NASA TECHNICAL MEMORANDUM NASA TM-77883

PRESENTATION OF THE ACOUSTIC AND AERODYNAMIC RESULTS OF THE ALADIN II CONCEPT QUALIFICATION TESTING

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Translation of "Presentation des Resultats Aerodynamiques et Acoustiques des Essais de Qualification du Concept Aladin II", IN: AGARD CP-143, April 1974, pp. 8-1 to 8-10

(NASA-TM-77883) PRESENTATION OF THE ACOUSTIC AND AERODYNAMIC RESULTS OF THE ALADIN 2 CONCEPT QUALIFICATION TESTING (National Aeronautics and Space Administration) 30 p HC A03/MF A01 CSCL 01A G3/02
N85-35161
Unclas 21932

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JULY 1985

STANDARD TITLE PAGE

1. Report No. NASA TM-77883	2. Government Accession No.
3. Recipient's Catalog No.	
4. Title and Subtitle PRESENTATION OF THE ACOUSTIC AND AERODYNAMIC RESULTS OF THE ALADIN II CONCEPT QUALIFICATION TESTING	5. Report Date July 1985
	6. Performing Organization Code
7. Author(s) M. Collard, C. Doyotte and M. Sagner	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address Scitran Box 5456, Santa Barbara, CA 93108	11. Contract or Grant No. NASW-4004
	13. Type of Report and Period Covered TRANSLATION
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Presentation des Resultats Aerodynamiques et Acoustiques des Essais de Qualification du Concept Aladin II", IN: AGARD CP-143, April 1974, pp. 8-1 to 8-10

16. Abstract

The aerodynamic design of the Aladin project is described, giving an estimation of wing aerodynamic performance and the planar circulation design. The design of the trailing edge flaps and the three-dimensional design are discussed. Test results are presented. The Aladin II concept is a development aimed at building short take-off (STOL) aircraft using only currently available engines with moderate bypass ratios.

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

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 29	22. Price

PRESENTATION OF THE ACOUSTIC AND AERODYNAMIC RESULTS OF THE ALADIN II CONCEPT QUALIFICATION TESTING

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1 - INTRODUCTION

The Aladin II concept is a development aimed at building short takeoff aircraft using only available engines with moderate bypass ratios, which can therefore be designed within a relatively short amount of time.

The drawing of the propulsion assembly is shown in Figure 1.

The jet flow of a moderate bypass engine is divided and spread laterally by a jet pipe called a "trapezoidal cup" whose shape is shown in Figure 5.

The jet flow is fed into a rectangular ejector where it is diluted in order to increase its momentum.

This assembly is located underneath a wing and blows on the trailing edge flaps.

The purpose of this system is to attain considerable damping of jet flow noise by dividing the jet flow into a certain number of elementary streams and by diluting it in an acoustically treated ejector. We also noted that the rectangular jet flow was left almost totally unaffected by the rise of noise due to the impact of a cylindrical stream against high-lift flaps..

Among the different methods for obtaining high lift, this system is a variation of the blown underwing systems. The momentum of the blown flow obtained with a large flow, a moderate speed and rectangular shape enables great effectiveness to be anticipated upon first analysis.

In order to judge the merits of the concept and materialize a possible example of usage we designed a four-engine pre-project aircraft with a total weight of 30 tons , equipped with RR SNECMA M 45 H engines.

Figure 2 gives the three-view drawing and Figure 3 a model of the preliminary draft. We only wish to point out the thick right wing comprising a large rectangular portion - characteristics that were dictated by a desire for simplicity, ease of aerodynamic design, wing/powerplant interaction, and the moderate speed range desired (Mach 0.5).

This speed is the optimum for an aircraft that is to transport 60 to 100 passengers or 6 to 8 tons of cargo over short distances (500 km maximum).

Using this pre-project as the starting point a design and testing program was set up. First there was an aerodynamic testing program on a 1/12 scale model.

The purpose of the aerodynamic tests was to explore the possible performance range of lift augmenting, to verify the computation methods used to establish the pre-project, to ensure the possibility of lateral control with classical aerodynamic methods, and to make an initial exploration of the possibilities of longitudinal balance.

Figure 4 shows the model installed in the Cannes wind tunnel.

The program also included tests on power plant models with the objective of roughing out the problems of noise and to optimize the design of the elements in the propulsion system.

Testing at approximately 1/2 scale using the high speed Aerotrain and its JT 12 engine, for the purpose of studying noise during run-up and transition were performed

This text briefly goes over the aerodynamic and acoustic results obtained during these tests and puts emphasis on points of general interest:

- The methods of predicting the performances of the ejector/??? wing system [text illegible]

8-2

2 - AERODYNAMIC DESIGN

The Aladin project was preceded by a preliminary aerodynamic development program in order to reduce empirical trial and error and to limit testing. The work described herebelow constitutes an example of the practical possibilities offered by computation in the design of a new aerodynamic configuration without necessarily involving extensive facilities.

2.1 - Estimation of Wing Aerodynamic Performance

The purpose of this first study is to provide an estimation of the blown wing characteristics (lift, drag) for variations in the following parameters: aspect ratio, proportion of wingspan equipped with flaps, flap chord and deflection, blowing coefficient, characteristics of the ejector. This enables the overall dimensions of the model to be defined so that the desired performance objectives can be satisfied. Subsequently, after adjustment of certain coefficients, the method can be used to interpolate the test results or to apply them to other configurations.

