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CRITICAL ANALYSES AND LABORATORY RESEARCH WORK AT THE STAGE OF AIRCRAFT PRELIMINARY DESIGN

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16. Abstract Whenever a new project is initiated, government services must collect a number of technical data leading to choice of the design best suited to a given program. These evaluation factors are frequently requested both from research laboratories and from the manufacturer design office, years before the project is initiated. At the preliminary design stage, the design offices will rely simultaneously on experience gained with previous projects, sophisticated computations, results of the tests ordered from the laboratories, a well informed Documentation Center, and the intuitive faculties of the project officer. On the other hand, the research center must forecast the main trends of aeronautical techniques in due time, in order to provide the government services and the manufacturers with the maximum of information. But it should also possess a very short reponse time capability in order to satisfy urgent requests. This requirement calls for large resources, as far as specialized manpower and up-to-date laboratories are concerned. These objectives for research centers are described in the second part of this paper.

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PART I. CRITICAL ANALYSIS OF PRELIMINARY DESIGNS (C. Liévens) /5-2*

1.1. Introduction

The method used in France to conduct a military aircraft program, frequently termed the "prototype approach," generally consists of five fairly distinct successive phases (Fig. 1):

-- the exploratory studies, financed by the industry or by a government organization determining the amount of investment required, reveal feasibility criteria and provide the basic information for an eventual program report;

-- the preliminary design stage begins with the publication of this program report. This phase, which leads to estimated performances and costs, is completed with the submitting of detailed preliminary designs to the government services; these should confirm that the statements of industrial firms are realistic or at least conform to a reasonable optimum.

-- the preparation of a prototype contract occurs after selection of the preliminary design and generally includes the publication of a modified or more detailed program report. The most difficult point in negotiations between governmental organizations and industry is to reach an agreement on the margins

* Numbers in the margin indicate pagination in the foreign text.

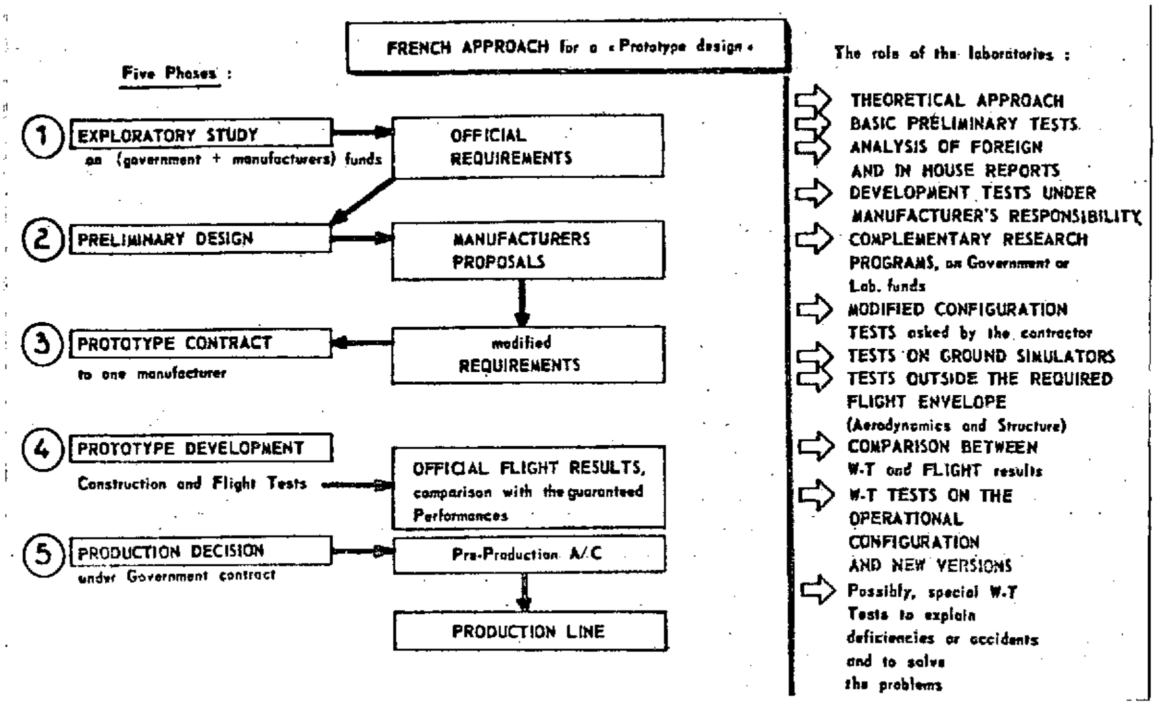

Fig. 1. "Prototype" approach for a military program in France.

permitting a change from estimated performances to guaranteed performances (more or less matched by financial penalties). This phase ends in notice of completion of the prototype contract.

-- the prototype phase consists of the manufacture and flight development of the prototype. It ends with acceptance on the advice of the pilots of the Flight Testing Center. It is during this phase that the basic aerodynamic options are finalized, primarily as a function of the guaranteed performances.

-- the production phase begins when the airplane has been ordered by the government.

Two characteristics of this approach should probably be emphasized: first, the government does not order a series of aircraft until a prototype has been evaluated; as a result, the prototype is generally not manufactured with production tooling.

This method, which is favorable from an overall cost standpoint, nevertheless has the drawback of increasing replacement time for aircraft of the preceding generation. Furthermore, the characteristics of the airplane have not been fixed at the preliminary design stage; unless there is some mandate imposed by manufacturing time, the choices are not final until the fourth phase.

To illustrate this distribution of choice over time, we will use the example of the Alphajet (Fig. 2). Since this was a training aircraft, one of the basic objectives was to obtain a preliminary design yielding a reasonable amount of spin. The spin tests were thus conducted very early, prior to the choice of one of the participating industrial firms. The design which was accepted at that time was not final, nevertheless: a clear possibility of further changes was allowed, on condition that they did not detract from the spin characteristics. Thus theoretical calculations, confirmed by wind tunnel tests, led to changes in the dihedral to modify the airfoils and cancel the spoilers. The fuselage and the wing box were settled somewhat later, just before the beginning of production. The leading edges and flaps were chosen still later; a replacement solution further improving the takeoff behavior of the aircraft still remains to be determined for the first phase of flight testing. Of course, this time distribution is closely linked to the length of the manufacturing cycles; in another program in which a titanium wing box might be used, this element would be fixed at the very beginning of the prototype phase.

Obviously, the existence of successive designs for the aircraft poses a problem of data management and requires extremely rigorous work on a computer. The degree of rigor required increases with the number of programs performed in cooperation, the contract holders and their plants being widely scattered geographically. Today it is of prime importance that there be a /5-3

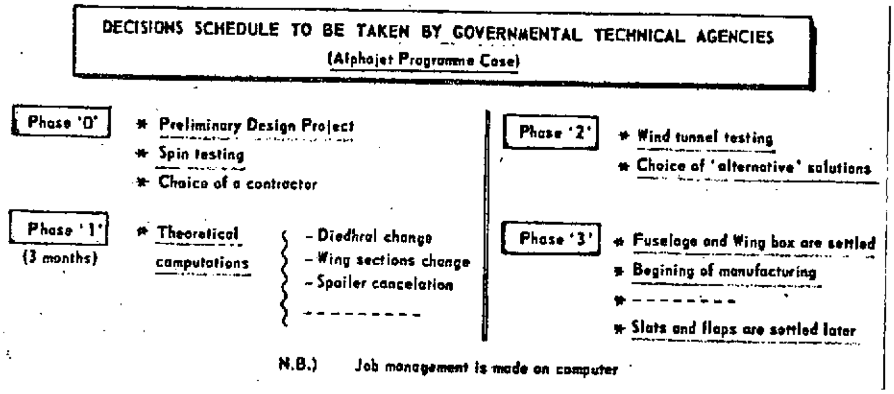

Fig. 2. Examples of distribution of choices over time for the Alphajet.

center for constantly updated data to be used by all the teams involved in the design and manufacture of the equipment.

Use of the French method has been facilitated by the relative lack of real competition in the area of military aircraft (a damaging factor in other respects). The industry is not tempted to choose excessively optimistic performances to eliminate competitive proposals. In the preliminary design stage, government agencies do not require that the designers define the most minute details of the aircraft. Documentation at this stage is not extremely plentiful, and the design of the aircraft may still evolve with considerable flexibility, depending on problems of design and manufacture, time factors, developmental costs and estimated risks.

In addition, the order of the various operations involved may not be clearly observed; this is especially the case with civilian aircraft, where the needs of the companies may not be translated into a simple program report as for military aviation, and where the prototypes may be constructed on production tools. Nevertheless, there are strong similarities between this exploratory and preliminary design stage and the launching of a civilian preliminary design project (STOL), as Fig. 3 shows.

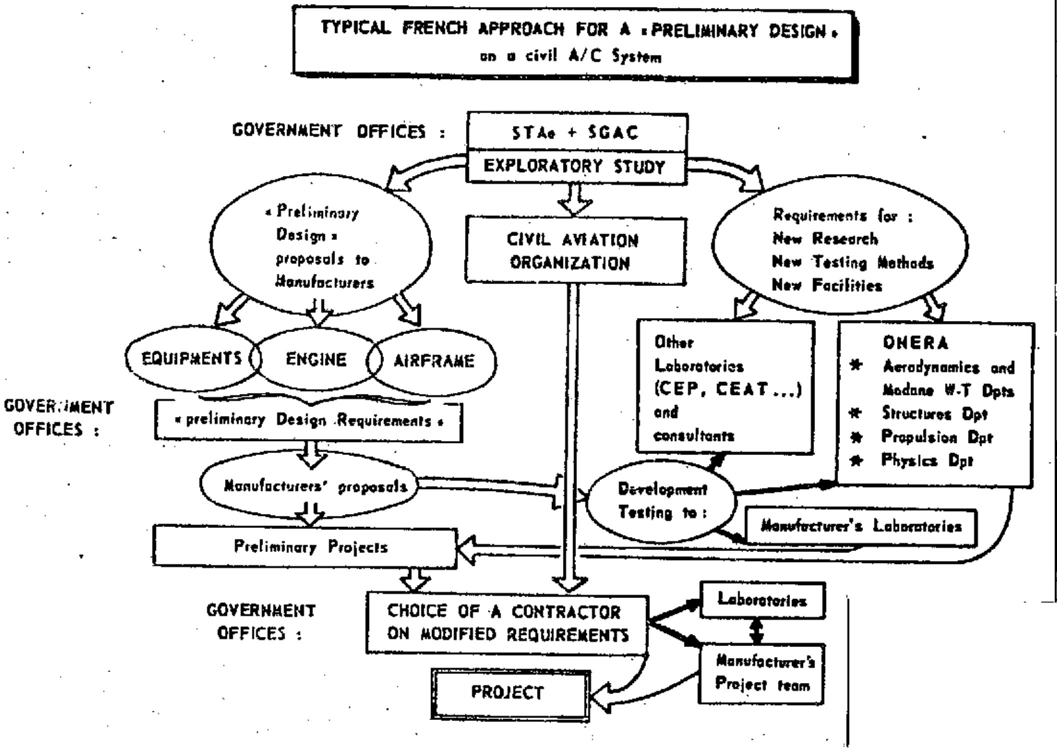

Fig. 3. Example of French approach to preliminary design study of an STOL civilian transport system.

It should be emphasized that for a totally new design formulas entailing high developmental risk, it is not desirable to enter directly into a sequence which will end in mass production. Here there should be an intermediate experimental model, an integral part of exploratory research. I would particularly like to emphasize the risks involved if the general staffs allow styles, passing whims or excessive enthusiasm to influence the statement of their needs, since this could lead to fatal errors. In an initial phase, the new formula -- like any type of research still in long-range perspective -- would be the object of moderate research whose yield would be inadequate to permit a convenient solution to reliability problems; at this point an overly enthusiastic general staff would immediately be pursuaded of the incomparable value of the new concept and would move on without hesitation to the preparation of a program report for an operating aircraft.

From that point, this unfortunate program would accumulate the problems encountered in any developmental process in addition to those of the new design, and under conditions not very favorable for reflection. The relative failure of the French vertical takeoff and landing program may be attributed to circumstances of this sort. Defining an experimental model is a difficult task, there- /5-4 fore, since if an aircraft with overrated operating characteristics will probably be doomed to failure, similarly, experimentation along clearly unrealistic lines would prove nothing: there would be no significant way to compare the advantages and drawbacks.

1.2. Critical Examination at the Preliminary Design Stage

We have now arrived at the stage where, on the basis of laboratory tests and in-house industrial studies, the preliminary designs are submitted to the government agencies (Fig. 4). Even with a relative lack of competition, critical technical analysis of these preliminary designs is an important procedure. The important thing is to determine whether the launching of a prototype phase entails excessive technical risk. It should be well understood that it would be absurd to try to answer for all the estimated performances: a project without any risk would produce an aircraft without any future. However, one should determine whether the risks are still reasonable; and our ability to make this evaluation will increase to the extent that we are less influenced by the state of the loading plans and the urgency of needs. In short, it is our function to give unambiguous technical information to the decision-making personnel, who are generally not technicians, and who must incorporate into their choice a large quantity of non-technical elements.

This task presents the twofold problem of evaluative criteria and analytical techniques.

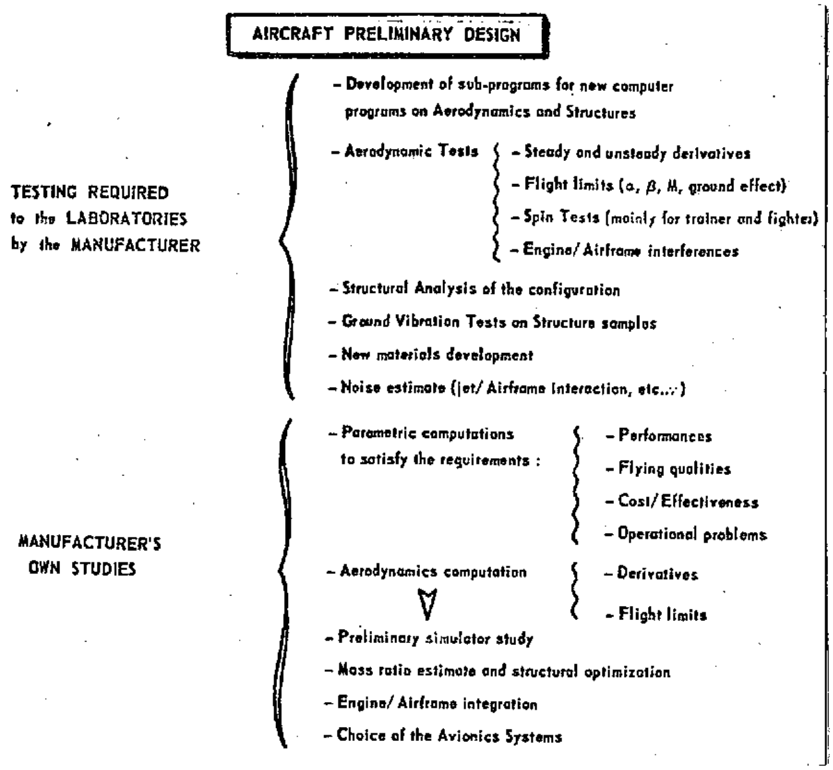

Fig. 4. Studies undertaken during the preliminary design stage.

1.2.1. Evaluative Criteria (see Fig. 5)

Satisfactory aerodynamic design is one obvious requirement; this, however, is not an end in itself. It is a function of the performances and flight qualities, which also depend on the available propulsion systems, the thrust and the specific consumption which may be expected, plus their potential for future development. The weight breakdown should be brought into play, and thus also the structural solutions adopted. It is increasingly necessary, from the preliminary design stages on, to take into account the control aid and stabilization systems, etc., initially used to correct defects in existing devices, but designed, with a view toward integration and use of the CCV principle, to replace traditional instruments for flight qualities analysis. Thus the performances and flight qualities of aircraft basically depend on the aerodynamics, the propulsion system, the structure, the weights and the systems, and these areas should consequently be examined in the preliminary design stage.

In regard to military aircraft, the performance criteria correspond to typical missions included in the program report. In this regard, critical anlysis of the preliminary design is based on studies of the sensitivity of the performances to "predictable or probable" variations in the aerodynamic and propulsive parameters. In the long run, flight qualities should be able to meet with the approval of Air Force and Flight Testing Center pilots; in the preliminary design stage, quantitative criteria close to those given in American standard MIL-F-8785 B are used; these criteria are only guidelines, however, without ever being set up as requirements. In regard to civilian aircraft, the performance criteria correspond to typical missions which are a more or less direct and more or less chance expression of the needs of potential clients; handling quality criteria correspond to the requirements of technical navigability conditions and the satisfaction of pilots from government agencies and the commercial firms using the aircraft.

However, no final decision may be made on the level of optimization of a preliminary design without reference to an operating cost criterion. In addition to performance data, this requires an initial analysis of reliability and maintenance aptitude, involving the cost of repairs and preventive maintenance operations. /5-5

Other elements come into play as restrictions: initially these are operating conditions, followed up by recent environmental problems: limitation of takeoff and approach noise, and, from a longer-range standpoint, limitation of the various forms of atmospheric pollution. All these limitations, whose future development is difficult to predict, will weight heavily on all future civilian -- and perhaps military -- aircraft projects.

