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Design and Analysis of Mechanical Micro-Swimmers

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ABSTRACT

Research is currently becoming more and more interested in studying microswimmers. When compared to the macroscopic world, the motion or mobility of an object in the microscopic world is distinctive and challenging to comprehend. In this research, we look into these little microswimmers, also known as swimmers. The fundamental design of a swimmer was initially presented as a three-sphere model, and it is frequently used extensively in theoretical, computational, and experimental study. In order to learn more about and gain insight into several general concepts of microswimmers, we have modified and developed the helical spring model in two ways.

An ideal design is produced in this research which is a conical shaped head with a helical spring as its tail. The current research work compares the analytical analysis of two models of microswimmers with different head designs. The values of numerous parameters, such as deformations, velocities, accelerations, stresses & strains etc., for micro-swimmer will be found in the current research effort. We can create the best design for a helical spring micro-swimmer by examining the data.

Keywords: Microswimmers, ansys fluent, self-propulsion, micro robots.

1. INTRODUCTION

This study focuses on mechanically propelled micro swimmers, commonly known as "swimmers." These are miniscule, as the name suggests. They can swim or move forward independently in fluids by using mechanical forces. Despite being at the micro level, there is no precise restriction. Micro swimmers include the majority of biological microorganisms, including bacteria, algae, archaea, and protozoa. This type of biomass on earth was reportedly included in some studies. There are numerous manufactured devices that are already in existence that are of microscopic size that swim in fluid environments, making them instances of micro swimmers in addition to these natural species. We shall focus our attention on the movements of mechanical microswimmers. The impact of microbes (also known as microorganisms) on the health of other creatures has been extensively investigated. Comparably, in order to use artificial micro swimmers effectively and securely for their intended uses, it is essential to thoroughly comprehend and forecast the features of their motion. At low Reynolds numbers, where fluid friction and viscosity prevail over inertia, swimming occurs at the microscopic scale. Evolution produced propulsion devices that combat drag and even take advantage of it. Numerous bacteria use rotating helical flagella as a means of propulsion, and sperm and algae use eukaryotic flagella that move in a manner like to a whip or snake.

The drug delivery mechanism that swims on its own in the direction of cancer cells before releasing its therapeutic load. A rapidly developing scientific field with numerous potential medicinal uses is autonomous swimming. When the bacteria is found then it enters the cancer cells, the medicine is internally released. Doxorubicin kills the invaded cancer cell and destroyed the carrier once it was liberated from the liposomes. Chemotaxis is the ability of motile cells to respond to chemical gradients in their environment and to migrate in one direction—either toward higher concentrations of chemoattractant or lower concentrations of chemorepellent—in order to do so. It can serve as a useful tool for laboratory investigations as well as be crucial in practical applications. To increase the forward-backward motion symmetry, a double-end helical swimmer is built on the common single-end helical one. Additionally, the ideal design and motion properties of sub-millimeter helical swimmers were examined. The outcomes will soon be confirmed on smaller helical micro swimmers. A promising development for the treatment of diseases is the development of intelligent nanomaterials therapeutic systems based on nanomaterials have the potential to outperform current molecular therapeutic and diagnostic approaches.

1.1 Fundamental concept of Reynold's Number:

The Reynolds number is the ratio of inertia forces to viscous forces. The Reynolds number is a dimensionless number used to categorize the fluids systems in which the effect of viscosity is important in controlling the velocities or the flow pattern of a fluid. Mathematically, the Reynolds number, *N*Re, is defined as

Re=

If the Reynolds number calculated is high (greater than 2000), then the flow through the pipe is said to be turbulent. If Reynolds number is low (less than 2000), the flow is said to be laminar. Numerically, these are acceptable values, although in general the laminar and turbulent flows are classified according to a range. Laminar flow falls below Reynolds number of 1100 and turbulent falls in a range greater than 2200.

Laminar flow is the type of flow in which the fluid travels smoothly in regular paths. Conversely, turbulent flow isn’t smooth and follows an irregular math with lots of mixing. An illustration depicting laminar and turbulent flow is given below.

Turbulent

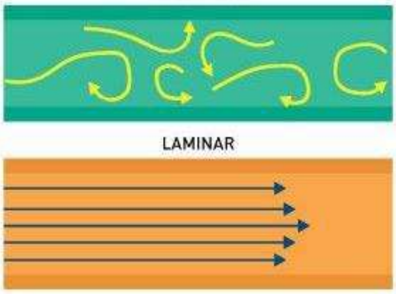

Figure 1: Illustration of Turbulent & Laminar flow.

2. Literature Review

1. The self-propulsion of microscopic organisms through liquids (G. J. Hancock)

The effect of the inertial forces is minimal because the Reynolds number of motion of tiny creatures through liquids, defined as$L\rho V/\mu$, where L is the length of the organism, V is the velocity with which it moves, the density of the liquid, and the viscosity, is small. The Stokes' solution for slow, steady fluid motion through a sphere, in which the velocity field may be characterised in terms of singularities located in the centre of the sphere, is the best-known problem that ignores all inertial forces. Placing distributions of these singularities inside the surface of the organism and meeting all boundary criteria determines how microscopic organisms move.The motions that are taken into consideration are only those that are propagated by organisms along filaments with circular cross sections and tiny radii. The first issue to be taken into consideration is the existence of an infinitely thin filament along which lateral displacement plane waves propagate. For I the limiting situation of zero radius and (ii) the case where the amplitude of the displacement is modest in comparison to the wave-length, formulae for the velocity of propulsion are obtained. When the amplitude is greater than that permitted in instance (ii) above and the filament radius is small but non-zero, calculations have been done to estimate the propulsion. It is also shown that the propulsion of a finite filament which forms itself into a single wave is very near to that of an infinite filament with the same wave motion.

The second problem is that of an infinite filament along which any general three-dimensional disturbance is propagated. The movement is then deduced for the propagation of a spiral wave along an infinite filament, and also for the propagation of longitudinal waves along a finite filament.

2. Biaxial fluid oscillations can propel a microcapsule swimmer in an arbitrary direction (Takeru Morita, Toshihiro Omori, and Takuji Ishikawa)

Numerous artificial micro-swimmers have been suggested because of their potential value in engineering and medicinal applications. Designers introduced a microcapsule swimmer that underwent amoeboid-like shape deformation under vertical fluid oscillation in previous paper and demonstrated the benefits of using a solid membrane and fluid oscillation in terms of swimmer controllability. The microcapsule could migrate in the Stokes flow regime, but it could only move in one of two directions: vertically up or down. Therefore, as a significant step toward potential applications, we attempted to control the propulsion of a microcapsule in this research by imposing biaxial fluid oscillations. By inducing biaxial fluid oscillations in the horizontal and vertical planes, respectively, numerical findings demonstrated that the microcapsule may migrate in both directions. A swimmer who propels themselves horizontally can be thought of as using effective and recovery strokes, whereas a swimmer who propels themselves vertically uses stiff body motion caused by a torque. We were able to correctly manipulate the microswimmer to sketch a -shaped trajectory by progressively applying three different forms of fluid oscillations. These outcomes demonstrate that the micro-swimmer's position and trajectory can be freely controlled in three dimensions. The information in this research is crucial for upcoming artificial micro-swimmer designs.

