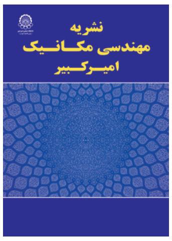

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Numerical Assessment of the Pulse Crossing Jet in Nozzle Fluidic Thrust Vectoring Using Unsteady Reynolds-Averaged Navier–Stokes Turbulence Approach

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ABSTRACT: In the present study, a software has been developed using the unsteady Reynolds-averaged Navier–Stokes method to simulate time variation of turbulence coherent structure and reduce computational cost and it is used for numerical simulation of a jet in the cross nozzle flow, accurate determination of the flow structure and nozzle fluidic thrust vectoring. Since this software can capture time dependent physics, in this paper, its capability has been investigated in the simulation of pulse jet in nozzle cross flow and variation of the fluidic thrust vectoring for three frequencies, 50, 100, and 200 Hz. Firstly, software validation has been performed by comparison the results with some experimental data, next, variation of jet in cross flow and its effect on the exhaust flow field and nozzle surface pressure distribution have been studied. Governing equation on the unsteady Reynolds-averaged Navier–Stokes algorithm has been explained and time step and applied boundary conditions have been presented. The Finite volume approach has been used for numerical discretization and the advection upstream splitting method has been utilized for flux computing. Also, to improve the solution accuracy, the multi-block grid and 2nd order monotonic upwind scheme for conservation laws method have been applied and to reduce computational time, the open multi-processing parallel approach has been used.

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1- Introduction

One of the most important goals of fighting airplanes design is to increase maneuver capability. This can be carried out using a supersonic jet in their nozzle exhaust flow. Accurate simulation of this phenomenon is so important. So, suitable numerical simulation with accurate unsteady turbulence algorithm is necessary to right capture the flow field [1, 2]. In the present study, a software has been developed using the Unsteady Reynolds-averaged Navier–Stokes (URANS) method for numerical simulation of a pulse jet in the cross nozzle flow, accurate determination of the flow structure and nozzle fluidic thrust vectoring for three frequencies, 50, 100, and 200 Hz. Software validation has been performed by comparing the results with some experimental data [3] and variation of the jet in the cross flow and its effect on the exhaust flow field and nozzle surface pressure distribution have been studied.

2- Methodology

The URANS approach can be driven by ensemble averaging of Navier Stocks equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u_i}{\partial x_i}=0 \tag{1}$$

$$\frac{\partial \rho u_i}{\partial t}+\frac{\partial \rho u_i u_j}{\partial x_j}=-\frac{\partial p}{\partial x_i}+ \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\rho\overline{\tilde{u}_i\tilde{u}_j}-\rho\overline{\left\langle u'_i u'_j\right\rangle}\right] \tag{2}$$

$$\frac{\partial \rho H}{\partial t}-\frac{\partial p}{\partial t}+\frac{\partial \rho H u_j}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\lambda\frac{\partial T}{\partial x_i}-\rho u''_j H\right] +\frac{\partial}{\partial x_j}\left[u_i\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\rho\overline{u''_i u''_j}\right]\right] \tag{3}$$

where $\overline{\rho u_i'' u_j''}$ is the Reynolds stress expression and show all flow fluctuations including the coherent structure and turbulent fluctuations.

3- Grid and Boundary Conditions

The boundary conditions, blocks, and grid used in the present solution are shown in Fig. 1. Sinus pulsing jet is simulated according to Eq. (4).

$$P_j=\left|P_{j0}\sin\left(\frac{\pi}{2}+\omega t\right)\right| \qquad T_j=\left|T_{j0}\sin\left(\frac{\pi}{2}+\omega t\right)\right| \tag{4}$$

4- Results and Discussion

Characteristics of the present solution are summarized in Table 1. Validation of the code is carried out by comparison of the nozzle surface pressure with some experimental data [3] (Fig. 2). Sample of thrust vectoring obtained by the present solution is observed in Fig. 3. The numerical simulations are performed for three different frequencies of the input jet, 50, 100, and 200 Hz. Sample of computed upper surface pressure of the nozzle for jet simulation with input frequency 50 Hz

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is presented in Fig. 4. Variation of the surface pressure in different time step is clearly observed.

