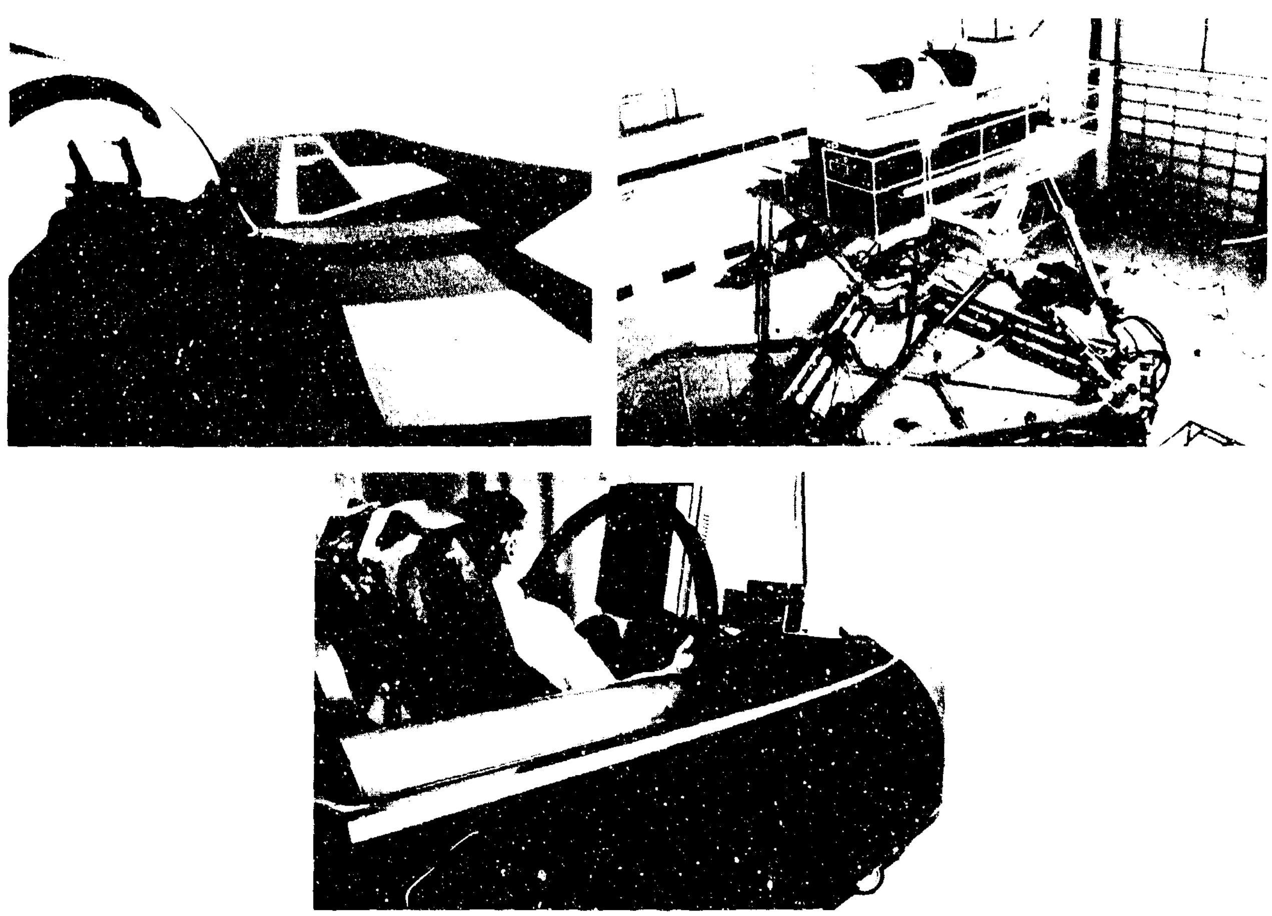


FIG. 39 - SIMULATORS

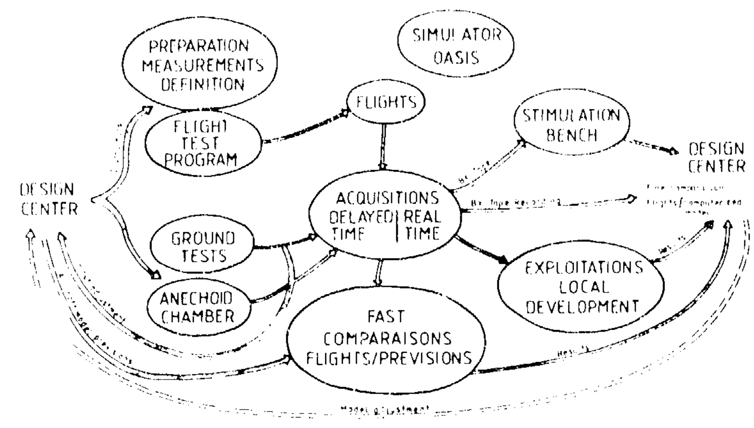


FIG. 40 - FLIGHT TEST ORGANIZATION

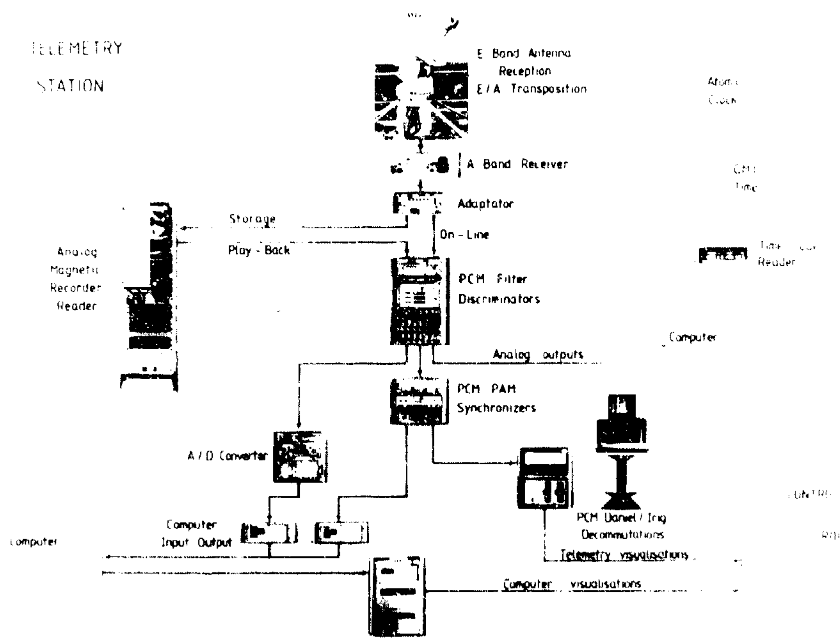


FIG. 41 - FLIGHT TEST SYSTEM

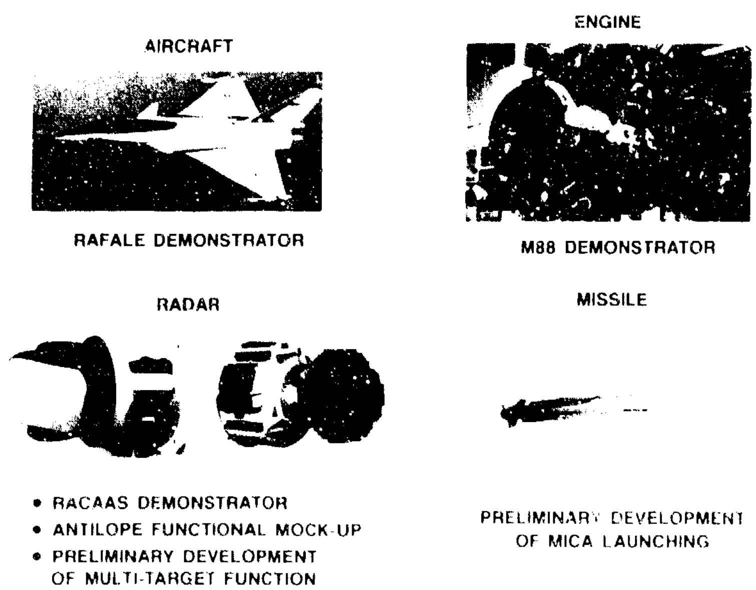


FIG. 42 - THE RAFALE PROGRAMME DEMONSTRATORS

FIG. 43 - RAFALE : AN ADVANCED TECHNOLOGY DEMONSTRATOR

- 1st FLIGHT : 4th JULY 86 - M 1.3 / 36000 FT
- M 1,8 AND LOAD FACTOR 8 g AT THE 5th FLIGHT — 17th JULY 86
- 98 FLIGHTS / 86 HOURS
- M 2 AT THE 93rd FLIGHT — 4th MARCH 87
- FLIGHT ENVELOPE EXPLORED : M 2 / 600 KTS / 47000 FT
- LOAD FACTORS SUSTAINED : + 9 g / — 2 g
- A o A : 31°
- APPROACH SPEED : 125 KTS
- MINIMUM SPEED : 100 KTS
- FULL DEFLECTION IN ROLL MANŒUVRE WITH RPU
- EXCELLENT AIR INTAKES BEHAVIOUR
- VERY GOOD JUDGMENT BY THE PILOTS ON THE NEW COCKPIT
- 8 PILOTS HAVE FLOWN THE AIRCRAFT
  - 3 FROM THE SOCIETE AMD-BA
  - 2 FROM FLIGHT TEST CENTRE
  - 2 FROM THE FRENCH AIR FORCE
  - 1 FROM NAVAL AERONAUTICS
- MAIN COMMENTS OF OFFICIAL PILOTS :
  - AFTER THE 11 th RAFALE FLIGHT (FIRST FLIGHT BEING DONE BY AN OFFICIAL PILOT) : "GENERALLY SPEAKING, ON THE ISSUE OF THE FIRST FLIGHTS ITS QUALITIES AND ON THE WHOLE ITS TECHNOLOGICAL INNOVATIONS GIVE THE IMPRESSION OF A VERY BRIGHT, OUTSTANDING AIRCRAFT"

