**Effect of Warhead on An Open Cavity at Supersonic Speed**

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**Abstract:** A time-averaged 2D flow simulation has been conducted over an open cavity like weapon bay. There can be significant changes in the flow physics of an open cavity with the presence of a warhead, especially at supersonic speeds. The computations are performed using commercial software package ANSYS and modelled with respect to the standard k-ω turbulence model. The computations namely the pressure, temperature, velocity and density distribution along the cavity have been plotted and a comparison has been done between the cases of the open cavity with and without warhead.

***Keywords* —*****Time-Averaged Flow, Cavity flow, Weapon Bay, Warhead.***

# **Introduction**

Flow over cavities has been an issue of a lot of research. Even though a cavity geometry might seem simple, it still has lot of problems accompanied when they are subjected to flows of subsonic range and especially vital during the supersonic operation [1]. An empty space within a solid object is called cavity. Engineering terms for the cavity could be a space left empty in an object intentionally. Here is a schematic diagram of a simple rectangular cavity flow [1]. The Length, width, and depth are labelled as L, W, D respectively.



**Fig. 1.1: Simple 3D cavity**

In general, flow over a cavity mainly depends on the Mach number of the external flow over it and L/D ratio where L is the length of the cavity and D is the depth. Flow characteristics come out to be very different between subsonic and supersonic flows. The weapon bay present in many fighter aircraft is also a cavity used to store warhead inside the aircraft which in turn reduces the radar signature of the aircraft by minimizing overall size. It’s been years since the cavity flow was first investigated and even today there are some areas to be known, that’s how broad is the study of a flow over a cavity.

# **Literature Review**

The aim of this section is to get to the objective and knowing some areas of importance along the way. Starting with experiments done by Stalling and Wilcox [1] who define pressure distributions over rectangular cavities of different sizes and at various freestream Mach Numbers. Another experiment done by Pletonvich and Stallings Jr. [2] over a rectangular cavity on different length to depth ratios to define pressure characteristics over the range of length to depth ratios. Another study is performed by K. Chung [3] on a rectangular cavity with compressible flow which indicates that the length to depth ratio of the cavities for open and transitional type cavities increases with increase in Mach Number. A study by A. Hamed, D. Basu and K. Das [4] gives the acoustic effects of higher Reynolds number flow over a cavity. Higher sound pressure levels are accompanied with higher Reynolds number value. Some unsteady flow simulations have been performed by Kim, Choi and Kwon [5] on the effects of internal weapon bay exposed to a flow field. It studies the aerodynamic, acoustic and structural loads on the weapon bay. A study by Sheta, Harris, George, Ukeiley and Luke [6] gives the effect of flow over weapon bay over the doors of the bay of different configurations using RANS-LES techniques. A study by Loupy and Barakos [7] gives some more insights of various stages of weapon bay where door is about to open, fully open to a certain angle and about to close in an unsteady transonic flow field. Another study by Loupy and Barakos [8] throws some light on the structural deformations on the store(weapon) when it is exposed to the unsteady flow field. It’s a multi-disciplinary simulation which talks about acoustics, structural deformations, trajectory of the weapon and upto some extent aerodynamics of the store too. Another study by Loupy and Barakos [9] describes the challenges occurring during the measurement and simulation of cavity flows such as statistics, experimental data, model generation, etc. Wang and Wu [10] have studies the self-sustained oscillations within the cavity at an unsteady supersonic flow using Dynamic Mode Decomposition algorithm to get a good understanding of shear layer convection and frequency characteristics of the velocity flow field. Gong and Wang [11] have sought to perform unsteady simulations of the ejection of a weapon from the weapon bay using direct eddy simulation technique. Deepu, Sadanandan, Vishnu and Aravind [12] have studied the effect of heat transfer on a 2-D open cavity at supersonic speeds using HLLC scheme based FVM solver. The study pretty much reveals the physics of alteration in the cavity flows along with heat transfer in the cavity. Qin, Qiao, Gu, Yin, Yang and Zhang [13] carried out the numerical study on a 2-D missile separation from weapon bay at high speeds, affecting the temperature and pressure distribution of the cavity and missile.

# **Objective**

In this paper, we compare the steady flow analysis of an open cavity like a weapon bay with a warhead and without a warhead at a supersonic speed of Mach 2, using commercial software ANSYS Fluent. The flow parameters such as pressure, temperature, velocity and density over walls of cavity have been computed and presented. The present work would result in a better understanding of the flow dynamics of an open cavity which would hold immense importance while designing the weapon bay of a fighter aircraft.