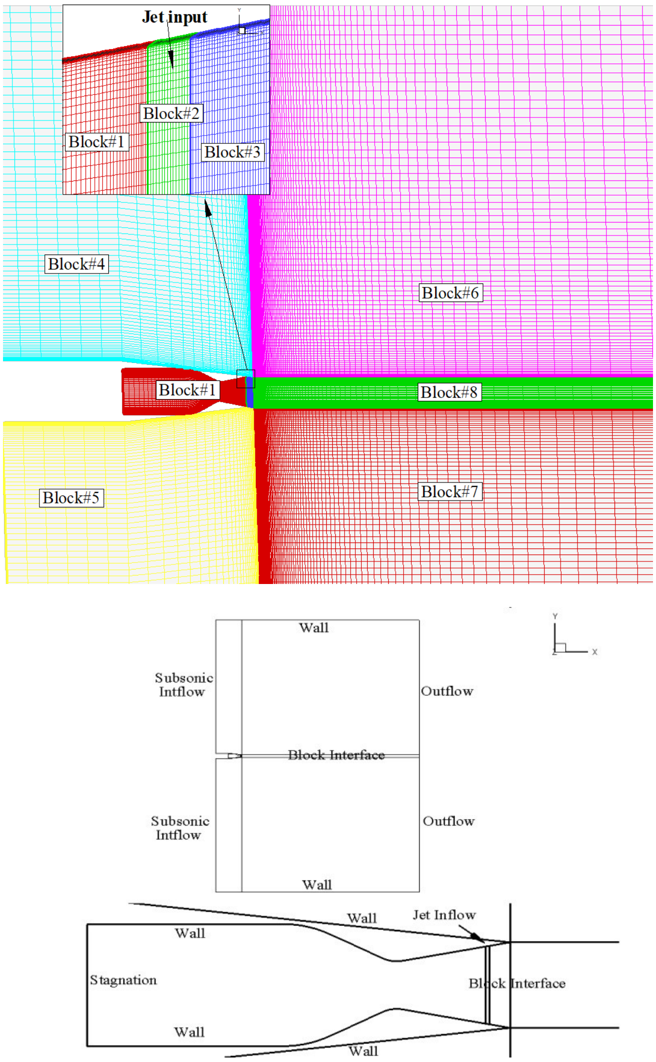

Fig. 1. Grid, blocks and boundary conditions in solutions

Table 1. An example of a table

Parameter	Value
Free Mach Number	0.3
Atmosphere Pressure (Pa)	101325
Free Temperature (K)	294
Nozzle Pressure Ratio	4.6
Nozzle Temperature (K)	294
Nozzle Pressure (Pa)	466095
Nozzle Area Ratio	1.8
Nozzle Exhaust Area (cm^2)	50
Nozzle Throat Area (cm^2)	27.85
Jet Mach Number	1.63
Jet Pressure Ratio	0.7
Jet Temperature (K)	294

