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Turbulent Flow in Induction Mechanisms

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Abstract:- It is the purpose of this research to study from the computational perspective the complex non-steady flow processes and induction mechanisms within a supersonic pressure-exchange ejector of turbulent flow to obtain fundamental information which would allow this technology to be utilized in many applications such as in ejector refrigeration systems. Three dimensional Navier-Stockes Equations with K-Epsilon turbulent model are used for the flow analysis.

This research is based upon utilizing a non-steady flow field resulting in the work of pressure forces acting at a fluid interface between primary and secondary fluids. Results demonstrate the actual mechanisms and processes of transferring energy through pressure forces and shear forces, from high energetic fluid to less energetic one.

Key- Words: Three Dimensional Oblique Shock Waves, High Speed Flow, Flow Induction, CFD.

1 Introduction

This research is based upon utilizing a non-steady flow field resulting in the work of pressure forces acting at a fluid interface between primary and secondary fluids. The pressure forces exert on an interface of two fluids having different level of energy is seen as an energy transfer mechanism. These interfaces are produced through the aerodynamic design of a flow field, non-steady in the laboratory frame of reference, consisting of rotating oblique shock waves and expansion fans, [1].

The numerical analysis and mapping of the flow induction between two fluids in a supersonic pressure exchange ejector flow for turbulent flow is investigated in this paper. The results show a promising achievement of the major goals which are first to understand the flow structure inside the supersonic pressure exchange ejector; second to use this knowledge to interpolate the numerical results in order to achieve a better design methodology; and finally, to show a benefit from this study in terms of industrial applications [1-4].

The work in this paper is based upon utilizing a non-steady flow field resulting in the work of pressure forces acting at a fluid interface between primary flow and secondary flow and the energy transfer by shear forces. These interfaces are produced through the aerodynamic design of a flow field, non-steady in the laboratory frame of reference, consisting of rotating oblique shock waves and expansion fans. Minimizing the possible losses from the oblique shocks and boundary layers offer the potential of achieving adiabatic efficiencies approaching those of turbo-machines [2-3&5].

Pressure exchange is a designation applied to any process whereby contiguous fluid bodies or flows exchange mechanical energy through the work of mutually exerted pressure forces at their interfaces, [6]. Pressure exchange cannot take place in steady flow, because no work is done by pressure forces acting on a stationary interface, [7]. Therefore, pressure exchange is always a non-steady process.

An ejector is a direct contact flow induction device which exchanges mechanical energy and momentum between a high-energy primary fluid and a relatively low-energy secondary fluid to produce a discharge of an intermediate specific energy level. The transfer of momentum gives rise to an increase in the stagnation enthalpy of the secondary fluid and enables the ejector to function as a compressor. In an ejector, energy can be imparted from the primary fluid to the secondary fluid through work, which is accomplished by two basic mechanisms: the shear stresses at the tangential interfaces between primary and secondary fluids as a result of turbulence and viscosity, or/and the work of interface pressure forces acting across moving interfaces separating the primary and secondary fluids.

In steady-flow devices, the direct transfer of mechanical energy from one flow to another is entirely accomplished through the work of viscous forces and irreversible transport processes. In contrast, the work of pressure forces is essentially non-dissipative, except when strong shocks are involved. Pressure exchangers can, therefore, be expected to be capable of producing higher efficiencies of energy-transfer than can be produced by steady-flow energy exchangers of comparable mechanical simplicity [8-11]. The utilization of this mode of energy-transfer is of interest because of its potential to produce high efficiency [12-14].

The goal is to create a flow induction machine which utilizes the work of interface pressure forces available in non-steady flows through direct contact of two fluids [15-20].

2 Problem Descriptions and Numerical Analysis

Direct flow induction, the direct transfer of momentum and energy from one fluid stream to another, generally involves both a dissipative and a non-dissipative component, the latter being provided by the work of interface pressure forces. For these forces to do work, the interfaces on which they act must be allowed to move. Therefore, the non-dissipative component of energy transfer can take place only where the interacting flows are non-steady,

The flow induction in the supersonic pressure exchange ejector is so complex that there exist direct fluid-fluid interactions, oblique shock waves, expansion fans, slip surfaces, and shock wave interactions and reflections. The flow is non-steady, viscous, compressible, and high-speed supersonic.

The governing equations are a set of coupled nonlinear, partial differential equations. In order to formulate or approximate a valid solution for these equations they must be solved using computational fluid dynamics techniques. To solve the equations numerically they must be discretized. That is, the continuous control volume equations must be applied to each discrete control volume that is formed by the computational grid. The integral equations are replaced with a set of linear algebraic equations solved at a discrete set of points. Three dimensional Navier-Stockes Equations with K-Epsilon turbulent model are used for the flow analysis.

