Determination of maneuvering force on spin stabilized missile based on Magnus effect under subsonic flow conditions

Prabhjot Singh
School of Mechanical Engineering
Lovely Professional University, Jalandhar-Delhi GT Road, Phagwara, Punjab, India, 144001
E-mail: rssbmrdhillon@gmail.com

Ashwani Kumar
School of Mechanical Engineering
Lovely Professional University, Jalandhar-Delhi GT Road, Phagwara, Punjab, India, 144001
E-mail: ashsm12345@gmail.com

Joshua Kumar Takri
School of Mechanical Engineering
Lovely Professional University, Jalandhar-Delhi GT Road, Phagwara, Punjab, India, 144001
E-mail: joshuatakri@gmail.com

Sharang Ahirekar
School of Mechanical Engineering
Lovely Professional University, Jalandhar-Delhi GT Road, Phagwara, Punjab, India, 144001
E-mail: sharangahirekar1@gmail.com

Manikandan S
School of Mechanical Engineering
Lovely Professional University, Jalandhar-Delhi GT Road, Phagwara, Punjab, India, 144001
E-mail: manikandan.25934@lpu.co.in
Commensurable Author: Manikandan S

Abstract
Contemporarily, innumerable technologies are being brought into operation for missile maneuverings. By the same token, this research provides a substitute as well an advanced tactic to the habitual tack of maneuvering missiles in which the reaction thrusters and the control surfaces installed on it has been utilized. Here, a force which is proportional to the crosswind direction and the flight path of a particular missile is journeyed on neutralizing the same with regards to its spin and geometry running under a unique velocity level. The force encountered by the missile is further named as the Magnus Force moreover the same force may also be applied for future maneuverings. In addition to this, it is observed that in absence of the Magnus Force in gyrating missiles, there exists an identical RPM. This paper ascertains the condition where no Magnus Fore occurs in the missile i.e. stable/equilibrium state; into the bargain, by commuting the swivel from the stable condition it also points out the Magnus Force.

Keywords - Spin Neutralization, Magnus Force, crosswind conditions, Missile Maneuvering.

Introduction

Predominantly, numerous control surfaces are exploited for missile maneuvering purposes. To exemplify, some of these surfaces are mid wing control, canard and split canard control, unorthodox control and tail control. A mid wing control surface corroborates the raise and steadiness for the missile at some point of massive maneuvers. Canard is a set of appendages placed ahead of the fundamental wing; it is a helping hand to control the wing airflow moreover comes up with contented maneuvering at low angle of incidence. Subsequently, split canard control possesses two units of fins; out of which one is stationary and other is mobile. The mentioned fins of the split canard control succor the engendering of vertices and impede in flow separations. Furthermore, it has an extra merit over the customary canard control so that it is employed in maneuvering at higher incidence angle also. Unorthodox thrust control is basically an approach to execute the obligatory rotations/turns for maneuvering of missile by providing a path to the thrust; by means of this control, the thrust produced from the tailpipe is sidetracked in order to avert the nose section. The tail control is comprehensively brought to bear for the applications with long range conditions because it gives the magnificent maneuverability even in case of exalted adjustment angles. This research provides the idea as well as the application to maneuver the missile excluding the use of these all surfaces and uncovers a unique of missile where the Magnus Force is negotiable under various inlet velocity conditions.

Problem Statement

Throughout the use of the control surfaces of the missile, it has been espied that missile suffers various problems due to the drawbacks of the control surfaces. For elaboration, in case of wing control surfaces, it is the obligation to fabricate humongous wings for better raise and control effectiveness but, by exploiting these wings, missile turns gigantic overall. Furthermore, vigorous vortices are effectuated by wings which rub elbows abominably with the tail and leads to adverse rolling of the operating missile.

On the other hand, on account of the fact that in canard control surface, the canard appears before the middle point; it gives rise to some wobble effects and demands the considerable tails to maintain the stability.