3. Physical Sensing of Surface Properties by Microswimmers (Jinglei Hu, Adam Wysocki, Gerhard Gompper)

Escherichia coli and other bacteria move in circular motions close to surfaces. Thus, the curvature and direction (clockwise or counterclockwise) rely on the surface characteristics. To quantitatively examine the curvature of the apparent circular trajectories, we use mesoscale hydrodynamic simulations of a mechanoelastic model of E.coli with a spherocylindrical body pushed by a cluster of rotating helical flagella. We show that the cell is responsive to variations in the surface slip length at the nanoscale. The findings are used to suggest an unique method for controlling bacterial motion on striped surfaces with various slip lengths. This method calls for changing the circular motion to a snaking motion at the stripe boundaries. The feasibility of this approach is demonstrated by a simulation of active Brownian rods, which also reveals a dependence of directional motion on the stripe width.

3. Modelling using CATIA

CATIA is an acronym of computer-aided three-dimensional interactive application. CATIA is a multi-platform software suite for computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), PLM and 3D, developed by the French company Dassault Systems.

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CATIA is a solid modelling tool that unites the 3D parametric features with 2D tools and also addresses every design-to-manufacturing process. In addition to creating solid models and assemblies, CATIA also provides generating orthographic, section, auxiliary, isometric or detailed 2D drawing views. It is also possible to generate model dimensions and create reference dimensions in the drawing views. The bi-directionally associative property of CATIA ensures that the modifications made in the model are reflected in the drawing. The CATIA suite is a powerful design tool that is growing in popularity due to the powerful functionality it offers. Since the software is vast, it is better to get professional training in CATIA to make maximum use of its features.

The 3D model of Microswimmers was designed in CATIA with their respective geometrical. dimensions. Following tables show the dimensions of Conical & Droplet Head type Microswimmer.

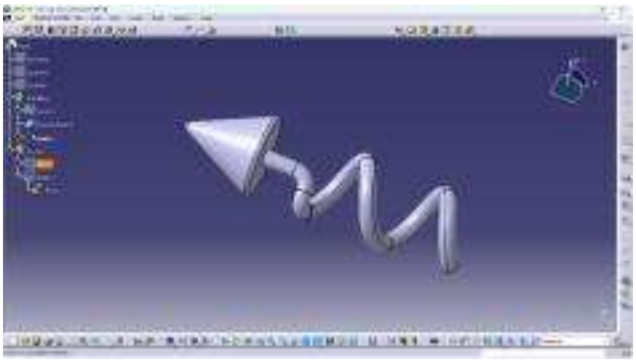


Figure 2: Conical Head Microswimmer.

S. No	Description	Values in µm
1.	Length of the Microswimmer	1600
2.	Length of the Helical Spring	1200
3.	Length of the Head	400
4.	Diameter of the Head	40
5.	Diameter of Tip of the Head	50
6.	Diameter of the Helical Spring	80
7.	Pitch of the Helical Spring	400
8.	No of Waves	2

Table 1: Geometrical Dimensions of Conical Head Microswimmer.

Figure 3: Droplet Head Microswimmer

S.No	Description	Values in µm
1.	Length of the Microswimmer	**1600**
2.	Length of the Helical Spring	**1200**
3.	Length of the Head	**400**
4.	Diameter of the Head	**320**
5.	Diameter of Tip of the Head	**100**
6.	Diameter of the Helical Spring	**60**
7.	Pitch of the Helical Spring	**400**
8.	No of Waves	**2**

Table 2: Geometrical Dimensions of Droplet Head Microswimmer.

4. METHODOLOGY

4.1 ANSYS fluent:

There are huge numbers of engineering applications that can benefit from computational fluid dynamics simulation. Whether you analyze commonplace fluid flow and heat transfer or work with complex transient reacting flows, ANSYS Fluent software should be an integral part of your product design and optimization process. A fully featured fluid dynamics solution for modelling flow and other related physical phenomena, Fluent offers unparalleled analysis capabilities.

It provides all the tools needed to design and optimize new equipment and to troubleshoot existing installations. The versatile technology offers insight into how a product design will behave in the real world, all before a single prototype is built.

4.2 ANSYS Explicit Dynamics:

If a product needs to survive impacts or short-duration high-pressure loadings, can improve its design with ANSYS explicit dynamics. Specialized problems require advanced analysis tools to accurately predict the effect of design considerations on product or process behavior. Gaining insight into such complex reality is especially important when it is too expensive or impossible to perform physical testing.

The ANSYS explicit dynamics suite enables to capture the physics of short duration events for products that undergo highly nonlinear, transient dynamic forces. ANSYS explicit dynamics specialized, accurate and easy-to-use tools have been designed to maximize user productivity.

In many cases, the accuracy of an explicit solution can be verified only via comparison with physical experiments. For some problems (such as explosions), it may be too expensive or impossible to perform tests. Yet ANSYS users around the world rely on the accuracy of explicit results: An extensive list of publications is testament to the correctness of our algorithms and models.

In ANSYS, we performed the following steps. In explicit dynamics we analyzed and compared the values of the 2 microswimmers. In this analysis, we found the values of following parameters. The parameters that we found are categorized as:

- Deformations
- Velocities
- Accelerations
- Stresses
- Strains

4.3 Material:

We have various materials available for micromanufacturing. Ti alloys are one of the bestmaterials for micromanufacturing. Especially **Ti6Al4v** is one of them.

Titanium (Ti) is as strong as steel but much less dense. It is therefore important as an alloying agent with many metals including aluminium, molybdenum and iron. These alloys are mainly used in aircraft, spacecraft and missiles because of their low density and ability to withstand extremes of temperature. They also used for biomedical sector for microsurgeries, heart stents etc.

Ti6Al4V is an alpha-beta titanium alloy with a high strength-to-weight ratio and excellent resistance to corrosion. It is one of the most commonly used titanium alloys and is applied in a wide range of applications where low density and excellent corrosion resistance are necessary such as e.g. aerospace industry and biomechanical applications. The high strength, low weight ratio and outstanding corrosion resistance inherent to titanium and its alloys has led to a wide and diversified range of successful applications which demand high levels of reliable performance in surgery and medicine as well as in aerospace, automotive, chemical plant, power generation, oil and gas extraction, sports, and other major industries.

