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AERO-THERMO ACTIVITIES FOR THE DEVELOPMENT OF A " PASSIVE INFRARED SUPPRESSOR " FOR HELICOPTER USE

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Summary

Reported herein are the R & D activities held by PIAGGIO in the I.R. Suppressor aerothermodynamic field.

This report summarizes the study on the suppressor background in the world and shows the correct methodology to define the design procedure. The most important aerothermodynamic problems are investigated and assessed by means of advanced computerized techniques. A self-contained device such a multi-stage ejector has been envisaged as the best solution for signature reduction. Heat transfer and aerodynamic processes within scaled-down suppressor models are under investigation by means of a specially devised test rig affording an adequate similitude of geometrical and aerothermal parameters. Special attention is payed to the test rig and computerized system description.

1. INTRODUCTION

As heat seeking missile technology has advanced, the infrared sensing detectors in the missiles have become more sensitive to the infrared signature target such as helicopter. With greater sensitivity, lower target signatures are required for adequate protection of the target. All aspects of helicopter infrared signature (e.g. hot exhaust tailpipe metal, exhaust plume, other radiating parts of the airframe external skin, etc.) should be taken into account if an effective passive system is to be designed.

PIAGGIO as a manufacturer of gas turbine engines that power helicopters became involved in developing infrared suppression systems for these power plants. The following paper describes the R & D activities in the aero-thermodynamic field in the recent years to define the design methodology and development means to produce passive infrared suppressors (SIR).

A deep analysis of the infrared suppressor already built and tested in the world, pointed out that the actual "*status of the art*" *of the suppressors* yields a device able to minimize the engine power loss and consequently the fuel consumption, with reduced weight *and without internal moving parts*. Hence all signature requirements of infrared countermeasures are so satisfied. The modern concept of a suppressor is referring to a self-contained device using the energy of the turbine exhaust gas to pump plume dilution and wall cooling air. Furthermore the general shape is such that the hottest parts of the engine are hidden to the I.R. detectors.

In order to develop such a suppressor, PIAGGIO R & D team analyzed the various aspects of the aerothermodynamic problems, the proper design techniques were investigated and set-up by means of advanced computerized techniques and specific tests on scaled-down suppressor models were accomplished. A dedicated low speed wind tunnel has been designed and employed at the R & D laboratory to verify the aero-thermo feasibility of the suppressor concept. Special instruments, metering devices and pressure probes have been developed to test the performance of the models. All testing parameters have been recorded by means of a computerized data acquisition system.

These works enable PIAGGIO to extend its aero-thermo background and fulfill its knowledge on suppressor philosophy allowing to design, test and qualify passive suppressors meeting the infrared and aero-thermo constraints required by customers.

2. STATUS OF THE ART OF SIR CONCEPT

Up to ten years ago, simple suppressors that hid the engines hot parts were built. Those suppressors, using *simple up-turned exhaust ducts*, were used for the hot metal protection and to obviate the direct line of sight into the engine exhaust area. This *simplified philosophy* did *not* take into account the need to lower the hot exhaust gas temperature, being that time kind of sensing detectors unable to lock-on this type of signature. Therefore this suppressor concept did not use secondary cooling flow for the hot gas dilution. See figures 2-1 and 2-2.

Subsequent step was a suppressor that attenuates the skin temperature of the visual parts of the exhaust duct.
A finned sleeve external to the exhaust duct was applied and a cooling flow powered by an electrical fan or a ram scoop was forced through. Just poor mixing of the hot cold streams was obtained outside the suppressor, the hot exhaust plume was still almost fully visible. See fig. 2-3.

In recent years suppressors that strongly attenuate the hot exhaust plume radiation were built and tested. These suppressors operated using the principle of an ejector to pump the dilution ambient air.

Further studies predicted that the kinetic energy of the turbine exhaust stream can be actually used to pump the ambient air to lower the hot gas stream down to the desired termal level. This kinetic energy was increased by a suitable nozzle system giving an ejector suction pressure capable to induce cooling ambient air both for plume and suppressor walls.

Then studies were directed to establish the best cooling schemes for the suppressor walls. High efficiency finned panels were employied to achieve the desired degree of cooling. However the heat transfer philosophy adopted, based on advanced "convective" cooling (the same as in the compact heat exchangers), required high cooling flow rates and pressure drops to force the flow through the fins and to increase the heat transfer coefficient: this resulted in relevant power loss to the engine, big weight, sizes and difficulties in the construction. See Fig. 2-4

Early in the last years an improved scheme of suppressor wall cooling allowed to reduce that penalities and to establish the present generation of suppressors. The new approach was to employ an "integral film cooling" design for the walls. Special louvered metal sheets were employed to film cool the exposed surfaces with less pressure drops. This was a significant improvement to reduce weight, size and power loss drawbacks of previous generations. A concept of the cooled wall configuration employed is shown on fig. 2-5 in comparison with the previous ones. Such a suppressor is shown in fig. 2-6.

Nevertheless suppressor different philosophies were adopted mixing some peculiar characteristics of the above generations with other cooling schemes. This was mainly done in order to fulfill specific requirements of helicopter mission, engine installation and infrared signature. So the simple ejector system was combined both with cooling schemes used in gas turbine combustors and afterburners (see fig. 2-7) and with using high efficiency open finned elements to take advantage of the rotor down-wash or cruise ram effects. (See fig. 2-8)

3. PIAGGIO DESIGN APPROACH

To reduce infrared emission from engine hot parts and exhaust plume, a modern suppressor must perform the following functions:

- Cool the engine exhaust plume
- Coll any visible surfaces
- Avoid the direct vision of engine or suppressor hot parts
- Avoid the images reflection of hot parts

The PIAGGIO R & D team has studied and defined an optimized method of design and has developed several computer programmes to simulate the phenomena through mathematical models. The whole R & D process includes the phases shown in the block diagram of fig.3-1.

4. ANALYTICAL MODELS

To establish the ejector suppressor overall aero-thermo performance a computerized analysis was used by means of suitable analytical models. A number of computer programmes, prepared in PIAGGIO and written either in FORTRAN IV or in BASIC language, was expressely dedicated to the phenomena simulation. The use of these programmes allows:

- To compute the aero-thermo performance and the geometric parameters of an ejector system both with circular and non circular duct shapes on the basis of the suitable flow rate ratio depending on the plume temperature required.
- To obtain a map of ejector families by varying specific geometric parameters. (See fig. 4-1)
- To draw a parametric map of suppressor families matching an ejec-

tor system to a specific engine so giving informations on the power loss. (See fig. 4-2)

- To deeply analize the aerodynamic field inside the suppressor by taking in special account both the bending and the shape of the ducts so allowing to optimize the visual blockage of hot parts and to control the inner reflection of the images. (See fig. 4-3)

- To predict the thermal level of the inner/outer metal walls of the suppressor on the basis of the specific cooling scheme adopted.

- To verify the aero-termo performance of a single suppressor over a range of different nozzle geometric setting.

- To estimate the temperature in localized parts of the suppressor whenever specifically required. Suitable coating materials or the control of the cooling rate to eliminate the hot spots can be taken into account.

- To define any specific geometric dimension of each part of the suppressor according to design or installation requirements.

The analytical models mainly take into account the following parameters:

- Wall cooling effectiveness

- Plume dilution effectiveness

- Ejector geometry

- Suction pressure both for the hot stream dilution and for the cooling of the walls

- Flow rates of hot, cold and mixed streams

- Fow rate ratios

- Pressures (total, static, dynamics) and pressure coefficients

- Temperatures

- Reynolds number

- Mach number

- Engine power and operating conditions

- Ram effects

- Fluid properties

- Weight

The above parameters as well as others not mentioned here, are computed basing on analytical formulas or experimental diagrams.