# **Solver Validation**

The commercial solver ANSYS Fluent has to be validated prior to its use, for which one of the computations of an already published paper by M.R. Gruber [14] have been compared following the same methodology and parameters. The very computation in the paper is about the normalized static pressure along the walls of cavity of LD3 configuration wherein a steady flow analysis is performed at a supersonic speed of Mach 3.



**Fig. 4.1: Solver validation plot.**

# **Computational Methodology**

**Geometry:**

The geometry consists of an open cavity of LD5 configuration of length (L) and depth (D) as 5m and 1m respectively. The cavity is embedded in a rectangular domain of its length and breadth as 75m and 20m respectively. The cavity at the top of the domain at a distance of 20m from the far left. The CAD is modelled using commercial software SOLIDWORKS.

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**Fig. 5.1: CAD model of domain for case simulation [13].**

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**Fig. 5.2: CAD model of domain focused on warhead [13].**

The warhead geometry has length and diameter of 4m and 0.4m respectively with a curvature of 0.01m at the tip of warhead. The warhead is placed below the cavity at a distance of 1D from the cavity bottom wall (since the cavity is inverted like a weapon bay, it is the topmost horizontal wall of cavity).

**Meshing:**

The domain has been meshed using a commercial software GAMBIT.

The case which is considered is 1D in which the warhead is located at a distance D, which is the vertical distance from the longitudinal axis of the cavity to the entry wall, equal to 300 mm. The first length for cavity, near the inlet and outlet warhead is kept 0.005 and 0.001 for zones near the warhead for fineness. The total cell count of the empty cavity is 93000.

|  |  |
| --- | --- |
| **Entity name** | **Cell count** |
| Inlet | 80 |
| Farfield 1 | 80 |
| Farfield 2 | 350 |
| Farfield 3 | 100 |
| Outlet | 80 |
| Entry wall | 80 |
| Cavity fore wall | 60 |
| Cavity Bottom Wall | 350 |
| Cavity Aft Wall | 60 |
| Exit wall | 80 |

**Table 5.1: Cell count for defined boundaries of domain.**



**Fig. 5.3 Defined boundaries of domain.**

Mesh for 1D case:

Total number of cells with the addition of warhead becomes 99160. In addition to the above walls which form the base of the domain, the mesh with warhead at 1D distance from entry wall also comprises of warhead specific parts that are meshed in the following pattern:

|  |  |
| --- | --- |
| **Wall name** | **Cell count** |
| Nose tip | 30 |
| Nose up/down (missile up/down) | 112 |
| Body up/down (missile up/down) | 200 |
| Missile Rear | 20 |

**Table 5.2: Cell count for different wall sections of warhead.**



**Fig. 5.4: Defined zones of cavity and warhead.**

**Solver setup:**

The computations have been performed using ANSYS Fluent. Being a compressible flow simulation, the solver is configured to be used as a density-based solver, with Green Gauss Cell Based scheme for mesh discretization.

Boundary Conditions:

Static Pressure: 39408.56 Pascal

Static Temperature: 167.65 Kelvin

Flow speed: Mach 2

Turbulence Model: Standard k-ω (same as used in [14])

# **Results and Discussion**

There are two types of results:

Qualitative results:

* Pressure contours:



**Fig. 6.1: Pressure contour of empty cavity.**



**Fig. 6.2: Pressure contour of cavity with warhead.**

* Density Contours:



**Fig. 6.3: Density contour of empty cavity.**



**Fig. 6.4: Density contour of cavity with warhead.**

Quantitative Results:

* Pressure plot:



**Fig. 6.5: Pressure plot of empty cavity and cavity with warhead**

* Density Plot:



**Fig. 6.6: Density plot of empty cavity and cavity with warhead**

* Coefficient of Drag:

|  |  |
| --- | --- |
| Case | Coefficient of Drag |
| Empty cavity | 0.091654563 |
| Cavity with Warhead (1D) | 0.12818402 |

**Table 6.1: Coefficient of drag for empty cavity and cavity with warhead**

1. **Inference**

Pressure along the cavity wall increases with the presence of warhead.

Similarly, density as well increases along the cavity wall in the presence of warhead and increase further as the warhead advances away from the cavity.

Drag along the cavity first increases as soon as the warhead comes into picture, and further increases as the warhead moves away.