Current Issue

Here, a newfangled methodology for missile maneuvering has been proffered in this research which capacitates the missile to maneuver without the assistance of any of the control surfaces. Under the aegis of the swivel spared to the missile, a force which is perpendicular to the flight path and the crosswind directions has come up which is known as the Magnus Force and thereupon used for the maneuvering purposes. The configuration of the missile which has been taken into account is somehow resembles with some other missile named as K4 missile such that wheeling axis of the missile and the crosswind direction are perpendicular to each other. A subsonic range (Mach<1) of the velocities is utilized for this missile moreover the appellation used here is free stream velocity where the object is stock-still and fluid is kept mobile.

Proposed Method

The subsonic conditions for the wheeling missile have been brought to bear in the proposed method which is thereupon employed to ascertain the null value of Magnus Force. On account of the fact that missile is swirling, the software named as ANSYS CFX was extortionately endorsed. Diversified simulations have been accomplished by fixing a unique value of free stream tempo and the crosswind paces. Every time, the swivel of the wheeling missile is kept fluctuating. The fundamental aim was to uncover the swirl where the Magnus Force becomes negotiable; ergo, the methodical anatomization is perpetrated until the result turns negative from positive or vice-versa. The graphical details of the analysis are also carried out and same study is done under different inlet velocity conditions.

Process

The Two velocities videlicet the traverse pace and free stream tempo are used in order to have a thoroughgoing surveillance on the pirouetting silhouette of the missile. The former is allocated a unique value whereas the latter is kept varying in accordance to the Mach number. The assorted values of the free stream paces and Mach number has vouchsafed the diversified results.

Since the paramount theme was to ascertain a particular birl which could bestow a zero value of the Magnus Force, an idiosyncratic value has been fed as the crosswind conditions and the free stream tempo under the allocated values of Mach number, static temperature, Prandtl number and other boundary conditions. On acquiring the numerical results of Force, the graphical representations of negative as well as positive values are made.

Algorithm and Boundary Conditions

The experimental details are carried out under various free stream velocity conditions such as V_1, V_2, V_3 and V_4. The numerical values assigned these velocities are 100m/s, 150m/s, 200m/s and 250 m/s respectively. Mach number also changes as these velocities change; to elaborate, the Mach number corresponding to V_1, V_2, V_3 and V_4 are 0.29, 0.44, 0.58, and 0.73 respectively. Since under every condition the whirl of the missile has been changed numerous times, therefor every time new value of force is acquired. To exemplify, when the rpm is set to a numerical value of 50 i.e. 50 rev/min. Under conditions of inlet velocity, crosswind velocity and Mach number as 200m/s, 5m/s and 0.58 respectively the corresponding value of force came as 274.467 Newton.

The boundary conditions which are kept same for each and every case are as follows:-

- Prandtl Number :- 7.04
- Static Temperature:- 225K
- Normal crosswind velocity:- 5m/s
- Atmosphere: Relative pressure 25000 Pa along vertical axis

Details of CFD:-

It is engineering software found by ICEM CFD engineering which gives the satisfactory configuration instruments for CAO, post-processing moreover it helps in meshing and provides optimization tools. It has been enormously used for engineering implementations such as **Computational Fluid Dynamics** and geometrical anatomization.

Due the fact that missile is gyrating, ANSYS CFX is exploited for operation

Here the meshing operation is completed using ICEM-CFD 19.2 and solver is done with the help of CFX-solver