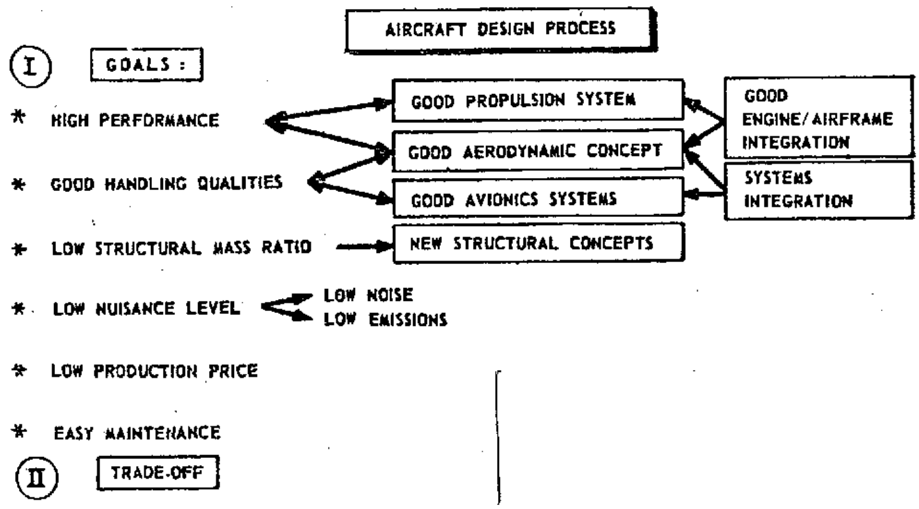

Fig. 5. Goals at launching of a project.

At any rate, the preliminary design appears to be a compromise among a number of criteria, resulting in the problem of coordination of all the teams involved. An initial method would consist in assigning a partial goal to the industry and to each team involved, along with the overall goals and all the limitations; this method would bring specialists into play at a very early stage. The French industry has preferred a second method: to decrease the role of specialists at the beginning, leaving the choice of large technical options to the project leader and his team. This requires, in industry, highly trained engineers with extensive knowledge of all aeronautical fields, and in government agencies, enlightened managing personnel.

Now that criteria and goals have been mentioned, the problem of their flexibility should now be emphasized. Let us take a few examples:

-- for a large-capacity commercial aircraft, the inability to perform a reference mission should not necessarily lead to automatic rejection. In practice, one of the most critical missions considered by a prospective client might not be performed under the best economic conditions; for example, one might take off from Mexico with one or two passengers less under unfavorable weather conditions. This might compromise a few controls without being fatal to the program as a whole;

-- let us now imagine that the Concorde is unable to make a trip from Paris to New York with the required payload: the program would probably be doomed. Fortunately, this eventuality is extremely improbable -- which is a miracle, incidentally, since the project began its developmental phase with medium range criteria;

-- the problem of noise may from now on introduce relatively severe limitations impairing a civilian program, and this problem is all the more difficult to take into consideration, since noise combatting is costly and there is hardly any way of knowing what level will be tolerated in 10 years. For example, an STOL program cannot be launched without entailing risk in this area, and this risk has a heavy influence on choice of the design and certain characteristics of the project. The takeoff noise of the Concorde is another striking example: today this is a problem, while when the prototype phase was first initiated, neither public opinion nor that of specialists had really been sensitized to it. Undoubtedly it was believed that landing fields could be constructed outside urban areas without attracting real estate promoters and a subsequent proliferation of homes and developments.

Evaluation of goal flexibility is an important phase in the work of government agencies in industry. If these goals are not flexible, it is important to set up margins which will be higher as the technical risks are greater, and which will draw the trade-off chosen away from the mathematical optimum.

1.2.2. Analytical Techniques

We have now arrived at the techniques used in critical analysis of preliminary designs. These techniques vary depending on whether they are defined on the basis of:

-- parametric analyses;
-- previous experience;
-- sophisticated computation;
-- test results;
-- or intuition (Fig. 6).

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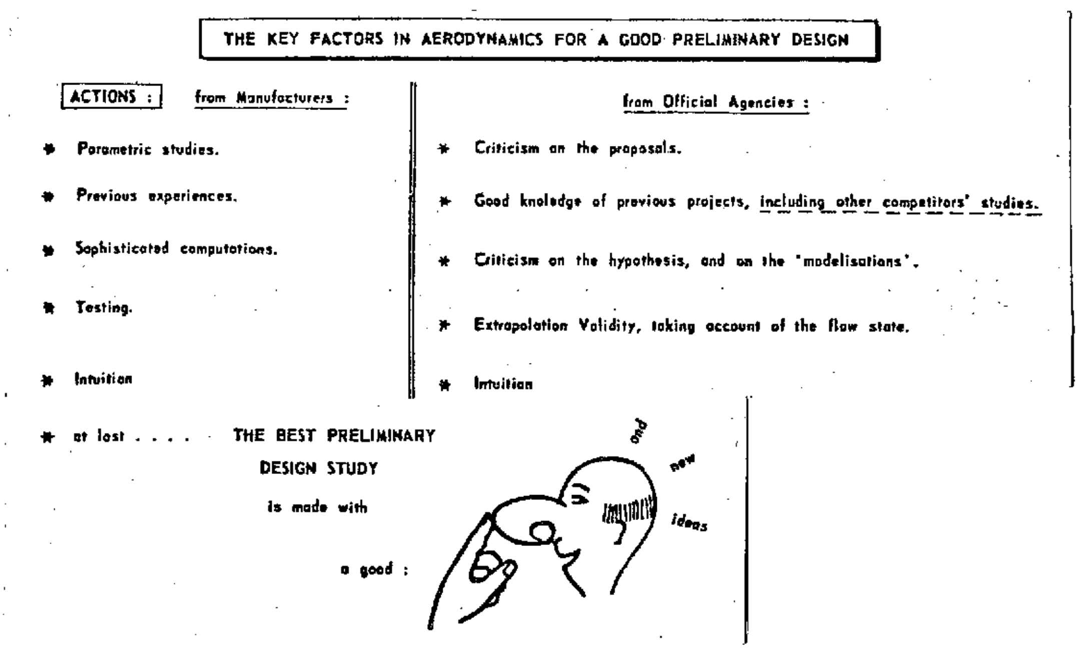

Fig. 6. Aerodynamic factors in a satisfactory preliminary design.

1.2.2.1. Parametric Studies

In an abstract sense, mathematical methods making use of a computer should be sufficient in themselves to permit complete optimization of a project on the basis of previously determined goals and limitations. Such studies (understood in this sense) generally have a fairly small audience in France, and seem to me to be dangerous (Fig. 7):

-- they are generally too sensitive; only slight changes in the assumptions, the basic missions or the weighing of criteria are necessary to produce completely different solutions. This fact has showed up very clearly in some presentations made to the AGARD conference on the V/STOL (Brussels, 1968);

-- there can be no purely mathematical solution for the choice of margins, taking technical risks and goal flexibility into account;

-- in the development of a program, there will be events which the project leader must be able to predict although no general mathematical formulation can be made;

-- finally, and most important, the assumptions underlying parametric studies are valid only within very limited ranges. There is every chance that the mathematical optimum will not fall within the marginal range of at least one of the assumptions and thus will not correspond to a realistic preliminary design.

Of course, criticisms applied to purely mathematical overall optimization by computer do not condemn design merely with the aid of the computer. The computer is an absolutely indispensable tool (see Section 1.2.3).

GLOBAL OPTIMIZATION THROUGH COMPUTER ALONE	CONCEPTION WITH PARTIAL USE OF COMPUTER
UNSUCCESSFULL	SUCCESSFULL
• Results too sensitive to input data. • No possible modelling of technical contingencies. • Experiments difficult to incorporate. • Assumptions valid only within a too confined area.	• Rigorous management and updating of projects characteristics. • Sophisticated computation required to master certain problems.

Fig. 7. Two approaches for parametric study.

Rather than perform mathematical studies, we prefer to scan prospective areas by drawing up several preliminary designs, evaluating them separately and comparing the results. One might take as an example the optimization of the wing area of a combat aircraft of given aerodynamic design (horizontal wings and stabilizers fixed as to shape and relative position, with the exception of one similarity factor). Although this problem is a simple one from a design standpoint, it cannot be studied mathematically: given the general structure of the aircraft, the amount of fuel, the attachment of external loads, etc., it can quickly be seen that the same aerodynamic design cannot be used due to the scale effect. It is therefore necessary to make several preliminary designs within the range of possible surface areas.

For a government agency engineer, therefore, critical analysis of parametric studies consists in the study of several preliminary designs.

1.2.2.2. Preliminary Experimentation

Insofar as possible, we try to progress by small steps. Certainly a degree of imagination is necessary to make up a preliminary design, but this should be concentrated on essential factors. We do not believe in the success of a program based on a multiplicity of clever gadgets which are difficult to develop and rely on poorly known techniques.

I feel that the success of French military aeronautics is related to the fact that each type of aircraft benefits directly from the experience gained by its predecessors. Take a look at Fig. 8: all four aircraft, although quite different from an aerodynamic standpoint -- one has delta wings, another swept-back wings, one variable shape and one VTOL -- basically resemble each other. The air intakes are appreciably the same. Prior to these variable shape designs, there had been the Mirage F2, and there was little change in the position of the horizontal stabilizer. All the aircraft which have followed those shown here -- the Mirage F1, the Mirage G8, preliminary designs for future combat aircraft -- are direct descendants of one or another of these four models. Furthermore, the fact that the same team responsible for advanced studies at Marcel-Dassault Aircraft had followed at least a dozen prototypes from the exploratory research to flight development over the last 10 years constitutes an extremely valuable experiential resource. /5-7

To make a critical analysis of preliminary designs, therefore, government agency engineers should have thorough knowledge of previous programs and the problems encountered to the point of flight development. When there is competition between several firms at the preliminary design stage, the government agencies will also benefit from information on preliminary designs put out by different firms, making it easier to reveal the critical points of each of these designs. Just as a relative lack of competition allows for greater flexibility in distributing technical choices, in the same way it is prejudicial at the critical analysis stage. Nevertheless we have been able to benefit from a competition situation over the last 5 years:

-- in defining the characteristics of the training aircraft which has become the French-German Alphajet;

-- in the STOL preliminary designs ordered by the SGAC [Secrétariat Général de l'Aviation Civile; General Civilian Aviation Administration].

Other important projects (Concorde, Airbus) have also involved competition among industrial firms.

* M = 2.2 multimissions
* All concepts tailored for LO-LO-300 nM radius mission

Ref. H. DEPLANTE, J. Roy. Aero. Soc., May 1967

WEIGHT				
Empty weight (+ pilot)	7.9 T	8.8 T	9 T	10.8 T
Fuel	3.5	3.7	3.6	5.2
Military load (bomb, munitions)	1.5	1.5	1.5	1.5
Take-off weight	12.9 T	14.0 T	14.1 T	17.5 T
CHARACTERISTICS				
Wing area (reference)	37 m²	25 m²	21 m²	40 m²
Wetted area	125 m²	130 m²	130 m²	165 m²
Wing loading W/S	350	560	670	440
Thrust to weight ratio	0.80	0.74	0.73	0.59
MISSION 1: LO LO PENETRATION				
Radius (nautical miles)	300	300	300	300
Gust sensitivity at 600 kts	2.8	2.4	1.4	2.1
Manoeuvrability at 300 kts	4 g	3 g	3 g (wing unswept)	3 g
MISSION 2: INTERCEPTION				
Climb time to M = 2.2 at 50000 ft	4.5 mn	4.8 mn	3.6 mn	10.7 mn
Pursuit time to M = 2.2 at 50000 ft	7.2 mn	5.7 mn	9.1 mn	3.3 mn
Cap-time to M = 2.2 at 50000 ft	1.5	1.2	2.7	0.7
TAKE OFF and LANDING				
Take-off roll	750 m	700 m	500 m	0
Lenght to clear 50 ft	1250 m	1100 m	800 m	0
Approach speed	180 kts	150 kts	125 kts	
Touch-down speed	150 kts	125 kts	105 kts	0

Fig. 8. Four designs for combat aircraft adapted to low-altitude penetration missions toward a target at x = 300 nM, with the same cruising engine (TF-306, T = 10.4 tons payload). Four Dassault "Mirage" combat A/C.

1.2.2.3. Sophisticated Methods of Computation

In the following discussion, in order to make use of concrete cases, I will cite a few examples taken from the field of aerodynamics. It is clear that other disciplines offer similar situations. Traditional methods of aircraft design, which were fairly solidly established 10 or 15 years ago, have since been shattered by several events:

-- the necessity of increasing the cruising Mach number of aircraft flying in the high subsonic range has led to the abandonment of traditional profiles. Whether a "plateau" speed distribution is produced, resulting in Mach numbers slightly higher than one over a large part of the chord, or whether one develops a supersonic region followed by recompression without impact or with an impact of relatively low intensity so that no separation is introduced, in both cases the work can be performed only with the use of sophisticated methods. This is also beginning to be the case for other aerodynamic problems (optimization of lift devices, for example);

-- the attainment of high subsonic speeds makes it impossible to handle interference problems ultimately, after partial optimization of the different elements of the aircraft. Furthermore, rough approximations of the "area rule" type can no longer be considered sufficient. The methods of computation should refer to a basis of data taking the entire aircraft into account, with all the problems involved in storing the data necessary for a correct representation of the aircraft in its various configurations, lift or otherwise. There would also be the necessity of eliminating aeroelastic deformation, but it should be recognized that there is still little known about this area;

-- the amount of wind tunnel tests performed on aircraft of recent generations has constantly increased. The cost of these tests is increased by their technical difficulty, the accuracy demanded of the results, and the more acute nature of the problems inherent in new designs; this cost inflation has been further increased by the use of questionable and much-debated bookkeeping methods which on the national level are far from optimum. In addition, the number and quality of the wind tunnels available is not increasing in proportion to needs. From now on it will be necessary to limit the number of solutions to be tested in wind tunnels and to decrease flight development. and thus to arrive quickly at nearly optimum solutions. The purpose of calculation is to enable us to take this step satisfactorily.

Naturally it is not possible here to describe in detail the elements involved in large computational programs. Again taking the example of aerodynamics, in my opinion the methods used may be divided into three groups (Fig. 9): /5-8

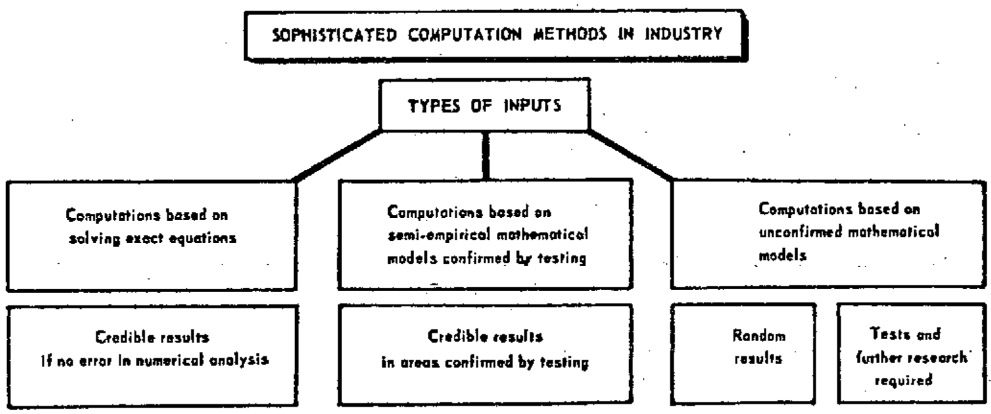

Fig. 9. Sophisticated computation methods used in industry.

-- some are very pure from a theoretical standpoint and consist in solving fluid mechanics equations; ultimately this is a problem of numerical analysis;

-- others, given the impossibility of theoretical or practical rigor, rely on semiempirical data which have however been confirmed by a number of available tests;

-- others, finally, in the absence of sufficient theoretical or experimental data, rely for lack of any other alternative on rough modeling which is valid on an initial approximation.

Clearly, given their semiempirical nature, which is more efficient than rigorous, and the complexity of introducing the geometrical characteristics of the different configurations, such computation programs typically contribute an industrial tool. I will now define what the roles of government agencies and research laboratories should be under these conditions.

It is inconceivable that the specialists responsible for critical analysis of preliminary designs in government agencies. would develop sophisticated computation methods competitive with those of industry. Naturally they must have "returns" and check-points to detect possible gross errors in the aerodynamic data, and the most solid basis will usually consist in a knowledge of previous projects. Most importantly, however, government engineers should always be precisely informed as to the state of industrial computation programs, which phenomena have been appropriately modeled (taking experimental checking into account), which have furnished convincing results, and which phenomena are poorly understood, allowing only unreliable modeling. They should be able to evaluate the impact of these uncertainties on the performances of the project. It should be noted that the dialogue with industry will be more open and the efficiency of the government agencies will be higher if these engineers have an active say in outlining the research programs. They can use their knowledge in areas where industry has fallen short to see that these needs are given consideration.

It seems to me that the role of research laboratories has undergone a mutation over the last 10 years. The second part of this discussion will show that the complete designs of super-sonic transport aircraft had undergone wind tunnel testing prior to initiation of the Concorde program, at the instigation of the ONERA [Office National d'Études et de Recherche Aérospatiales; National Office of Aerospace Study and Research]. In defining future aircraft, it does not seem very likely to me that this office will study complete configurations prior to their study by industry. Furthermore, I feel that this is a good thing, since the function of this agency now lies elsewhere. A large number of aerodynamic phenomena are still poorly modeled due to a lack of adequate basic knowledge: shock wave/boundary layer interaction, airstream separation, turbulent mixing, etc. give rise to extremely rough modeling which entrains too high a risk in predicting the behavior of aircraft in the course of development or in the preliminary design stage. It is the responsibility of research laboratories to perform basic "simple and clean" tests, to collect and store all data of any importance, and to take the initiative in determining appropriate modeling. On the other hand, attempting to develop computation methods which are already operational in the industry and yielding credible results and insisting on making up for one delay or another year after year is one of the best ways for a research organization to waste its budget. The classical distinction between the short-term goals of industry and the long-term goals of research is becoming obsolete. What is required of research organizations today is, first of all, to furnish information and schematic outlines of poorly understood basic phenomena which are introducing too many unknowns into programs currently in progress and may do the same to future programs.

Having completed this digression on the role of the laboratory, we will now return to the main subject.