4.4 Meshing:

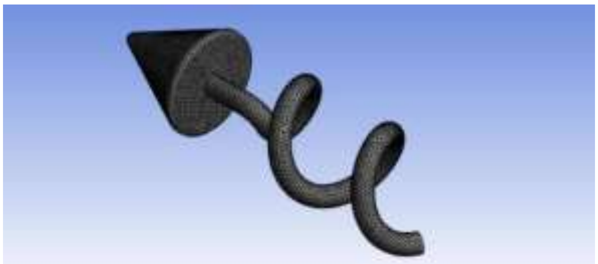


Figure 4: 3D Model of the Meshed Conical Microswimmer.

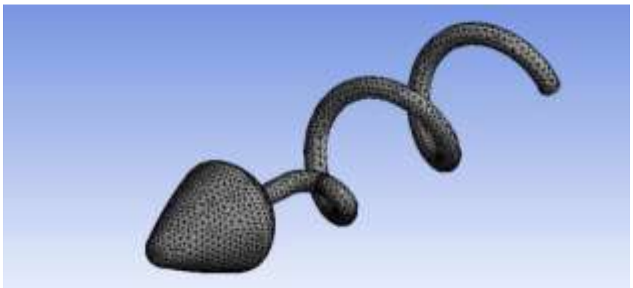


Figure 5: 3D Model of the Meshed Droplet Microswimmer.

4.5 Analysis of microswimmers in ANSYS:

We analyzed the explicit dynamics of two microswimmers by considering they are in a blood vessel. Here we considered the motion of microswimmers and the blood in opposite directions.

We made the setup of the analysis in model segment. Here we gave the materials to the microswimmer and enclosure as Ti6Al4V and blood which we already imported to the material in “Engineering Data” from the material library. We gave the velocity of the blood 0.2416 mm/s and the blood velocity for the microswimmers is 158.829 mm/s.

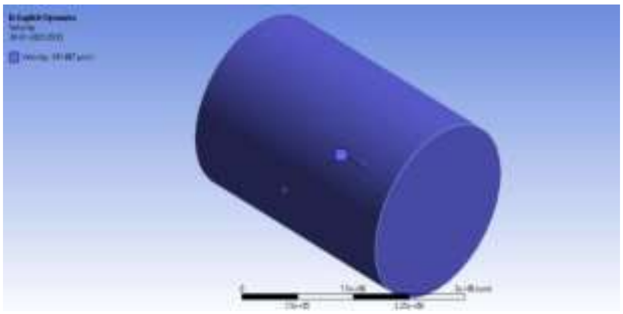


Figure 6: Blood Velocity

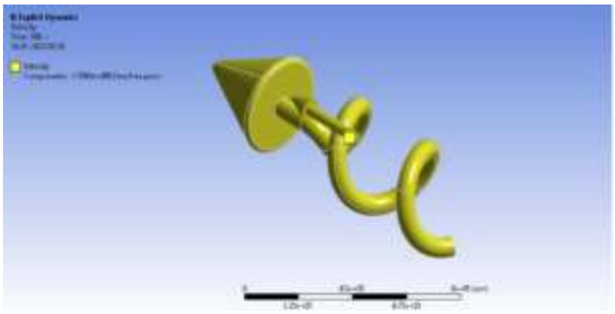


Figure 7: Velocity of Conical Microswimmer.

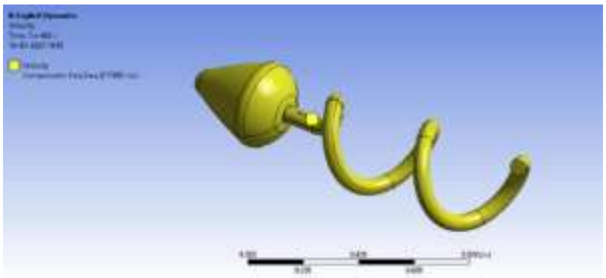


Figure 8: Velocity of Droplet Microswimmer.

5. RESULTS OF ANALYSIS & DISCUSSIONS

5.1 Deformations:

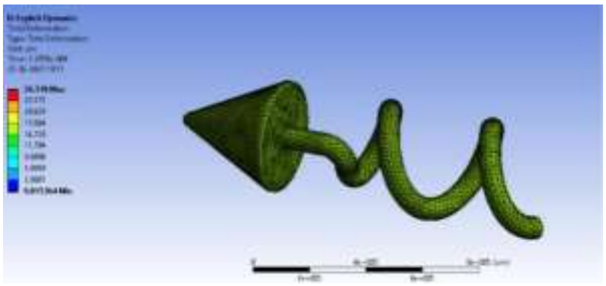


Figure 9: Total Deformation of Conical Microswimmer.

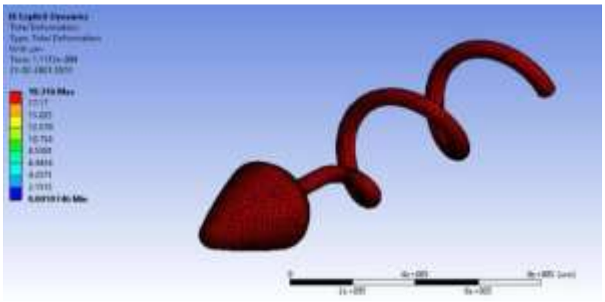


Figure 10: Total Deformation of Droplet Microswimmer.

5.2 Accelerations:

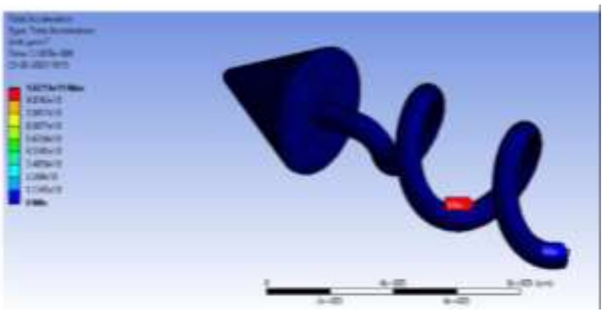


Figure 11: Total Acceleration of Conical Microswimmer.

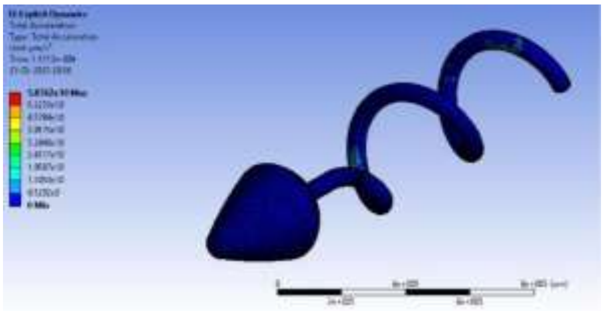


Figure 12: Total Acceleration of Droplet Microswimmer.

