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A LOUVRED AUXILIARY INTAKE SYSTEM FOR A TURBOJET POWERED TARGET AIRCRAFT

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ABSTRACT

An assessment of an auxiliary intake design fitted to a turbojet powered unmanned aircraft is made with the view to improving its take-off performance. A three-louvred design has been adopted on the basis of wind tunnel and full scale tests. Wind tunnel tests of a 1/4 scale model of the air intake duct incorporating the new design were carried out at ARL to verify the predicted aerodynamic performance and optimise its geometry in terms of louvre angle and aircraft forward speed. A substantial improvement in intake pressure recovery was achieved using this intake modification. Subsequent full scale tests at static conditions on an in-service aircraft confirmed the wind tunnel results.

NOTATION

A	Duct cross sectional area [m^2].
JPT	Jet Pipe Temperature [K].
m	Engine air mass flow [kg/sec].
$m\,T_o/P_o$	Engine air mass flow parameter.
N	Engine rotational speed [rpm].
P_o	Ambient or tunnel free stream total pressure [kPa].
P_t	Total pressure at the engine face [kPa].
$(P_t/P_o)_{av}$	Pressure recovery (average of 30 separate P_t/P_o values at the engine face).
T_o	Ambient or tunnel free stream total temperature [K].
U	Aircraft forward speed or tunnel air velocity [m/sec].
ϕ	Louvre angle with the streamwise direction.

INTRODUCTION

The take-off performance of a turbojet powered target aircraft was deemed inadequate under hot day conditions. With the air intake duct aerodynamically optimised for altitude and high subsonic cruise, engine performance was limited by an intake/engine mismatch under static and low speed conditions. Under take-off conditions, flow separation immediately downstream of the relatively sharp main lip inlet results in reduced engine air mass flow and pressure recovery at the engine face. Thus restrictions on maximum engine power were imposed on hot days to avoid exceeding jet pipe temperature (JPT) limits. The adopted approach to overcome this problem and minimise these effects, was to increase the total intake flow by the incorporation of an auxiliary intake which would only be deployed during the take-off phase.

The use of an auxiliary intake concept was explored theoretically by Abdel-Fattah and Fisher (1991). The significant theoretical improvements were then verified experimentally with a 1/4 scale model of the air intake duct. The experimental program involved tests of a range of geometries both at static conditions (Abdel-Fattah, 1991) and at forward speed in the wind tunnel (Abdel-Fattah and Link, 1992). It was shown that substantial improvement in pressure recovery with acceptable levels of flow distortion at the engine face can be achieved with practical modifications to the air intake duct.

Using the above results, a three-louvred auxiliary intake design was adopted for the final configuration, subject to wind tunnel and full scale tests. In this paper, the performance of the three-louvre configuration is assessed based on 1/4 scale model tests. The purpose of these tests was to optimise the geometry in terms of louvre angle, and verify its predicted performance. Results of the wind tunnel model tests are presented in terms of pressure recovery at the engine face.

The model scale pressure recovery results are compared with the results of tests of a full scale intake duct attached to an engine under static conditions. Engine performance was also assessed in terms of engine compressor face flow distortion, but these aspects are omitted from this paper for the sake of brevity.

Preparations for taxiing tests and actual flight trials are underway.

EXPERIMENTAL SETUP

Wind Tunnel

Details of the 1/4 scale intake test model, which was fully representative of both internal and external profiles of the full scale airframe (excluding wings) are shown in Fig. 1-a. A schematic of the louvred auxiliary intake geometry is shown in Fig 1-b. Total pressure distribution at the engine face was measured with a 30 probe rake comprised of six strakes equally spaced about the engine face annulus, each having five probes radially disposed on an equal area basis. Internal static pressure was measured with 6 flush tappings equally spaced around the circumference of the engine face location in the duct. Each pressure tube was attached to a port of a pressure scanning unit containing 32 ports, each with its own pressure transducer. The transducers in the unit were scanned simultaneously using a PSI system 8400 calibration and data processing unit. The pressure results were recorded digitally using a computer-driven data acquisition system. The engine air flow was simulated with a remote blower as is shown in Fig. 2, and was measured with a Venturi meter.