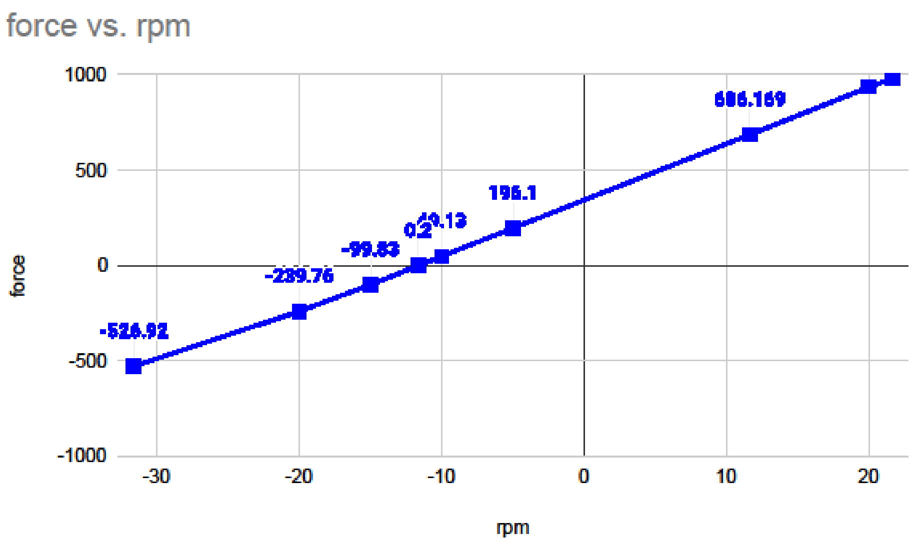
19.2
ANSYS 19.2 is implemented to carry the analysis of flow.
The CFX-Pre 19.2 has been used for the purpose of pre-processing whereas for post-processing CFD-Post 19.2 is exploited for post processing.

Result and Graphical Representation:-

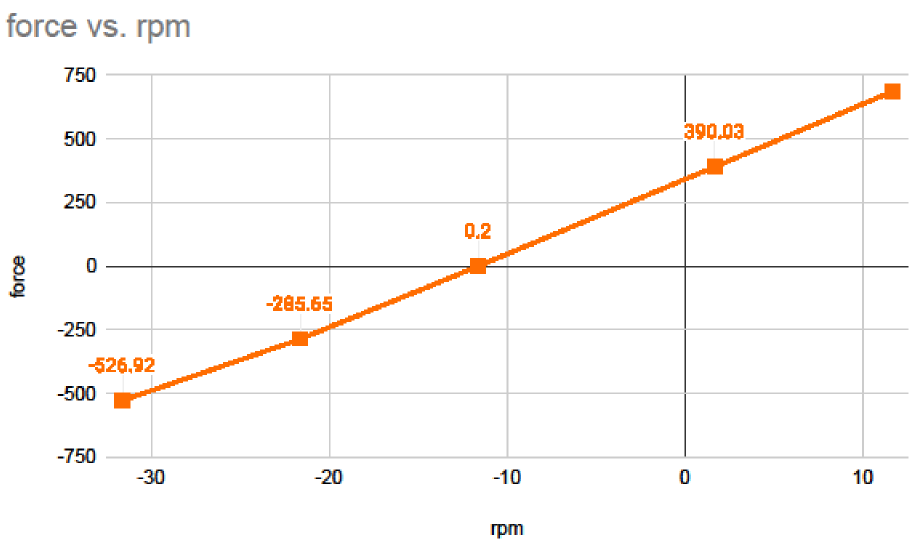
1. Under the conditions i.e.
   - Mach Number :- 0.29
   - X-axis Direction (Inlet Velocity):- 100m/s
   - Z-axis direction (Crosswind Velocity):- 5m/s