5.3 Velocities:

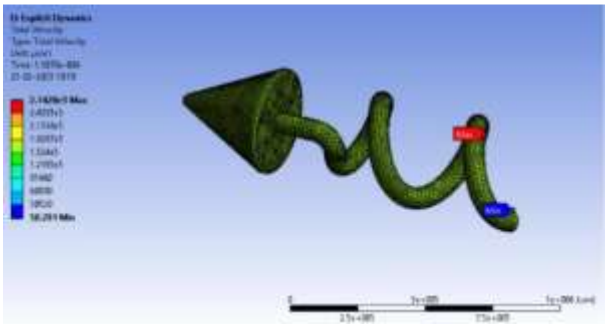


Figure 13: Total Velocity of Conical Microswimmer.

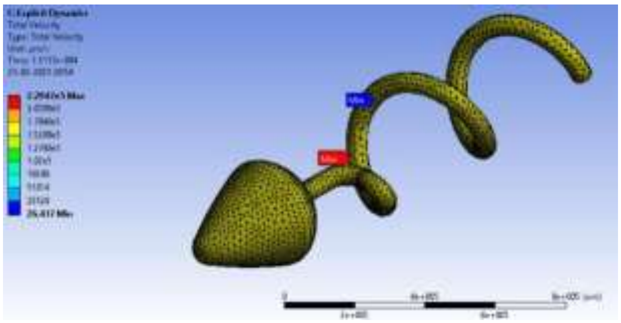


Figure 14: Total Velocity of Droplet Microswimmer

5.4 Stresses:

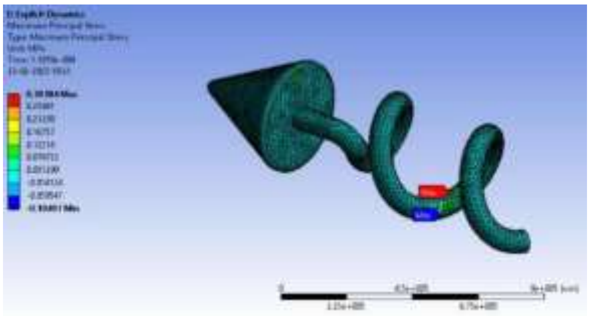


Figure 15: Maximum Principal Stress for Conical Microswimmer.

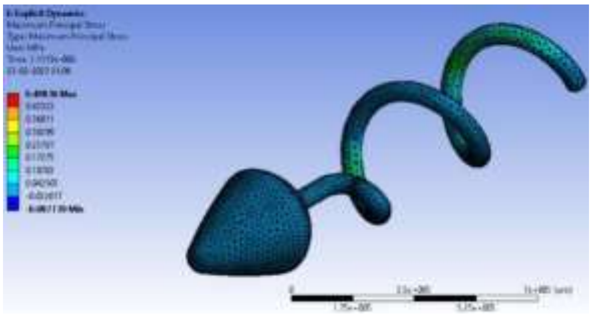


Figure 16: Maximum Principal Stress for Droplet Microswimmer.

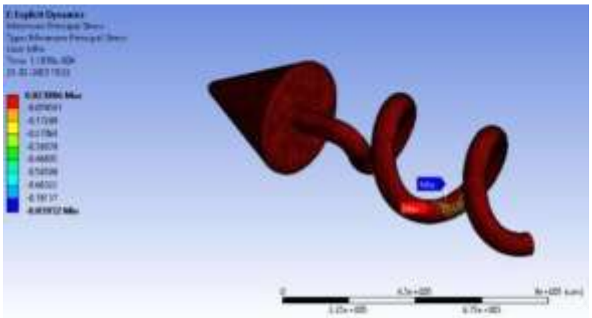


Figure 17: Minimum Principal Stress for Conical Microswimmer.

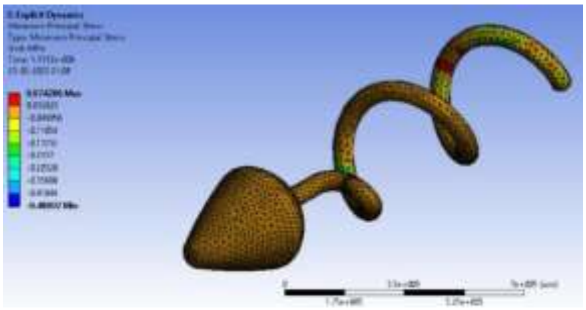


Figure 18: Minimum Principal Stress for Droplet Microswimmer.

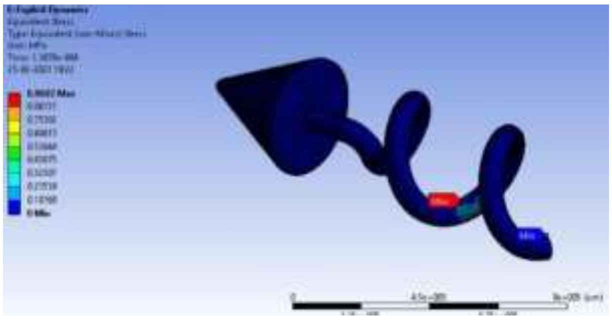


Figure 19: Equivalent Stress for Conical Microswimmer.

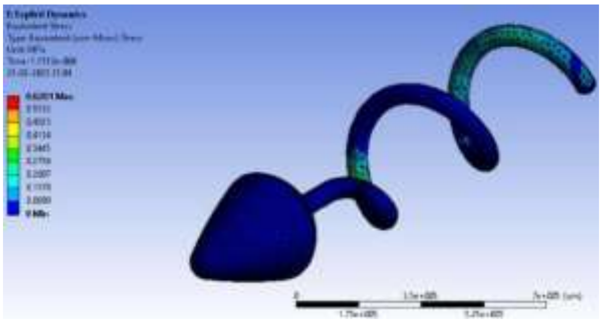


Figure 20: Equivalent Stress for Droplet Microswimmer.

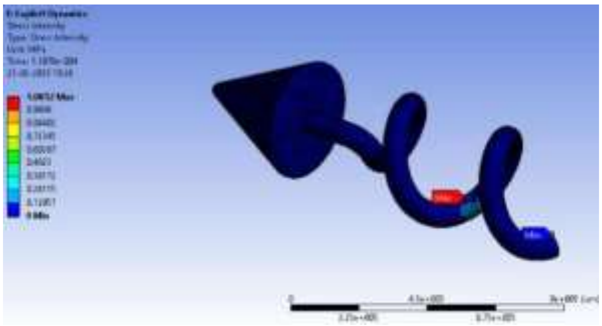


Figure 21: Stress Intensity for Conical Microswimmer.