Each of the intake configurations was tested at wind tunnel speeds of 0, 30, 65 and 80 m/sec. For each of these speeds, pressure measurements were taken at various mass flow settings to simulate a range of engine speeds. Due to limitations on the blower it was not always possible to obtain a sufficiently high mass flow to simulate the maximum design engine speed. All tests were carried out with the model aligned with the free stream. In previous wind tunnel tests, (Abdel-Fattah and Link, 1992), the effect

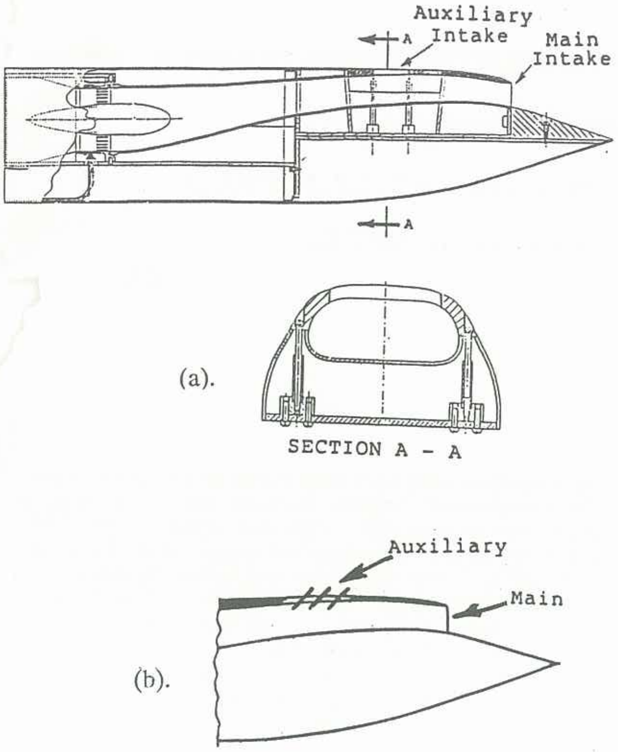

Fig. 1: Details of the intake duct model.
(a). Sectional views.
(b). Schematic of the louvred auxiliary intake configuration

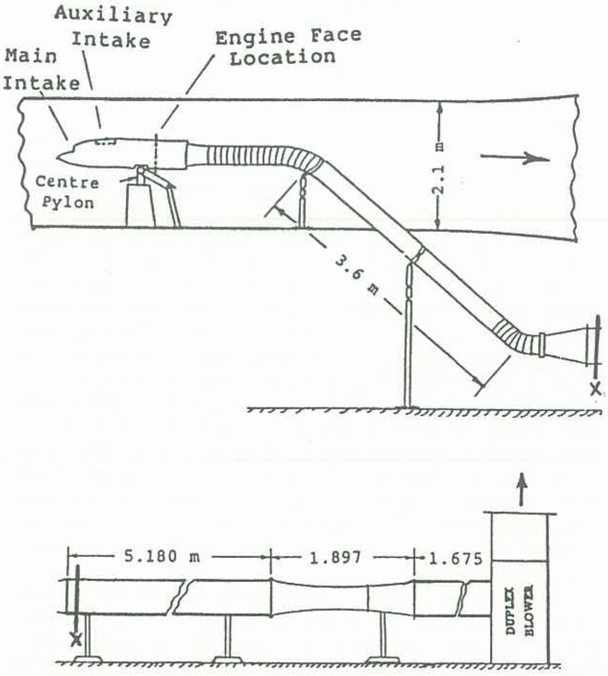

Fig. 2: Experimental setup of the intake duct model in the wind tunnel.

of yaw and pitch angles up to 10 degrees were found to be negligible.

Full Scale

Full scale tests were carried out on a stand mounted Viper II engine with standard and modified intake ducts attached. The pressure measurements at the engine face were made with a 40 probe total pressure rake and 8 static pressures as opposed to the 30 total and 6 static measured with the wind tunnel instrumentation. The pressure tubes were connected to a scanning valve, and pressures were measured with strain gauge transducers and recorded on an X-Y plotter. Engine air mass flow was determined using the pressure measurements at the engine face.