This is a simple, semi-empirical method of calculation that relies on classical data.

Lift is expressed as a sum of different terms:

- Lift of the naked wing
- Additional lift from flaps without the effect of blowing, depending on the flap chord, span and deflection (ref. 1)
- Additional lift due to hypercirculation induced by blowing, depending on the blowing coefficient of the jet flow angle, with the values being deduced from the Spence computations (ref. 2)
- Lift due to the jet flow with the true thrust and the actual deflection angle $\Delta Cz = 70\ C_\mu \sin(\theta_j + \alpha)$ being taken into account

Likewise, drag is broken down in the following way:

- Drag due to friction and form Cx_o
- Additional form drag due to the flap (ref. 1)
- Induced drag solely related to the lift effects in connection with circulation around the wing
- Horizontal thrust component of the jet stream $Cx = -7\emptyset \; C_\mu \cos(\theta_j + \dot{L})$
- Drag due to buildup on the ejector.

One will note that some of these estimations are pessimistic - for example the additional lift of the flaps is probably underestimated. Other factors, however, are optimistic - for example, the hypercirculation effect is probably overestimated due to linearly applied theories at large deflection values.

One will also notice a considerable deviation of this model from the jet flap theory as far as drag is concerned: firstly, only the horizontal component of the deflected jet stream thrust is taken into consideration instead of total thrust; secondly, the induced drag is only relative to that portion of lift that is connected with circulation. This purely empirical hypothesis is justified by comparison with the experimental results; it gives more realistic values for high C_μ and large deflection.

The results obtained with this very simple model are satisfactory provided that the following particularities are brought into the picture:

- The lower ejector fairing fitted with its leading edge slat greatly curved downward constitutes a non-negligible airfoil surface adjusted negatively in relation to the wing, resulting in a considerably high zero-lift-angle value ($i \sim 5°$).

- The effective deflection angle of the jet stream for a given angle of the flaps is smaller than for classical external blowing systems as was indicated by the run-up tests.

The lift and drag coefficients for different flap deflections and for variations in C_μ are shown on Plate 6. One can note that agreement between calculation and testing is relatively good on the whole.

Notice that the calculation is rather pessimistic for $C_\mu > 2$ and for C_z at small deflection values. It would undoubtedly be possible to obtain a better harmony by adjusting the different coefficients of the model. A loss in flap efficiency for a deflection of 70° and an angle of attack of 20° is also observed.

The mockup enabled the overall dimensions of the model to be defined:

- Aspect ratio: 5
- Proportion of wingspan occupied by flaps 60%

8-3

- Relative chord of flaps 30% (20% + 10%)
- Approximate deflection of the flaps:

	First flap	Second flap
Takeoff	15	30
Approach	30	60

NOTE - Evaluation of maximum lift is very difficult before testing. A rough estimation can be made by setting the angle of attack of maximum lift between 20° and 25° for efficient leading-edge high-lift devices.

2.2 - Planar Circulation Design

The primary purpose of this stage is to define the shapes and positions of the various profiles (main profile, leading edge slat, ejector fairing, profile of propulsive jet pipe, flaps) in the central portion of the rectangular wing.

A specificity method was used to calculate the ideal fluid flow around the various profiles. The suction effect of the ejector is simulated by an artificial means (Plate 7) in which the profile of the ejector's lower fairing is extended by a fictitious cone so that an induced flow evaluated elsewhere (monodimensional calculation of ejector) is obtained at the rim of the ejector. The distribution of the speeds calculated in this way are only significant for the upstream part of the flow, but this limitation is of no consequence in the design of the leading edge outlines. The shapes and positions of the various elements were modified until reasonable, well-distributed overspeeds were obtained in the different zones so that the risks of separation were limited. Determination of the flow lines also enables the outline of the forms to be guided. According to the problems analyzed, 2, 3, or 4 profiles can be considered; depending on the desired degree of precision in the distribution of speed, each profile is defined by a larger or smaller number of points (from 12 to 96).

After a preliminary examination which led to an integrated ejector concept in which the primary profile constitutes the upper fairing of the ejector, work focused on the following parameters:

- Longitudinal position of the ejector: a forward position favors flow on the leading edge of the profile, an aft position favors the outline of the lower fairing.
- Form of the lower fairing: the leading edge had to be equipped with a drooping slat.
- Leading edge slat: the form, position and angle of incidence of the slat were chosen in order to minimize overspeeds. Two slats were tried, one measuring 20% of the chord, the other 15%. The latter was chosen to limit interaction with the engine nacelles and was found to be sufficiently effective.
- Tapered jet pipe: although the tapered jet pipe is not strictly bidimensional, the position and angle of incidence of an "average" profile were determined in order to minimize disturbances in the supply of the ejector.

Plate 8 shows the speed distributions obtained with the different leading edges; one notes that the overspeeds on the different airfoil profiles are relatively moderate and more or less balanced. The tests revealed that there were in fact no flow problems in this domain, and it was not necessary to adjust the setting of the leading edge slat during testing.