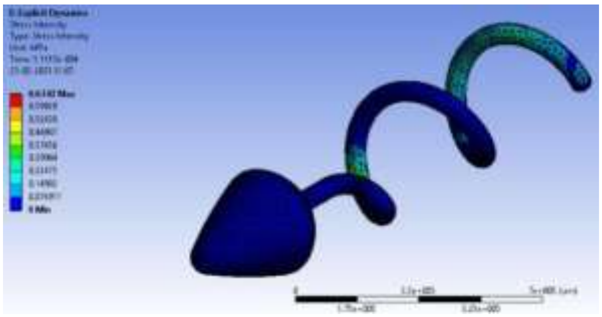


Figure 22: Stress Intensity for Droplet Microswimmer.

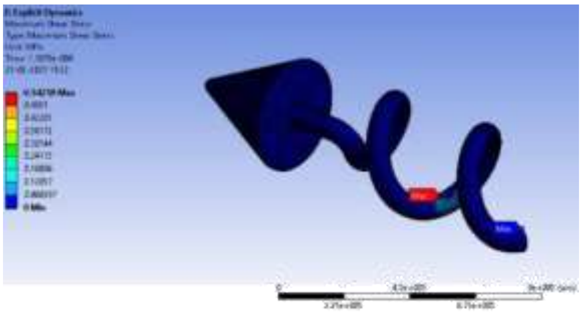


Figure 23: Maximum Shear Stress for Conical Microswimmer.

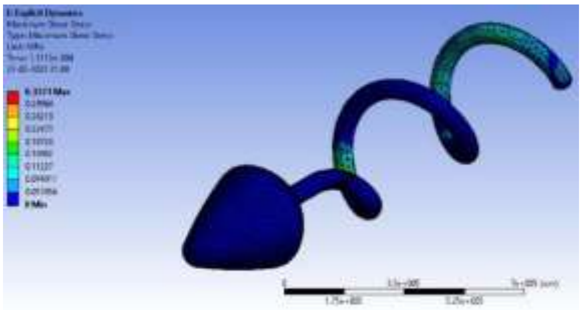


Figure 24: Maximum Shear Stress for Droplet Microswimmer.

5.5 Strains:

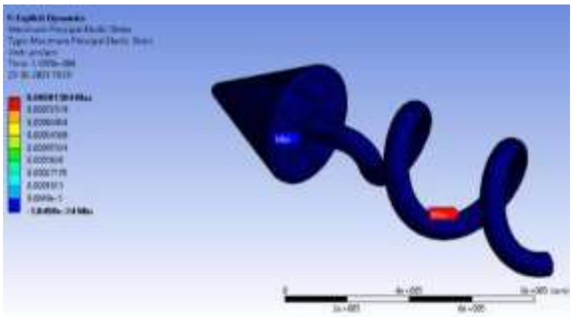


Figure 25: Maximum Principal Elastic Strain for Conical Microswimmer.

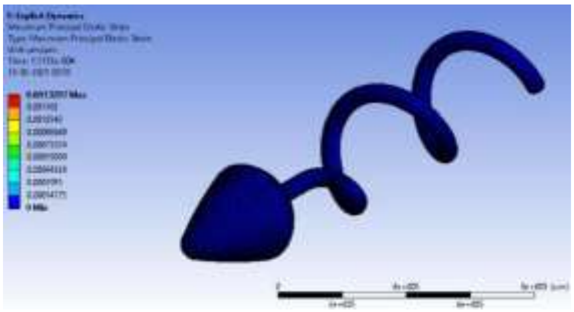


Figure 26: Maximum Principal Elastic Strain for Droplet Microswimmer.

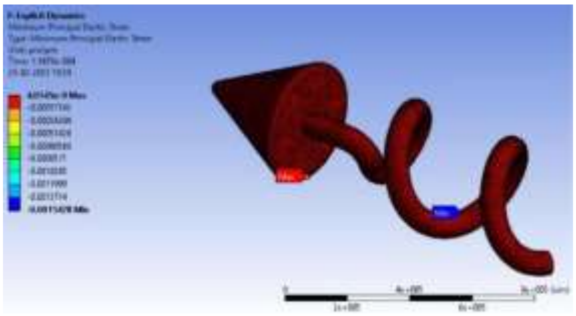


Figure 27: Minimum Principal Elastic Strain for Conical Microswimmer.

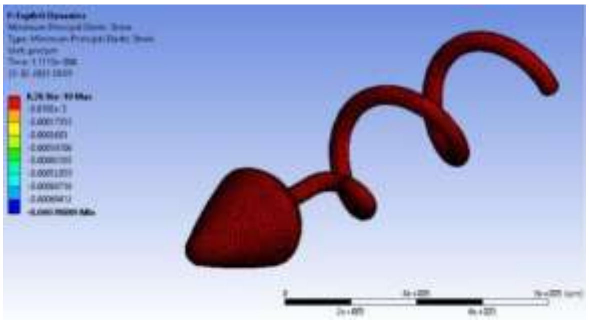


Figure 28: Minimum Principal Elastic Strain for Droplet Microswimmer.

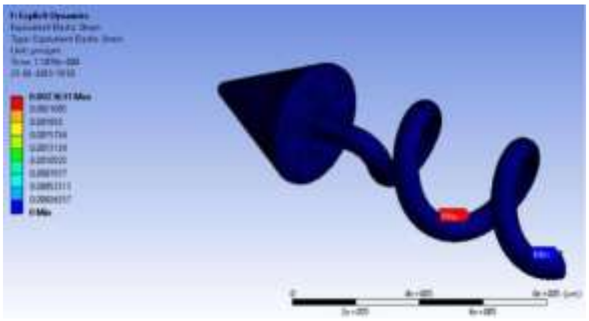


Figure 29: Equivalent Elastic Strain for Conical Microswimmer.

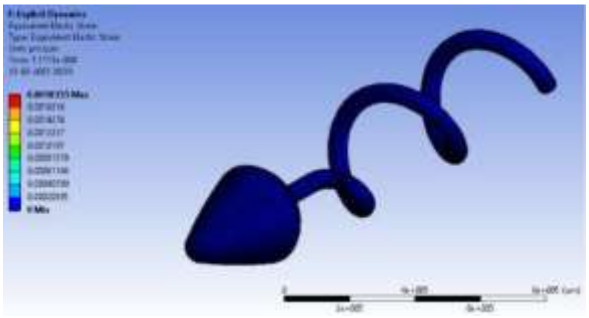


Figure 30: Equivalent Elastic Strain for Droplet Microswimmer

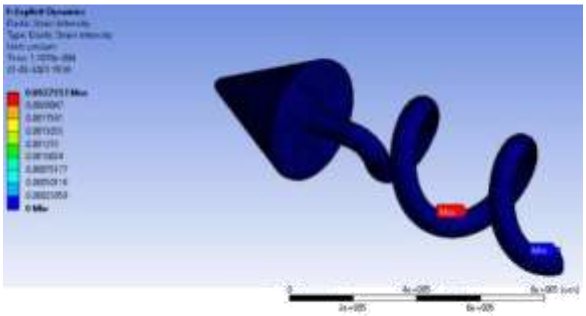


Figure 31: Elastic Strain Intensity for Conical Microswimmer.