The specially written software programs presented by Link (1990), were used to process both the wind tunnel and full scale test data.

Test Configurations

Two series of tests were conducted:
a. the unmodified configuration, and
b. the louvred auxiliary intake.

In the case of wind tunnel tests five removable plugs were manufactured to each simulate a fixed louvre angle setting, namely; $\phi = 0, 10, 20, 30, \& 40^o$.

For full scale tests one set of three louvres were fitted in the auxiliary intake aperture, with variable angle settings in the range $\phi = 0$ to 37.5^o.

RESULTS AND DISCUSSIONS

Wind Tunnel

The intake pressure recovery - engine air mass flow parameter characteristics obtained at static conditions with the louvred auxiliary intake for various louvre angle settings are compared with that corresponding to the unmodified configuration in Fig. 3. It can be seen that pressure recovery increases with louvre angle, with best pressure recoveries achieved at $\phi = 40^o$. Similar comparisons at forward speed of U = 80 m/sec are presented in Fig. 4. The best performance in this case was achieved with $\phi = 25^o$. A line is marked on each of the pressure recovery plots to indicate the specification mass flow corresponding to the maximum design engine speed of 13800 rpm.

It can be concluded from these plots that substantial improvement in engine face pressure recovery can be achieved with this simple intake modification. With the louvres in the fully closed position ($\phi = 0^o$), a cavity is created with a depth equal to the difference between the thickness of the louvre and the aircraft skin structure. A slight reduction in performance is evident in Figs. 3 and 4 but this is small compared with the gains obtained at other louvre angles.

The pressure recovery variation with louvre angle ϕ for various forward speed U at N = 13800 rpm is shown in Fig. 5. The corresponding variations with U for various ϕ settings tested are compared with that of the unmodified configuration at N = 13800 rpm in Fig. 6. These plots clearly indicate that the trends in pressure recovery are dependent on the ranges of U and ϕ. The $(P_t/P_o)_{av}$ for a given forward speed increases with louvre angle until it reaches a maximum. The louvre angle at which this maximum occurs decreases with increasing forward speed. The optimum combination can roughly be achieved with $\phi = 25^o$ and U = 65 m/sec.

Full Scale

The pressure recovery - corrected mass flow characteristics measured at static conditions for the unmodified duct and the louvred intake set at various angles are compared with wind tunnel results in Fig. 7. The engine air mass flow in the case of full scale was determined using the total and static pressure data at the engine face, as opposed to the Venturi meter used in wind tunnel tests. Based on the wind tunnel measurements, the mass flow calculated from the engine face pressure data consistently

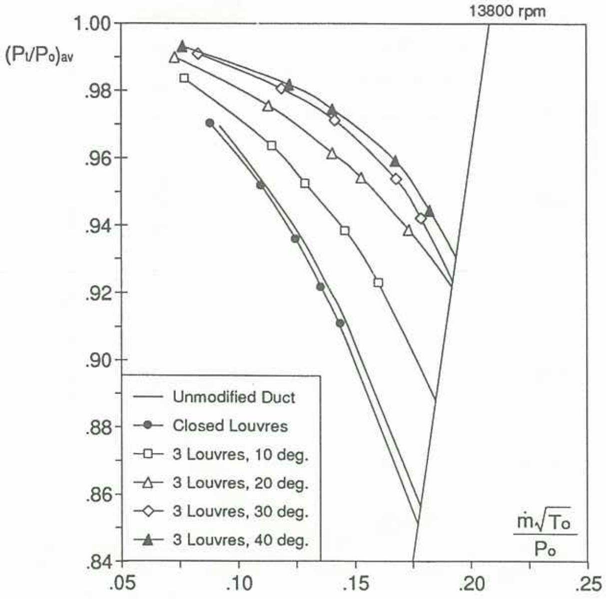

Fig. 3: Effect of louvre angle on intake performance at U = 0 m/sec.

