PRELIMINARY AERODYNAMIC EVALUATION OF A SUPERSONIC STEALTH INTAKE

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***Abstract**: It is the purpose of this paper to investigate the aerodynamic properties of a supersonic intake converted to be used in stealth aircraft. The information sought regard both the airflow inside the intake duct and also the mechanical loading of the added elements. A computational fluid dynamics series of tests have been carried out and the results synthesized. It was found that although the intake could still be used for supersonic flight; the airflow will be severely distorted therefore imposing the use of circulation control. Also we could derive that the stresses on the fan rotor will be quite higher and asymmetrical in nature which will lead to shorter component life. The work could prove useful in understanding the limitations of stealthy supersonic aircraft and provide leads to further improvement in this field.*

***Keywords**: supersonic, stealth, CFD, circulation control.*

1. INTRODUCTION

Stealth aircraft became part of the United States Air Force in the late 70s proving useful in increasing the survivability of an aircraft over a hostile terrain. Since then, a multitude of stealthy aircraft have been produced or modified to incorporate stealthy materials or structures. Perhaps the most problematic aspect in stealth aircraft is masking the rotating fan or compressor blades from the enemy radar (Danitis, 2003). This is necessary because of the fact that rotating metallic fan blades are an excellent radar reflector and will help the enemy spot the target. One common solution (Abhinav, 2007) is to use a serpentine intake or S-duct system which obstructs the direct line of sight to the engine eliminating the problem. However this technique has proved to be challenging due to the fact that a fighter aircraft would require shorter intake ducts – in order to save weight while the serpentine bends cannot be too sharp in order to avoid excessive flow unevenness. This meant the introduction of boundary layer control techniques in order to eliminate parasitic vortices emerging along the S-duct (Rabe, 2003).

In the current paper we investigate the usefulness of a modified supersonic intake not unlike the one found in the Rockwell-Boeing B-1B supersonic bomber. Although the differences between the original and modified versions of the aircraft are clearly visible in terms of performance reduction, see Table 1, we seek to better understand the limitations and advantages of the new intake system used by the B-1B.

Table 1 Comparison between B1-A and B1-B

Variants	Maximum Mach No	Reduced RCS
Rockwell B-1A	2.2	No
Rockwell B-1B	1.25	Yes

2. THE COMPUTATIONAL FLUID DYNAMICS TEST

2.1 The mathematical model. For this particular test, we chose a Reynolds Averaged Navier-Stokes (RANS) method, the k-epsilon turbulence model. This choice was motivated by the fact that RANS methods are generally quicker to converge than Large Eddy Simulations (LES) techniques which, because of their nature are more labor intensive

(FLUENT USC, 2005). The viscosity model, k-epsilon, is one of the most popular in the literature due to its fewer model constants (by comparison to other two equation turbulence models such as k-omega). The lower number of model constants leads to a lower probability of erroneous case modeling therefore being more reliable.

2.2 The case setup. The geometry was modeled after the above mentioned intake system, Fig.1 shows the computational domain, geometry and computational mesh. With this simulation the turbulence model was k-epsilon standard, all the other relevant parameters are shown in Table2.

Table 2 Boundary conditions for the CFD tests

	Test 1	Test 2
X-velocity [m/s]	375	550
Ambient pressure [Pa]	11325	11325
Ambient temperature [K]	205	205
Fan intake pressure [Pa]	3325	3325
Wall rugosity [µm]	200	200

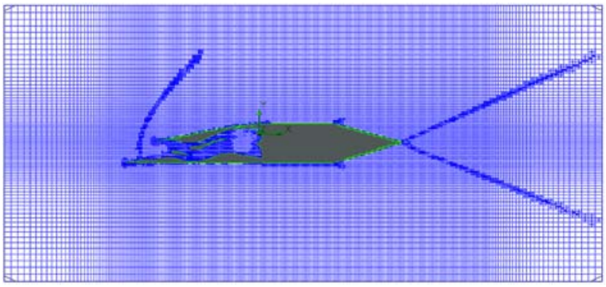

Fig. 1 The CFD Mesh with adaptation (550m/s – Mach 2.2 case)

The airfoils were initially modeled after the NACA 4 series as follows:

1.The front airfoil NACA 3417

2.The leading part of the aft airfoil NACA 2316-83 and the trailing part of the aft airfoil NACA 5411.