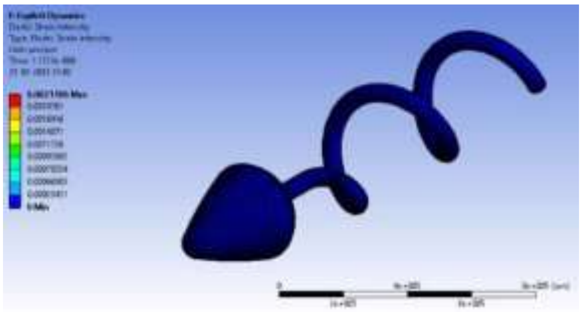


Figure 32: Elastic Strain Intensity for Droplet Microswimmer.

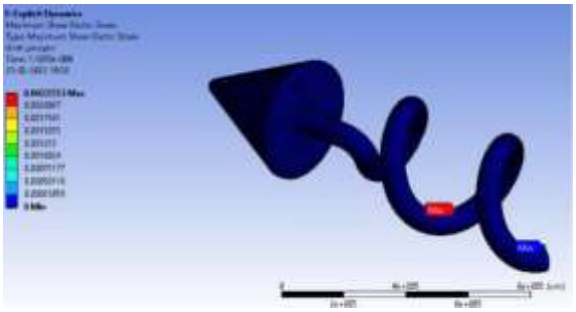


Figure 33: Maximum Shear Elastic Strain for Conical Microswimmer.

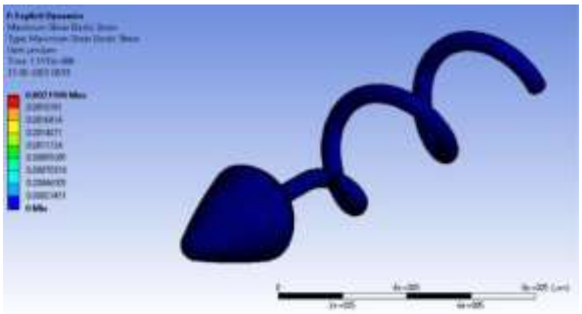
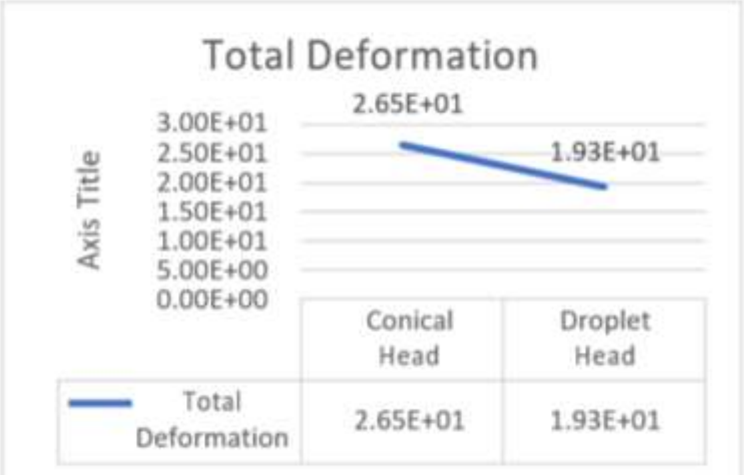
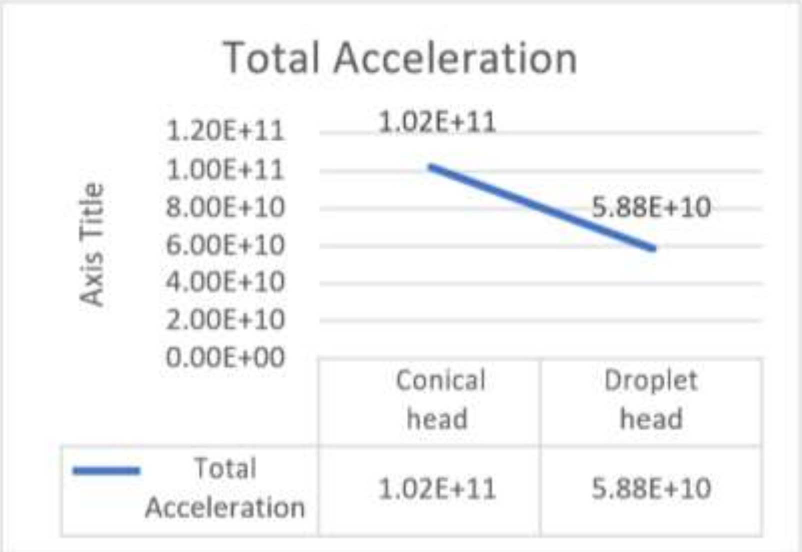


Figure 34: Maximum Shear Elastic Strain for Droplet Microswimmer.

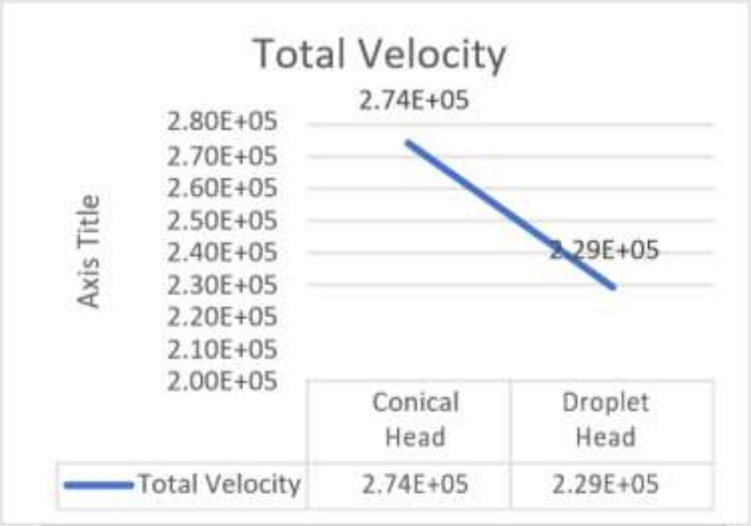
5.6 Comparison of results through graphs:



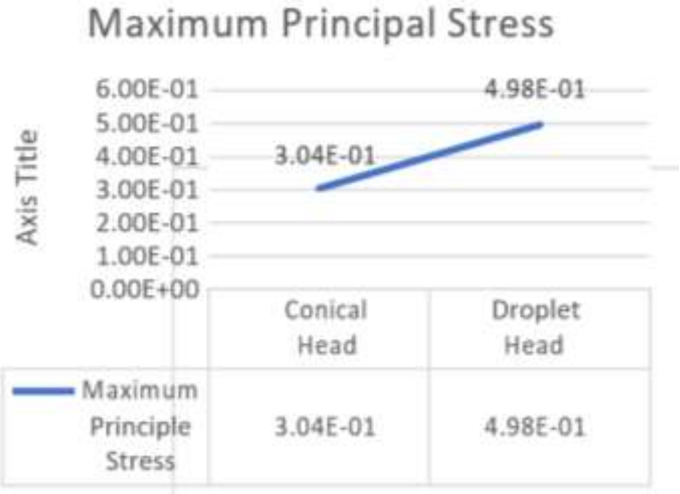
Graph 1: Total Deformation of 2 Microswimmers.