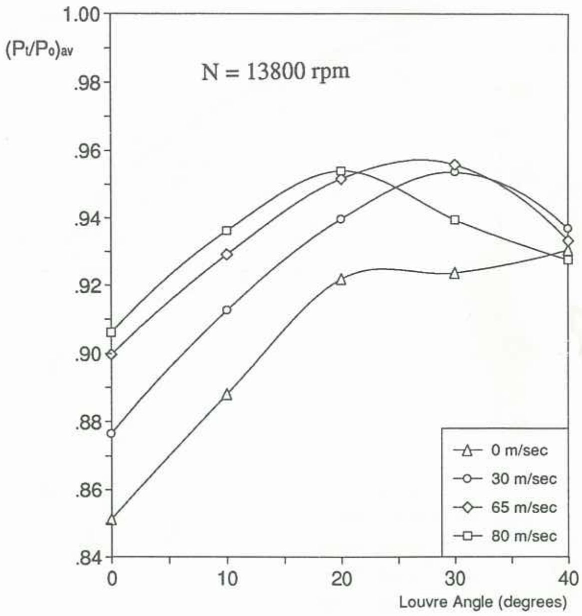

Fig. 5 Pressure recovery against louvre angle for various forward speeds.

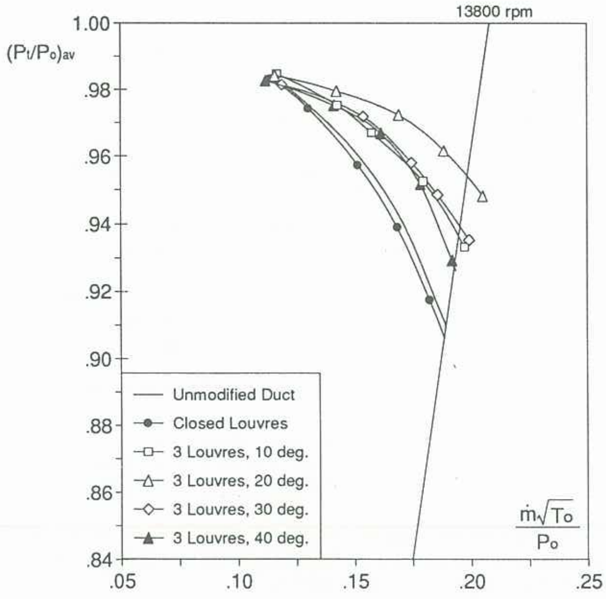

Fig. 4: Effect of louvre angle on intake performance at U = 80 m/sec.

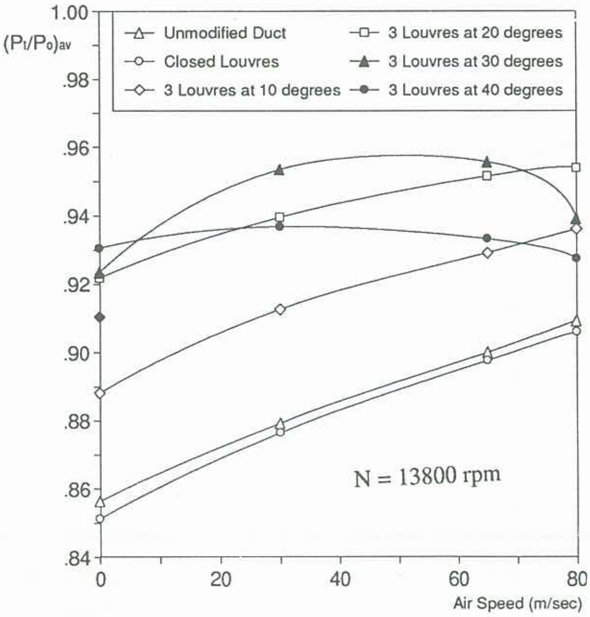

Fig. 6: Pressure recovery against forward speed for various louvre angles.

over-estimated the results obtained with the Venturi meter by about 2%. A correction factor of 0.98 was therefore applied to the full scale mass flow data to arrive at the results shown in Fig. 7. This figure shows an abnormal trend in the pressure recovery characteristic at $\phi = 30^{o}$. The $(P_t/P_o)_{av}$ value at this louvre angle appeared to be relatively low when compared with other characteristics in the plot. While the effect is more pronounced in the low range of engine speed it is still evident at high engine speed.