1. **Conclusion**

A steady flow analysis has been performed over 2-dimensional cavity with and without warhead, to study the impact of presence of warhead on cavity. The computations have been performed using ANSYS Fluent solver. Based on the outcomes of the flow analysis, the pressure and density distribution along the cavity wall is such that it increases in the presence of warhead. All in all, the drag along the cavity wall as well increases in the presence of warhead.

1. **Scope of Study**

The study can be further carried out with warhead at different distances from the cavity. Also impact of shockwaves on the cavity wall can be studied further. This study may result in a better weapon bay design.

**References**

1. Stallings Jr R, Wilcox Jr F. Experimental cavity pressure distributions at supersonic speeds. Technical Paper 2683, NASA; June 1987.
2. Experimental Cavity Pressure Measurements at Subsonic and Transonic Speeds Static-Pressure Results E. B. Plentovich Langley Research Center Hampton, Virginia, Robert L. Stallings, Jr. Lockheed Engineering & Sciences Company Hampton, Virginia M. B. Tracy Langley Research Center.
3. Characteristics of Compressible Rectangular Cavity Flows, K. Chung, National Cheng Kung University, Tainan 711, Taiwan, Republic of China JOURNAL OF AIRCRAFT Vol. 40, No. 1, January–February 2003.
4. Effect of Reynolds Number on the Unsteady Flow and Acoustic Fields of a Supersonic Cavity A. Hamed, D. Basu, and K. Das Department of Aerospace Engineering & Engineering Mechanics University of Cincinnati, Cincinnati, Ohio, FEDSM2003-45473.
5. Duk Hyun Kim, Jae Hoon Choi, Oh Joon Kwon, Detached eddy simulation of weapons bay flows and store separation, Computers & Fluids, Volume 121, 2015, Pages 1-10, ISSN 0045-7930, https://doi.org/10.1016/j.compfluid.2015.07.022.
6. Sheta, E. F., Harris, R. E., George, B., Ukeiley, L., and Luke, E. (April 13, 2017). "Loads and Acoustics Prediction on Deployed Weapons Bay Doors." ASME. J. Vib. Acoust. June 2017; 139(3): 031007.
7. G. J. M. Loupy and G. N. Barakos, eds., Understanding Transonic Weapon Bay Flows, 7th European Conference on Computational Fluid Dynamics (ECFD 7). Glasgow, UK, 2018.
8. Loupy, G.J.M. and Barakos, G.N. (2018) Multi-Disciplinary Simulations of Stores in Weapon Bays using Scale Adaptive Simulation. In: AIAA Science and Technology Forum and Exposition (SciTech2018), Kissimmee, FL, USA, 8-12 Jan 2018, ISBN 9781624105241.
9. Loupy, Gaëtan & Barakos, George & Taylor, N. (2017). Cavity Flow over a Transonic Weapons Bay During Door Operation. Journal of Aircraft. 55. 1-16. 10.2514/1.C034344.
10. Wang, J. & Ming, X. & Wang, H. & Ma, Y. & Wu, J.. (2019). Flow Characteristics of a Supersonic Open Cavity. Fluid Dynamics. 54. 724-738. 10.1134/S0015462819050124.
11. Gong, Junfeng & Wang, Fang. (2019). Simulation of the Store Separation from Internal Weapons Bay Using M\_SST DES Model. Journal of Physics: Conference Series. 1215. 012001. 10.1088/1742-6596/1215/1/012001.
12. A.S. Vishnu, G.P. Aravind, M. Deepu, R. Sadanandan, Effect of heat transfer on an angled cavity placed in supersonic flow, International Journal of Heat and Mass Transfer, Volume 141, 2019, Pages 1140-1151.
13. Yunpeng Qin \*, Xiaohui Qiao, Tianlai Gu, Geling Yin, Yang Yang and Yang Zhang Numerical Study on a 2D Simplified Missile Separation from High-Speed Aircrafts, IOP Conf. Series: Journal of Physics: Conf. Series 1064 (2018) 012020.
14. Gruber M R, Baurle R A, Mathur T and Hsu K Y 2001 Jr. Propulsion and Power 17 146–153.
15. Nayal, Sanchayata & Lamb, Sampada & Sahoo, Devabrata & Raghavendra, N. & Bellary, S.A.I. (2020). Computational analysis of novel cavity-based flame holder designs for supersonic combustion engines. IOP Conference Series: Materials Science and Engineering. 814. 012018. 10.1088/1757-899X/814/1/012018.