A useful observation is that at the Mach 1.25, there is no justification for using a two ramp intake system since the second ramp will either have to be minuscule in length or have a very small angle.

2.3 Results

Due to the Coandã Effect, the serpentine airfoils are accelerating the air, as shown in Fig.2 – in this case beyond the speed of sound, Fig.3 resulting in shock waves which mechanically stresses the airfoil structures.

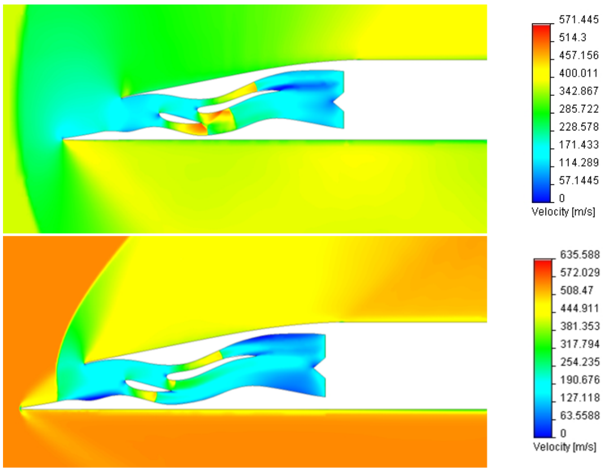

Fig. 2 The velocity plots for the Mach 1.25 (up) and Mach 2.2 (down) case.

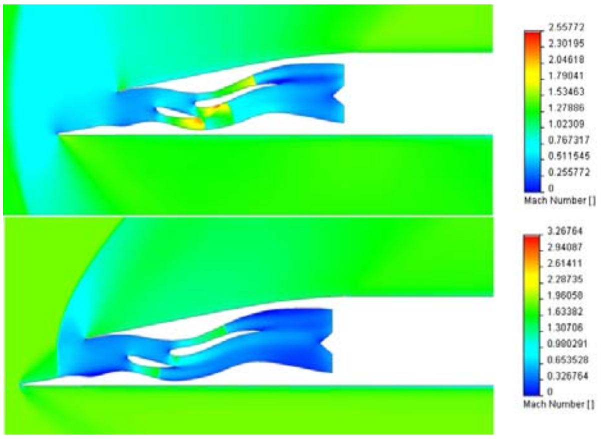

Fig. 3 The Mach number plots for the two cases. Both cases show supersonic flows on the positive curved airfoil guide vanes

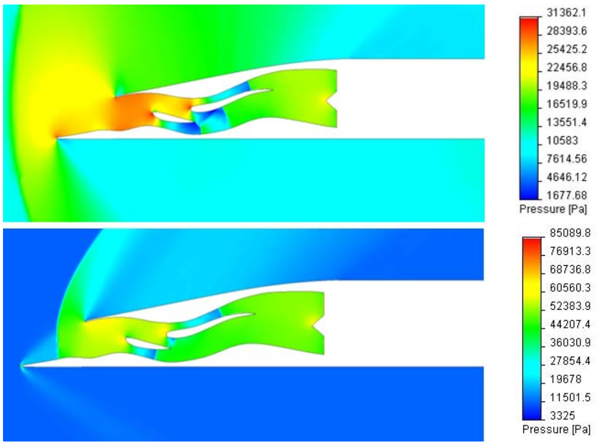

Fig. 4 The static pressure plots for the Mach 1.25 (up) and Mach 2.2 (down) case

Also as a result of the acceleration, the dynamic pressure is not converted to static pressure at the same level as it would in a conventional intake thus lowering the turbine engine's performance. Figure 4 shows that both cases have largely homogenous pressure fields however the values in front of the compressor are lower than those measured in front of the guide vanes. This indicates that the static pressure is re-transformed into dynamic pressure as a result of passing the vanes.