Fig. 8 shows the comparison in terms of $(P_t/P_o)_{av}$ versus ϕ under static conditions and at the maximum design engine speed of 13800 rpm. The model and full scale results generally display the same trends, including the above mentioned deficiency in performance at $\phi = 30^{o}$, although differences between the two curves approaching 2% in pressure recovery are also evident. The discrepancies may be due in part to errors involved in extrapolating some of the figure 7 results to 13800 rpm, but are thought to be mainly due to the different methods used for determining mass flow in the two experiments.

Included in Fig. 7. is a characteristic which was reported by Wrigley (1961). This was measured at full scale with a bellmouth (or "horse collar") fitted to the main intake lip. This device is currently in use during static ground runs to permit the engine to be run at full rpm for test purposes on hot days. The plot shows that the characteristics measured with louvre angle set at $\phi > 35^{o}$ are comparable to those obtained with the "horse collar".

Values of JPT measured with the louvred intake set at $\phi = 25^{o}$ are compared with those obtained for the unmodified intake in Fig. 9. As indicated, the auxiliary intake produced

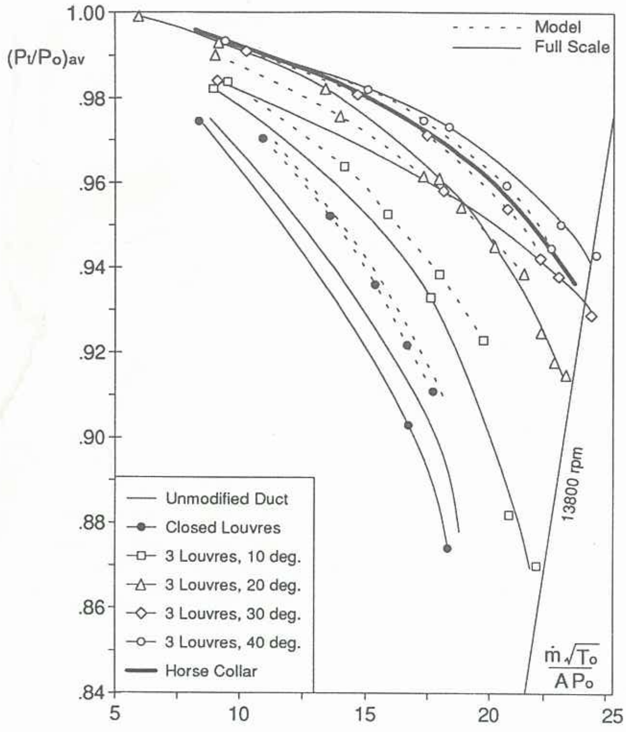

Fig. 7: Pressure recovery versus engine air mass flow parameter.

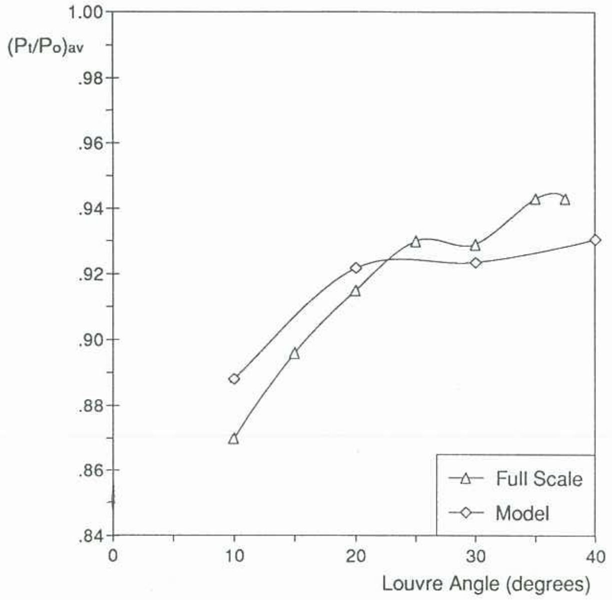

Fig. 8: Comparison of model and full scale pressure recovery versus louvre angle setting at static conditions

a drop in JPT of about 40°C. Although not presented here, this temperature drop was also achieved for louvre angles as low as 10°. These are also comparable to those measured with the "horse collar" as shown in Fig. 9.

