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<i>Praveen Kumar, Department of Energy Studies and Construction Management, Wollega University, Ethiopia</i>	

The atmosphere is the layer of gases surrounding the Earth and retained under its gravity. The atmosphere of our planet is made up of blankets of air that contain numerous gases such as oxygen, nitrogen, carbon dioxide, and others. Earth's atmosphere can be differentiated into five regions based on their physical properties such as temperature and pressure. Troposphere, stratosphere, mesosphere, ionosphere or thermosphere, and exosphere are these zones. The atmosphere provides the platform for these aerospace vehicles, which have taken off from Earth to operate at different altitudes. To investigate and understand the performance of flight tests, wind tunnel tests, and the design of aerospace vehicles or any other flying objects, there is a need for standard values to evaluate the parameters of the airplane or any other objects influenced by aerodynamic forces. Finally, the purpose of this chapter is to help the reader understand what the standard atmosphere is and how it can be utilized to analyze aeronautical vehicles.

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<i>Surekha Rathi Samundi D., Bharath Institute of Higher Education and Research, India</i>	

The atmosphere is the layer of gases that surrounds the planet. The atmosphere is retained by the gravity of the planet. Hence, it is also called planetary atmosphere. The performance of the aircraft and rockets depends on the physical properties of the atmosphere in which they fly. It is therefore advisable to study the variation of pressure, temperature, and density with the altitude. The real atmosphere is composed of dust, water vapor, and moisture, and it never remains constant. Hence, a hypothetical model called a standard atmosphere was employed. This chapter elaborates the international standard atmosphere, atmospheric boundary layer, and the stability of the atmosphere.

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Kaliappan S., Velammal Institute of Technology, Chennai, India

Raj Kamal M. D., Velammal Institute of Technology, Chennai, India

Balaji V., Loyola Institute of Technology, India

Socrates S., Velammal Institute of Technology, Chennai, India

Andrii Kondratiev, O. M. Beketov National University of Urban Economy, Ukraine

Here, the authors explain the Magnus effect. The ball is deflected in the same direction as the rotation. The most common exposure and welcome statement of the Magnus effect is that a spinning object creates a vortex of fluid swirling around it. On the side where the movement of the vortex is in the same direction as the direction of the flow to which the object is exposed, the speed will increase. On the opposite side, where the directions are opposite, the speed will decrease. It is explained here, according to Bernoulli's principle, that the pressure is lower on the side with the greatest velocity, and therefore, there is an unbalanced force orthogonal to the flow of the fluid.

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Kumaran T., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Sivarasan E. N., National Chung Hsing University, Taiwan

One of the most important design impacts in aircraft is an airfoil. This airfoil is also considered the cross-section of the wing, so the flow characteristics of air depend on the airfoil's shape. There are some airfoil theories we can consider for the design consideration while designing the wing. The airfoil theories describe the nature of fluid flow over the wing based on the angle of attack for variable speed conditions. This chapter deals with airfoil terminology and the theories of airfoil like the methodology of conformal transformation, Cauchy-Riemann relations, complex potential, Kutta-Joukowski, thin airfoil theory, and their applications. The theories mentioned above explain transformation and its applications, Kutta condition, Kelvin's circulation theorem, starting vortex creation of airfoil for variable speed considered for aircraft, and the advantages of the optimization.

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Madhankumar G., Sathyabama Institute of Science and Technology, India

Mothilal T., KCG College of Technology, India

Kumar K. M., St. Joseph's College of Engineering, India

Muralidharan G., Surya Group of Institutions, India

Mala D., University College of Engineering, Panruti, India

Wing design is a very complicated and intricate issue. It is not feasible to cover everything in this chapter; however, it is possible to discuss some of the essential ideas that underpin design for high lift and low drag. Lift may be increased in four ways for fixed air characteristics and free-stream speed: increased wing area, increased angle of attack, increased camber, increased circulation through the use of high-momentum fluid. One of the most important applications of potential flow theory was the study

of lifting surfaces such as aircraft wings, since the boundary conditions on a complex geometry can significantly complicate any attempt to tackle the problem via analytical techniques, which involves some simplification assumptions in order to arrive at a solution. These assumptions will be related to the concept of three-dimensional thin wing issues in this chapter.