1.2.2.4. Test Results

The introduction of airflow computation methods did not eliminate the importance of the wind tunnel. A great deal has been said about the necessity of developing test methods at high Reynolds numbers to permit a direct transposition to flight conditions. It is true, for example, that if one converts from a maximum lift coefficient measured in a wind tunnel (at a low

Reynolds number) to the estimated flight value by applying a cancellation differential, there is a risk that serious disappointments will result (cf. Specialist's Meeting AGARD/FDP, Lisbon, 1972). It may be that in one case there is double separation at the leading edge, and in another, trailing edge separation on the last flap. These two types of flow are so different that it is impossible to change from one to the other by a mere overall correction.

I feel that the best approach is to combine tests and computations as shown in Fig. 10. Taking the types of flow into account, a computer is used to evaluate the significant aerodynamic coefficient at the flight Reynolds number and at the wind tunnel Reynolds numbers. The latter are compared with the wind tunnel /5-9
results, and a given configuration is considered unusable unless all the differences have been explained and the computation models modified as a result. Consequently the configuration tested in the wind tunnel and earlier optimized by computation must be satisfactory at both the flight and wind tunnel Reynolds numbers. I am unable to say whether this twofold optimization is always possible; however, we have been involved in two cases of establishing lift device design at low speeds for two very different types of aircraft (one transport, and the other combat) and in both cases the twofold optimization was possible, after a fairly long period of trial and error.

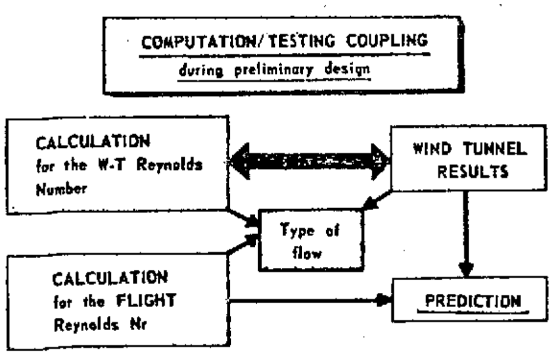

Fig. 10. Computation/test coupling during preliminary design.

Any attempt at flight-wind tunnel extrapolation should thus take into account the types of flow at different Mach numbers and should ultimately be based on sophisticated computation methods. Some problems in recent French aircraft which were discovered in flight and which resulted in costly errors or correction procedures were already showing up in the wind tunnel test results. In several cases, the specialists involved were too overwhelmed by the mass of results to get down to the significant areas; in others, the aerodynamicists had hastily decided that "everything would get straightened out with the Reynolds number." The solution for the role of specialists in government organizations is theoretically simple: they should make sure that the significant phenomena have been tested in the wind tunnel, check to see that all abnormalities detected in flight testing have been reasonably explained, and should not accept the transposition to a flight Reynolds number until the types of flow have been analyzed -- in cases of any conflict, with the use of credible computation methods.

I would like to cite two more important results of what has just been said:

-- there is no "magic" Reynolds number beyond which an immediate transposition to flight conditions is possible and where the specialist may assume a priori that he will not have to think;

-- one must be able to model the aerodynamic phenomena over a large range of Reynolds numbers; as a result it is important to qualify the computation methods by basic tests and fine flow studies performed with high Reynolds numbers in wind tunnels and in flight.

1.2.2.5. Finally, in addition to what has just been stated, a considerable role is played by intuition. A satisfactory project head and effective criticism from the government organization should both have a sufficient dose of this faculty; however, this can hardly be described within the limits of this discussion.

1.2.2.6. Illustration by Example

I will limit myself to one example describing our approach to an external aerodynamic problem in the case of our future combat aircraft ("B" aircraft). Without prejudging the solution which will finally be used, it can be stated that this aircraft will probably be derived from the Mirage G8 ("A" aircraft). The following approach will be used for all problems in external aerodynamics (Fig. 11):

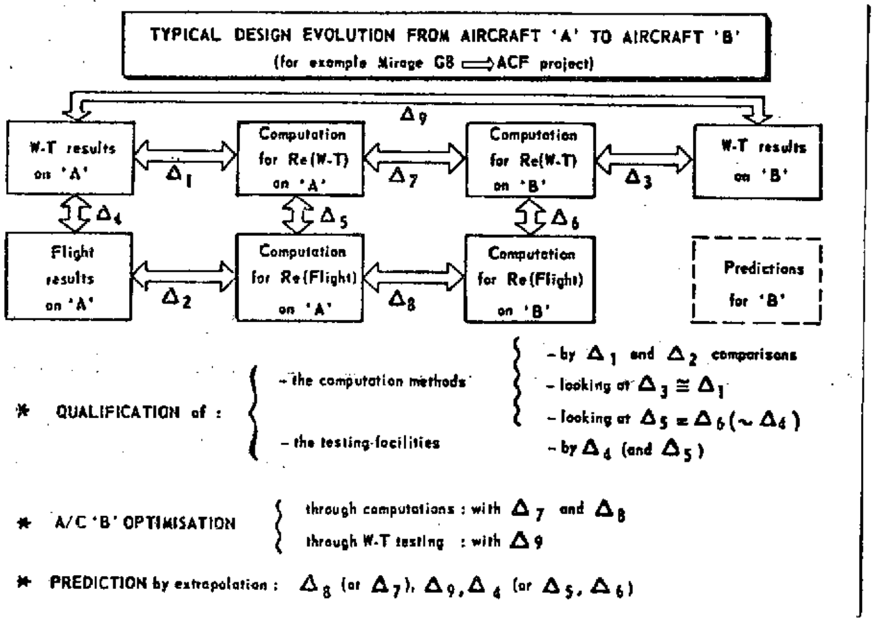

Fig. 11. Use of the experience gained in a previous project.

-- qualification of computation methods: /5-10

comparison of computations and wind tunnel tests for A and B;

comparison of computations and flights tests for A;

-- qualification of test methods:

comparison of wind tunnel and flight tests for A (based on the results of computation);

-- optimization of B aircraft:
twofold optimization by computation (flight Reynolds -- wind tunnel Reynolds);

-- prediction of aerodynamic coefficients of B:
application of different variations from the results of: flight tests of A, computations (flight Reynolds) for B, and wind tunnel results for B.

Our attention has been drawn to the problem of flow in transonic flight (especially in regard to the leading edges); not that the results obtained with previous aircraft were poor in this area, but because available methods of investigation appear inadequate. Action is being taken on two fronts:

-- research: testing of a large wing with slotted leading edge (Modane S1 wind tunnel); fine analysis of the flow within the slots and behind the leading edges; determination of a model;

-- development: the basic model for the B aircraft (on a scale of 1:19) is designed for the Modane S2 wind tunnel (1.70 m x x 1.70 m; pressurized at 2.5 bars). The corresponding size makes it possible to study leading edges without slots, without, however, abandoning the possibility of fine flow analysis. A model of the A aircraft with the same dimensions was built for the S2 and a comparison between S2 and flight tests will make it possible to qualify this test method;

Since it is not possible to construct slotted leading edges with a model of this size, we intend to build another model on a scale of 1:8, designed for the Modane S1 wind tunnel (8 m in diameter, non-pressurized). A comparison of the 1:19 model in the S2 and the 1:8 model in the S1 at the same Reynolds number will make it possible to qualify this second assembly;

Finally, it will not be possible to make a fine analysis of the flow in the slots over the entire wing span with the 1:8 model. We therefore intend to construct a 1:4 wing for the S1; the validity of this assembly will be tested by comparison with the results from the 1:8 model.

In conclusion, this "cascade" qualification of test methods seems to me to provide an illustration of a policy deliberately oriented toward the minimization of risks and a maximum utilization of the results gained in the previous program.

1.2.3. A Look at Organization

The critical analysis of a preliminary design is performed at the Aeronautics Technical Agency under the direction of an engineer responsible for the entire evaluation (including costs). This engineer-in-charge relies on two or three crews, the most important of which, consisting of five engineers, deals with problems of aerodynamics, weight, performance, handling qualities and reliability. Similarly, these five engineers are in turn responsible, within their own areas, for the following:

-- to monitor the development of civilian and military programs in progress;

-- to participate in the choice of research operations;

-- to monitor the development of studies being performed and methods being used in industry.

In my opinion this situation offers heavy advantages, since it allows the engineers responsible for the analysis of preliminary designs:

-- to obtain thorough knowledge of previous programs;

-- to bend the research toward the needs of industry;

-- to know what confidence level may be assigned to the prediction methods used by industry.

Finally, the limited size of this team keeps it from attempting to conduct research by itself which should be performed by industry, and tends to keep it concentrated on the basics of its assignment.

All these elements seem to me to be very helpful to the quality of critical analysis in the preliminary design stage.

PART II. THE ROLE OF THE LABORATORY IN THE PRELIMINARY DESIGN STAGE (P. Poisson-Quinton)

2.1. Introduction

In the first part of this discussion, certain functions of the laboratory were mentioned in several instances:

-- highly specific basic research indispensable to the more correct modeling of poorly understood phenomena, especially in the areas of aerodynamics and aeroelasticity (this is just as true for batteries as it is for turbo machines);

-- specialized tests performed with maximum speed and accuracy at the request of the designers.

Actually, although this twofold function is absolutely necessary, I feel that it is not sufficient, especially when the design being studied is not a relatively conventional preliminary design based on a certain amount of continuity of the "state of the art," but rather a competely new design requiring a /5-11 "technical leap." The most "vital" part of the Research Center must prepare for the future by its exploratory research toward long-term prospective programs initiated by the government agencies. This small group responsible for bringing up innovations and qualifying them by tentative probing may represent only a small proportion of the total work force -- less than 5%, for example -- but it should be given considerable freedom of movement and logistical support by the Research Center (access to general computational and test means, with their specialized personnel). A little later on I will give a few examples of this type of exploratory research conducted by ONERA over the last few years. It is easy to foresee several "technological leaps" in the new generations of aircraft during the next few years, which will deal, for example, with the use of new active control systems (C.C.V.) and new supercritical profiles. The role of the laboratory appears to be especially important prior to and during the development of these concepts.

This is why the role of the Research Center appears to be important in the preliminary design stage, especially when new concepts are involved; this will occur in the following three phases (Fig. 12):

-- prior to the initiation of a preliminary design request by a governmental organization, the research center is particularly well suited to participate in a "state of the art" synthesis on the proposed concepts, to furnish some elements of choice on the basis of theoretical or semiempirical studies, and finally to initiate preliminary tests (tentative probing) to confirm or deny the value of the designs considered;

-- when the contractors for the preliminary design have been chosen, the primary function of the laboratory is to meet the requests of the designers as quickly as possible, whether they involve theoretical computations or specific tests;

-- finally, at the end of the preliminary design study, the government organizations will frequently find it necessary to give a new orientation to their Research Programs, either to have the laboratory supply more in-depth knowledge of the weak points revealed by the study, or to have them develop new test methods to be ready for service as soon as a new major project is initiated. The latter point is especially important for the Research Center, since it ensures its future usefulness and efficiency.

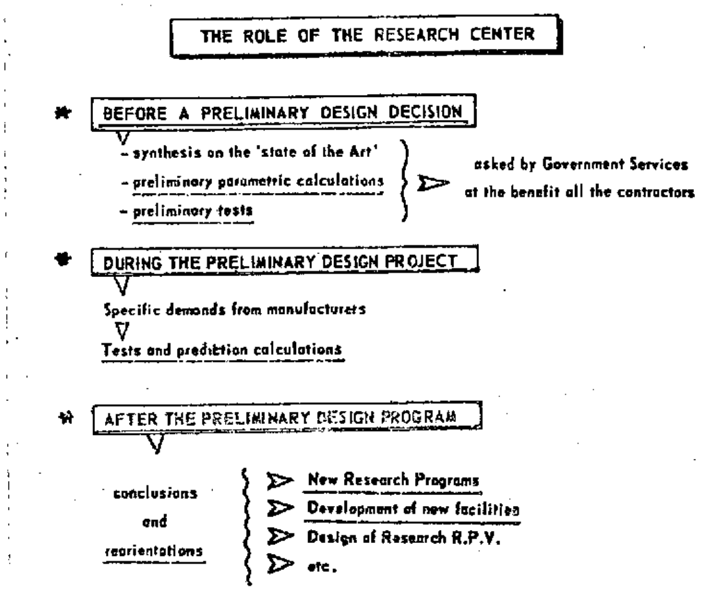

Fig. 12. The role of the Research Center in preliminary design.

The Research Center should by definition be technically in advance of the designer responsible for a preliminary design. This is the first problem, since it must be able to predict in due time, that is, at least 5 years in advance, what the needs of the designer as to test methods will be. (At least 5 years are required to develop a new wind tunnel, for example.) The center must be able continually to reorient long-term plans to allow for rapid developments in the field of aeronautics and the needs of both the civilian and military sectors.

Actually, researchers should be able to adapt very quickly to new trends, ranging, for example, from the vertical flight problem of a VTOL to that of the heating of a structure in hypersonic flight, including the optimum adaptation of wing shape in transonic flight. In all three cases, it must be able to prepare test methods which are often highly specialized and costly and whose cost schedule is often extremely difficult to predict. Beginning a new installation always involves a certain amount of risk, therefore; sometimes it will be used for tests which were not predicted originally (for example, a large part of the activity of the Modane S1 currently consists of low speed tests, while this wind tunnel was primarily designed for tests in the high subsonic range). Frequently, future needs will show up during a preliminary design study; one example of this occurred during our recent prospective study on the civilian transport STOL's requested of designers by the French Government Services (Fig. 13). This preliminary design study clearly revealed current gaps in our methods of investigation dealing with the noise of STOL aircraft and the analysis of their handling qualities with correct simulation of the environment (ground effect, gusts, ascent and approach speeds, etc.). To meet these needs in a reasonable period of time, ONERA has initiated two important new test methods thanks to the financial support of the Commercial Aviation Administration (S.G.A.C.):

-- a highly sophisticated assembly (Figs. 14 and 15) for the study of handling qualities, making use of the large size of the Modane S1 wind tunnel; /5-12

-- an anechoic tunnel (Figs. 16 and 17) for the study of overhead engine noise, rather than merely the noise emitted at a fixed point, by means of tests on the noise propagation around motorized models or propulsion systems.

Simultaneously, specific problems related to the STOL characteristics are examined in flight and on a simulator (at the CEV and at Ames) with the use of an operational Air Force Bréguet 941.

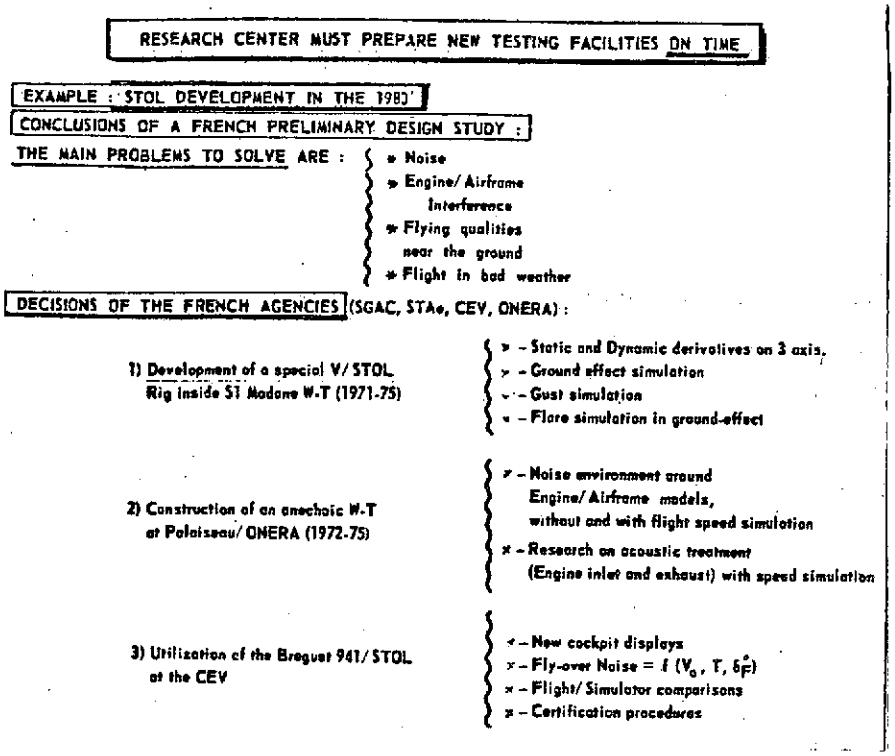

Fig. 13. Planning of new test methods following a preliminary design study.

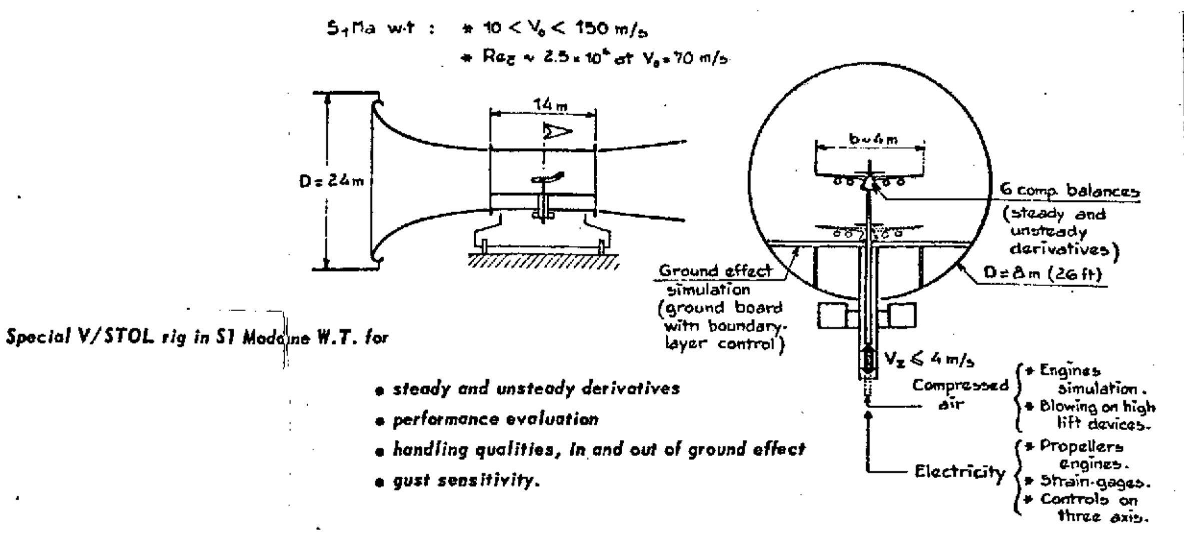

Fig. 14. Rig for study of handling qualitities in the Modane S1 wind tunnel.