Design of Trailing Edge Flaps

The trailing edge system must satisfy two conditions:

- Effectively divert the blowing flow;
- Prevent separation on the top skin of the flaps.

For lack of a directly usable method for calculating the non-isentropic flow around the flaps (viscous flow or jet stream calculation in an ideal fluid) work was limited to a few simple tests in deviating a jet stream from an ejector of the Aladin type with a full flap during engine run-up, using an installation designed for acoustic testing. Figure 9 shows the speed samples in the symmetry plane for various configurations.

8-4

One notes qualitatively that the deviation angle of the jet stream is less than the angle of the flap, especially as the angle of the flap increases and the chord decreases; this is one of the specific characteristics of the ejector blowing design which results in a thicker jet stream than that of classical external blowing. The flaps should be specially designed for this case.

Samples in a lateral plane showed that the jet stream has a small initial diffusion angle (about 7°) which suddenly increases upon reaching the flaps (about 25°). Pressure measurements on the lower skin of the flap enabled very approximate evaluation of the blowing flow of the slots.

It is interesting to note that the largest defects in the model were to be found in the design of the trailing edge flaps for which there were no means of calculation.

2.3 - Three-dimensional Design

Analysis of the lift distribution in span and of the various three-dimensional effects was performed using a non-linearized ideal-fluid calculation. The method designed at the Centre de Calcul Analogique (Analog Calculation Center) of Professor Malavard (ref. 7) uses a specificity distribution on the surface of the wing. Unlike the usual methods for linearized airfoil surfaces, it remains valid for high incidence angles and deflections that blowing makes possible.

The wing sketched as part of the calculation comprises a rectangular central portion equipped with a single flap, and a twisted trapezoidal end equipped with ailerons.

The ejector, the blowing system, and the leading edge slat are not shown; it is assumed that the effect of a flap in an ideal fluid is equivalent to that of a blown flap in a real flow. Analysis was limited to the following parameters:

- Deflection of flaps
- Deflection of ailerons
- Twist of the end

The spanwise distribution of Cz (Plate 10) reveals a very large reduced-lift zone just to the outside of the flaps. This drop in Cz corresponds to a lower-skin depression near the trailing edge induced by the tip vortex coming from the flap. Study of the overspeeds on the leading edge show that there is no risk of premature stall of the section equipped with ailerons for a moderate twist of -5° of the end chord; greater twisting (-8°) was nevertheless adopted to improve the maximum efficiency of the ailerons with the result that 2% of the total Cz is lost and 3% is gained in induced drag.

Three-dimensional analysis provides some indications concerning lateral control in the case of failure of one engine: the efficiency of the ailerons can be estimated through calculation. The interaction effect with the flap tip vortex is experienced as an improvement in aileron efficiency on the side of the lowered aileron. Also, the moment related to engine failure can be broken down into an easily estimable jet stream component and a hypercirculation effect; in order to estimate the latter element two extreme hypotheses can be brought up:

- Optimistic hypothesis. Blowing of the remaining engine is distributed over the entire flap.
- Pessimistic hypothesis. All blowing effect is lost in the area corresponding to the malfunctioning engine.

Tests gave intermediary results which could be incorporated into a more perfected method of prediction.

3 - TESTS

The tests were performed in the S_1 Ca ONERA wind tunnel in Cannes with a 3-m diameter airflow. Most of the tests were carried out at 22 m/s, with the maximum C_μ at this speed being 2.7.

Firstly the tests enabled the aerodynamic performances to be measured; secondly they enabled lateral control to be studied in the case of engine failure.

The model consists of a half-model without tail fins mounted to the wall. The engines supplying the ejector nozzles in the form of a trapezoidal cup are themselves simulated by ejectors supplied with compressed air; their dimensions hold within nacelles that are close in size to those of real engines equipped with intake silencers. The support pylon, however, was enlarged to allow for sufficient air flow. The blowing nozzles are of a simpler fabrication than the real nozzles. They have a thrust coefficient of 1.12 at run-up.

8-5

Measurements include lift, drag, pitching moment, and the rolling moment of the wing. The C_μ values are for the momentum of the trapezoidal cup that were determined thanks to a previous setting made in relation to the kinetic pressure. Wool thread visualization allowed flow defects to be detected.

The variable parameters are the following:

- Blowing coefficient C_μ with simulation of external engine failure;
- Deflection θ_1 and θ_2 of the trailing edge flaps;
- Setting of the leading edge slats (in actuality this did not have to be modified)
- Ailerons at 25% depth.

RESULTS

Visualization

The visualizations show qualitatively that flow is good on the whole up to high incidence angles which increase as C_μ increases (20° for $C_\mu > 1$). Stall occurs with a vortex at the wing root. For the maximum deflection ($\theta_1 = 40° - \theta_2 = 70°$) the top skin of the second flap is poorly supplied; this flaw most probably originates from poor design of the blowing slot which was made for less deflection.

Run-up Tests

Measurement of the thrust vector for variations in deflection reveal the following:

- A coefficient of ejector thrust increase (at zero deflection) of 1.12.
- A deviation efficiency (thrust/thrust with zero deflection) which decreases quite sharply with deflection according to a law similar to that obtained through other external blowing tests (refs. 3-6).
- A smaller deviation angle than in the above references (Plate 11).