The use of computerized techniques provides a prompt answer to a range of thermal problems relating to suppressor design.

All the analytical models have been or will be validated by comparison both to rigorous testing on scaled-down models and to results available in the literature.

The computer management is based on the use of the following PIAGGIO computer systems:

- I.B.M. 4341

- DIGITAL PDP 11/35

- HP 9835

5. PIAGGIO SUPPRESSOR CONCEPT

The *suppressor concept that PIAGGIO* started to develop is meeting the actual "status of the art" of the most advanced USA technology as far as both plume and hot metal radiation attenuation are involved.

A film cooled tailpipe ejector system is envisaged by PIAGGIO to be the best solution.
This approach seems attractive since it suggests a highly reliable suppressor having no blowers or moving parts, both high capability of airframe integration and mechanical integrity with

good maintenance features.

The concept is a two-stage ejector both to dilute the hot exhaust gas and to cool the hot metal of the visible walls. It involves a structure of small size and light weight, offering in addition features of mechanical simplicity.

The first ejector stage uses the engine hot gas as primary power source and the main plume dilution air as secondary, while the second stage uses the mixed flow from the upstream stage as the primary and the wall cooling air as secondary source.

This suppressor was analitically designed to satisfy a specific infrared signature target of a PIAGGIO manufactured engine.

6. SUPPRESSOR SCALED-DOWN MODELS

The technique of modelling is employed when the full-scale experiment is prohibitively expensive for time, money, materials or when its nature is such that certain measurements are too difficult to be made with sufficient accuracy. Satisfactory model experiments are correspondingly those which are cheap and quick to perform and yield good results as for quantity and reliability.

It seemed attractive to PIAGGIO to get out preliminary design information from scaled-down models that allow to establish the feasibility of the adopted suppressor concept. They also enable both the choice of the best configuration and the optimization of the shape by a geometric and aero-thermo point of view.

In order to meet the basic requirements of the dimensional analysis for gaseous fluids, the Reynolds number, the Mach number and pressure coefficient are kept constant.

Back pressure, power loss and mixing rates as far as the wall film cooling effectiveness can be directly measured or computed.

To verify the aerodynamic performance of the adopted suppressor design and to establish the best wall cooling configuration, three scaled-down models were designed for R & D laboratory testing.

All the models are provided with the capability of changing the nozzle geometry. Thus the two stage ejector performance can be varied allowing to perform an extensive test of the analytical models already developed for design. The differences of the three models are the following:

- The first is a simply sheet metal model with no cooled walls. It is used to test the first stage ejector, the mixing process, the inner aerodynamic field predicted by the analytical models without the film cooling effect.
- The second is the true scaled-down model of the PIAGGIO suppressor concept. It allows to fullfill the knowledge on the ejector stages performance predicted by the analytical models with the film cooling effect. Also film cooling performance are determined.
- The third is a model for flow pattern visualization. Both the curvature effects and visual blockage of hot parts can be noticed; furthermore the wall cooling layer can be studied and optimized by a full-coverage point of view. The boundary-layer thickness along the walls is shown and dead or stagnation points along the streams path can be easily pointed out. So it is possible to make corrections getting rid of the relevant hot spots.

7. AERO-THERMODYNAMIC LABORATORY

7.1 General description

PIAGGIO at his plant of Finale Ligure, has at its disposal a newly built

R & D laboratory dedicated to test both scaled-down SIR models and their parts of special interest.

This laboratory is provided with:

- a subsonic, thermostatized wind tunnel (hereafter said test-rig);
- a computerized system both to control the test-rig and to collect and process the test data;
- mechanical, electric and electronic work-benches.

By the above test-rig PIAGGIO is able to develop a wide program of tests on SIR models, simulating several engine ratings under precisely assessed scaled-down condition. The test information allow to optimize the computer programs and to foresee the SIR prototype performances.

Furthermore it is possible to compare different SIR models concepts and to optimize their shape.

Specific analysis on parts of them of special interest can be performed so getting complete information on proper working of the adopted solutions.

The R & D test-rig can be also employed to perform a wide range of aerodynamic tests for specific engine components.

7.2 Test-rig and running

The test-rig of SIR models is set-up in a soundproof cabin (see fig.7.2-1) to keep the environmental conditions at a acceptable noise level to operators.

Air is used as working fluid.

Some silencers are installed outside the laboratory. Air passes through them before suction and after exhaust from the test-rig.

Three centrifugal fans supply the SIR model undergoing the test with suitable rates of primary, main diluent and wall cooling flow respectively.

The primary flow duct has square section. It is equipped with devices to lower the turbulence of flow (metallic mesh screens), to control and to meter the flow rate (by-pass duct, butterfly valve, total and static pressure probes).

A modular and thermostatically controlled electric heater is installed inside the duct to adjust the thermal level of the primary flow.

The same devices as in the square duct are provided also in the secondary circular ducts to control the rate and to lower the turbolence of the flow. They supply the main diluent and the wall cooling flows to the SIR models. Betterfly valves, orifice plates and a Venturi tube allow to adjust and meter the flow rates.

The down-scaled SIR model is set-up in a test chamber divided into two sealed parts to which the test-rig ducts are connected.

The primary and main diluent flows are blown into the larger one on which the nozzle of the model is assembled. The wall cooling flow of SIR model is supplied into the smaller. The side and upper walls of test chamber are plexiglas made to control the test running. Also this chamber acts as a plenum to lower the secondary flow turbulence.

The exhaust air of the model is metered by a traversing rake set-up downstream the test chamber and then it is piped outside the laboratory.

The table in fig.7.2-I shows the most important test-rig general features.

7.3 Probes and comouterized system

The computerized system designed and assembled in the aerothermodynamic laboratory allows to collect, process and show the pressure and temperature measurements, to control traversing rakes, movable parts of models and pressure scanning systems. The physical and electrical connections are shown in fig.7.3-1

The pressure signals are releaved by wall static taps and static, total and dynamic pressure probes as shown in figg.7.3-2 and 7.3-3.

They were designed and made in PIAGGIO by the R & D team to be easily integrated with the special shape of the SIR models.

Small, metallic and nylon pipes connect probes to the scanning system. This interfaces pressure transducers with capacitance type sensors.
Thus it was possible to replace manometer banks with few pressure transducers increasing the measurement accuracy without excessive costs. The pressure scanning system is remote controlled manually or by means of a computer through a stepping motor.
Mechanical and optical encoders are provided to control the step position.
An air operated dead weight tester supplies the pressure transducers with a reference pressure to calibrate the metering system on every complete scan. The electric analog signals are sent to data acquisition control unit. They are also shunted, and sent to analogue recording testers (oscilloscope and oscillograph) for checking purposes.

The temperatures of flow and walls are measured by sheathed, ungrounded thermocouples (fig.7.3-4). Their installation on the test rig and the SIR models was studied by R & D team as deeply as their shape, to minimize metering errors.

The data acquisition control unit includes a scanner and a digital voltmeter. The scanner receives through its optional plug-in assemblies all the signals collected from pressure and temperature transducers. It sends them, one at time, to voltmeter for measuring, statistical processing and digital transmission to the computer. Moreover the scanner allows the automatic control of actuators and stepping motors and hence the motion of pressure scanning systems, traversing rakes and variable geometry parts of SIR models.

A desktop computer controls the whole data acquisition system, stores and processes the measurements by suitable programmes. Its peripherals, plotter and printer, output the results in a suitable form for examination and analysis by test operators.

The computerized system is completed by a traversing gear. This allows automatic scans at the exit section of SIR models to evaluate the exhaust flow rate by a total pressure/temperature rake (fig.7.3-5).

A linear actuator is used to change the nozzle geometry of the model on test.