CFX is used in the current research to model the flow in the supersonic pressure exchange ejector. CFX is a finite volume method, but is based on a finite element approach of representing the geometry. Thus, the method used here possesses much of the geometric flexibility of finite element methods as well as the important conservation properties of the finite volume method.

It should be possible to model the interaction of the shock waves and expansion fans around the rotating vanes and describe how the secondary flow is drawn into the interstices. It should be possible to study the mutual deflection and pressure exchange processes between primary and secondary flows using the CFD analysis [1& 20-22].

The flow conduction mechanism in the supersonic pressure exchange ejectors was conducted from previous work using the laminar flow analysis [1-3&15-20]. In this research further development was carried out but using turbulent analysis. It was found out that with the turbulent model the transfer of energy from the primary fluid to the secondary fluid is increased because of the viscous mixing between the two fluids.

3 Results and Discussion

In this paper, a numerical analysis was conducted to study the flow structure inside a three-dimensional, non-steady supersonic flow in a complex region. Three dimensional Navier-Stockes Equations with K-Epsilon turbulent model are used for the flow analysis. A numerical model was also developed to predict the best flow configuration for the fluids inside the supersonic pressure exchange ejector [17-18].

In the non-steady flow ejectors, the primary gas expands; therefore, it acts on the secondary fluid in a manner to induce the secondary fluid to perform the exchange of energy between the two gases at their interface.

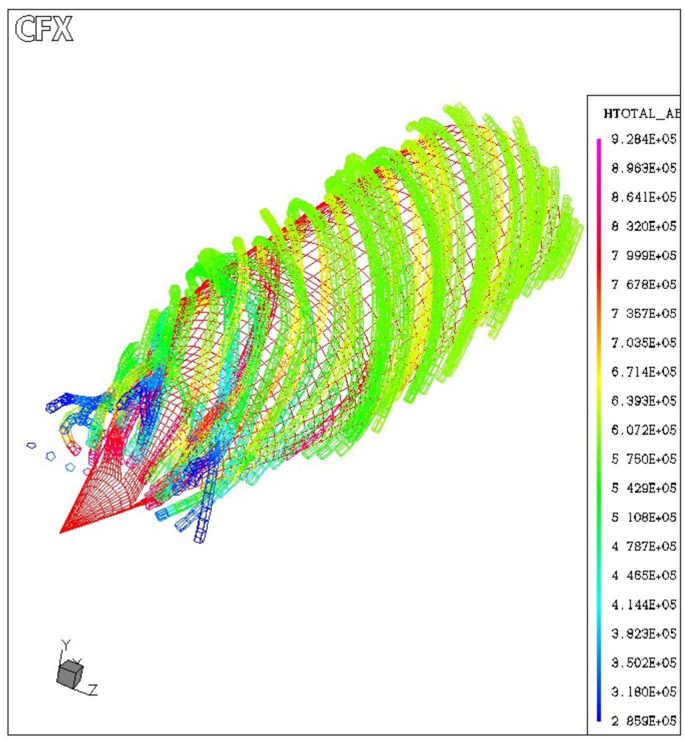

Fig.1 Path lines top view relative frame of reference colored by total enthalpy

At every instant of this process, the driving fluid is found to occupy spiral or helical regions in the interaction space, which rotate about the same axis and at the same angular velocity as the rotor. Figure 1 shows path lines to illustrate the interaction of the two fluids during the flow induction mechanism, starting from a region ahead of the vanes. In this figure the secondary and primary fluid are colored differently: blue for the secondary and red for the primary.

The flow induction apparatus is a device whereby energy is transferred from one fluid to another fluid directly, without intermediary conversion to work such as in an axial-flow combination of turbine and compressor. In effect, the energy-extracting action of a turbine and the energy-adding action of a compressor are here compounded in a single step. The transfer of energy from the driving to the induced flow is a process that takes place between the boundaries of the helical surfaces.

The rotating primary flow forms helical interstices into which the secondary flow is trapped and driven by direct momentum exchange between primary and secondary fluids. Therefore, each of the two flows acquires an angular momentum in the energy transfer process and this is accomplished by the mutual pressure forces which are normal to the helical boundaries of the helical surfaces.