    (FLIGHT TEST CENTRE)
  - THEN, FOLLOWING THE ASSESSMENTS BY OPERATIONAL PILOTS : "... POWERFUL AIRCRAFT, MODERN AND WELL SHAPED... EASY TO FLY... QUICK FAMILIARIZATION"

    (FRENCH AIR FORCE)

    "THE WORK THAT HAS BEEN DONE , SHOULD ALLOW TO DESIGN AN ACT/ACM OF FIRST COMPETITIVE CLASS. THERE IS NOT ANY DOUBT ABOUT THE POSSIBILITY OF THE "NAVALISATION" OF THE RAFALE

    (NAVAL AERONAUTICS)

FIG. 44 - RAFALE DEMONSTRATOR - FLIGHT TESTS RESULTS (MARCH 87)

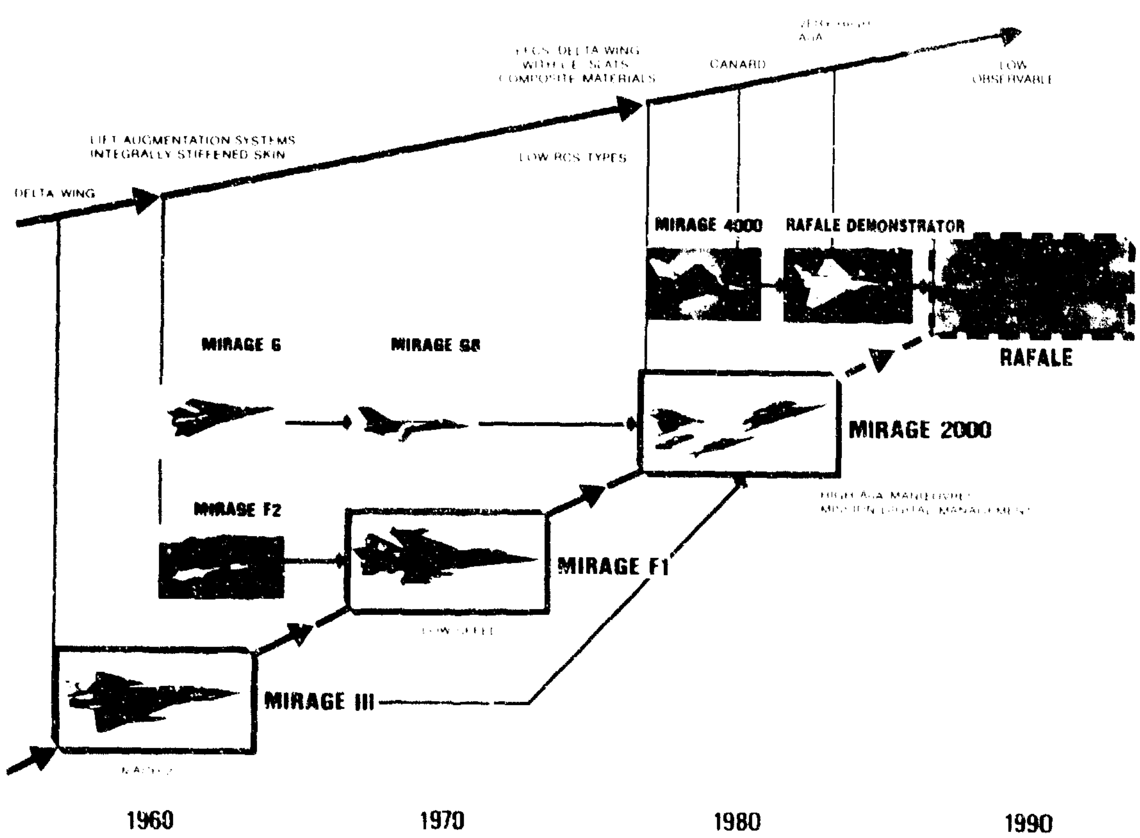


FIG. 45 - A FAMILY OF COMBAT AIRCRAFT