A high precision digital barometer supplies the environment pressure.

Several d.c. power supplies are integrated to power the electronic instrumentation.

During tests, moreover, the R & D team can satisfy specific needs using auxiliary instrumentation including:

- digital hand-held thermometers with special kit of probes;
- kits of thermosensitive paints;
- multichannel digital control units;
- pressure gauges;
- manometer banks.

8. FUTURE DEVELOPMENTS

The results on the scaled-down suppressor models supplied the expected aero-thermo informations needed to complete suppressor design. On completion of test on the models, the suppressor will be built and tested in a special free-field test bed. Accurate measurements of both aero-thermo performance and space distribution of infrared signature will be conducted with a reference of the standard exhaust pipe.

9. CONCLUSIONS

The actual "status of the art" of infrared suppressor has been presented. The PIAGGIO suppressor concept is in line with the present status and follows a well defined methodology of design.

The concept is based on the two-stage ejector action to dilute the hot exhaust gas and to cool the SIR walls.

The SIR shape is optimized to hide the inner hot parts from the external sight.

To verify the adopted concept three scaled-down models have been designed by means of expressely written analytical models, then built. These are undergoing tests on a dedicated test facility.

From the work up to now performed, it can be concluded that:

- An ejector system can satisfactory accomplish the function of diluting the engine exhaust plume and cooling the SIR walls with ambient air without dramatic power penalties on the engine.
- The adopted configuration and shape allow to improve the mixing of flows and to hide the inner hot parts.
- The test allowed to verify the proper working of the analytical models for simulation. Further activity should be performed in this area.
- The computerized system has been optimized and the data acquisition programmes have been assessed and verified. The testing procedures and instrumentations have been proved to be usefull for laboratory purposes and for the subsequent full-scale testing phase.

10. ACKNOWLEDGEMENTS

The writers wish to thank Mr. Massone and Mr. Bertoluzzo of R & D team whose substantial contribution made possible to perform the work herein reported.