   The results for various Mach numbers are shown graphically below:-

Graph1:- RPM vs. Magnus Force at inlet velocity 100m/s



Graph 2:- Swivel of missile and maneuvering force at inlet velocity 100m/s

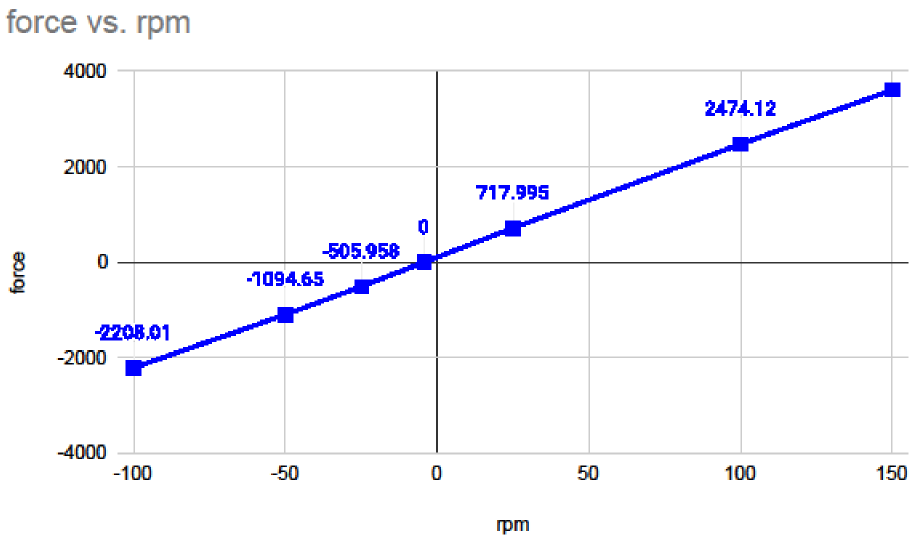


2. Under the conditions i.e.
   - Mach Number :- 0.44
   - X-axis Direction (Inlet Velocity):- 150m/s

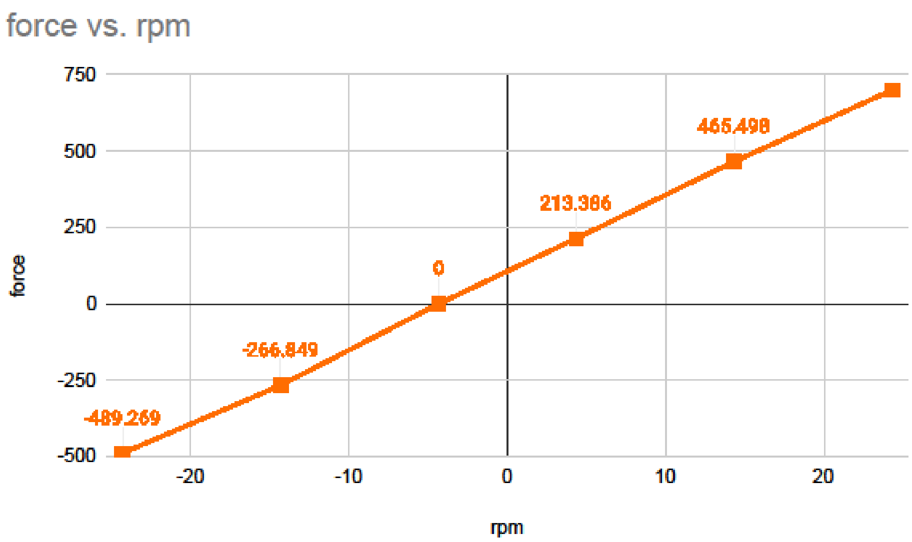
- Z-axis direction (Crosswind Velocity):- 5m/s

The results for various Mach numbers are shown graphically below:-

Graph1:- RPM vs. Magnus Force at inlet velocity 150m/s



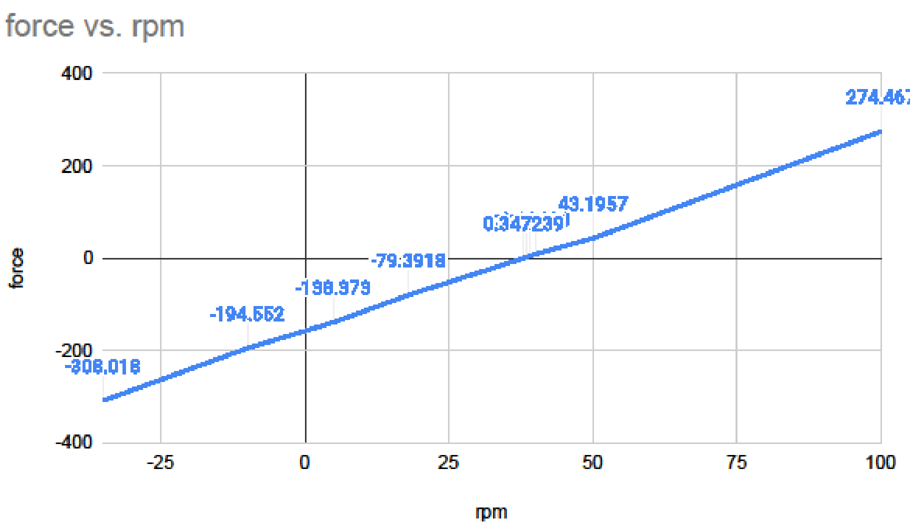
Graph 2:- Swivel of missile and maneuvering force at inlet velocity 150m/s