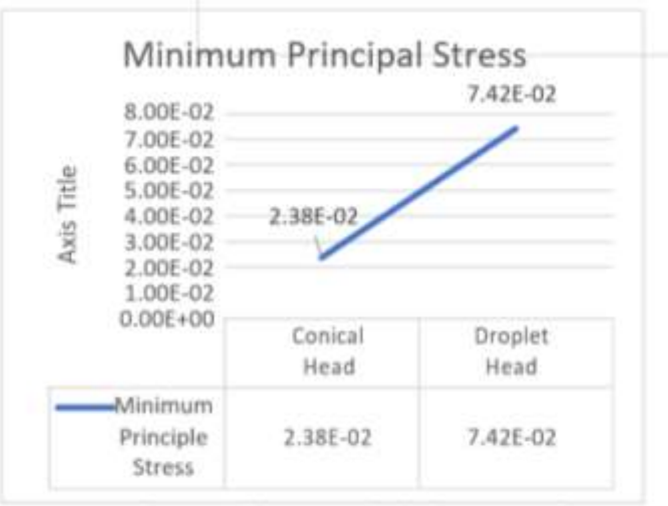
Graph 2: Total Acceleration of 2 Microswimmers



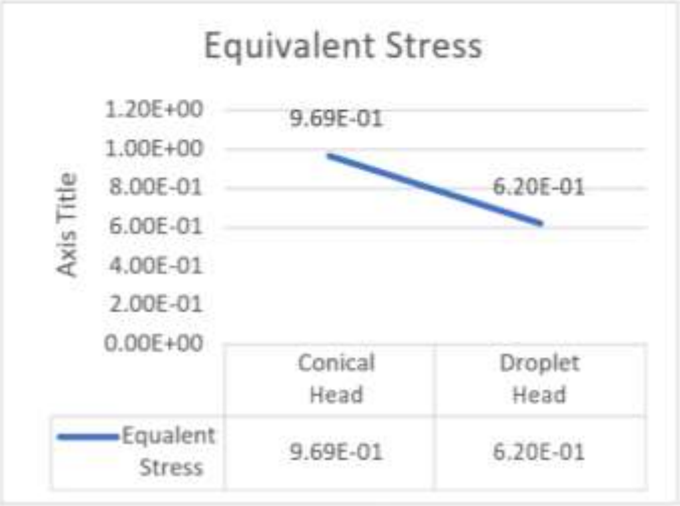
Graph 3: Total Velocity of 2 Microswimmers.



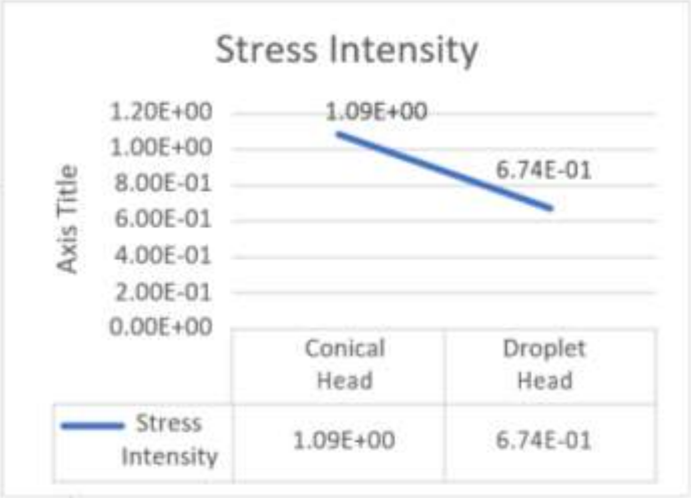
Graph 4: Maximum Principal Stress of 2 Microswimmers.



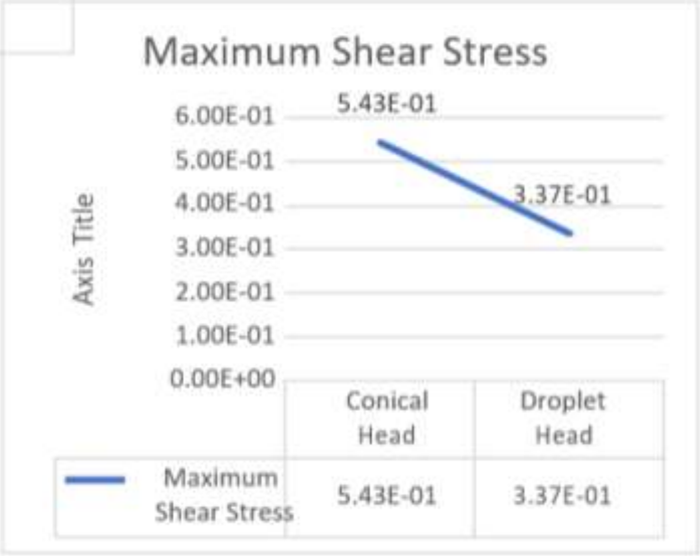
Graph 5: Minimum Principal Stress of 2 Microswimmers.



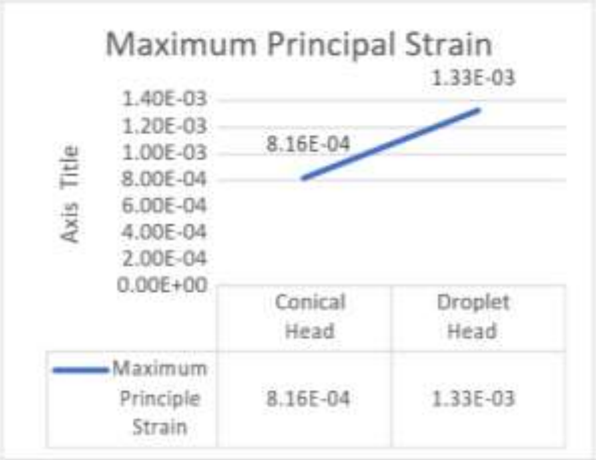
Graph 6: Equivalent Stress of 2 Microswimmers.