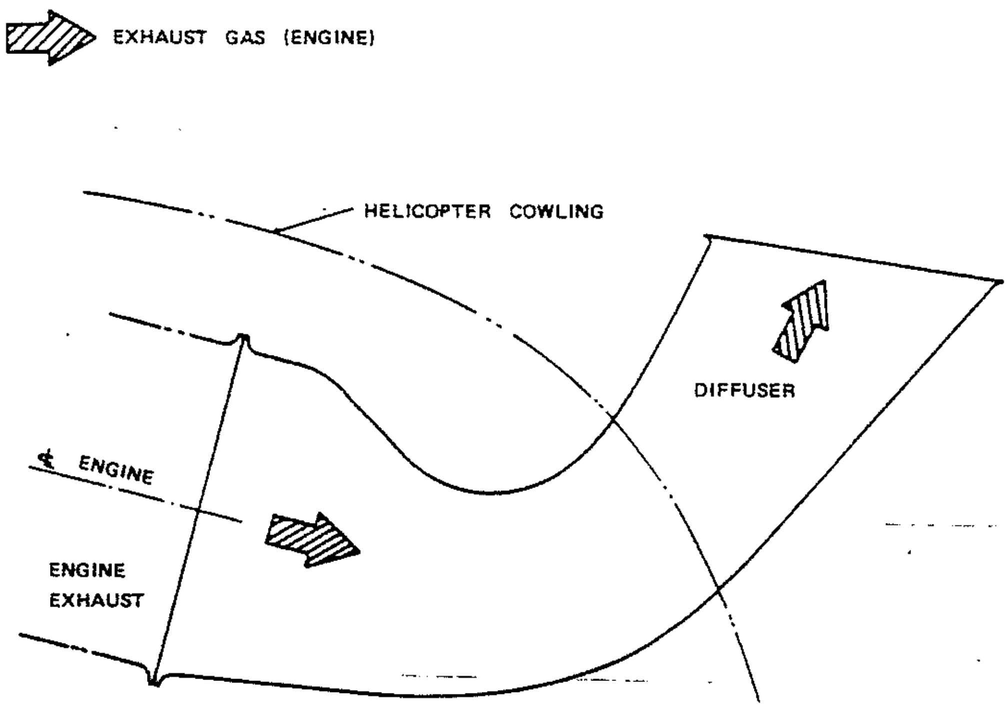

FIG. 2–1 ELBOW I. R. SUPPRESSOR

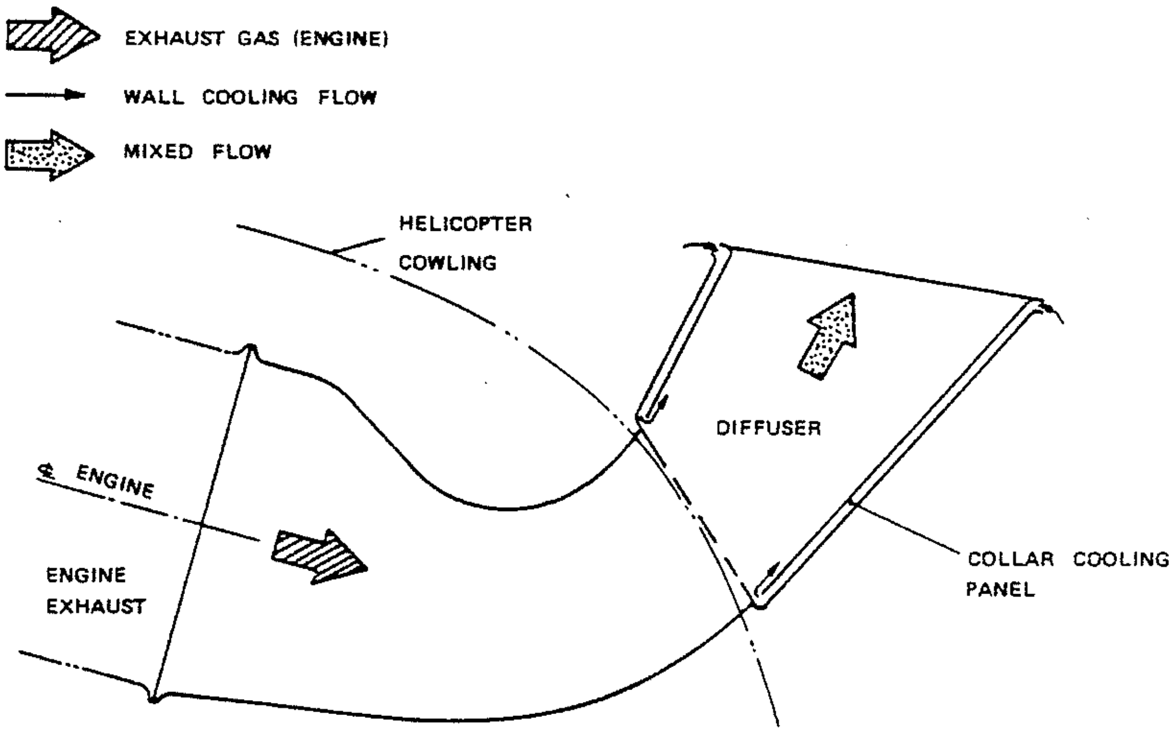

FIG. 2–2 ELBOW I.R. SUPPRESSOR WITH COOLED DIFFUSER

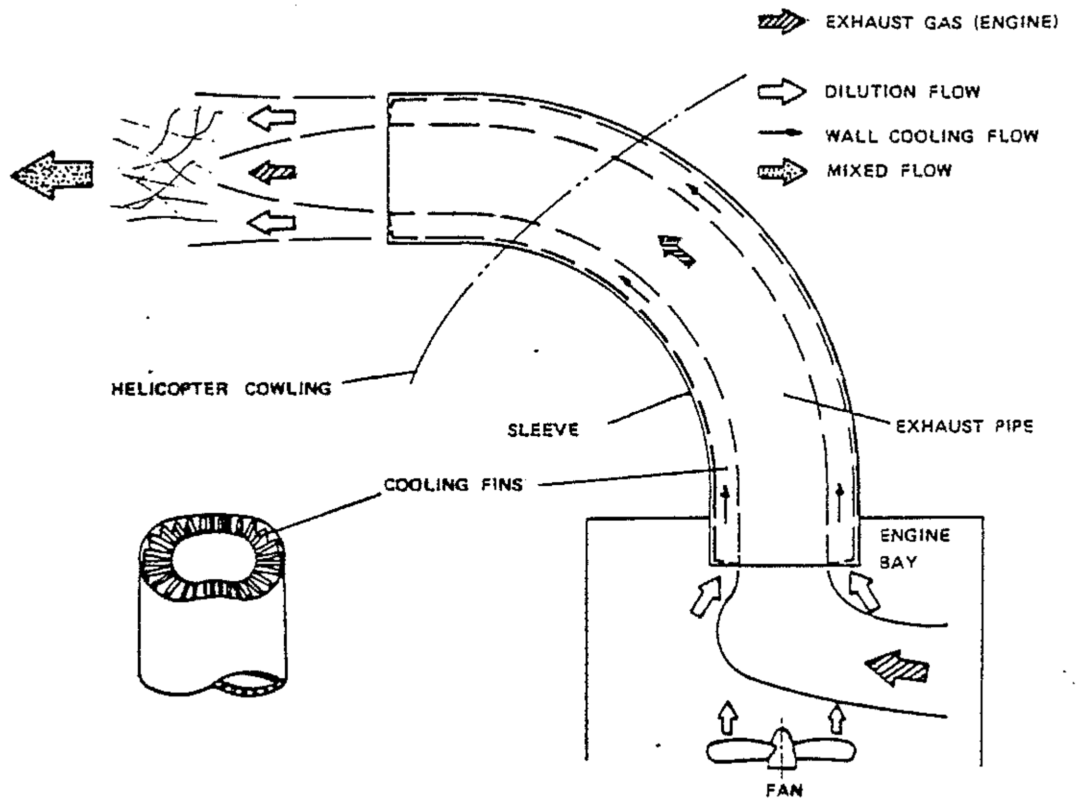

FIG. 2-3. FINNED SLEEVE I.R. SUPPRESSOR

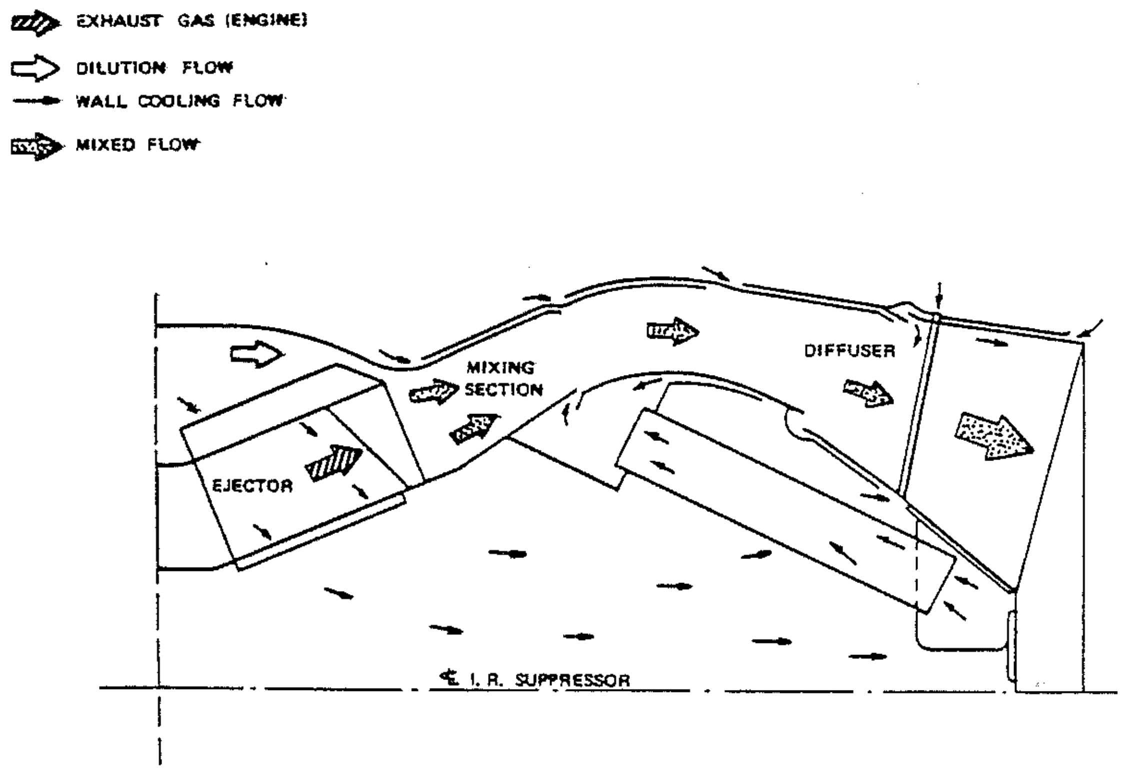

FIG. 2-4 EJECTOR I. R. SUPPRESSOR WITH PLUG AND WALL PANELS PHILOSOPHY

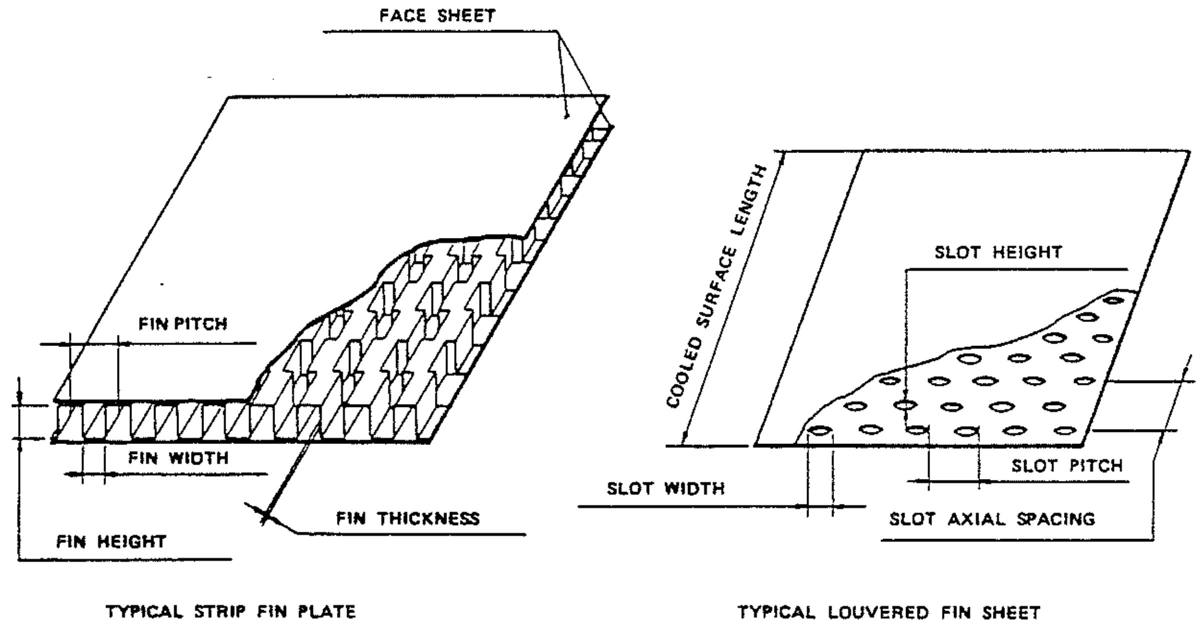