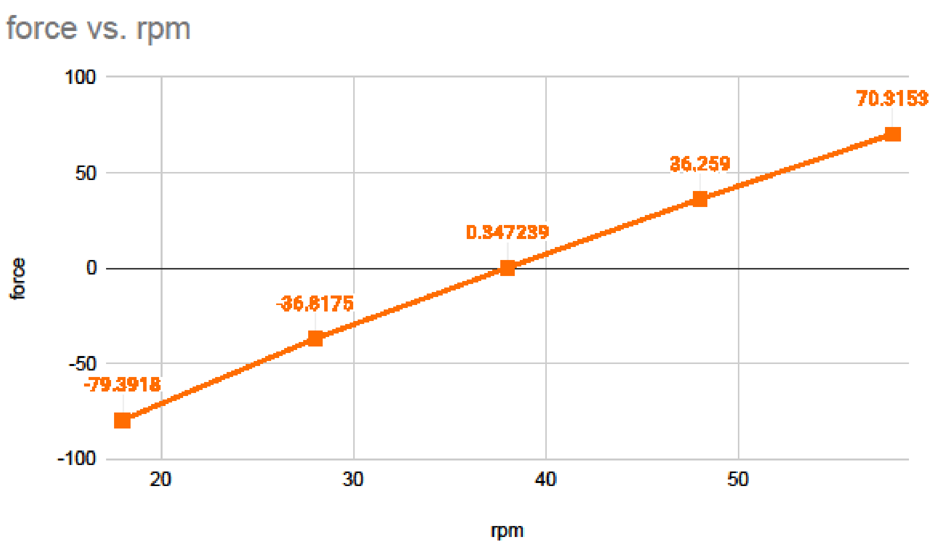
3. Under the conditions i.e.
   - Mach Number :- 0.58
   - X-axis Direction (Inlet Velocity):- 200m/s
   - Z-axis direction (Crosswind Velocity):- 5m/s

The results for various Mach numbers are shown graphically below:-

Graph1:- RPM vs. Magnus Force at inlet velocity 200m/s



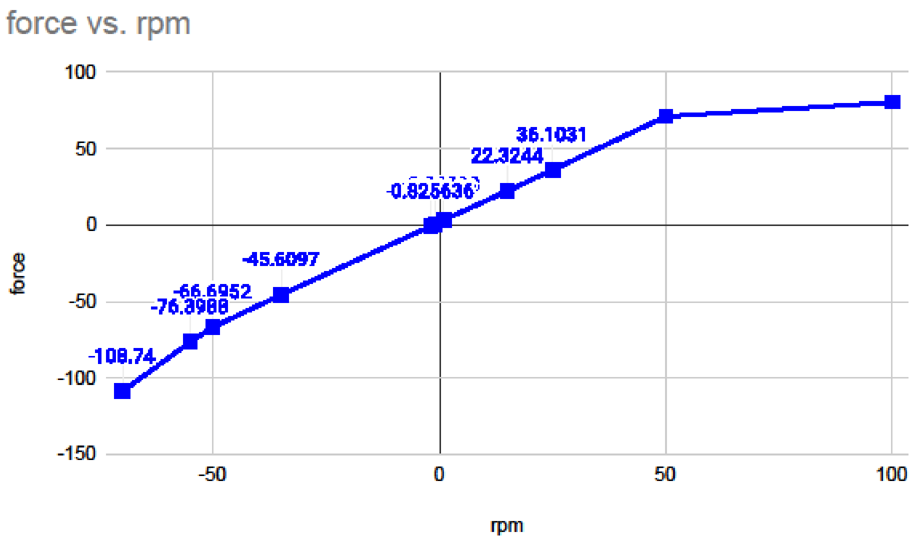
Graph 2:- Swivel of missile and maneuvering force at inlet velocity 200m/s