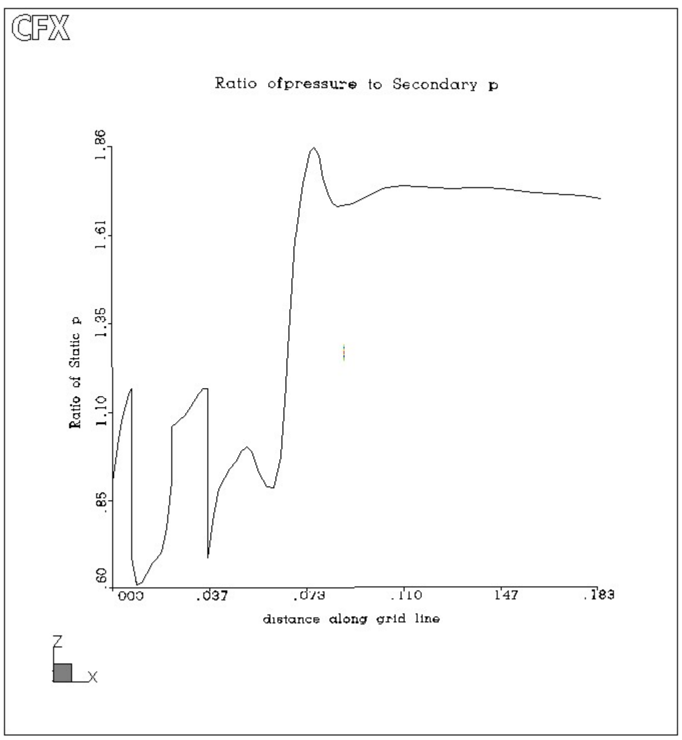

Fig.2 Ratio of static pressure inside the ejector to the static pressure of the secondary fluid

Figure 1 shows a contour plot of the total enthalpy for ejector with spin angle of 20-degree, [5]. Working fluid is air and primary Mach number is 3.0. The ratio of primary inlet to secondary inlet is 0.30, [19]. This figure shows that the secondary fluid is rotated due to the presence of these pseudo-blades. During this rotation the secondary fluid gains mechanical energy represented by the increase in the total enthalpy rise as shown in figure 1. The rise of the total enthalpy of the secondary fluid is an important figure in pressure exchange ejectors and this shown in figure 1.

In the pressure-exchange ejector system, the interaction of primary stream and secondary fluid are completed in two consecutive processes, the deflection phase and the mixing phase. During this flow induction process, energy transfers from the primary fluid to the secondary fluid, and the energy level of the secondary fluid is increased in consequence of the process. The rotating primary jets form helical interstices into which the secondary flow is trapped and driven by direct momentum exchange between primary and secondary fluids.

Figure 2 shows the ratio of the static pressure inside the ejector to the secondary static pressure. This figure is important in this analysis because this ejector is intended to be used in refrigeration system where one wishes to maximize the pressure recovery. Figure 2 shows that the pressure recovery in high.

4 Conclusion

A computational model that illustrates the physics of flow induction through non-steady shock waves and expansion fans was developed. This provides strong insight into the mechanisms through which the supersonic pressure exchange ejector operates. Through this computational analysis, a better interpretation of the physical phenomenon of the non-steady pressure exchange ejector can be achieved.

The flow conduction mechanism in the supersonic pressure exchange ejectors was conducted from previous work using the laminar flow analysis. In this research further development was carried out but using turbulent analysis. It was found out that with the turbulent model the transfer of energy from the primary fluid to the secondary fluid is increased because of the viscous mixing between the two fluids.