This discrepancy can be attributed to the fact that the jet stream at the outlet of the ejector is much thicker than the jet stream produced by flattening of the sonic jet stream. Indeed, the deviation tests (Plate 9) showed that the ratio of the flap chord to the height of the jet stream is an important parameter. Ideal fluid calculations confirm this (ref. 8). It seems that significant improvement could be achieved in flap efficiency by working on the depth, the width, and the design of the slots; it can be estimated that a 10° gain in the effective deviation angle would yield a $\Delta Cz \sim 0.5$ for $C_\mu = 1$.

Performance Tests

The lift graphs (plate 12) indicate good linearity up to about 20° for $C_\mu \geq 1$. For a deflection of $\theta_1 = 15°$, $\theta_2 = 30°$, the incidence angle of maximum Cz could not be reached and is in the neighborhood of 32°; at a greater deflection a maximum Cz of 7.3 was measured at $C_\mu = 2.7$.

The polar curves (Plate 13) are similar in shape to those obtained in other external blowing tests. They indicate 1) good efficiency of the leading edge slats, 2) the effect of the ejector which increases the gross thrust of the jet stream, but introduces a build-up drag, and 3) the limitation of deviation at large deflection values.

Lateral Balance in Case of Failure

The problem here consists in balancing the lift on both sides, with failure of the external engine being the most critical.

The means of verification experimented are the following:

- Differential deflection of the ailerons ±25°
- Deflection of a spoiler
- Differential deflection of the second trailing edge flap.

The tests show that flame-out of the external engine results in a slightly greater loss in lift than the decrease linked to the sole drop in C_μ (with both engines operating), but which is still less than half the total effect of blowing. The remaining engine therefore probably provides a partial supply to the flap zone corresponding to the failed engine. This is confirmed by the position of the application point of this force. A ±25° deflection of the ailerons yields an efficiency ($\Delta Cz \pm 0.3$) approximately equal to that found through three-dimensional calculation of an ideal fluid at a lesser deflection (20°).

The interaction effect between the aileron and the tip vortex of the flap seems to be encountered once again; indeed the lift of the lowered aileron is greater than that of the raised aileron, however, the application point is closer to the flap, which indicates that the gain in lift is located in a zone near the flap.

Deflection of the spoiler has a very minimal influence (ΔCz - 0.15) regardless of the configuration.

Differential deflection of the second flap, though, is very effective.

On the whole, use of the ailerons alone is sufficient to balance an external engine flame-out for a C_μ value in the vicinity of 1. Additional differential deflection of $\pm10°$ of the second flap ensures a margin of at least 30% over the entire range of configurations of the project (Plate 14).

In the case of failure, the laterally balanced polar curves are approximately the same as those without failure for the same total C_μ. The effects of pitch and yaw balancing remain to be added. As for pitch, the Cm and downwash measurements on the tail fins showed that a horizontal tailplane surface of 40% is enough to ensure a comfortable aircraft balance margin.

CONCLUSIONS CONCERNING AERODYNAMIC DESIGN

The design of the model resulting from the foregoing work turned out to be almost entirely satisfactory, enabling the tests to be kept to a minimum. The primary correction made consisted in increasing the deflection of the flaps in order to compensate for their lack of deviation efficiency. Performance could undoubtedly be improved by better design of the flaps; this work would be facilitated by a calculation method which, it seems, could be developed rapidly. Performance could be predicted with an acceptable degree of accuracy during the pre-project stage, and perhaps even the effectiveness of lateral control in the case of engine failures could also be evaluated.

Accurate prediction of the maximum lift is certainly more difficult and requires careful boundary-layer and separation calculations. One should note that the values obtained in a wind tunnel at a low Reynolds number (0.5×10^6) are probably pessimistic.

4 - ACOUSTIC AND PROPULSIVE DESIGN OF THE EJECTION SYSTEM

The propulsion system consisting of the M 45 H engine, of acoustic treatment, the rotating elements, and the ejection system (trapezoidal cup and ejector) make up an assembly whose optimization conditions the overall performance of the aircraft.

The acoustic treatment of the rotating parts consists of a treated intake section enabling an damping of 12 PNdB of the noise radiated to the upstream side, and a treatment of the fan flow duct up to the junction with the warm flow yielding a 20 PNdB damping level of the noise radiated toward the downstream side.

In order to reduce the noise levels due to engine ejection, the solution considered consists firstly in mixing the two flows to bring down the ejection temperature and speed of the gases; the jet flow is then divided by a trapezoidal-cup-shaped duct with the ejector performing a considerable amount of dilution during the final phase. The ejector is acoustically treated in order to reduce the noise coming from the mixture of the engine flow and the induced flow.

The acoustic and propulsive designing of the ejection system was conducted at the same time as aerodynamic design and testing of the aircraft, on small-scale models (1/10 scale), and during the final stage on engines of the 1200-daN takeoff thrust range.

Since this work primarily consisted of run-up configurations, translation testing scheduled for the near future on the Aerotrain with a GE J85 engine will enable the acoustic and propulsive performance of the installation to be confirmed for the entire assembly up to a Mach number of about 0.25.