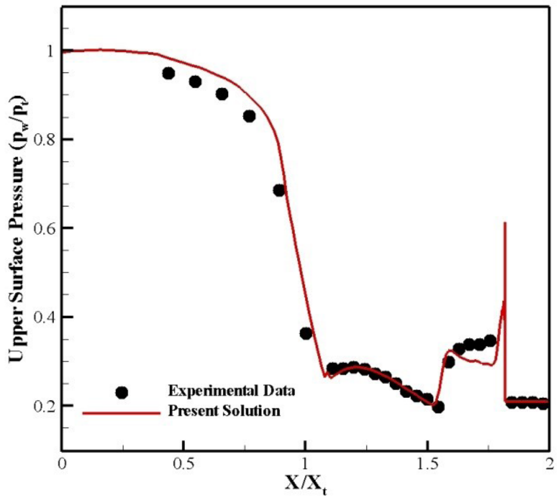

Fig. 2. Comparison of upper surface pressure

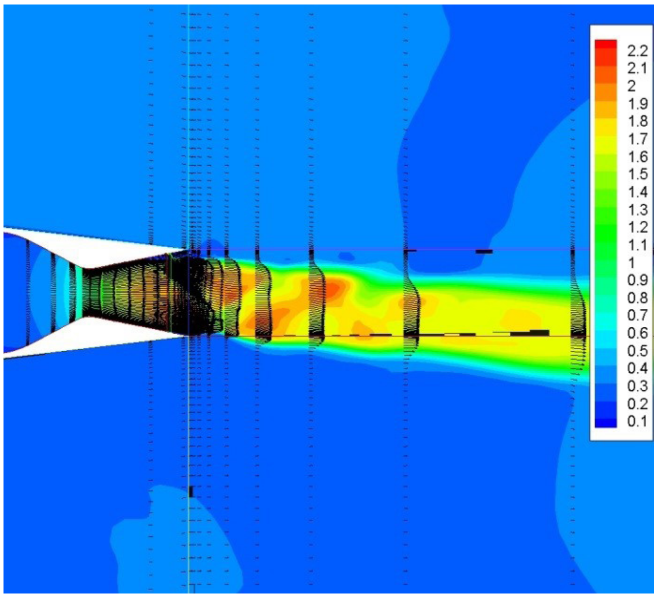

Fig. 3. Mach contour and thrust vector

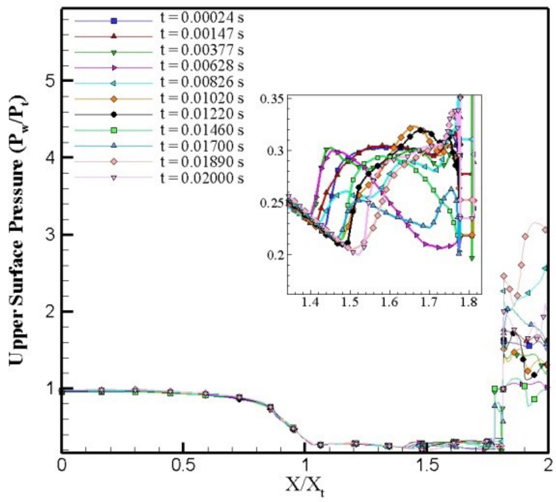

Fig. 4. Comparison of upper surface pressure for f=50 Hz in the first cycle

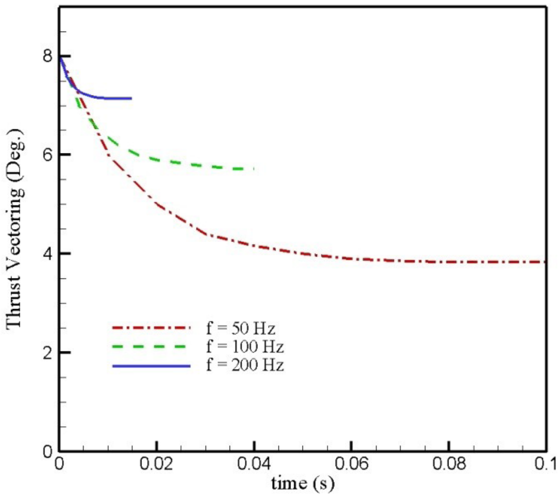

Fig. 5. Variation of thrust vector for different frequencies

5- Conclusions

A URANS based software has been used for numerical simulation of a pulse jet in the cross nozzle flow and accurate determination of the flow structure and nozzle fluidic thrust vectoring for three frequencies, 50, 100, and 200 Hz. Software validation has been performed by comparison the results with some experimental data [3]. Variation of a jet in the cross flow and its effect on the exhaust flow field and the nozzle surface pressure distribution have been studied. Conclusion of the obtained results has been summarized in Table 2. It is found that pulsing jet of 200 Hz changes the initial angle of thrust vector less than that of 100 and 50 Hz. Variation of thrust vector is also shown in Fig. 5 for different frequencies. It is seen that exponentially decreasing trend of thrust vector is the same for different frequency, but by enhancing the frequency, effecting time of pulsing jet on exhaust flow and thrust vector decreases due to increasing of average pressure of crossing jet.

Table 2. Variation of thrust vector versus frequency

f (Hz)	Convergence Cycle	Solution Time (s)	Thrust vector angle (Deg.)
50	5	1,000,000	3.84
100	4	400,000	5.72
200	3	150,000	7.12

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