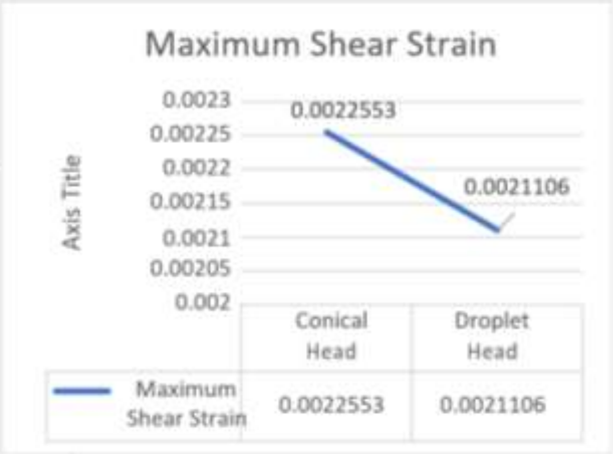
Graph 7: Stress Intensity of 2 Microswimmers.



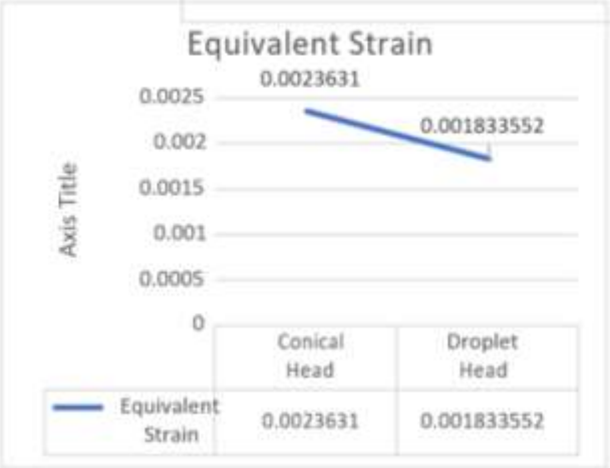
Graph 8: Maximum Shear Stress of 2 Microswimmers.



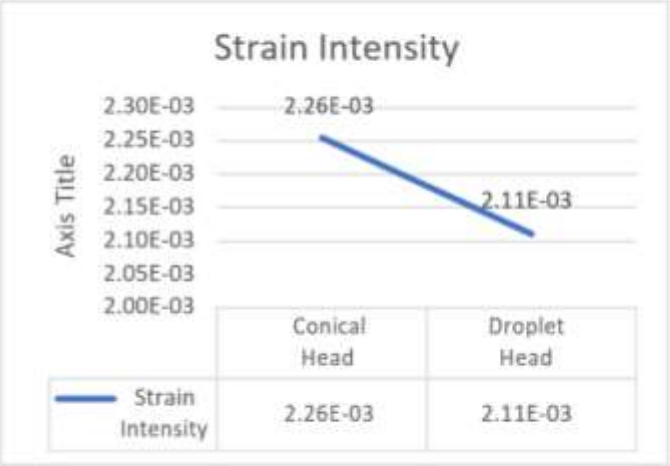
Graph 9: Maximum Principal Elastic Strain of 2 Microswimmers.



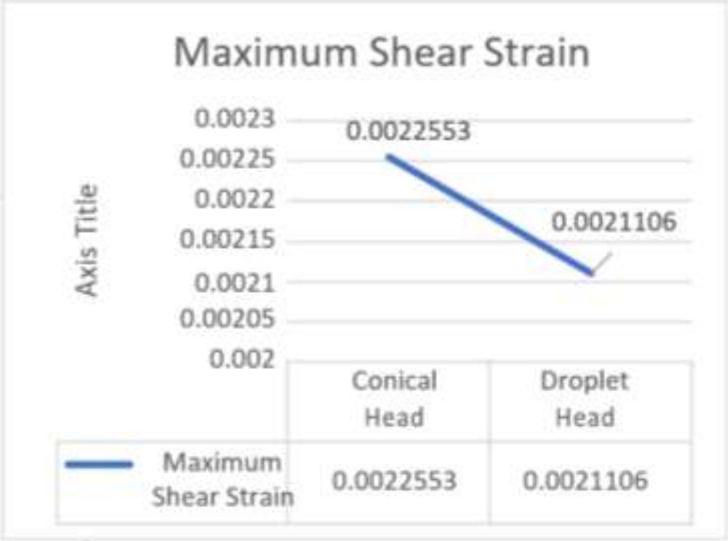
Graph 10: Minimum Principal Elastic Strain of 2 Microswimmers.



Graph 11: Equivalent Elastic Strain of 2 Microswimmers



Graph 12: Elastic Strain Intensity of 2 Microswimmers.



Graph.6.28: Maximum Shear Elastic Strain of 2 Microswimmers

6. CONCLUSION & FUTURE SCOPE

In this thesis we have endeavored to explain some fundamental properties of microswimmers through analytical study and accompanying simulations of the helical – spring swimmer models. We have shown that a force–based study of the swimmer, with its starting point the driving forces acting on the swimmer, enables the identification of some features of motion which are lost in a stroke-based study.

In addition, we have discovered a number of interesting influences on microswimming which have before our work gone unknown. For instance, we have examined the various parameters like deformations, velocities, accelerations, stresses and strains and found how microswimmers react. This provides one possible explanation of many experiments reported in the literature in which some bacteria swim quicker in more viscous fluids.

In this research we consider the microswimmers inside a blood vessel and made an environment like microswimmer travelling inside blood. Here we assumed counter flow i.e. microswimmer travels opposite direction of blood flow that gives us a clear picture of microswimming. We have found the values of deformations, velocities, accelerations, stresses and strains.

In deformations the droplet head stood optimal with less deformation.

In velocities and accelerations conical stood optimal compared to droplet head type microswimmer.

Stresses induced in conical are comparatively less.

The conical head helical spring microswimmer stood as an optimal microswimmer design.

We have used our models to shed the light on many known and unknown features of microswimming are considered by suggesting some other extensions of present work. By using explicit dynamics in ANSYS to model the micro swimming inside a blood vessel, numerous factors, including deformations, velocities, accelerations, stresses, and strains on the micro swimmers, have been discovered. These metrics can be used to conduct future research in the fields of biomedicine and microrobotics. Only blood is taken into account for the study, but further research can be done by including a more intricate environment around the microswimmer, like including blood cells in blood when the microswimmer is moving. This study can be expanded to include an analysis of micro swimmers based on inertia. The investigation of a single Micro swimmer in a blood vessel with a counter-traveling condition points to potential areas for future study, including parallel travelling and the introduction of many Micro swimmers simultaneously.

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