CONCLUSIONS

The main conclusions are:

1- The louvred modification enabled full engine power to be reached under hot day take-off conditions.

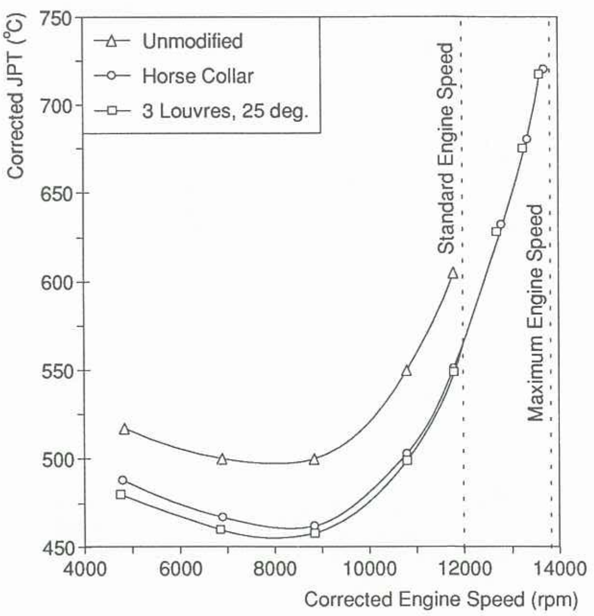

Fig. 9: Variation of jet pipe temperature with engine rotational speed.

2- Improvement in pressure recovery was found to be dependent on the range of both forward speeds and louvre angle settings. Optimum results were measured with the combination of $\phi = 25^o$ and U = 65 m/sec.

3- Pressure recovery for a given forward speed increased with louvre angle until it reached a maximum. The louvre angle at which this maximum occurred decreased with increasing forward speed.

4- The performance of the auxiliary intake with louvres set at $\phi > 35^o$ was similar to that obtained with the "horse collar" currently in use for full scale static engine running.

5- Significant improvements in jet pipe temperature at static conditions were achieved for louvre angles as low as 10°. These were comparable to those measured with the "horse collar".

6- The full and model scale pressure recovery results at static conditions displayed similar behaviour with respect to louvre angle, while displaying differences in absolute performance levels approaching 2%. This is thought to have been due mainly to the different methods of measuring air mass flow.

7- The cavity caused by the auxiliary intake when the louvres are closed results in a small but acceptable loss in performance at all flight conditions.

REFERENCES

1. Abdel-Fattah, A.M., and Fisher, S.A. "An Auxiliary Intake System for Unmanned Aircraft." Proceedings of the 10th ISABE, Nottingham - England, Sept., 1991.

2- Abdel-Fattah, A.M., "Modification of Jindivik Air Intake Duct with an Auxiliary Intake". Aeronautical Research Laboratory - PROP-TM-460, Aug., 1991.

3- Abdel-Fattah, A.M., and Link, Y.Y. "Low Speed Wind Tunnel Tests on Jindivik Air Intake Duct With and Without an Auxiliary Intake". Aeronautical Research Laboratory - PROP-TM-472, March, 1992.

4. Link, Y.Y., "A FORTRAN Program for Processing Low Speed Wind Tunnel Test Data for the Jindivik Auxiliary Intake. "ARL - Flight Mechs-TM-426, Sept., 1990.

5- Wrigley, A.K.", A Note on the Effect of Jindivik Installation on Ground Running of Viper II Engines". Government Aircraft Factories - Aero. Note B3/24, April, 1961.