FIG. 2–5 WALL PANEL TYPICAL CONFIGURATIONS

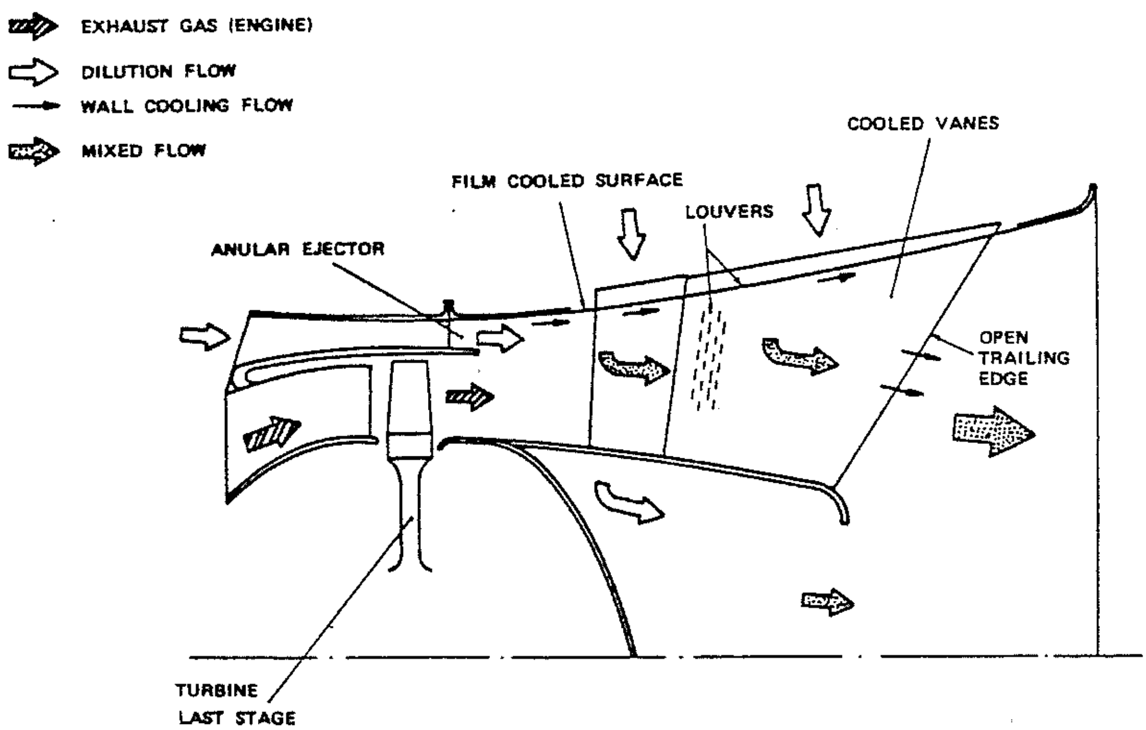

FIG. 2–6 ANULAR I.R. SUPPRESSOR WITH LOUVERED VANES AND FILM COOLING

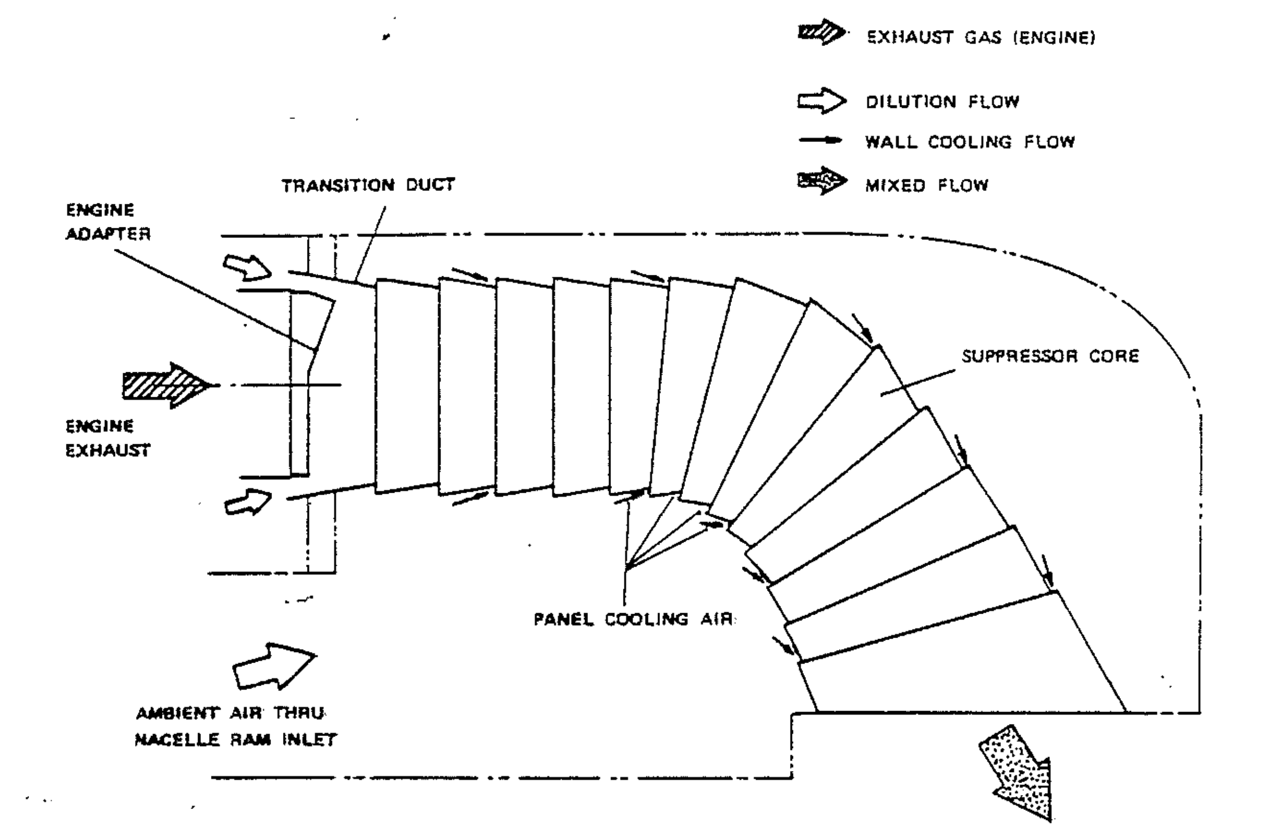

FIG. 2-7 PANEL COOLED I. R. SUPPRESSOR

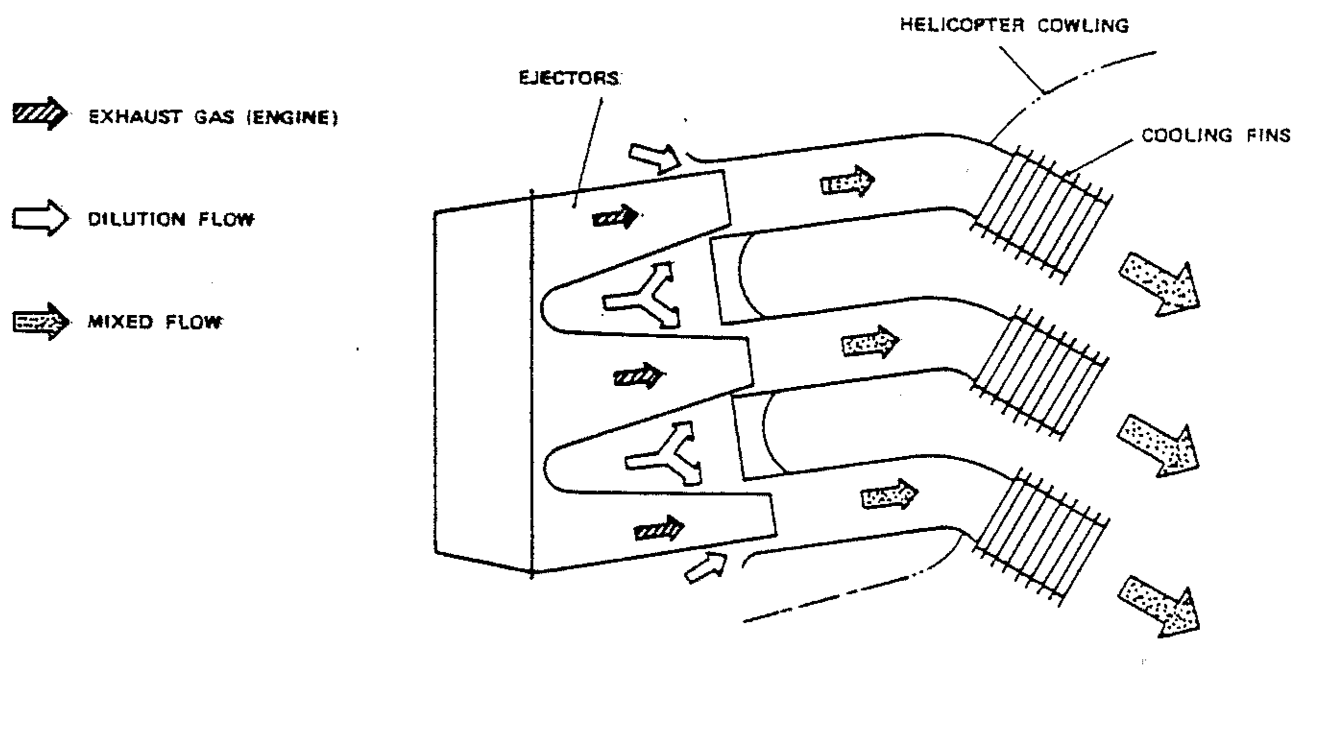

FIG. 2-8 FINNED DIFFUSER I. R. SUPPRESSOR

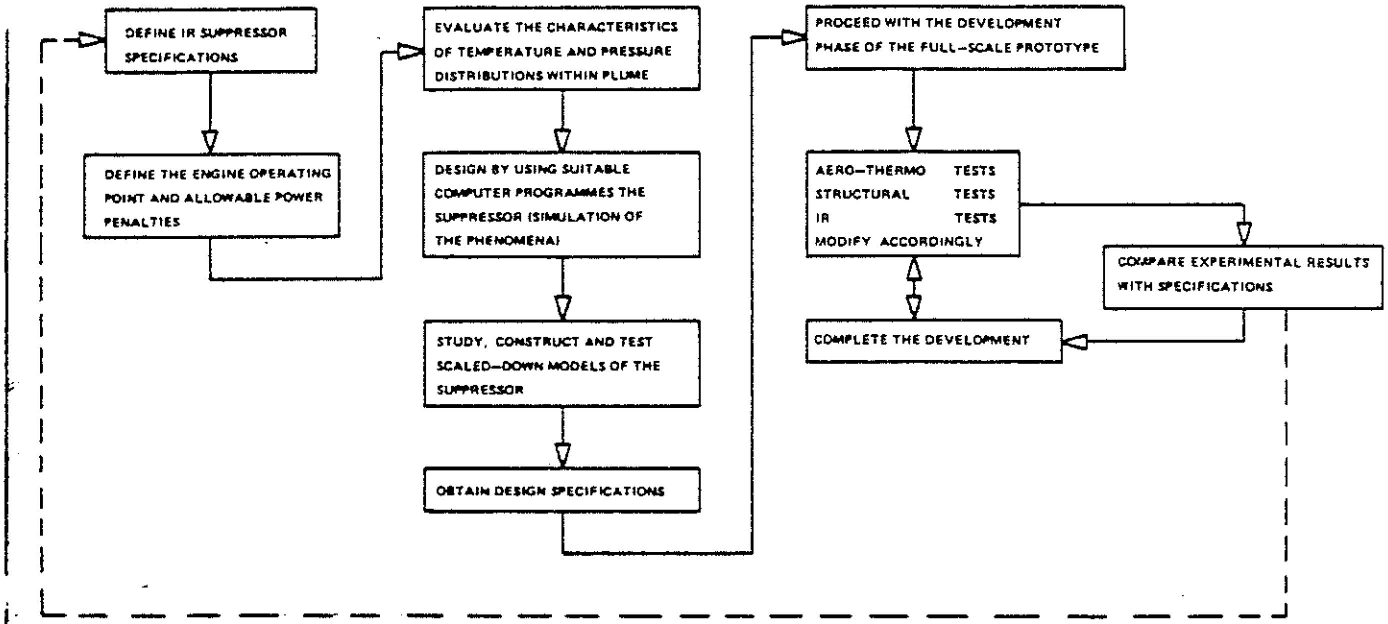

FIG. 3-1 PHASES OF DESIGN PROCESS