4.1 - Subsequent Design Stages - Models

Insofar as propulsion is concerned, the design of the installation made it possible to minimize the internal losses of the relatively complex-shaped duct while maintaining its acoustic performance. In addition, the influence of the geometric parameters of the ejectors used during the different phases of perfecting the duct and modifying its external form, was analyzed.

The testing facilities which we have available determine the overall dimensions of our ducts. The scale adopted was near 1/10. Propulsion performance was measured on our thrust bench on Quai de la Gare in Paris and in the facilities of the Propulsion Test Center in Saclay; the same models were also used to monitor the acoustic performance in hot gas at the Propulsion Test Center, and in cold gas in our own facilities.

This evaluation program using small models was conducted on three metal-formed ducts of the type shown in Figure 16, corresponding to the various stages of development.

A model of a fourth of a nozzle made of molded plastic allowed us to improve the internal shapes through visualization on a hydraulic bench and to position the vanes necessary for good distribution of the flow in the entire ejection zone.

Due to the uncertainties concerning the conversion of acoustic results on the scale of the M 45 H, a complementary program was initiated with the objective of analyzing the ejection device on a real engine (JT 12 A6 by Pratt and Whitney) for which the scale is half in relation to the M 45 H. The model of the nozzle (Figure 5) constructed for this engine, which is hotter than the M 45 H, also enabled us to confront the technological problem linked to the fabrication of such an installation and to arrive at satisfactory solutions.

As for the ejectors, analysis of the parameters (acoustic and propulsive) essentially covered the influence of σ_c, of the presence or lack of a diffuser, and acoustic treatment.

4.2 - Test Results

4.2.1 - Propulsive Performance

As compared to the first nozzle used to rough out the performance of the unit, a gain of 4% in the thrust coefficient was obtained during the successive development tests. This improvement was reached by optimizing the internal forms in such a way as to eliminate separation, by reducing the surface area of the internal vanes in order to limit losses due to friction, and by adjusting the section laws so as to reduce the speeds in the most critical zones.

The thrust coefficient curves (Plate 15) show that for the nozzle alone the losses drop off when the expansion ratio of the jet stream increases; in reality the losses remain somewhat the same but the induction which occurs in the area of the injectors compensates for them in increasing proportions as the ejection speed increases. On the whole, under the conditions of the M 45 H for an expansion ratio of about 1.56 for the mixed jet stream, the injector losses in relation to a reference converging nozzle will be about 3 to 4%.

The tests with an ejector enabled us to determine the influence of the geometric parameters σ_c and σ_d in particular on the propulsion performance and for configurations with acoustic treatment, and to estimate the corresponding thrust losses. We summarized these principal results in the table below with the ejector gains being expressed in per cent in comparison to the reference nozzle.

Run-up thrust gain of the ejector as compared to the reference nozzle $\frac{P_i}{P_a} = 1.6$

	σ_c	$\sigma_d = 1$	$\sigma_d = 1,17$
Smooth ejector	4	14,5 %	20 %
	4,5	16,5 %	22 %
	5	20,5 %	25 %
Treated ejector	4	12,5 %	17,5 %
	4,5	14 %	19 %
	5	18 % %	21 %

The diffuser effect is of considerable consequence during run-up; at higher speeds, however, with its influence becoming less beneficial, optimization will be necessary. Estimation of thrust losses due to acoustic treatment for the project is dependent upon the value of the friction coefficient on the wall that is adopted. Model tests compared with our prediction calculations enabled us to evaluate this friction coefficient. The value adopted corresponds to about 2.5 times that of the friction coefficient on the smooth flat plate - a value which, incidentally, seems to be consistent with friction measurements on perforated sheet metal in a hydrodynamic tunnel.

As far as interpretation of these results is concerned, by taking into account the effect of the scale and, in particular, the caps which cannot be avoided in the fabrication of the nozzles, we estimate that the gain during run-up of the system at takeoff power is at least 15%.

8-8

4.2.2 - <u>Acoustic Performance</u>

Acoustic development of the system is intimately linked to the propulsive performance. Division of the jet streams implies a large increase in the perimeter of the nozzle and therefore in the friction surface. As a general rule the best compromise is obtained when complementary damping, due to a modification with respect to the optimized solution, is equivalent to what would have existed if a reduction in thrust equal to that created by the loss complement, were effected.

The subsequent stages of both acoustic and propulsive optimization enabled us to obtain a damping of 13 PNdB of the jet stream noise at 150 m laterally from the power plant installation on a model at the present stage. During overhead flight the bidimensional form of the blowing jet stream is favorable to a decrease in interaction noise with the flaps when compared to a cylindrical jet stream having the same pressure ratio. On the model the corresponding damping obtained reached 10 PNdB. The directivity diagrams shown on Plate 5 provide an estimation of the shape of the linear noise field transposed from run-up tests on a model.

The tests carried out on the JT 12 A6 engine (installation without wing) confirmed the results obtained on the model.

CONCLUSION AND CONTINUATION OF DEVELOPMENT OF EJECTION SYSTEM

The model tests demonstrated to us that this type of propulsion installation has the advantage of providing about 15% more thrust at takeoff when compared to the reference engine, while keeping acoustic disturbance down to acceptable levels.