Let us now try to reconstruct the desirable relationship /5-13 between the laboratory and the manufacturer in the preliminary design stage. First it should be emphasized (Fig. 18) that

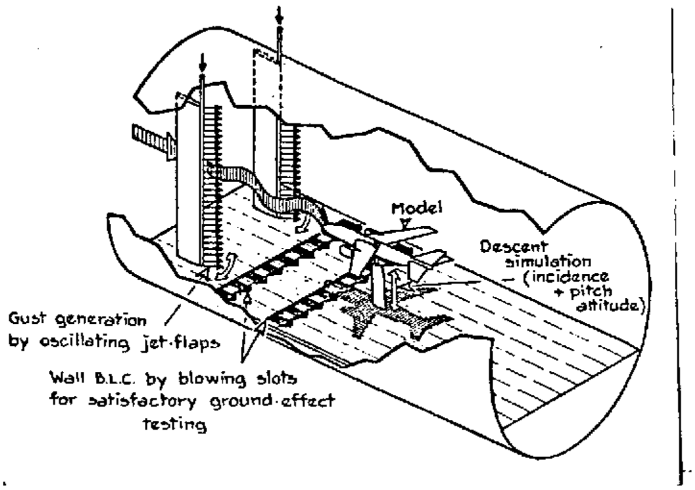

Fig. 15. Simulation of transverse gusts during approach in ground effect at the S1 Modane wind tunnel.

the initiation of a preliminary design project is an essential motivation for the researcher permitting him to:

-- meet with the manufacturers and "speak their language."

-- determine what problems must be solved on a short-term basis;

-- develop new theoretical approaches and new testing techniques;

-- finally, learn to work <u>fast</u>.

This is also the occasion for the manufacturer preliminary design group to:

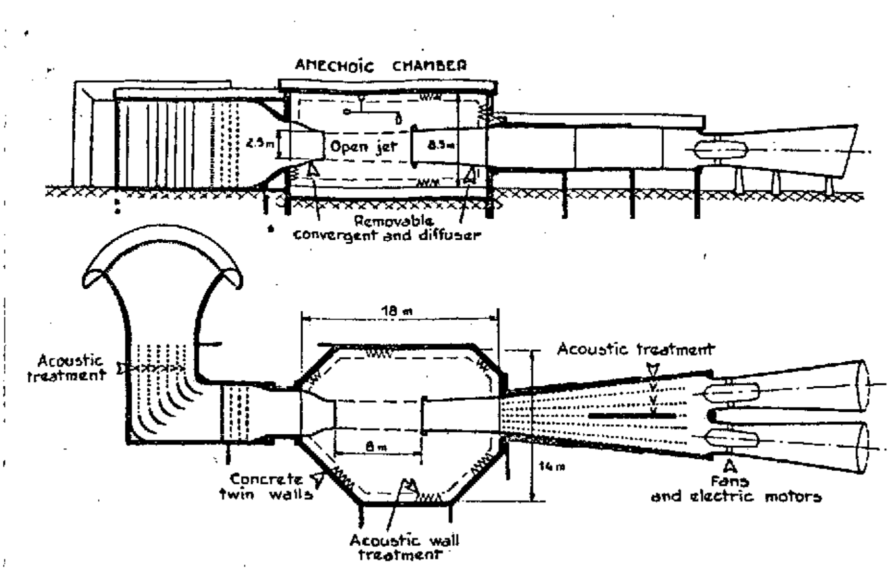

Fig. 16. ONERA Palaiseau Project of an anechoic chamber with integrated open tunnel (Smax = 10 m², Vomax = 55 m/sec).

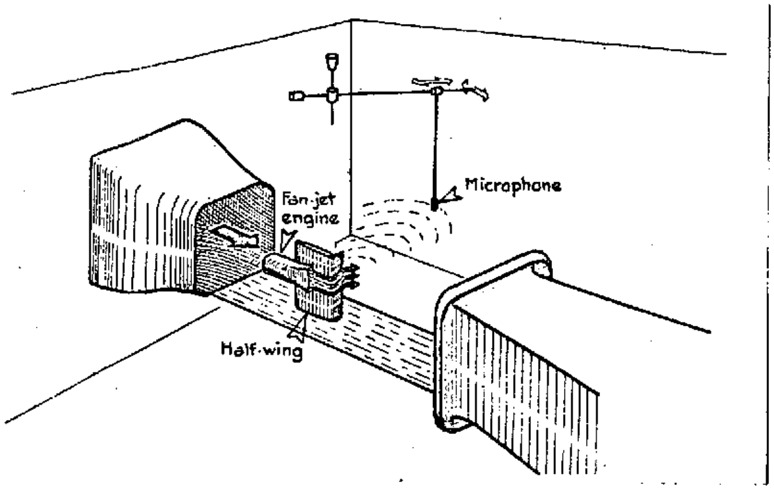

Fig. 17. Study of flight noise on a motorized model in the free jet of the anechoic tunnel.

-- meet with the researchers in their laboratories;

-- convince them to begin work on their projects immediately;

-- discover new ideas and attempt to apply them.

-- finally, encourage the development of new research methods which they will be the first to benefit from.

The function of the government agencies, finally, is to coordinate and distribute the tasks between the manufacturer and the laboratory. In the initial stage of the project, the Research Center frequently makes a large contribution to the synthesis of available technical information: a satisfactory information service and knowledge of the essential reports at the specialist level are basic to an efficient Research Center.

IMPACT OF A PRELIMINARY DESIGN POLICY ON THE RESEARCH CENTER EFFICIENCY :

1) For Governmental RESEARCHERS, it is the best MOTIVATION :
* TO MEET MANUFACTURERS,
* TO KNOW THE SHORT TERM PROBLEMS,
* TO DEVELOPP NEW THEORETICAL APPROACH AND NEW TESTING TECHNIQUES,
* TO WORK QUICKLY

2) For the MANUFACTURERS, it is the best OPPORTUNITY :
* TO MEET LAB'S PEOPLE,
* TO CONVINCE them to work on their short-term project,
* TO look at NEW IDEAS and apply them,
* TO PUSH NEW RESEARCH CAPABILITIES

Fig. 18. Impact of a preliminary design policy on Research Center efficiency.

The second phase is the joint preparation of tests indispensable in the preliminary design stage (Fig. 19). The main factors involved in the choice of tests are perhaps, first, the speed of execution and the costs, and second, the testing conditions offered (Reynolds and Mach numbers, type of model and dimensions). /5-14

At this stage, the manufacturer frequently has only a very small budget (Fig. 20), and he has a tendency to economize on tests, especially if the response time for obtaining access to the results is too long. Here we should emphasize the value of fast data processing permitting the manufacturer to monitor the tests virtually in real time and to modify the program at his convenience.

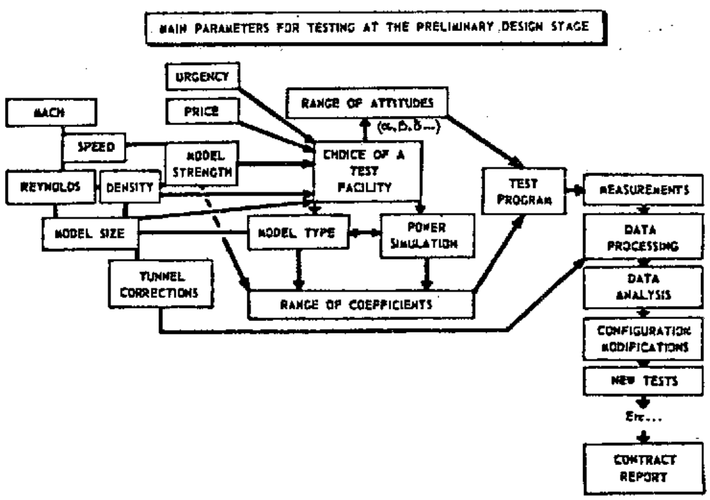

Fig. 19. Parameters of choice for test methods at the preliminary design stage.

As the shape of the project becomes more defined, the manufacturer will tend to require greater accuracy from the test results, making it necessary to continue the study on larger and more sophisticated models.

From the very first tests, it is of prime importance to examine a wide range of model attitudes (incidence, yawing, etc.), which should be far beyond the predicted flight values, especially if the project is based on a new concept. A typical example we have been involved with is that of a VTOL aircraft (Fig. 21) with very strong aerodynamic interference between the airframe and the

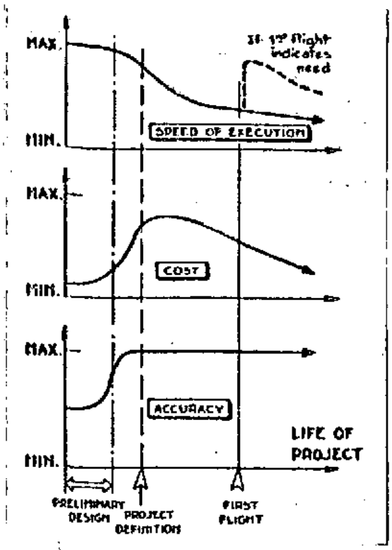

Fig. 20. Relative desirability of test attributes (after C. Russel, BAC/UK).

lift jets. At the time when this research was performed, these problems did not show up clearly in the course of fairly rough preliminary testing; in fact, after a flight accident involving the experimental prototype, it was possible to explain the accident by extremely detailed studies which determined its cause as a heavy rolling torque occurring when the aircraft was yawing (difference in lift drop due to a "shower" effect between the left and right wings).

Along the same lines, it might be noted that with some classical aircraft configurations, a longitudinal instability occurs at high incident angles (Fig. 22), the tendency to "pitch up," which may bring the aircraft to an extreme incidence on the order of 40° at at which it will become stable once again; but it will not be able to leave this difficult position due to a lack of power in the elevator. The laboratories reconstructed this phenomenon in a wind tunnel only after a fatal accident had occurred.

These two examples -- among many others, unfortunately -- /5-15
show that it is not sufficient to accumulate wind tunnel testing hours during study of a project, but that it is essential to analyze the results in detail and, if necessary, to complete the tests immediately. This is the responsibility of the manufacturer's representative, assisted by the engineer in charge of the tests. The latter should be informed of the goals sought and should not be considered merely as a "shopkeeper": his previous experience may be valuable for the manufacturer at this exploratory stage.

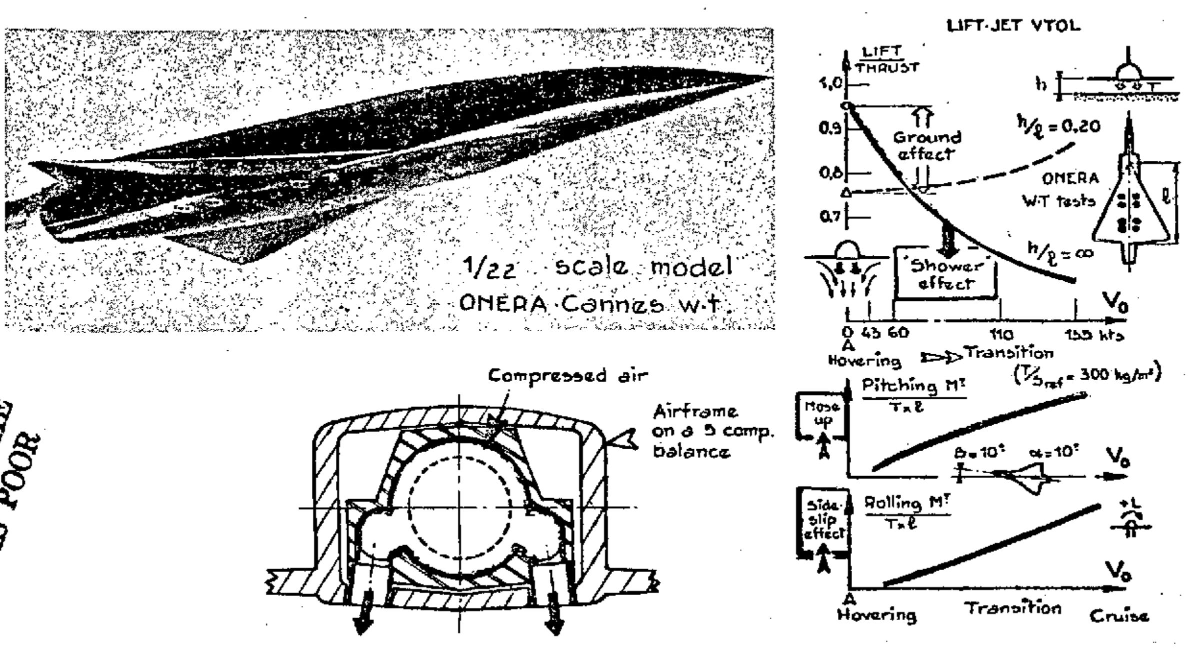

Fig. 21. ONERA - Lift jets/airframe interference on a VTOL in hovering and during low-speed acceleration.

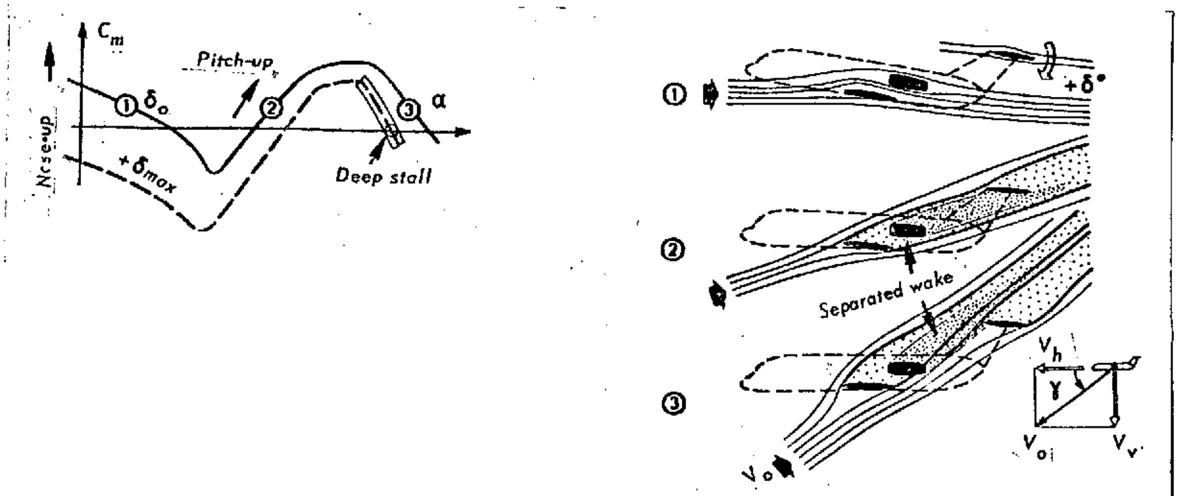

Fig. 22. Wind tunnel analysis of the deep-stall after an accident.

2.2. The Role of Research in Initiation of New Aircraft Concepts

I would now like to show that the use of radically new concepts may lead to satisfactory developments if close collaboration between the researcher and the manufacturer is organized by the government agencies. As examples (Fig. 23), I will use some of the French projects in which the preliminary design study raised problems which were completely new at the time of their initiation.

SOME EXAMPLES of French PRELIMINARY DESIGN
on a NEW AIRCRAFT CONCEPT

* VTOL SUPERSONIC FIGHTER (A.M.D. 'Balzac' and 'Mirage 3V')
* STOL TRANSPORT (Breguet 940 ⇨ 941)
* VARIABLE SWEEP FIGHTER (A.M.D. 'Mirage G ⇨ G-8')
* SUPERSONIC TRANSPORT (UK/FR 'Concorde')
* RAM-JET and TURBO-RAM-JET (ONERA RPV, ONERA SCRAM-JET, Nord 'Griffon' A/C)

Fig. 23. Some examples of French preliminary design on a new aircraft concept.

2.2.1. Vertical Flight Supersonic Combat Aircraft

Here the problem was to integrate a lift system using vertical jet engines into a delta configuration, which had already been proven by use with supersonic fighters and bombers. As we have seen earlier, serious problems of vertical jet/airframe interference did not show up until the flight stage due to a lack of sophisticated testing methods in the preliminary design stage. However, it was possible to make full-scale operating tests in a wind tunnel, followed by optimization of the lift jet system in the Modane S1 wind tunnel based on a close collaboration between the Dassault and Rolls Royce companies and ONERA at the time the Mirage 3V project was being launched. This wind tunnel study permitted extremely rapid flight development of the lift system.

2.2.2. Short Takeoff Transport

This concept had been proposed toward the end of the war by the Bréguet Company, which performed basic research at that time, at the Saint-Cyr Aerotechnical Institute, on the deflection of airscrew flow by means of multiple-curvature flaps. The successive stages in development of this STOL concept -- the experimental Bréguet 940 aircraft, followed by the military cargo 941 aircraft -- were preceded by painstaking research in the ONERA wind tunnels and those of the manufacturer, ultimately involving semi-free flight testing of a motorized model with similar dynamics in the Chalais S1 wind tunnel. This new testing technique allowed pilots to familiarize themselves with the behavior and control of the aircraft at low speeds under heavy airflow and strong airscrew deflection.