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Kaliappan S., Velammal Institute of Technology, Chennai, India

Raj Kamal M. D., Velammal Institute of Technology, Chennai, India

Joseph Manuel D., Velammal Institute of Technology, Chennai, India

Balaji V., Loyola Institute of Technology, India

Murugan P., Jimma Institute of Technology, Ethiopia

Viscosity is a property that expresses the internal drag of a fluid to motion; impact of viscosity states the statics and flows. Statics means whenever fluids at zero velocity have no relative movements between layers of fluid and thus $du/dy = 0$. At the time there is no shear stress and viscosity of the fluid is free. Fluid viscosity plays a major role on the fluid floating in it. The authors focused on solids and fluids and the no slip condition, momentum transfer through molecular motion, shear stress and viscosity, Couette flow, and Poiseuille flow. Here the authors made a discussion the Newtonian viscous flow, and the statement of Newton's law of viscosity was examined. The discussion has been extended up to viscosity and the effect of their temperature and impact of increasing in temperature has been explained along with surface tension.

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Suresh Chinnasamy, ACS College of Engineering, India

Paramaguru Venugopal, ACS College of Engineering, India

Ramesh Kasimani, Government College of Technology, Coimbatore, India

This chapter describes the basic concepts of aerodynamics, evolution of lift and drag, types of drag, reduction of wing tip vortices, non-planar wing concepts for increased aerodynamic efficiency, various methods for determination of aerodynamic forces of an airplane, classification of wind tunnels, blower balance tunnels, and a case study report on aerodynamic force measurement of the non-planar wing systems. To increase the aerodynamic efficiency of the monoplane configuration, the 'C-wing' configuration is presented in this chapter. The aim is to prove, at all angles of attack, C-wing produces a higher (L/D) ratio than straight wing for the same wetted surface area. The aerodynamic characteristics of three different wing models with NACA-64215 aerofoil such as straight wing, C-wing, and inverted C-wing at different angles of attack and low Reynolds number are shown. The inverted C-wing created more lift but produced more vibration, which may lead to lesser structural integrity.

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Rathinavel S., Nehru Institute of Engineering and Technology, Coimbatore, India

Senthil Kumar S., SRM Institute of Science and Technology, Tiruchirappalli, India

Senthilkumar T. S., SreeSowdambika College of Engineering, Aruppukkottai, India

Vignesh Kumar V., St. Joseph College of Engineering, Chennai, India

Thermodynamics is a science that deals with energy (heat and work) transformations and properties of substance that are affected by these transformations. Thermodynamics has been a significant part for a long time in engineering field with broad application areas such as power plants, transportation vehicles, and some direct energy conversion devices. Generally, the chemical scientist focuses on chemical reactions, phase equilibrium, and catalysis. Also, it is necessary to check whether the reactions were completed or proceed to a precise limit only. Thermodynamics also contributes to the above-mentioned chemical arena. This chapter discusses the introductory part of thermodynamics, work and energy transfer, laws of thermodynamics, principles of energy conversion, combined forms of first law and second law of thermodynamics, thermodynamic relations, and fluid compressibility. The above-mentioned issues have been well presented with inclusion of short notes. Also, illustrative example problems are solved.

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Nithya Subramani, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Manigandan Sekar, Sathyabama Institute of Science and Technology, Symbiosis International University, India

Yasin Sohret, Anadolu University, Turkey

Gowtham Gajapathy, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

The nozzle flow is considered to be much more important in aerospace applications. Based on the pressure, velocity and temperature, flow velocity, Mach number and area, the nozzle shape will vary to meet the required condition. Nozzle is a part where the potential energy is converted into kinetic energy. The high pressure and temperature combustion product of gas is converted into high velocity and low-pressure gas as exhaust. In aviation, the main force of thrust is generated due to high velocity exhaust. This chapter gives an explanation and mathematical expression of various nozzles in both subsonic and supersonic flow along with the flow associated issues. The 3D model of convergent chevron nozzle was analyzed for the characteristics of jet mixing and acoustic effect at the exit. These results were compared with the same dimension chevron nozzle with wedges. The added wedges enhanced the jet mixing.