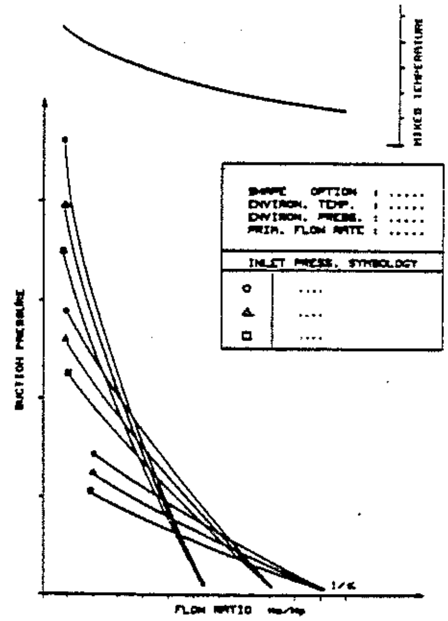

FIG. 4-1 EJECTOR PERFORMANCE MAP

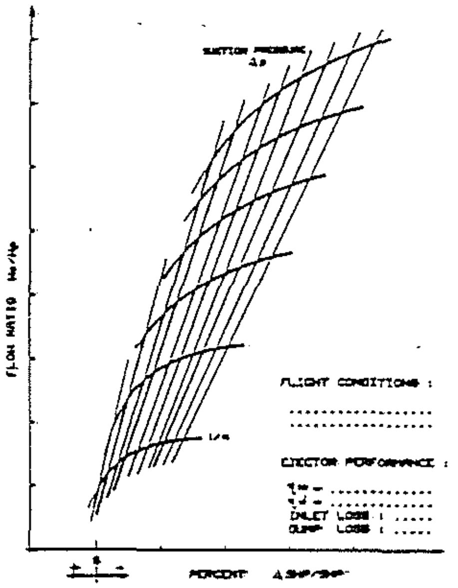

FIG. 4-2 EJECTOR IR SUPPRESSOR DESIGN PERFORMANCE MAP

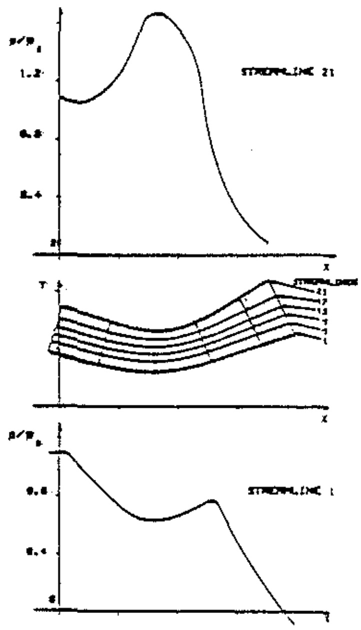

FIG. 4-3 TYPICAL AERODYNAMIC FIELD

AERO-THERMO RIG FOR SIR MODEL TESTING

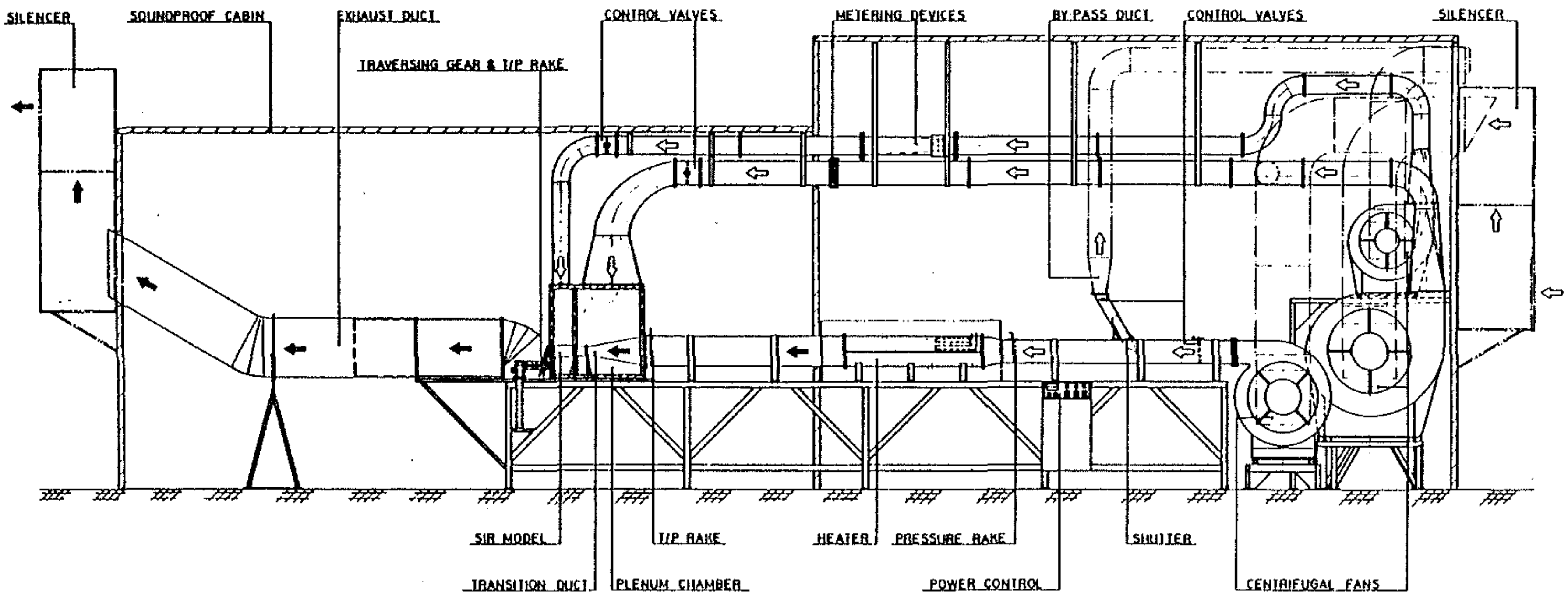

FIG. 7.2-1 AERO-THERMO RIG FOR SIR MODEL TESTING

WIND TUNNEL CHARACTERISTICS		PRIMARY FLOW	MAIN DILUENT FLOW	WALL COOLING FLOW
Max flow rate	(m^3/s)	2.4	2.1	0.6
Max total head	(mm H_2O)	800	1150	400
Fan power	(kw)	30	30	3
Heater power (one module)	(kw)	92.2	-	-
Duct section size	(m^2)	0.0576	0.0314	0.0177
Max flow temperature (one module)	(°C)	204	-	-
Mach number range	(-)	0 ÷ 0.4	0 ÷ 0.2	0 ÷ 0.1
Test chamber size	(m)	0.6x0.7x0.77	0.6x0.7x0.77	0.2x0.7x0.77