2.2.3. Propulsion by Ram-Jet Engine

The idea of ram-jet propulsion dates back to the early development of aviation (Lorin, 1913), and the pioneer in this area was René Leduc, who flew the first experimental models immediately after World War II. At that time, the French government was also initiating research on the military applications of the ram-jet at the Aeronautics Arsenal, which was subsequently to become Nord-Aviation. For more than 10 years (Fig. 24), a crew of specialists assisted by several research and testing centers undertook a succession of preliminary designs followed by experimental models tested in wind tunnels and then in flight. This alternating research and development process was to lead to a remarkable experimental supersonic aircraft, the Griffon, propelled by a turbo-ram-jet (Fig. 25), and to operational ram-jet missiles.

Following the success of these projects, the government requested advanced studies from ONERA on the application of the ram-jet to hypersonic flight (Fig. 26). These studies were to lead to the successful launching of several experimental missiles /5-16
which would reach Mach 5 in high altitude flight and to the qualification testing of a supersonic hydrogen combustion ram-jet

adapted to flight at Mach 6. Tests of this sort were made possible by the development of a hypersonic wind tunnel at the Modane Center capable of simulating the temperature and pressure conditions of real flight at Mach 6. This installation will now be used for full-scale laboratory testing of the Scorpion experimental missile to optimize its internal aerodynamics and its subsonic kerosene combustion ram-jet at Mach 6.

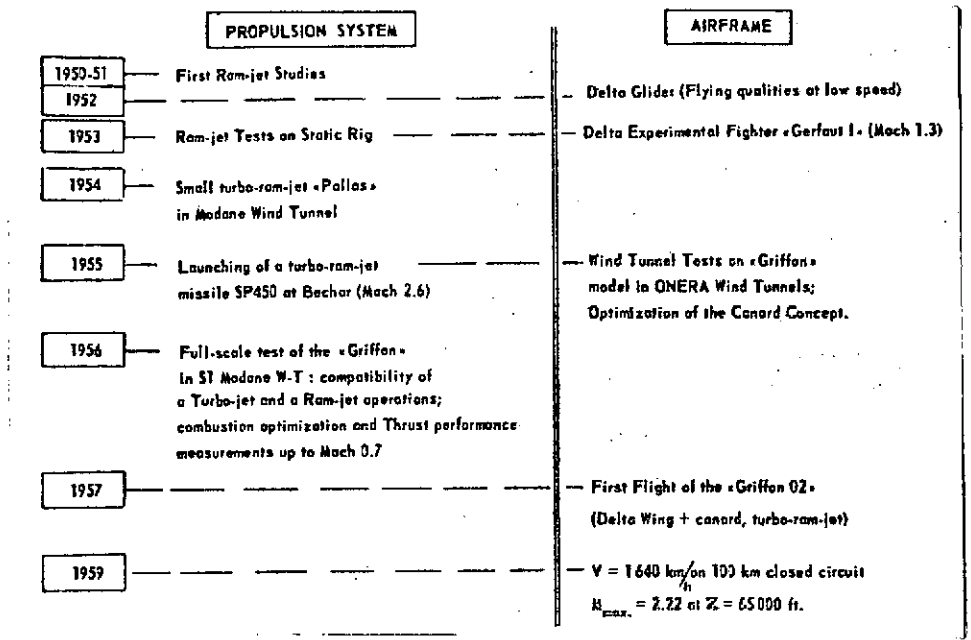

Fig. 24. From preliminary design to an experimental turbo-ram-jet aircraft at Nord-Aviation.

Continuity of this sort over more than 20 years of research efforts followed by experimental development is fairly exemplary, and the success of the project is directly linked to this continuity of small research and manufacturing teams working in /5-17 close collaboration on the responsibilities and qualification of each project.

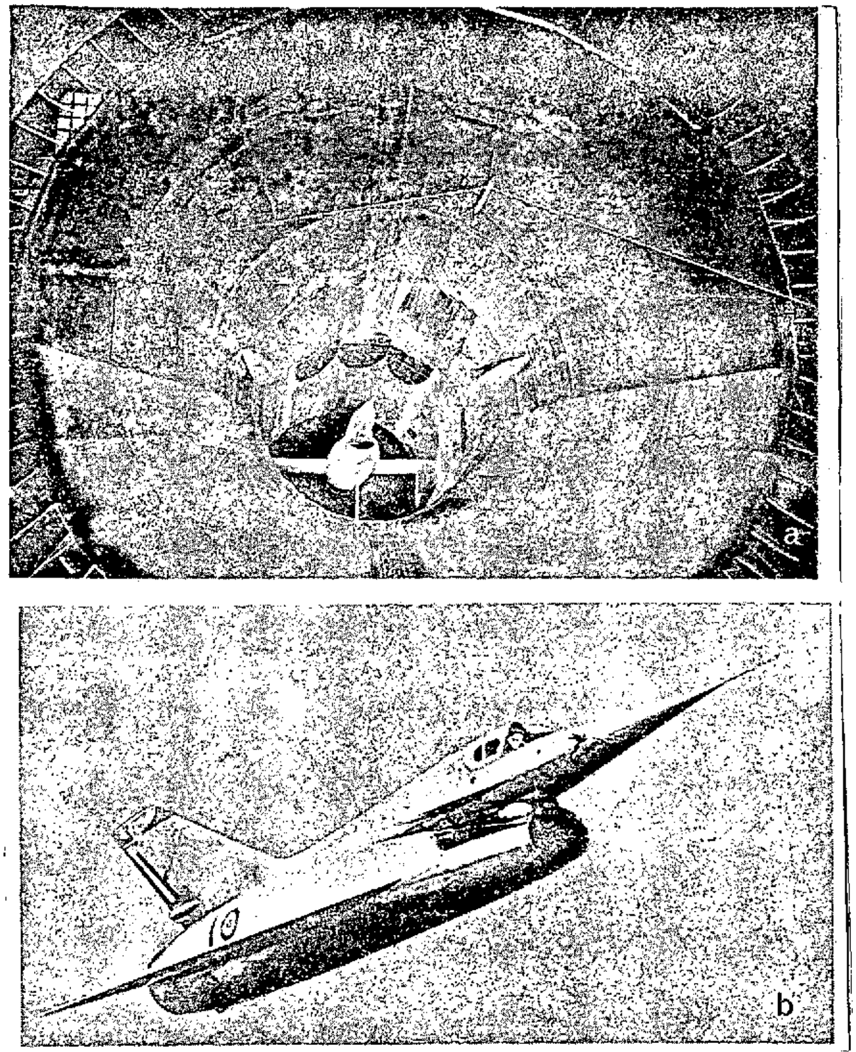

Fig. 25. Wind tunnel and flight study of the Griffon 02 turbo-ram-jet aircraft.

2.2.4. Supersonic Transport Aircraft

Over the last 10 years, the Concorde project has heavily influenced the development of research and test centers, particularly in England and France, but also in Holland, all of whom actively participated in the program:

-- first, prior to the initiation of the program,
-- second, during the preliminary design stage,
-- and finally, during the development of the aircraft.

FOLLOW-ON RESEARCH ON RAM-JETS
at ONERA, after the N.A 'Griffon' qualification

1960/64 — RAM-JET Research R.P.V. 'STATALTEX'

- Subsonic combustion, kerosene
- Flights up to Mach 5 at Z = 35 km

1970/72 — SCRAM-JET 'ESOPE' : Preliminary design study :

- Supersonic combustion, Hydrogene
- Qualification of the performances at simulated flight conditions in the S4 Modane W-T at large scale : { M = 6, Z = 30 km, T = 1650°K }

1971/74 — RAM-JET 'SCORPION' : Preliminary Design Study of a ram-jet missile { M = 3 to 6, Z ≤ 30 km }

- Fixed geometry
- Subsonic combustion, kerosene
- Qualification of the internal aerodynamics and the combustion in the S4 Modane W-T at Mach 6

Fig. 26. ONERA program on the application of ram-jets to hypersonic flight.

Here the new element was the pooling of scientific and technical information gained by England and France, respectively, at the time the project was launched. At the research level, the RAE and ONERA had been collaborating for several years on the aerodynamic problems presented by supersonic flight and they were closely connected with the development of the preliminary designs requested by their respective governments. Here I will mention only a few ONERA research projects which were more or less directly used, or examined, for the Concorde project in the fields of aerothermodynamics and propulsion. Fig. 27[1] gives a highly schematic summary of the studies undertaken beginning in 1950 on the aerodynamics of slender wings, which are especially well suited to supersonic flight.

At that time, the biggest surprise was the discovery of the additional lift which a stable vortex state could produce on the

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[1] On this subject see M. Salmon, "Concorde and aeronautic research," Aéronautique et Astronautique, No. 11 (4-1969).

top skin of heavily sweptback wings (cornet vortex, Fig. 27A), which compensated somewhat for their low lift per unit area at low speeds. Through painstaking experimental research it was possible to obtain tapered leading edge shapes with a heavily swept back apex and rounded wing tips (immediately christened "flamboyant gothic," Fig. 27C), respectively increasing the vortex lift and precluding pitch-up at high incident angles. An unpleasant surprise, on the other hand, occurred during the initial flights of a small experimental aircraft launched by ONERA, the Deltavieix (Fig. 27B), which had a "swallow tail" wing with accentuated leading edge sweep: the combination of the slight elongation and the small scale of this aircraft resulted in a loss of damping effect during rolling which rendered it virtually uncontrollable. This was a productive lesson, however, since it forced us to develop an original system for automatic stabilization during rolling. This was undoubtedly the first application of the "jet-flap" concept in the form of hot air galleries installed at the trailing edge of the wing and fed by diversion of the air from the compressor of the jet engine. The response time of this "pneumatic control" slaved to a roll rate gyro was a few hundredths of a second, permitting satisfactory damping of the aircraft during subsequent flights.

Another "fallout" of this exploratory advanced study was to allow researchers to leave their laboratories for a short time to deal with the real problems of flight testing. It was at this time that ONERA was formed from a research division responsible for the design of experimental aircraft, their flight testing and exploitation of the results obtained.

In the high speed range, preliminary design studies at that time were oriented toward computation of adaptation of the leading edge (conical camber, Fig. 27E) or the whole of a delta wing (twist and camber, Fig. 27F), allowing considerable improvements in aerodynamic efficiency in the subsonic and supersonic ranges, respectively.

The great turning point in research on supersonic aircraft was reached in 1958 when the Aeronautics Technical Service asked ONERA to "look into" the characteristics of a transport aircraft capable of a supersonic cruising speed, from the twofold standpoint of aerothermodynamics and propulsion.

Small-scale theoretical and experimental studies were /5-18
quickly initiated to determine the basic problems involved in a civilian goal of this type, which required both an aerodynamic efficiency and a safety level much higher than those obtained with contemporary military supersonic aircraft.

A parametric study based on the theoretical knowledge available at that time was undertaken to determine the optimum configuration for a "delta" configuration at a supersonic cruising speed (Fig. 27I). This was a highly instructive undertaking, since it made it possible for the first time to determine the sensitivity of a project:

-- to the slenderness and diameter of the fuselage;

-- to the adaptation of the airframe and its relative thickness.

Fig. 28 shows these tendencies at a cruising speed of /5-19
Mach 2.2 in the case of a delta wing with a 70° sweep. It was necessary for us to obtain aerodynamic efficiency at least one-third higher than that of current military aircraft if we were to have a chance of being competitive on the civilian market. In addition, the optimum configuration for supersonic flight also had to be acceptable for takeoff and landing; here again, a preliminary experimental study showed (Fig. 29b) that the additional vortex lift compensated for the loss due to the increase

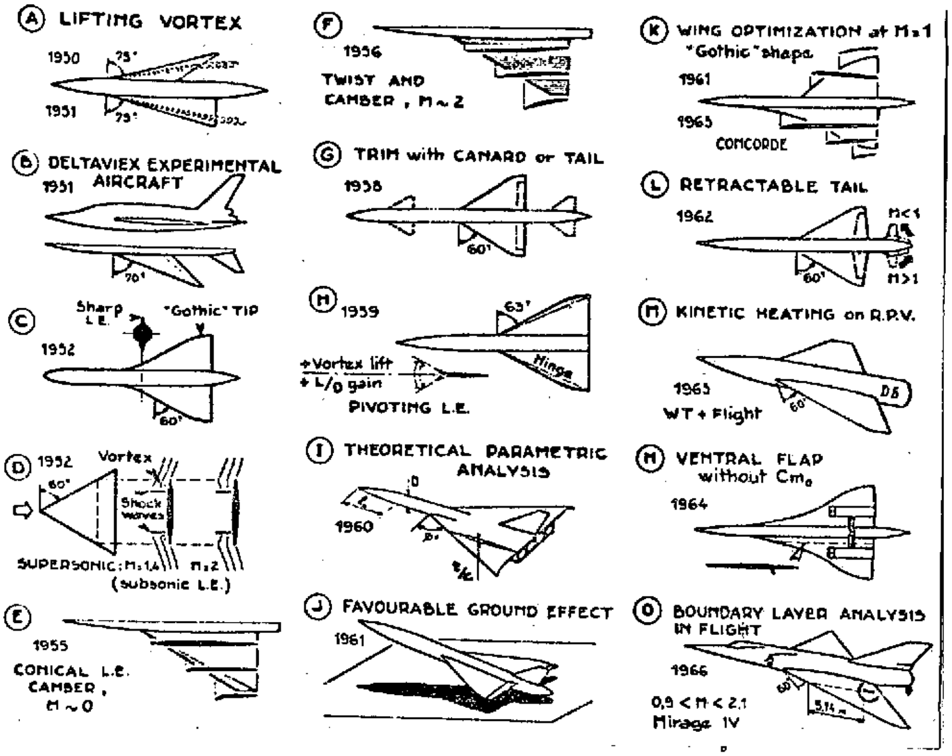


Fig. 27. ONERA (1950-66). Slender wind aerodynamic research before and during the Concorde design.

in sweep sufficiently so that the overall lift was still acceptable for sharp sweeps on the order of 70°, which would be desirable for satisfactory supersonic efficiency at Mach 2.2. Simultaneously, the tests showed that a pivoting leading edge (Fig. 27H) permitted either an increase in lift during approach (accentuation of vortex lift by upward deflection) or an improvement in efficiency during climb and at subsonic cruising speeds (downward deflection). Much higher equilibrated lift was obtained in the wind tunnel with the use of a tail or canard (Fig. 27G). An extremely efficient blown flap canard was then developed, making it possible to obtain an approach lift twice that obtained with the "tail-less aircraft," without serious aerodynamic interference at high incident angles (Fig. 30).

Simultaneously, preliminary transonic and supersonic experimental studies on simplified models made it possible to orient

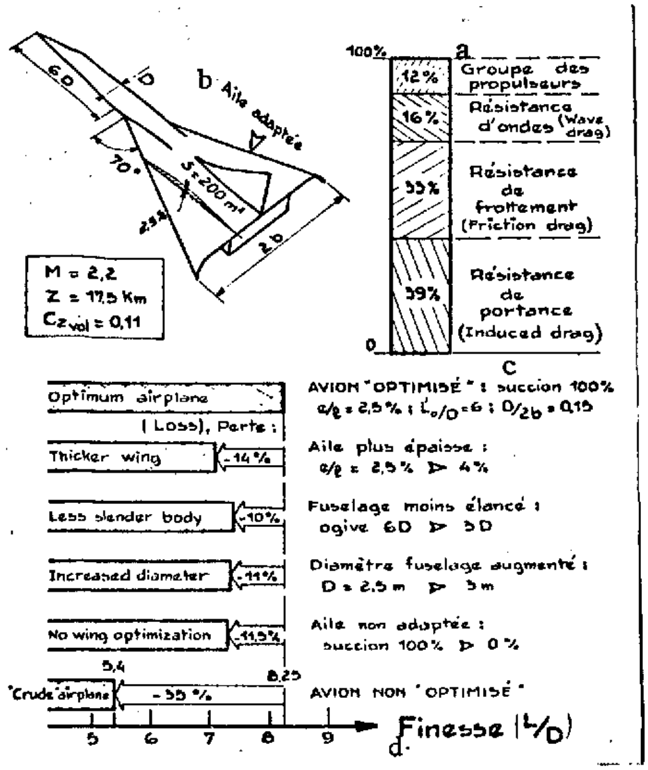


Fig. 28. Supersonic drag calculation on the SST. (ONERA, 1959).

Key: a. Propulsion unit; b. Adapted wing; c. Suction; d. Aerodynamic efficiency

the choices and to furnish adequate aerodynamic derivatives quickly in the preliminary design stage (Fig. 31). During these limited tests, we were able to show the value of inverting the cockpit so that it would contribute to the longitudinal balance of the aircraft at supersonic cruising speeds (Fig. 32), while at the same time permitting satisfactory downward visibility during high-angle approach.

In November 1959, the Aeronautics Technical Service initiated preliminary design studies for a medium-range supersonic transport (R = 3000 km, 80 passengers, Mach number between 2 and 3) to which three designers (Nord, Sud, Dassault) responded. It is interesting to review two of the preliminary designs presented, both adapted to a cruising speed at Mach 2 to 2.2 to be able to use an aluminum alloy structure:

-- a "gothic" wing four-engine design without stabilizers, by Sud-Aviation (Fig. 33);

-- a delta wing four-engine design with blown canard stabilizer by G.A.M. Dassault, with airframe and air inlets which were quite similar to those of the Mirage IV bomber (Fig. 34).