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References

1. Alhussan, K.: “Direct Fluid-Fluid Interaction in Three Dimensional Supersonic Non-steady Flow”, The George Washington University, D.Sc. Dissertation, August 2002.
2. Garris, C. A.: “Pressure Exchanging Ejector and Refrigeration Apparatus and Method”, US Patent 5,647,221; July 15, 1997
3. Garris, C. A.: “Pressure Exchanging Ejector and Method of Use”, US Patent 6,138,456; July 15, 1997.
4. Alhussan, K., Garris, C., “Computational Study of Three-Dimensional Non-Steady Steam Supersonic Pressure Exchange Ejectors” IASME Transactions Issue 3, Volume 1, pp 504-512, ISSN 1790-031X, 2004.
5. Hong, W. J., Alhussan, K., Garris, C. A.: “The Supersonic/Rotor-Vane/Pressure-Exchange Ejector”, 39th AIAA Aerospace Science Meeting & Exhibit, Paper No. AIAA-2001-8058, Reno, NV, January 2001.
6. Foa, J. V.: “A Method of Energy Exchange”, American Rocket Society Journal, v.32,no.9, September 1962.
7. Dean, R. C., Jr.: “On the Necessity of Nonsteady Flow in Fluid Machines”, Trans.ASME, v81, Series D, No.1, pp.24-28, March 1959.
8. Hung, B.J., Jiang, C.B., Hu, F.L.:”Ejector Performance Characteristics and Design Analysis of Jet Refrigeration System”, Journal of Engr. For Gas Turbine and Power: ASME, 1985; 107:792-802.
9. Matsuo, K., Sasaguchi, K., Tasaki, K., Mochizuki, H.: “Investigation of Supersonic Air Ejectors: Part 2 effects of throat-area Ratio on Ejector Performance”, Bulletin of the Japanese Society of Mechanical Engineers: JSME, 1982; 25:210.
10. Addy, A. L., Dutton, J. C., Mikkelsen, C. D.:”Supersonic Ejector-Diffuser Theory and Experiments”, Report No. UWU-ENG-824001, Department of Mechanical and Industrial Engineering, University of Illinois, Urbana, August 1981
11. Chow, W.L., Addy, A.L.: “Interaction between Primary and Secondary Streams of Supersonic Ejector Systems and Their Performance Characteristics” AIAA Journal, pp686-695, April, 1964.
12. Garris, C. A., Hong, W. J., Mavriplis, C. M., Shipman, J.: “An Experimental and Numerical Study of the Pressure-Exchange Ejector; forum on Fluid Machinery, 1998 ASME Fluids Engineering Division Summer Meeting, Washington, D. C., June, 1998.
13. Garris, C. A., Hong, W. J.: “A Radial-Flow Pressure-Exchange Ejector”, Proceedings of the Third International Symposium on Pumping Machinery, Vancouver, Canada, ASME, June 1997.
14. Garris, C. A., Hong, W. J., Mavriplis, C. M., Shipman, J.: “The Pressure-Exchange Ejector Heat Pump”, 1998 ASME International Mechanical Engineering Conference and Exposition, Anaheim, CA, November 15-20, 1998.
15. Hong, W. J., Alhussan, K., Zhang, H., Garris, C. A.: “ A novel Thermally Driven Rotor-Vane/Pressure-Exchange Ejector Refrigeration System with Environmental Benefits and Energy Efficiency, Energy Journal, In Press.
16. Alhussan, K., Garris, C. A.: “Non-Steady Three-Dimensional Flow Field Analysis in Supersonic Flow Induction”, Fluids Engineering Summer Conference Montreal, Canada, Paper No. FEDSM2002-13088, July 2002.
17. Alhussan, K., Garris, C., “ Comparison of Cylindrical and 3-D B-Spline Curve of Shroud- Diffuser for a Supersonic Pressure Exchange Ejector in 3-D, Non-Steady, Viscous Flow” IASME Transactions Issue 3, Volume 1, pp 474-481, ISSN 1790-031X,2004.
18. Alhussan, K., Garris, C., “Computational Study of Three-Dimensional Non-Steady Steam Supersonic Pressure Exchange Ejectors” IASME Transactions Issue 3, Volume 1, pp 504-512, ISSN 1790-031X, 2004.
19. Alhussan, K., Garris, C., “Study the Effect of Changing Area Inlet Ratio of a Supersonic Pressure-Exchange Ejector” 43rd AIAA Aerospace Science Meeting and Exhibit, Paper No. AIAA-2005-519, Reno, NV, USA, 2005.
20. Alhussan, K., Garris, C. 2005, “Computational analysis of flow induction phenomena in three-dimensional, non-steady supersonic pressure exchange ejectors” 6th KSME-JSME Thermal and Fluids Engineering Conference, Jeju City, South Korea, Paper Number: tfec6-404, March 20-23, 2005.
21. Alhussan, K., Garris, C. 2005, “Study the effect of changing throat diameter ratio of a supersonic pressure exchange ejector” 6th KSME-JSME Thermal and Fluids Engineering Conference, Jeju City, South Korea, Paper Number: tfec6-406, March 20-23, 2005.
22. Alhussan, K.," Computational Analysis of High Speed Flow over a Double-Wedge for Air as Working Fluid", Proceedings of FEDSM2005 ASME Fluids Engineering Division Summer Meeting and Exhibition FEDSM2005-77441 June 19-23, 2005, Houston, TX, USA
23. Alhussan, K.," Study the Structure of Three Dimensional Oblique Shock Waves over conical rotor-Vane surfaces", Proceedings of FEDSM2005 ASME Fluids Engineering Division Summer Meeting and Exhibition FEDSM2005-77440 June 19-23, 2005, Houston, TX, USA
24. Alhussan, K.," Oblique Shock Waves Interaction in a Non-Steady Three Dimensional Rotating Flow",Proceedings of FEDSM2005 ASME Fluids Engineering Division Summer Meeting and Exhibition FEDSM2005-77442 June 19-23, 2005, Houston, TX, USA.