Continuation of this work with the objective of optimization for the various phases of flight should enable us to come up with a propulsion installation project having a very homogeneous performance range. As far as the acoustics are concerned, effort must be focused on the efficiency of the ejector treatment and on the influence of the flying speed on the effective performance range of the system; our next translation tests will provide us with valuable information in this regard.

GENERAL CONCLUSIONS

The tests summarized above enabled the feasibility of the "Aladin II" concept to be considered as a silent power plant. Application to a STOL aircraft project is possible at the cost of a motorization rate limited to 0.4, with transverse and longitudinal control of the aircraft at low speeds appearing to be possible with classical control surfaces.

8-9

NOTATION

C_μ	Blowing coefficient added to the momentum of the propelling jet pipe
Cx	Drag coefficient
Cz	Lift coefficient
Cm	Pitching moment coefficient
C_L	Rolling moment coefficient of the wing
η	Deviation efficiency $\frac{\text{Deviated thrust}}{\text{Thrust without deviation}}$
ϕ	Thrust increase coefficient of the ejector $= \frac{\text{Gross thrust of ejector}}{\text{Jet pipe thrust}}$
θ_1	Deflection angle of first flap
θ_2	Deflection angle of second flap
θ_j	Jet stream angle
i	Angle of incidence

σ_C = $\frac{\text{section of ejector mixer}}{\text{effective section of the nozzle}}$

σ_D = $\frac{\text{outlet section of the ejector cone}}{\text{section of the mixer}}$

C''_T Thrust coefficient in reference to the isentropic thrust of the engine flow.