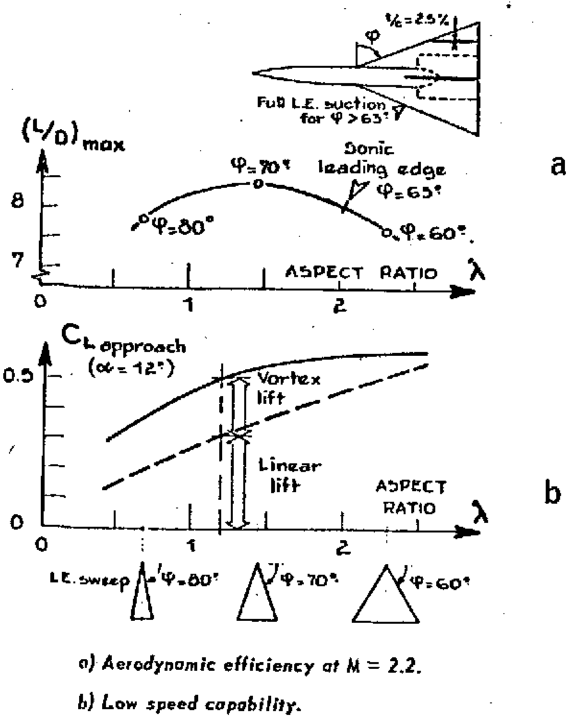


Fig. 29. SST parametric study on delta wings (ONERA, 1959).

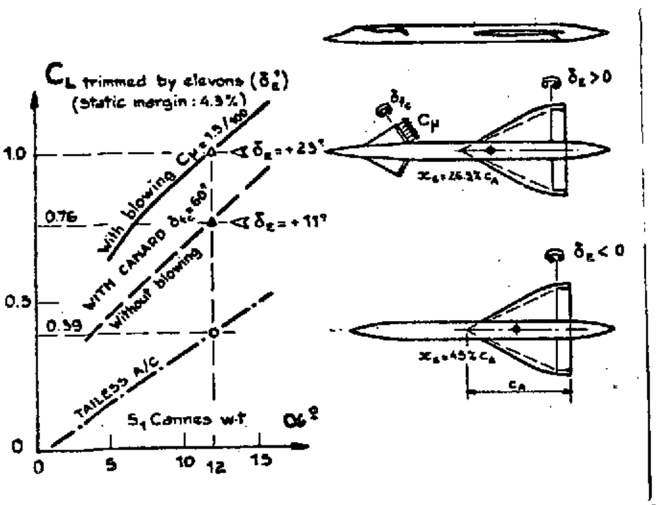


Fig. 30. ONERA: Research on SST lift increase at low speed with a canard configuration.

In Great Britain, a combined government and aeronautical industry research committee had been set up in 1956 to undertake aerodynamic and structural research on the configuration of a future supersonic transport aircraft. In 1960, the British Aircraft Corporation was granted a contract for a "long range SST capable of cruising at Mach 2.2." Fig. 35 shows the results of this study: gothic wing design with propulsion pods, each with three jet engines, tapered fuselage and /5-20
droop nose at low speeds. As with the Sud-Aviation project, this design was derived directly from research on slender wings conducted in both countries. In 1961, bilateral accords were signed between B.A.C.-Sud and Bristol-Snecma for joint research on a long-range four-engine aircraft based directly on respective preliminary designs. Finally, the decision to build prototypes for what was to become the Concorde was made by the French and British Governments in November 1962.

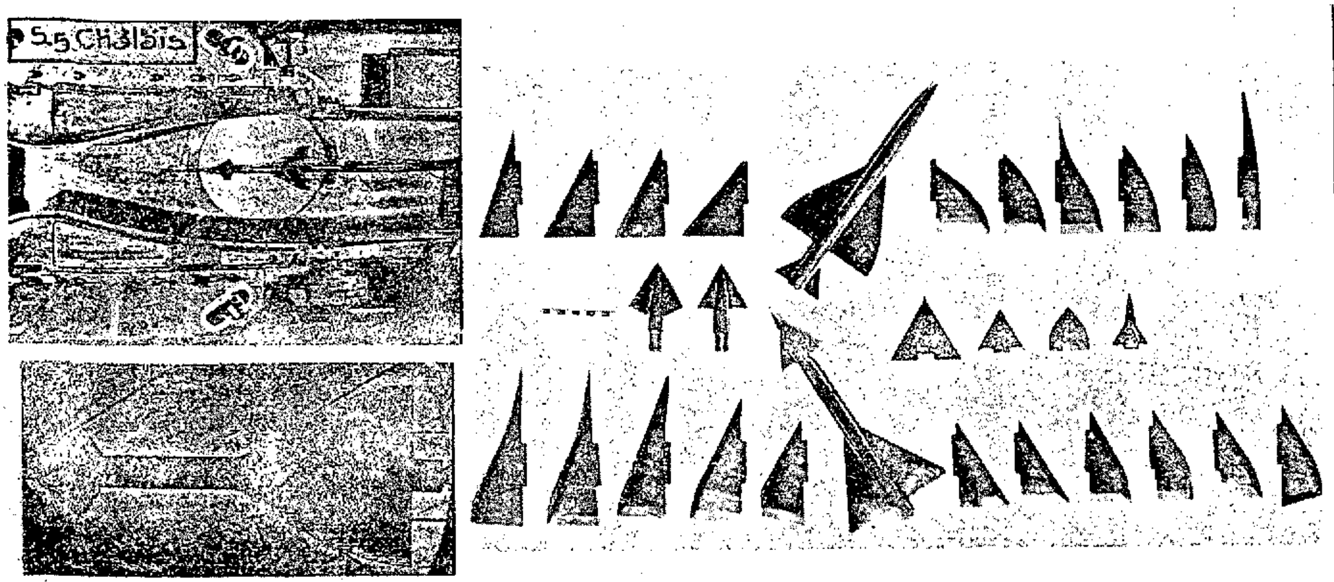


Fig. 31. ONERA, 1959: first experimental approach on SST shapes in small transonic and supersonic tunnels.

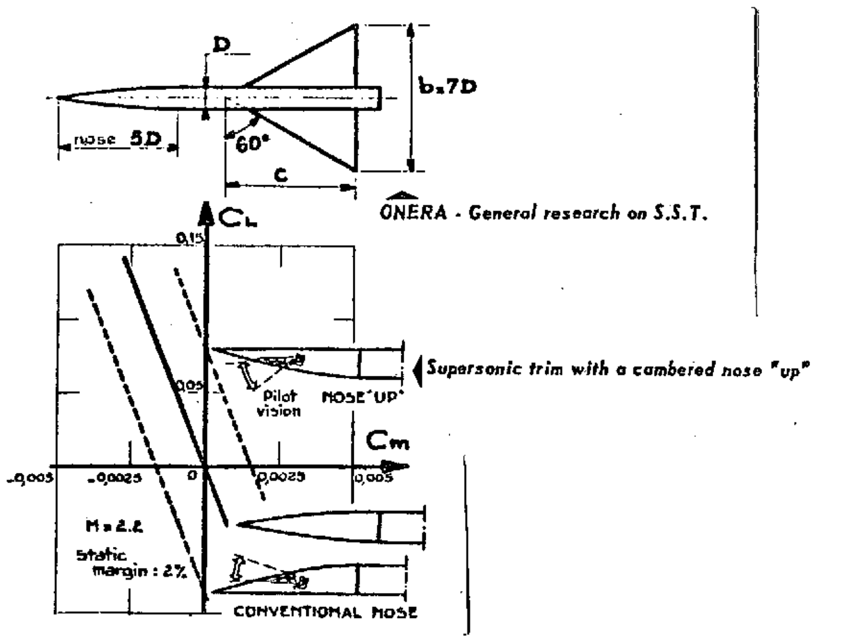


Fig. 32. Study of an inverted cockpit contributing to the longitudinal equilibrium of a supersonic cruising SST.

The initiation of preliminary design projects by the French Technical Service had been accompanied by a "mobilization" of the

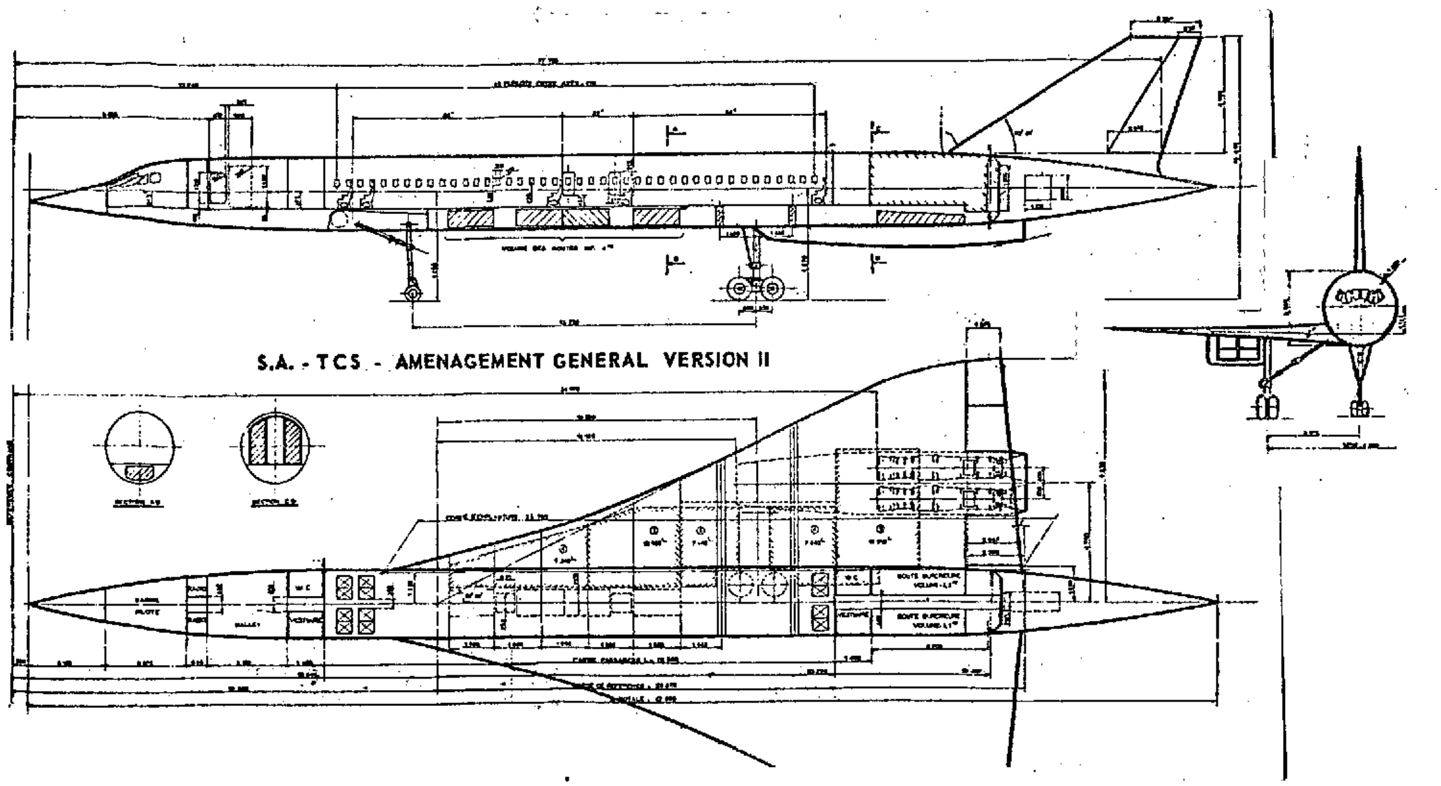


Fig. 33. French Air Ministry: July 1961. SST medium-range preliminary proposals; Sud-Aviation project.

Key: a. S.A.-TCS: Layout of general version II

research and testing means of ONERA for the benefit of the manufacturers:

-- in regard to the <u>external aerodynamics</u>, theoretical research undertaken for optimization of slender wings resulted in the proposal (Fig. 27K) of an adaptation of this design to Mach 1 under slender body theory, since, for the purposes required, the aircraft needed satisfactory aerodynamic efficiency not only at a cruising speed of Mach 2.2, but also at a possible subsonic cruising speed of about Mach 0.93 (flight over areas sensitive to sonic boom, case of engine failure) and finally during holding flight and diversion at about Mach 0.75. The spin and camber laws computed by ONERA will serve as a basis for generation of the Concorde airframe.

During the same period, at the Cannes wind tunnel ONERA researchers revealed a considerable favorable ground effect on slender wings in addition to the gain resulting from vortex development at high takeoff and landing angles. This twofold advantage was confirmed by NASA-Ames in wind tunnel tests and in flight using the experimental F-5D aircraft equipped with an airframe with a similar shape to that of the Concorde (Fig. 36).

Finally, it was of prime importance to set up an accurate drag breakdown for the project throughout the flight range by performing computations to extrapolate the wind tunnel results at Reynolds numbers of a lower order of magnitude than in flight. /5-21
The Concorde program for the first time permitted serious attempts to measure drag accurately in wind tunnel tests, by taking into account the position of the boundary layer transition or by artificially generating a turbulent flow on surfaces with calibrated roughness. Painstaking tests performed on a single model for the project (Fig. 37) in the large transonic wind tunnels available in France, England and Holland made it possible for the first time to obtain correct correlations of data from the different laboratories, which were subsequently used for development of the Concorde, and which are still being used for continuous updating of the mass-produced aircraft.

The Technical Service also asked ONERA to perform two extensive basic research programs involving wind tunnel and flight testing to confirm the validity of theoretical computations of friction and kinetic heating as a function of Mach and Reynolds numbers, since accurate prediction of these characteristics was vital for the computation of performance and variations in the heating of the Concorde structure at supersonic cruising speeds.

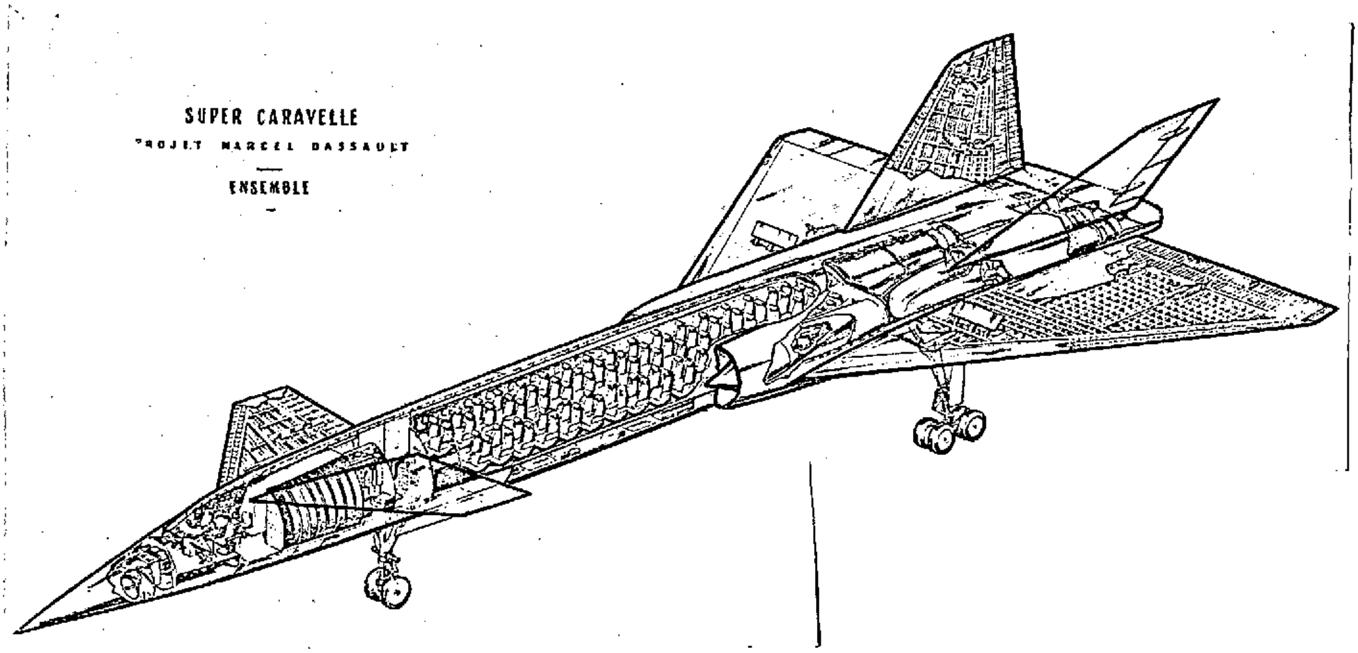


Fig. 34. French Air Ministry: July 1961. SST medium-range preliminary proposals. G.A. Marcel Dassault project.

The influence of Reynolds and Mach numbers and the effect of roughness in the wing skin were studied by analysis of the boundary layer on the top skin of the delta wing of the Mirage IV bomber, with the cooperation of the Dassault Company (Fig. 270), between Mach 0.9 and 2.1. Similar wind tunnel tests on a delta half-wing at low Reynolds numbers provided a convenient means of checking the equations used to compute the turbulent friction of the Concorde over a wide range of Reynolds numbers (Fig. 38).