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Paramaguru V., ACS College of Engineering, India

Suresh C., ACS College of Engineering, India

Sankaran A., Nehru Institute of Engineering and Technology, India

Bernard A. P. Francis, Deepwater Technology, Singapore

This chapter is dedicated to the shock wave reflections and intersections. Each topic offers a pictorial representation of the physical and shock polar plane for a better understanding of the shock wave reflections and intersections. This chapter contains an introduction to the shock-shock interference under the various real-life examples of the intersection of different and same family shock waves in a solid boundary, wave reflections from the free boundary, Mach reflections (lambda shock wave), intersection of shock from different or opposite families (Type I Interference), intersection of intense shocks of opposite families forms normal shock (Type II Interference), intersection of strong and weak oblique shocks of different families (Type III Interference), intersection of normal shock with oblique shock (Type IV Interference), intersection of weak oblique shock with intense shock (Type V Interference), intersection of the weak shock of same families (Type VI Interference).

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Shiva Prasad Uppu, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

K. M. Sree Vaibhav R., Politecnico di Milano, Italy

Dilip Raja N., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Sathish Kumar K., Nehru Institute of Engineering and Technology, India

Progress in future aeronautics depends purely on the new understandings of flow physics coupled with the interactions of various tools and disciplines. Emerging numerical computing tools and experimental aptitudes play a key role in the technological progress of aeronautical studies. This chapter presents an insight on the air foils, three-dimensional geometries attached to an airplane with an emphasis on computational tools. A countless number of small and large steps have taken place over many other disciplines. Design evolution has resulted in many geometrical changes in air foils, wings, fuselages, and stabilizers come in a whole range of shapes and sizes, both in the aerospace industry and in nature – really, nothing is standard. The application the airfoil operates and dictates its shape and size. Finite wing and infinite wing shapes are still sprouting today, driving the new challenging flight conditions. More efficient flights will drive the new and intelligent wing designs to obtain better load factor and reduced drag.

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Naren Shankar R., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Irish Angelin S., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Habib Gurbuz, Suleyman Demirel University, Turkey

Hypersonic vehicles attain a speed five times more high-speed than the speed of sound, which is beyond Mach 5 and nearly equal to 6174km/h. Hypersonic flow has certain characteristics, essentially a reedy shock layer, formation of entropy layer, viscous interactions, high temperature, and low-density flow. Only if these characteristics are subjected in the flow can the flow can be called hypersonic. While designing a

hypersonic flight vehicle, the characteristics of the hypersonic atmosphere should be understood clearly. This comes as a major design constraint. A brief overview of the hypersonic vehicle design and high-speed flow characteristics will be presented in this chapter. A few characteristics of hypersonic flow and the ideal design conditions will also be reviewed.

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Naren Shankar R., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Irish Angelin S., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Vitalii Pertsevyi, Dnipro National University of Railway Transport, Ukraine

Humans longing to fly higher and quicker have prompted the improvement of hypersonic vehicles. Typically, hypersonic streams are described by high temperature fields and a thin layer of shock close to the object wall or the body surface. To ease the reduction of thermal loads, a blunt nose is forced in a hypersonic vehicle which is more imperative. In any case, increase in the wave drag is one of the quick outcomes of a constrained bluntness. Consequently, investigation in the hypersonic field is constantly fixated on the wave drag decrease. The flow features around the blunt body get changed because of the attachment of spike in front of the vehicle. This chapter aims to give a detailed review of a hypersonic vehicle that involves an aerospike design in front of the blunt body, which tends to reduce the drag at the forebody. Views of various researchers are investigated, and efforts are taken to summarize the reported results on how the drag has been reduced using aerospike technique.