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Cross-sectional view

of engine from the rear

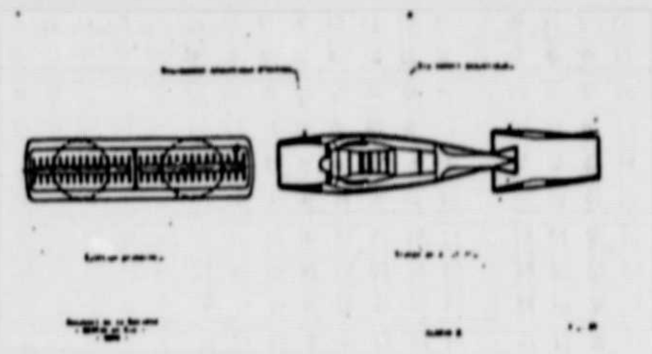


Figure 1

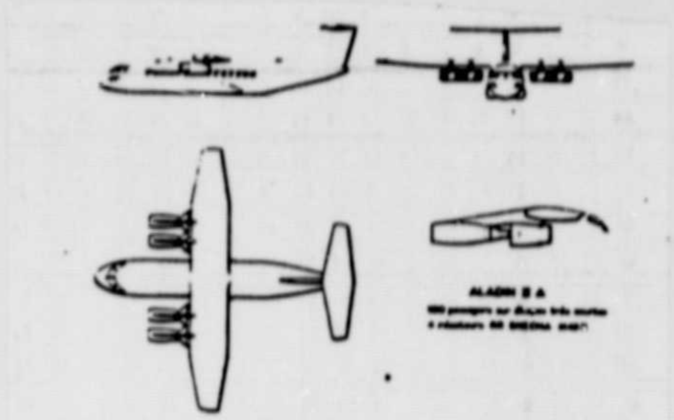


Figure 2

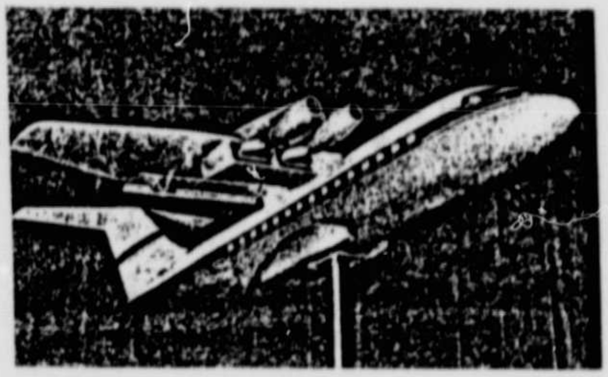


Figure 3

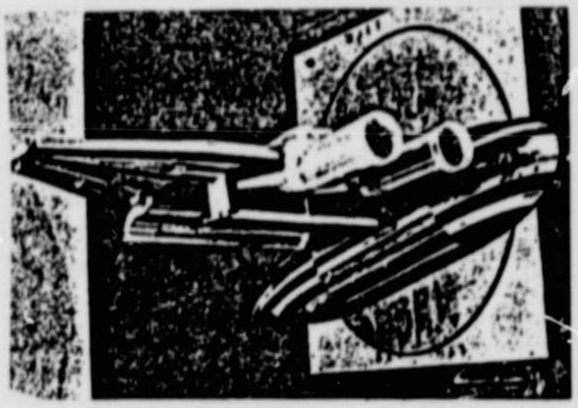


Figure 4

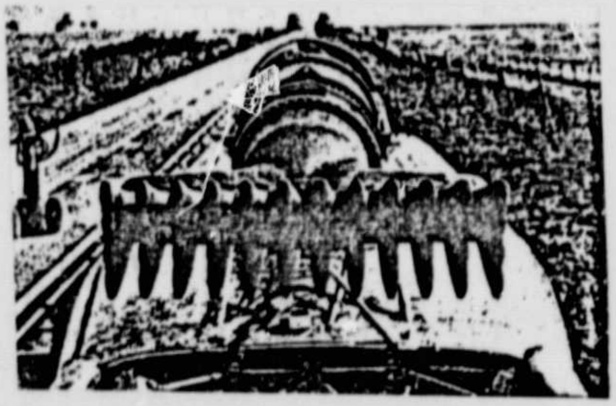
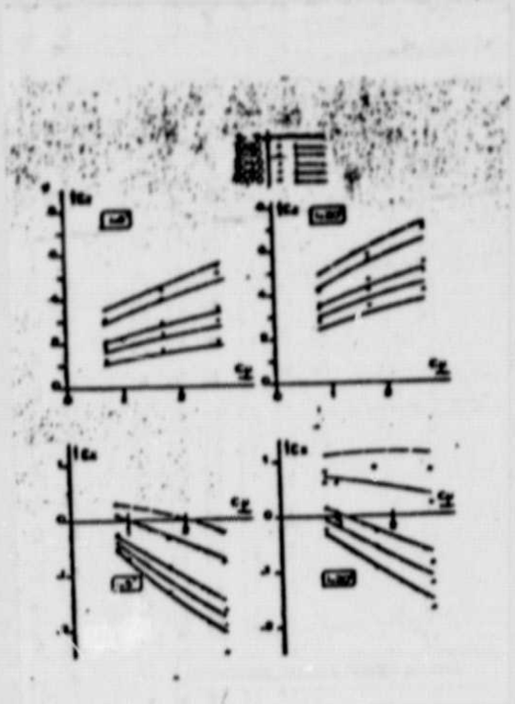


Figure 5



Calculation/testing comparison

Plate 6

BIDIMENSIONAL CALCULATION OF AN IDEAL FLUID - Plate 7

Plate 7

Key: 1 - Actual profile 2 - Sketched profile

3 - Flow lines

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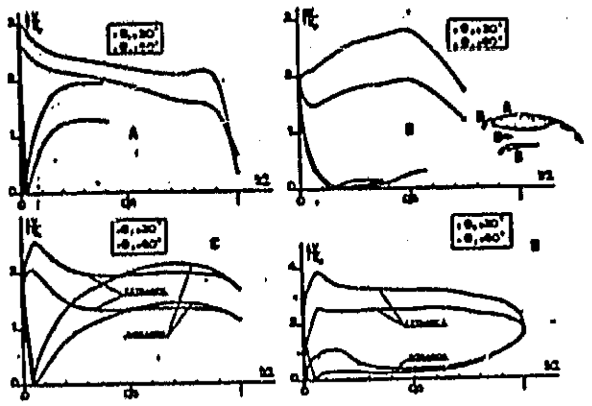
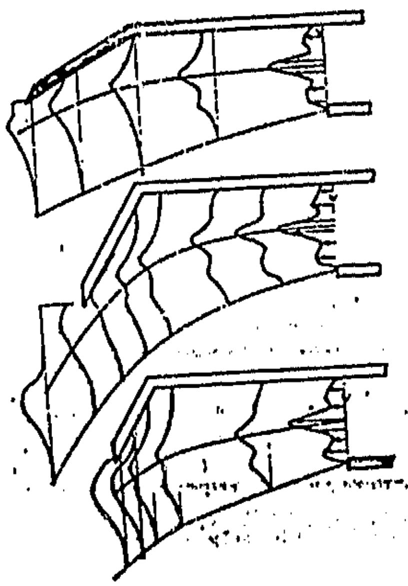


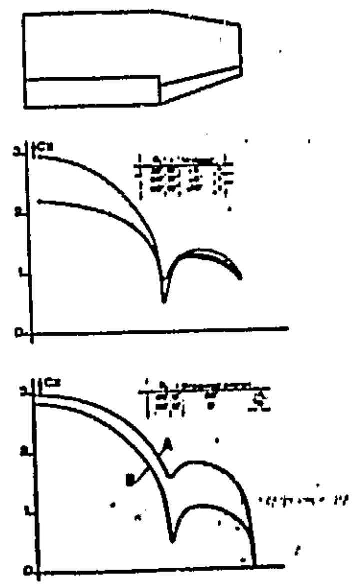
Distribution of the speeds on the profiles - Plate 8