The experimental study of kinetic heating presented com- /5-22
letely new and difficult problems with regard to test methods and instrumentation. To perform this research effectively, a series of delta wings (Fig. 27M) with a perfectly calibrated stainless steel skin and equipped with a large number of thermocouples were tested at the wall of a hot gust wind tunnel (Modane S3) and on an experimental missile (D-6, Fig. 39). Several missiles were fired, and the temperature measurements which were

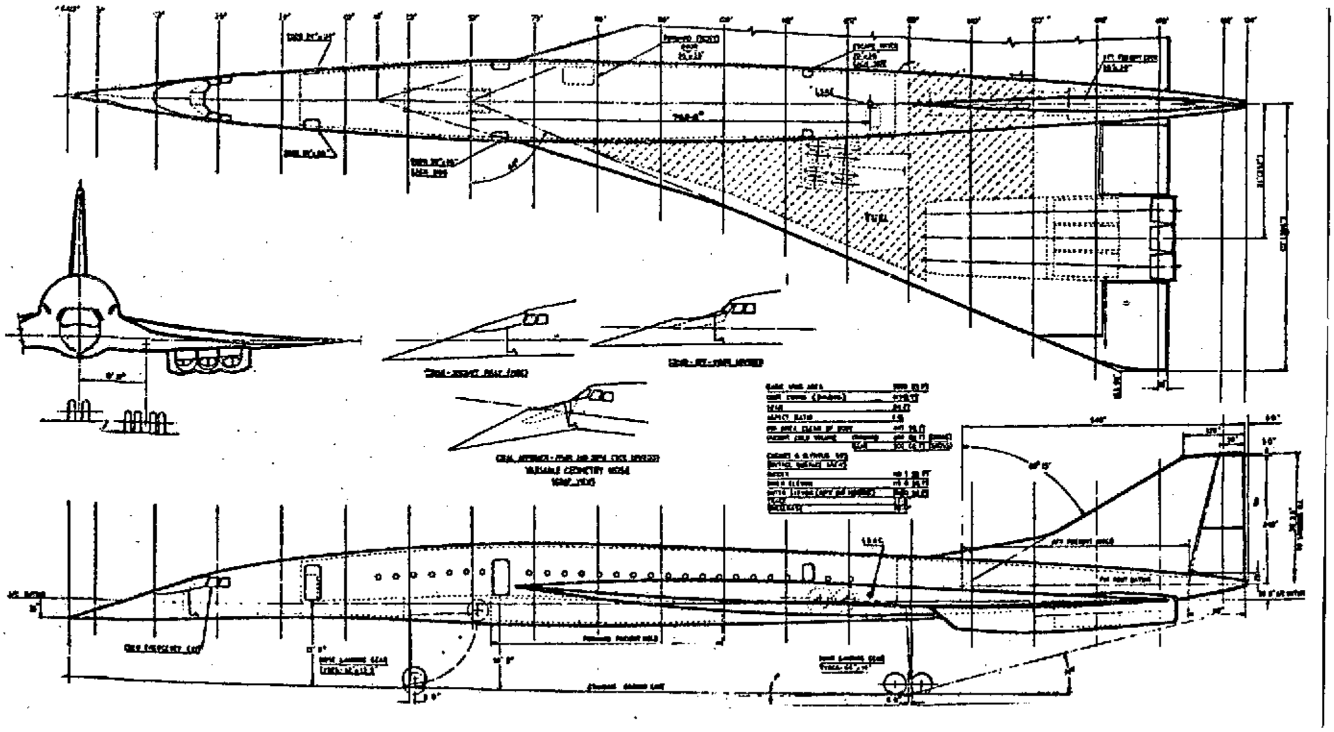


Fig. 35. Bristol Aircraft Limited SST project, 1961.

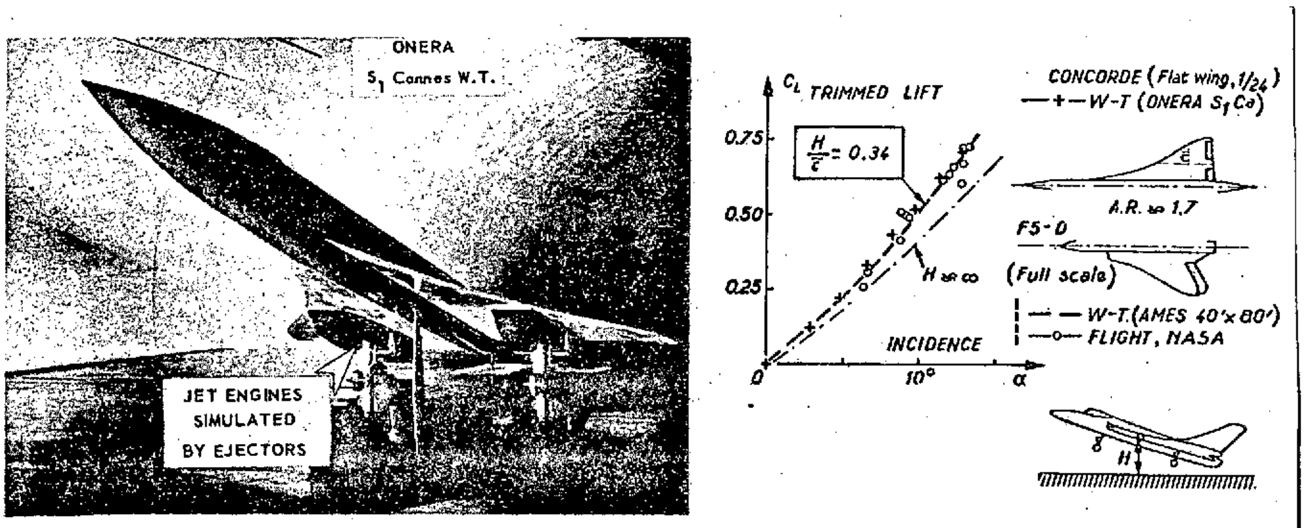


Fig. 36. Favorable effects of vortex lift and ground effect on slender wings of the Concorde type.

transmitted to the ground during stabilized flight in the vicinity of Mach 2.2 at an altitude of 9 km made it possible to compute thermal fluxes which were in satisfactory agreement with those

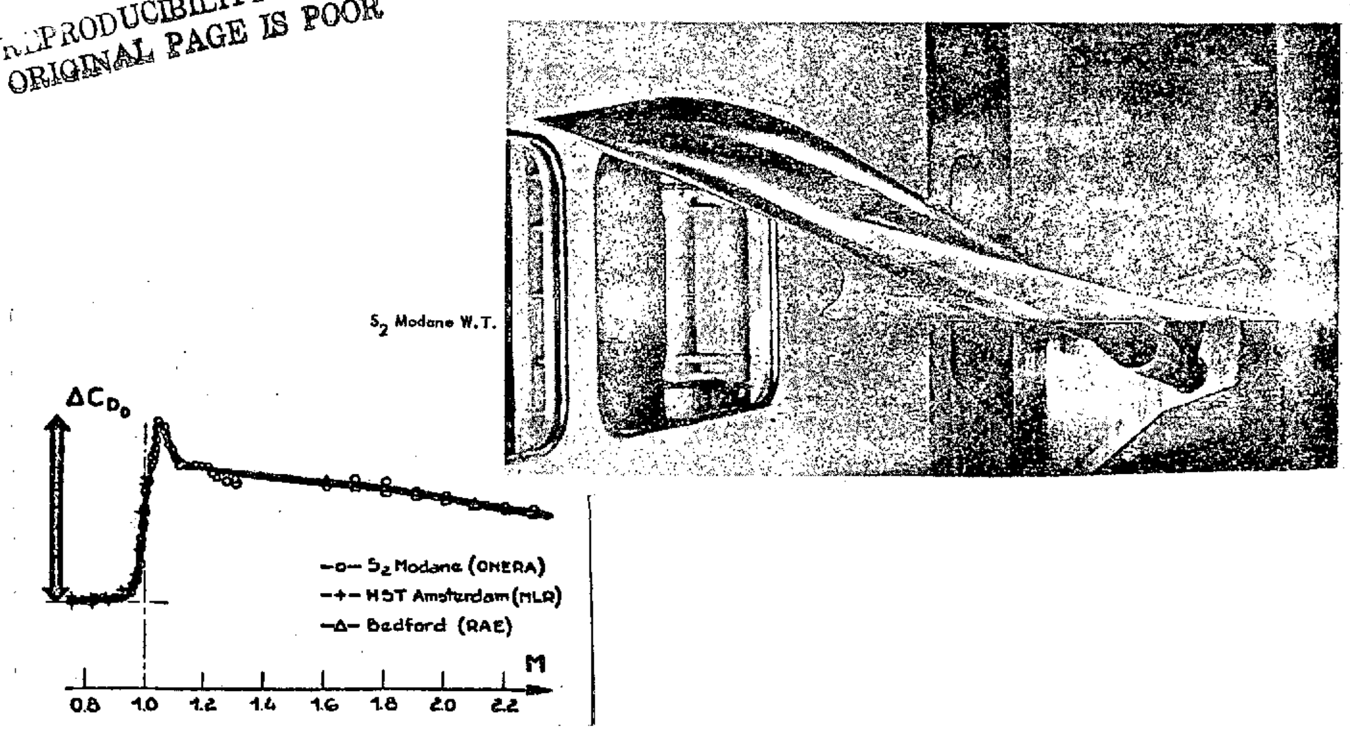


Fig. 37. Comparative tests on the transonic and supersonic drag on the Concorde preliminary design model (scale 1/30th).

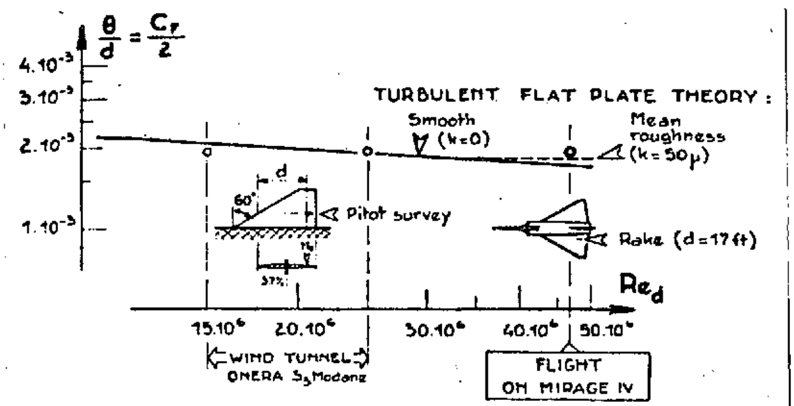
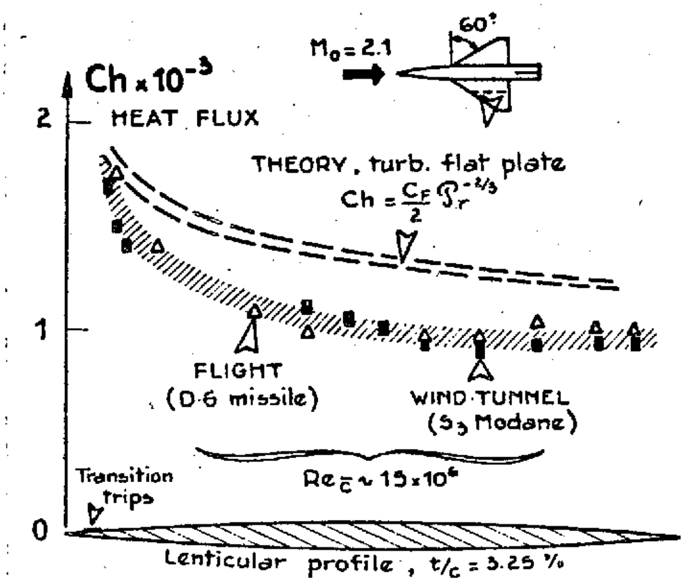


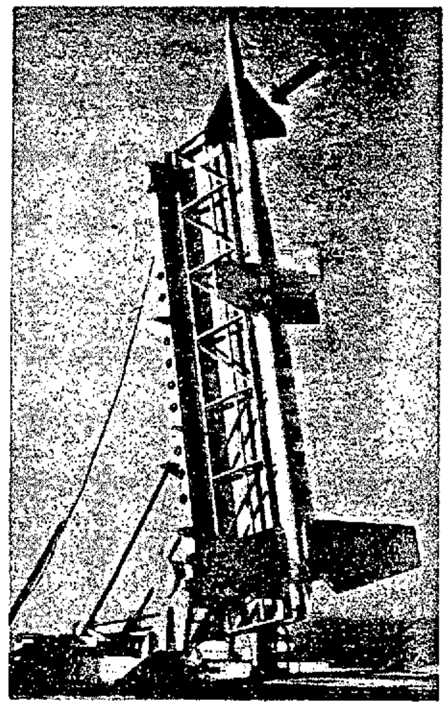
Fig. 38. Mean friction drag at supersonic speed (M_e = 2.15). Correlation between theoretical estimation and experiments in W.T. and in flight.

obtained from the wind tunnel tests. On the other hand, these experimental values were appreciably lower than those predicted by computations based on the classical factor of the Reynolds analogy. It was thus easy to correct the value.

The sum total of these developmental studies, financed under the Concorde program, made it possible to form a reserve of researchers and technicians and to make a considerable improvements in testing methods on the ground and in flight.

In conclusion, I would like to describe the important internal aerodynamic studies which have been performed by ONERA since 1958 toward development of the propulsion system of the supersonic transport.





D.6 experimental missile (3 stages)

Fig. 39. ONERA: research on supersonic kinetic heating during Concorde studies.

Experience with the air inlets of military supersonic aircraft (of the Mirage III and IV classes) and experimental ramjet missiles had been accumulating for a long time. However, the air inlets of a supersonic transport aircraft, like the airframe, had to have a much higher performance than that of contemporary military aircraft to obtain the low specific fuel consumption necessary for a large operating range. From the beginning, the choice was a two-dimensional air inlet of varying shape. Computations and preliminary tests in the preliminary design stage quickly showed that the "outside compression" solution was simpler than and almost as efficient as a "mixed compression" solution for a cruising speed of Mach 2.2, making use of the favorable precompression of the wing when the air inlet is flush with the underside of the wings. A specially designed test bench was installed in the ONERA S5 wind tunnel in Chalais, permitting the development of movable compression ramps, as well as the boundary layer bleed, which was essential for obtaining a correct flow to the right of the jet. This configuration was used for the Concorde project from the outset, but the final plans evolved during the development of the project following a large number of tests which are still being conducted in several English and French wind tunnels. ONERA is still working on these tests in close collaboration with the manufacturers, SNIAS/BAC (Fig. 40a: identical assembly to that used in the Chalais S5, currently in use at Vernon).

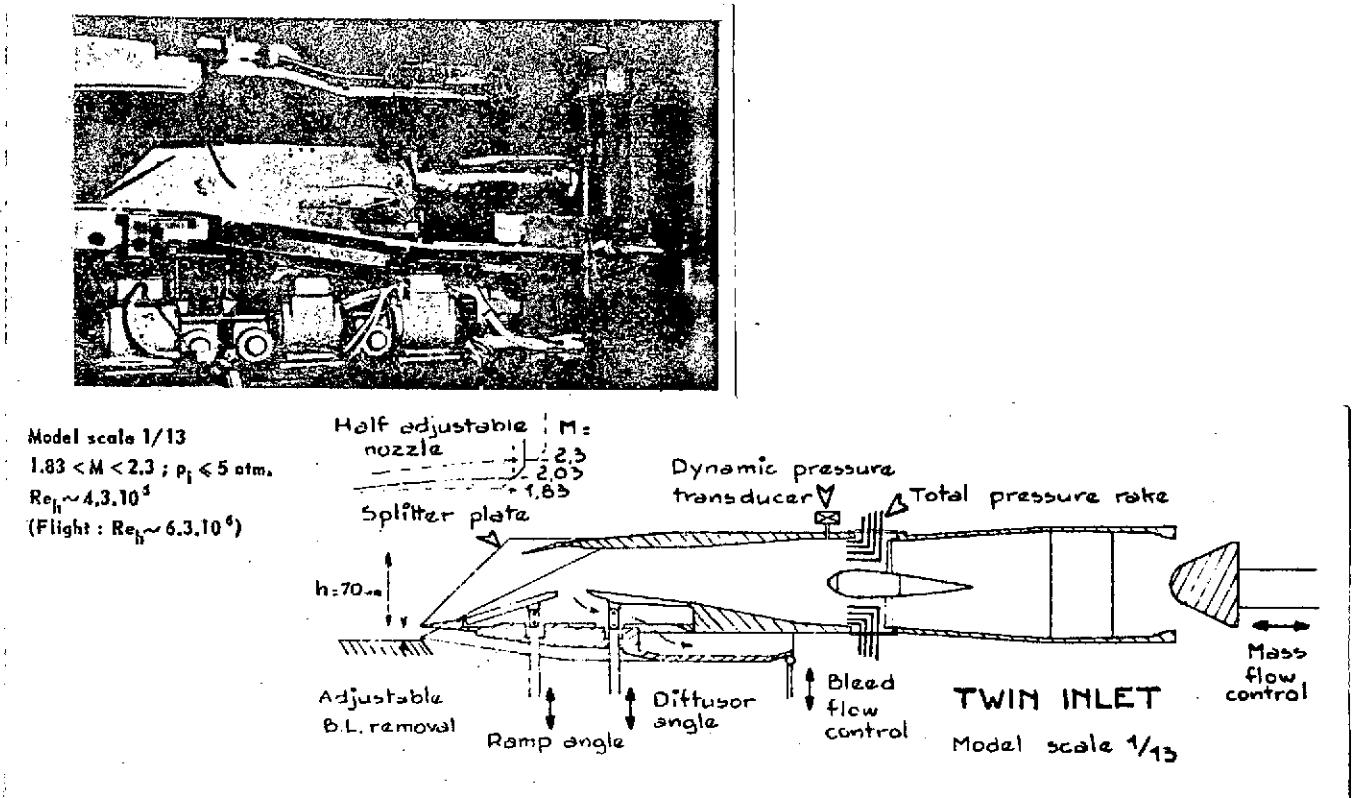


Fig. 40a. ONERA/LRBA (Vernon): wind tunnel tests on Concorde twin inlet at high Reynolds numbers.