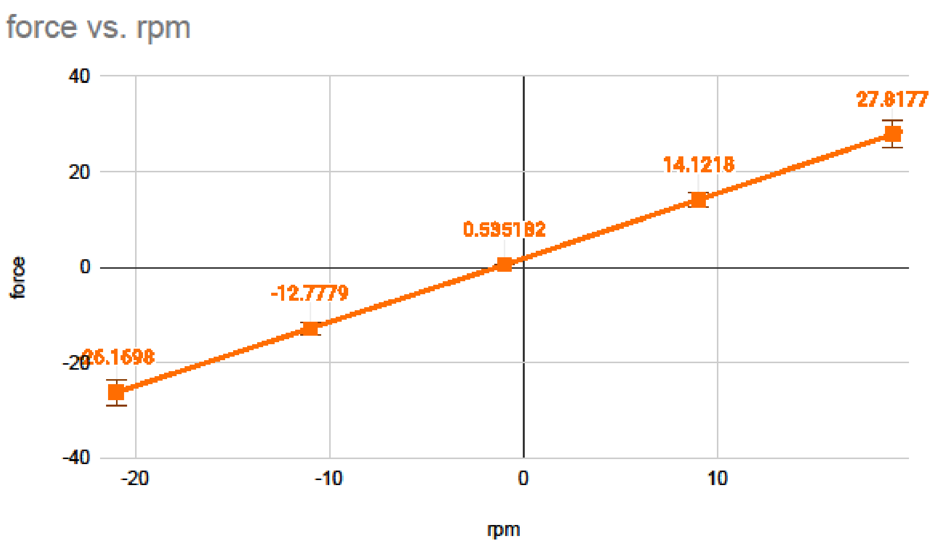
4. Under the conditions i.e.
   - Mach Number :- 0.73
   - X-axis Direction (Inlet Velocity):- 250m/s
   - Z-axis direction (Crosswind Velocity):- 5m/s

The results for various Mach numbers are shown graphically below:-

Graph1:- RPM vs. Magnus Force at inlet velocity 250m/s



Graph 2:- Swivel of missile and maneuvering force at inlet velocity 250m/s



Output and Discussions:-

The paramount aim of the project has been fulfilled by taking the zero value of Magnus force under diversified inlet velocity and whirl conditions.

Firstly, as shown in the graph 1, on projecting the missile at inlet velocity 100m/s and an rpm of it underwent the zero Magnus force.

Secondarily, when the missile is given free stream velocity and rpm as 150m/s and rev/min, it encountered null Magnus force as shown in the graph 2.

Thirdly, operating on 200m/s as inlet velocity and a swirl of 38 rpm, the Magnus force experienced by the missile was zilch as shown in graph 3.

Fourthly, on projecting the missile at inlet velocity 250 m/s an rpm of it underwent the zero Magnus force.

Conflict of Interest

It is ensured that there is no conflict of interest to declare for this publication.

Acknowledgments

No specific grant is acquired by this research especially from any source of funds in the communal, trading or not-for-profit sectors. The authors are indebted to the editor and all incognito commentators for their utterance which ameliorate the standard of this experiment.

References

1. Manikandan and Amit Kumar Thakur, “Effect of magnus force on spin stabilized missile in normal cross wind conditions” (2020).
2. Manikandan and Amit Kumar Thakur, “ Effect of magnus force on spin stabilized missile in oblique cross wind condition” (2020).
3. Thorsten Kray, Jorg Franke, Wolfram Frank, “Magnus effect on rotating soccer ball at higher Reynolds numbers” (2014).
4. Jooha Kim, et al, “Inverse magnus effect on rotating sphere” (2014).
5. Zhenhua Fu, Yaping Dai, “Research progress on design methods for missile integrated guidance and control” (2017).
6. S. Pezzotti, S. Franchini, “Experimental study of Magnus effect in cylindrical bodies with 4, 6, 8, 10 sides” (2020)