Plate 8



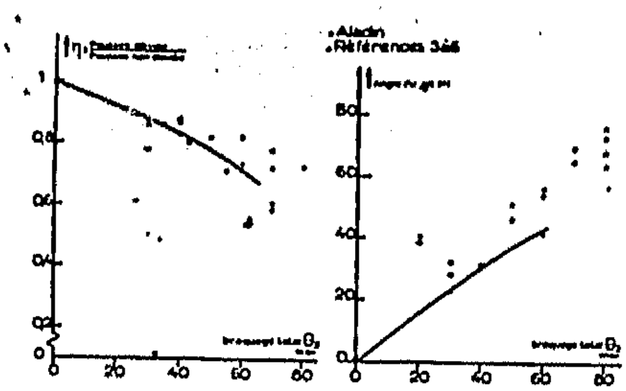
Jet deflection test

Plate 9



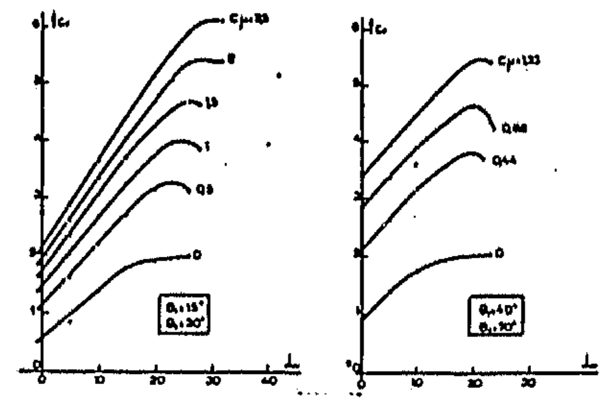
Three-dimensional calculation

Plate 10



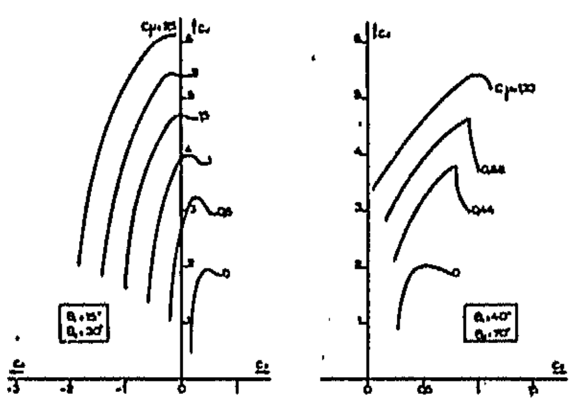
Run-up tests

Plate 11



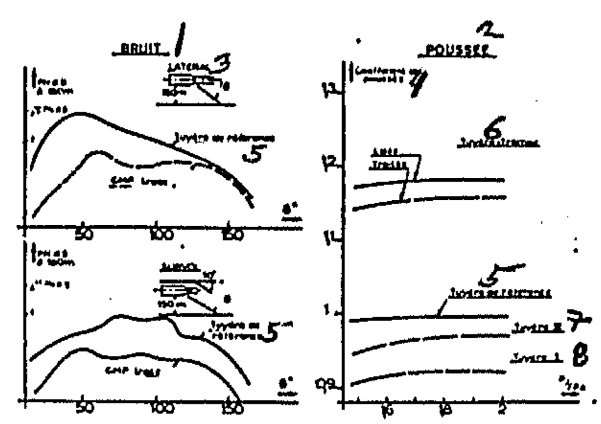
Lift

Plate 12



Polar curves

Plate 13



Jet pipe performance

Plate 15

Key to Plate 15: 1 - Noise 2 - Thrust 3 - Lateral 4 - Thrust coefficient 5 - Reference nozzle 6 - Ejector nozzle
7 - Nozzle X 8 - Nozzle I

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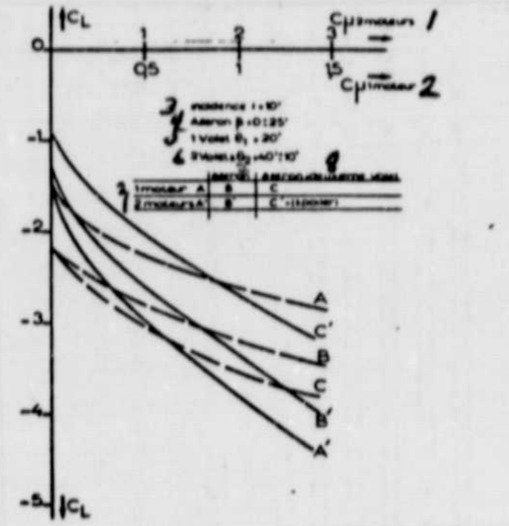

Lateral control

Plate 14

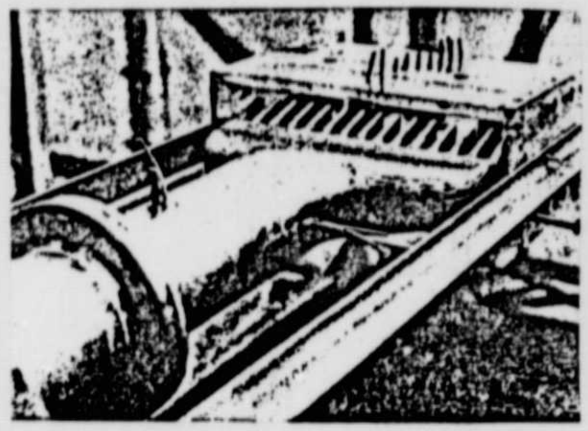

Figure 16

Key to Plate 14: 1 - 2 engines 2 - 1 engine 3 - Angle of incidence i = 10° 4 - Aileron β = 0±25° 5 - 1 flap θ_1 = 20° 6 - 2 flaps θ_2 = 40±10° 7 - Aileron 8 - Aileron + second flap