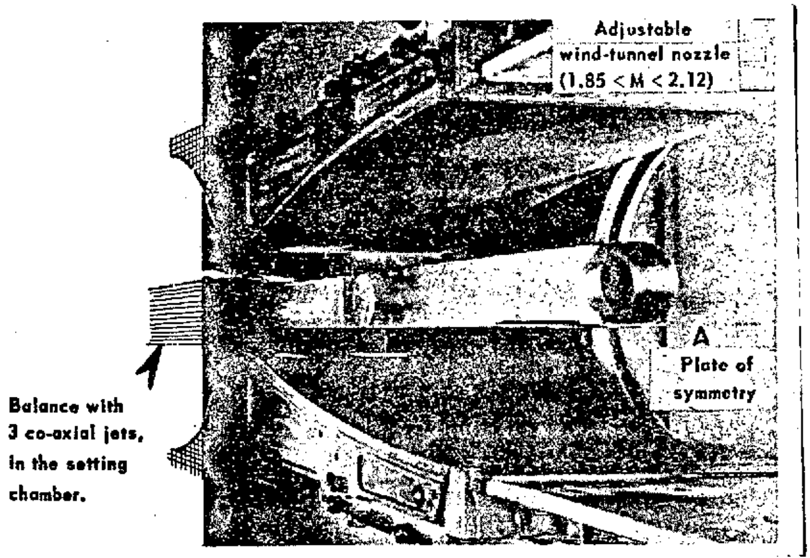


Fig. 40b. ONERA S5 wind tunnel, Chalais: thrust and drag on Concorde nacelle after-body (SNECMA). Scale: 1/20.

With the nacelle after-body, the problem was still more difficult, since our knowledge and testing methods were completely inadequate at the time of the preliminary design study. It was first necessary to develop sophisticated test setups for measurement of the thrust from multiflow nozzles in the core of a transonic or supersonic flow (Fig. 40b), and also benches for extremely precise measurement of the thrust at a fixed point. All these setups are still being used for step-by-step improvements in the performances of the Concorde nozzles in the different flight ranges, in close collaboration with the manufacturers, SNECMA/Rolls Royce. At the same time, ONERA is participating in acoustical, theoretical and experimental studies designed to reduce the noise level from these nozzles. /5-24

During the development of the Concorde project, ONERA also furnished continuous technical assistance to the manufacturers in the field of aeroelasticity, which is especially important for this extremely flexible wing configuration. This assistance included participation in structural computations, vibration testing of the prototype on the ground, wind tunnel studies of flutter on models with similar aeroelasticity, in-flight analysis of the aircraft response to turbulence, etc.

2.2.5. Variable Sweep Aircraft

In conclusion, I would like to give a brief description of the role ONERA will be playing in the future and during the preliminary design of a variable-shape multipurpose aircraft.

In 1963, the Technical Aeronautics Service requested ONERA to make a general study, both theoretical and experimental, on variable sweep design, and simultaneously requested the Bréguet Company to undertake a preliminary design study on a multipurpose combat aircraft (Fig. 41). Shortly thereafter, a similar study was requested of the Dassault Company, which was to be followed by an order for a single-engine experimental prototype from this company, the Mirage G, in October 1965. This aircraft made its first flight 25 months later, and a large part of the flight envelope was explored in the following 2 months (beginning of 1968). The unquestionable success of this program and the speed of its execution demonstrate the solidity of a prototype policy based on experience gained with previous aircraft: in developing a new concept (variable sweep wing), the Dassault Company had actually reused most of the elements already tested in flight on the Mirage F_2 fixed wing experimental aircraft (same PW-TF-306 jet engine, same fuselage with already qualified side air inlets and nozzle, and virtually identical pivoting horizontal stabilizers; see Fig. 8).

The function of ONERA in this case was the very rapid furnishing of aerodynamic data on configurations which were completely new to us (since foreign research was classified), throughout an extensive range of Mach numbers.

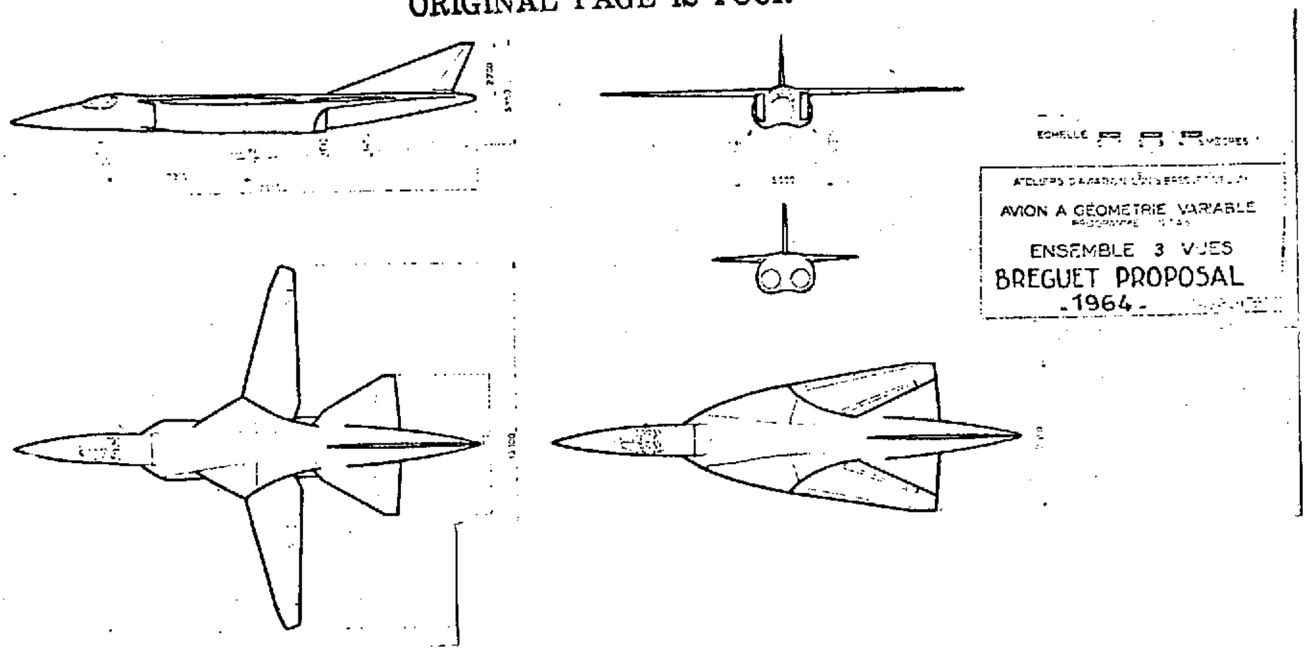


Fig. 41. French Air Ministry. Variable sweep preliminary design.

Key: a. Variable shape aircraft: entire assembly, three views

However, on the theoretical level we gained considerable skill at this time in the use of Perès-Malavard electrical analogies for computation of lift surface areas and subsonic flow (Fig. 42). Furthermore, this same laboratory had just developed an analog method for wing computation in supersonic /5-25
flight based on the use of an inductance-capacity network. Finally, the Theoretical Aerodynamics Division had developed tested numerical computation methods at this time, both for optimization of wings at Mach 1 using slender body theory and for computation of wings of any shape in the supersonic range.

On an experimental level, it was absolutely necessary to be able to check the validity of these different theoretical approaches quickly by wind tunnel tests on schematic models. For example, to obtain the aerodynamic derivatives, classes of flat wings which can be built easily and inexpensively will be used both for incompressible conditions and for transonic and supersonic conditions (Fig. 43).

All these computational and limited testing methods were used simultaneously for approximately 1 year on parametric study of a series of variable sweep wings. The same shape was used for spread configuration, and the position of the pivot was changed to rotate the movable wing up to a sweep of 70° (Fig. 44). The analog study showed that the backward shift in the center of thrust between the maximum and minimum sweeps (15° and 70°) varied linearly with the position of the pivot on the span. Thus there was an excentric for this pivot resulting in identical longitudinal stability at extreme operating speeds (spread and folded wings). All these theoretical characteristics for an incompressible medium were quickly confirmed by experimentation in the Cannes wind tunnel (Fig. 43a). These tests also revealed problems in longitudinal stability at high incidences with spread wings when the area of the fixed tip became large (case of an excentric pivot which was otherwise desirable due to the low sensitivity of its static margin to sweeping of the wing).

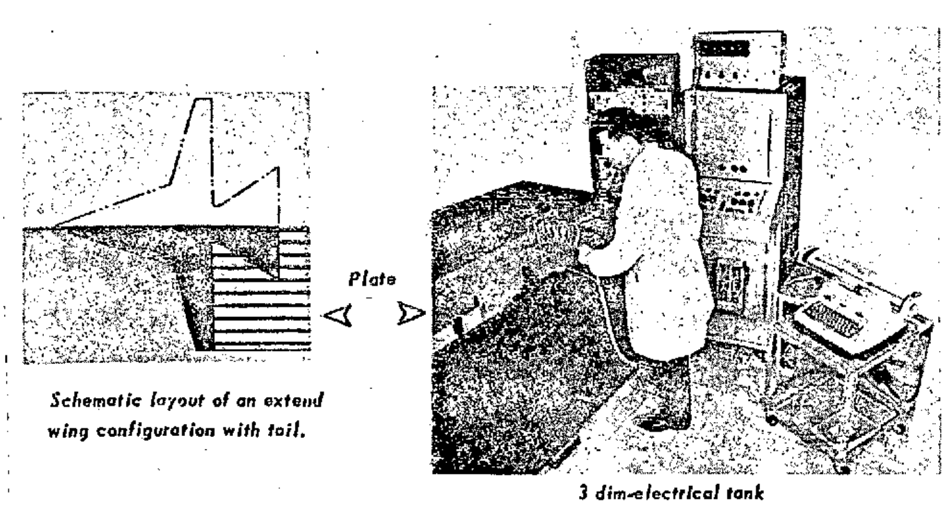
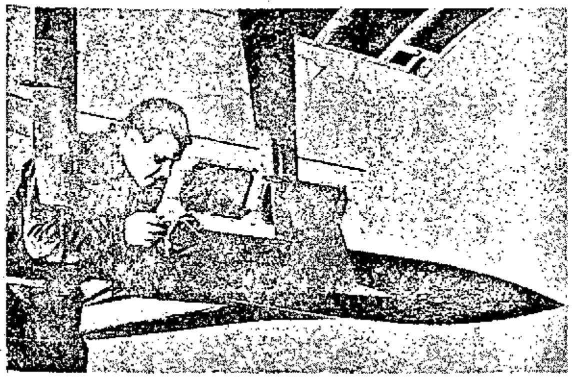
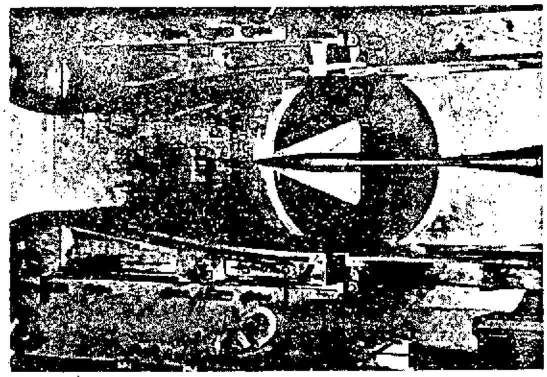


Fig. 42. ONERA: Basic research on variable sweep concept. Theoretical approach with rheoelectrical analogy method.



a) S_1 Cannes W.T. (low speed).



b) S_5 Chalais W.T. (trans-supersonic).

Fig. 43. ONERA: preliminary tests to check theoretical approaches on variable sweep aircraft concept.

Supersonic testing of schematic models in the Chalais S5 wind tunnel also confirmed the variations in the center of thrust with the position of the pivot on the span computed for supersonic speeds by two theoretical approaches: the backward shift in the center of thrust between Mach 0.1 and Mach 2.1 (Fig. 44) was appreciably the same for all the configurations studied with folded wings at 70°, and was thus independent of the position of the pivot.

Finally, previous ONERA experience with increases in the maximum aerodynamic efficiency provided by a conical camber for the leading edge of a delta wing (Mirage III) led us to compute a camber of this type for the wing in folded position (wing with 70° sweep and the addition of a horizontal stabilizer, Fig. 45). This computation for adaptation of the leading edge was performed at Mach 1 with the use of slender body theory. The original idea was to make simultaneous use of satisfactory adaptation of the wing to transonic combat (folded wings) and a sharp camber in "spread wing" configuration, which should permit an improvement in low-speed stall characteristics. Wind tunnel tests and the use of this theoretical approach in flight fully confirmed this expectation.

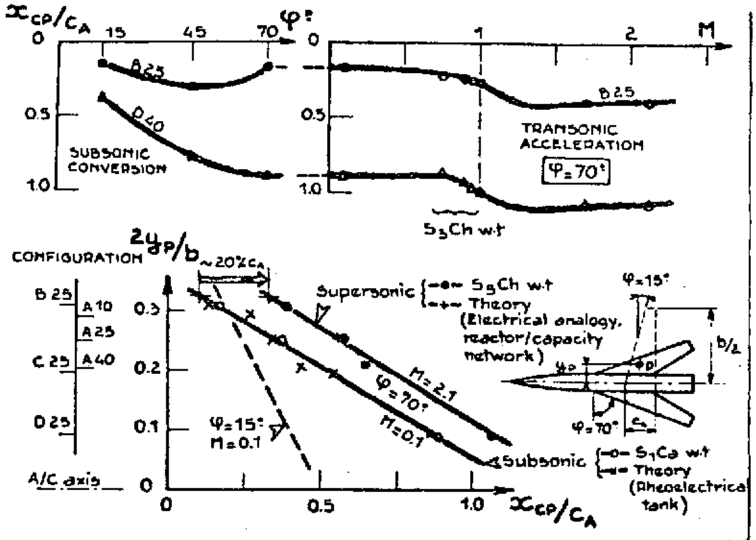


Fig. 44. Influence of the span position of the pivot on a series of variable sweep wings; comparison of theory and experiment in the subsonic and supersonic ranges.

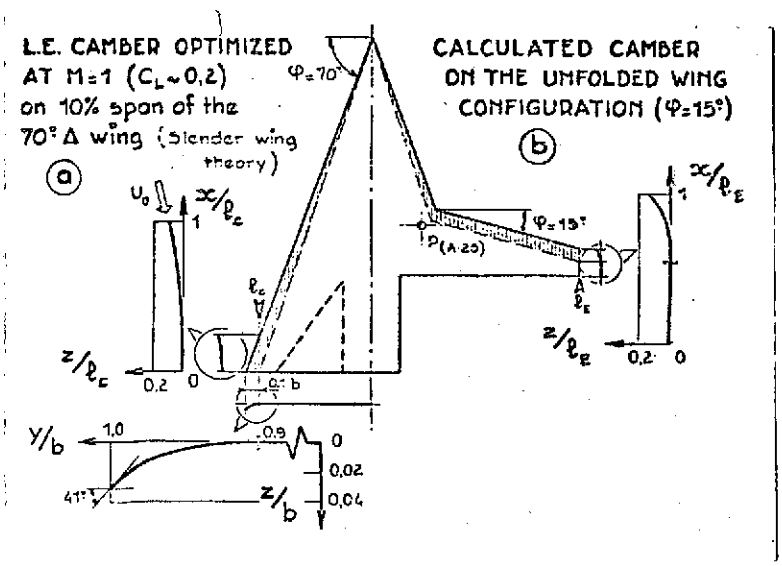


Fig. 45. Theoretical approach (Mach 1) for a leading edge conical camber on a variable sweep configuration.

This last example /5-26 shows that the Research Center may be effective with a limited budget at the preliminary design stage, due to an extremely short response time obtained by the "mobilization" of small groups of researchers, theoreticians and experimentors toward a well-defined goal in direct cooperation with future clients.

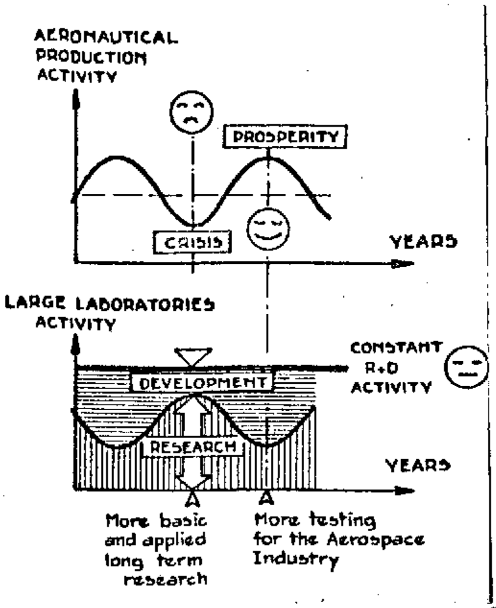


Fig. 46. Long-term research should make use of technical assistance, which decreases during crisis periods, to keep aeronautics laboratories fully active.

2.3. Conclusions

It has been my intention to use a few of the projects with which I have been involved in France during the last two decades to attempt to show that it was often economically feasible to make use of the research laboratory at the beginning of a new preliminary design project, with the manufacturer subsequently continuing to rely on the technical assistance of this laboratory during the development of the project and after the initial flights.

Unfortunately, this procedure is becoming increasingly rare in most countries at present, for several interrelated reasons:

-- initiation of fewer new projects,

-- lack of any long-range aeronautics policy permitting the development of experimental aircraft;

-- the cost and complexity of the few remaining projects, which are thus assigned directly to groups of manufacturers which are frequently multinational.

This trend obviously makes it increasingly difficult to obtain a direct dialogue between government, manufacturers, and laboratories in the preliminary design stage. In addition, it is increasingly difficult to introduce new ideas at this stage, due to the financial risk which must be taken when the project is not "conservative." This is why the government should take on the responsibility of initiating general research to generate new ideas long before assigning projects to manufacturers, so that these ideas may be used directly when the time comes.

This "pilot" action is especially necessary during the cyclic crisis periods in the aeronautics industry, so that the Research Center is not subject to these sudden fluctuations in industrial activity (Fig. 46). A long-range research program will compensate for a temporary decrease in technical assistance and ensure the continuous employment of highly qualified personnel. This is also the best solution to provide a short response time for the laboratory to meet manufacturers' requests during active periods when several projects are being launched at the same time.