FIG. 7.2-I WIND TUNNEL CHARACTERISTICS

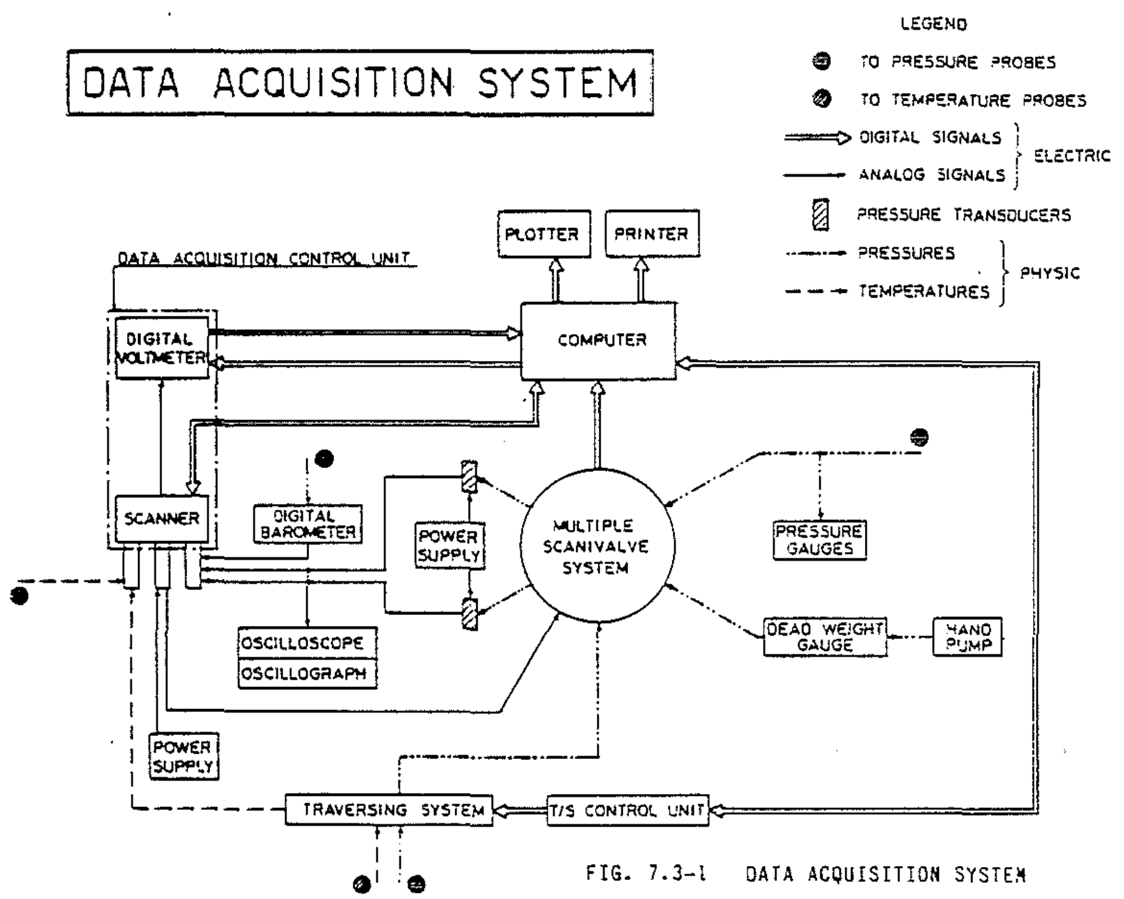

FIG. 7.3-1 DATA ACQUISITION SYSTEM

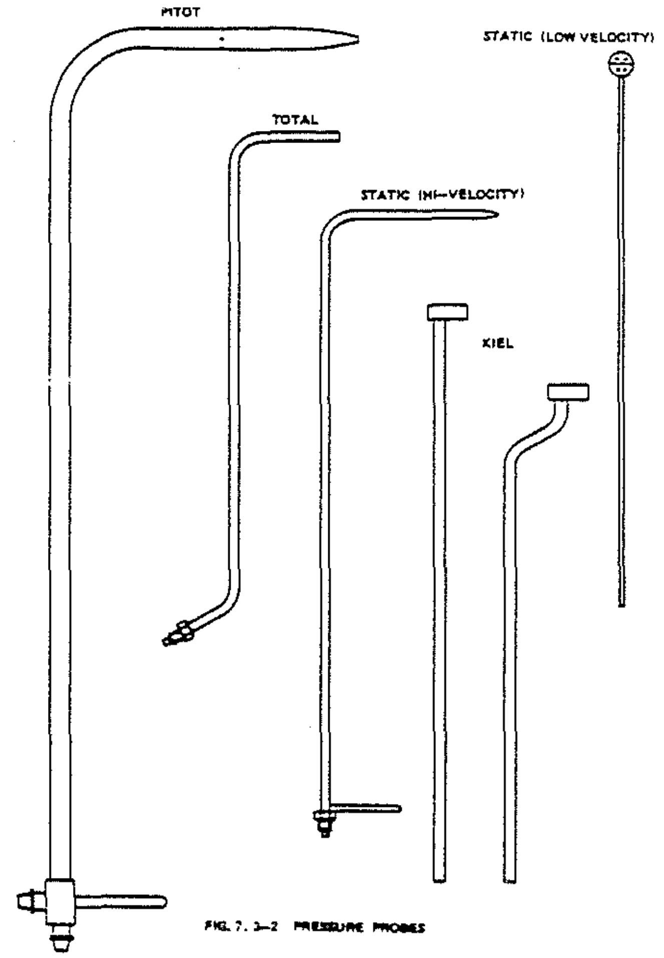

FIG. 7. 3–2 PRESSURE PROBES

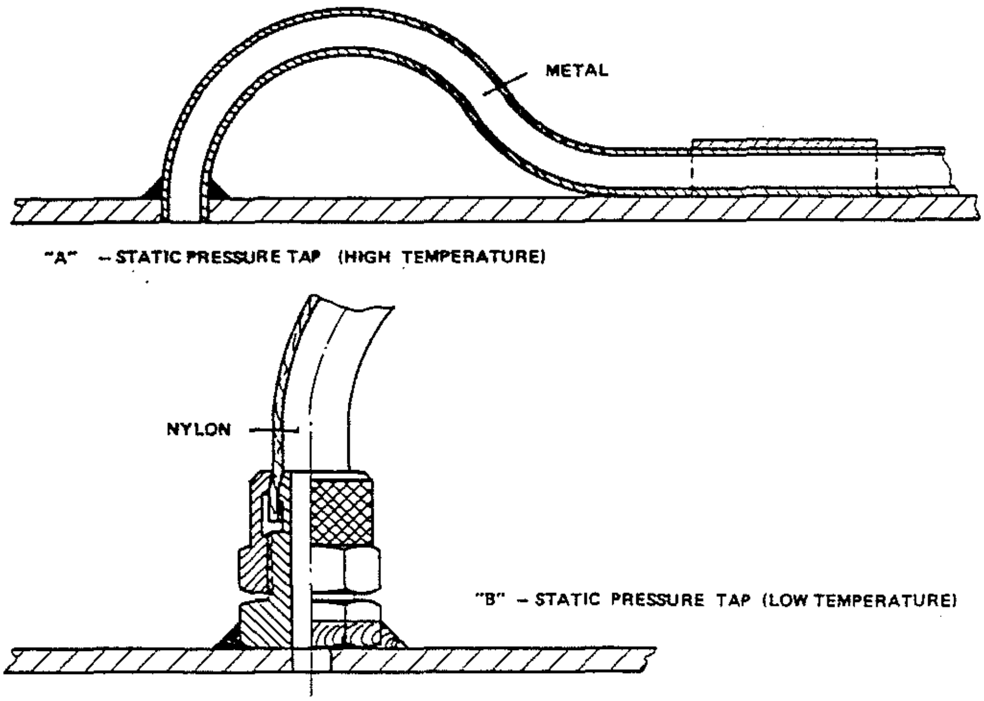

FIG. 7. 3–3 TYPICAL PRESSURE TAPS

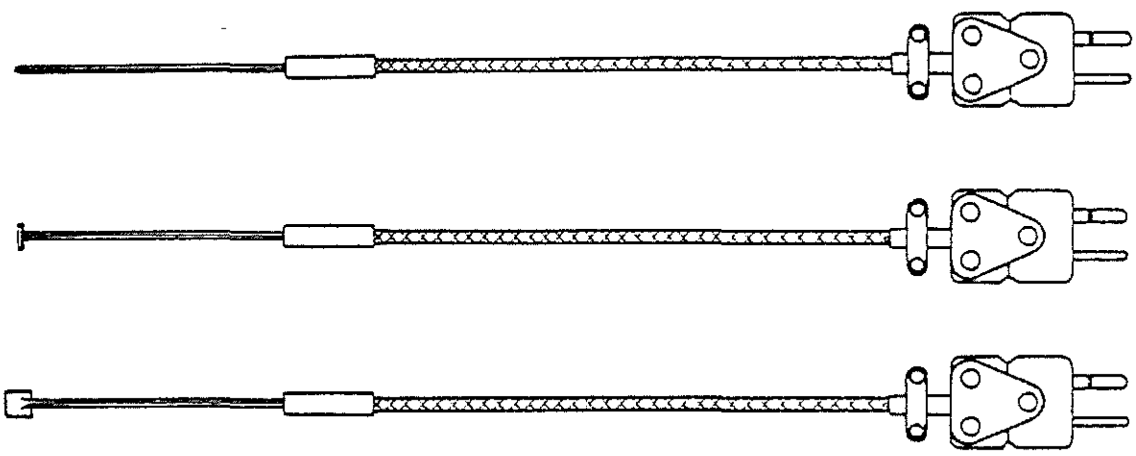

FIG. 7. 3–4 THERMOCOUPLES

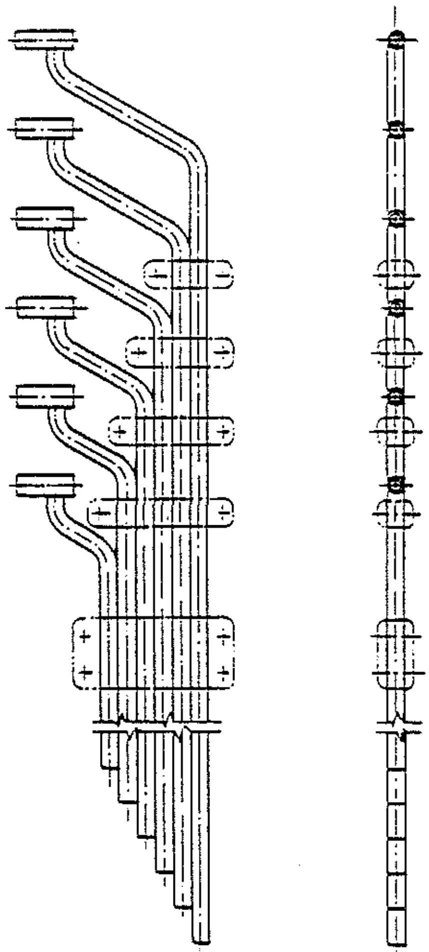

FIG. 7.3–6 TOTAL PRESSURE RAKE