Another key observation is that the total pressure drops as a result of the drag induced by the airfoil surfaces leading to lower engine efficiency and higher fuel consumption.

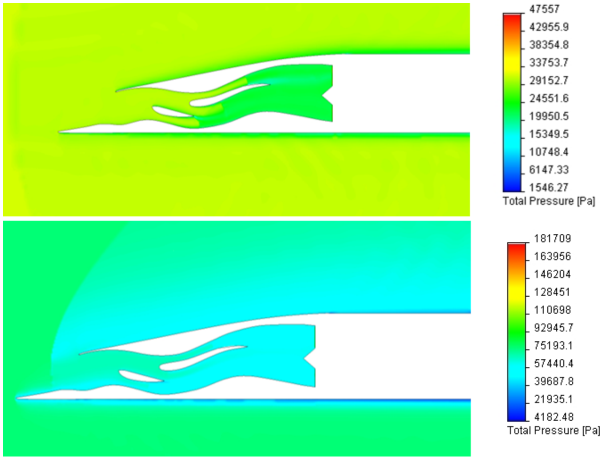

Fig. 5 The total pressure plots for the two cases

As seen in Fig. 5, the total pressure losses are slightly higher in the Mach 2.2 case hence the decision to limit the maximum velocity to just above Mach 1.25 is justified in the B-1B case. The wake trail of the second airfoil is quite long and as a result the transition from the rectangular section of the intake system to the circular section of the engine must be made longer in order to avoid excessive stresses to the fan rotor. However this will not fully eliminate the unevenness in the velocity and pressure fields.

3. DISCUTIONS AND CONCLUSIONS

A Computational Fluid Dynamics investigation has been carried out in order to assess the feasibility of modifying a supersonic intake for use in a stealth aircraft. The method chose to mask the direct view of the compressor blades was a serpentine intake with airfoil shaped guide vanes.

It was found that the guide vanes have a negative impact on the airflow to the engines resulting in limitations in use.

1. Because of the curved shape, inherent to the serpentine surfaces, air is accelerated under the Coandã Effect, and in some cases reaches supersonic speeds which results in shock waves.
2. As a result, the static pressure immediately ahead of the engine is lower than the one encountered in a similar conventional supersonic intake. This is a combined result of the static pressure being converted back into dynamic pressure because of the Coandã Effect acceleration and also due to the fact that the total pressure of the airflow is lowered by the frictions induced by the presence of the guide vanes.
3. The presence of the guide vanes generates aerodynamic forces and moments which have a negative impact on the structure of the engine nacelle by mechanically stressing it.
4. The drag induced by the guide vanes lead to a low overall efficiency of the engine by inducing enthalpy losses.
5. The velocity and pressure fields are uneven which leads to asymmetric stresses on the compressor rotor and, in time, to higher mechanical degradation trough metal fatigue.

As a result of these findings, the following recommendations have been expressed:

1. Due to the fluid accelerations inside the intake serpentine, the maximum air speed must has been limited, in the B-1B case as low as Mach 1.25. The simulations however show that the performance of the intake is actually acceptable in the Mach 2.2 case, i.e. the total pressure losses across the intake are approximately 1.5 higher than the Mach 1.25 case. Also the dynamic pressure is better transformed into static pressure. One may interpret that this is a result of the intake ramp which was specifically designed for this Mach number, hence the air flow in front the serpentine is better managed.
2. At the 1.25 Mach number, the double movable ramp intake system is not justified.

3. The use of a variable stator in front of the compressor rotor might be used to raise the efficiency of the engine by converting the high dynamic pressure of the air into static pressure. Also this stator would help even out the velocity and pressure fields reducing the mechanical stress on the rotor.

4. The use of circulation control could prove useful in reducing the wakes of the airfoil shaped guide vanes, hence improving the airflow to the engine.

The conclusions are that the airfoil serpentine intake is feasible for the use in supersonic aircraft, however the use of it leads to efficiency losses due to guide vane drag and flow unevenness..

4. ACKNOWLEDGMENT

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