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G. Gowtham Gajapathy Gajapathy, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Vishal Naranje, Amity University, Dubai, UAE

A. H. M. Hussein, Helwan University, Egypt

Sundharasan R, Jaya Polytechnic College, India

Nature helps a lot to create and recreate new concepts to enhance our existence. Using nature-inspired means to address new engineering problems gives a better solution that is very quick, easy, and environmentally friendly. The goal of this chapter is to explore the overall performance increase by bioinspired design elements. Simulations of computational fluid dynamics are utilized to compare existing designs to experimental data in various flow regimes.

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Sundharasan R., Jaya Polytechnic College, India

Gowtham G., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Kumaran T., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Elumalai K., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Flow separation and wind gusts affect the aerodynamic performance of low-Reynolds number flyers with a chord-based Reynolds number of 105 or below. Active flow control provides information into fluid dynamics as well as potential vehicle performance enhancements. Aircraft engines, as well as stationary flow devices, exhibit undesirable flow states that have a significant impact on noise output and aerodynamic loss. Vibrations and aerodynamic performance are likely to suffer as a result of flow and boundary layer separations. Flow management can be an effective approach for lowering noise levels, increasing efficiency and thereby lowering fuel usage. Various forms of flow can be controlled using both passive and active flow control strategies. The active alteration of aerodynamic flows utilizing small time-dependent actuators in well-chosen places is defined as adaptive flow control. Micro-adaptive flow control has a significant overall system benefit in a variety of large-scale applications, which are presented.

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Bruce Ralphin Rose, Anna University Regional Campus, Tirunelveli, India

Bibal Benifa J. V., Indian Institute of Information Technology, Kottayam, India

Ramzania M., Anna University Regional Campus, Tirunelveli, India

The chapter addresses an extensive numerical investigation for the optimization of static pressure recovery in the dump diffuser of annular combustor for modern aero-gas turbine engines. The modelling and simulation processes are accomplished through the commercial ANSYS fluent module with SST k-epsilon ($k-\epsilon$) turbulence model with the atmospheric conditions prevailing at 9 km altitude. The effect of velocity changes on the flow recirculation and vortex mixing phenomena is also addressed with novel dome-shaped optimization at the velocity of 25 m/s. The dome geometry can also be considered as a flame tube head, and the influence of vortex pattern and pressure distributions caused by the different dome shapes are analyzed using CFD. The dome-shaped optimization strategy addressed herein could initiate more potential studies on dump diffusers with hot and cold flow conditions to enhance the overall combustion efficiency in the near future.

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Shiva Prasad Uppu, Sandip University, India

Rathan Babu Athota, Universitat Politecnica, Spain

Sathish Kumar K., Nehru Institute of Engineering and Technology, India

Dilip Raja N., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

This chapter is focused on the roughness effect to evaluate the flow in order to examine the flow dynamics around airfoil for better aerodynamic efficiency. CFD analysis is done on the airfoil with circular roughness placed at two different positions, 25% and 65% chord length with two different Reynolds number. In this case, the boundary layer increased significantly due to decrease in velocity of flow resulting in increment of pressure gradient. From the computational and experimental investigation from many researchers, it is evident that adverse pressure gradient even becomes so large that the flow is forced back against the actual flow direction. In the current chapter, at 15 degrees angle of attack there was an effective increase of 65% in the aerodynamic efficiency due to roughness. There was an increase in stall angle, which refers to sudden increment of drag resulting from the aerodynamic and geometric variations over the infinite wing. With increase in Reynolds number, there is an increase in the effect of roughness at higher angles of attack.

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Backiyaraj A., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Kumaran T., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Parthasarathy M., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Murugu Nachippan N., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Senthilkumar P. B., Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

One of the most adaptable inventions is motor-powered vehicles, especially cars. The majority of the time, safety, SFC, and operating area were considered. Vehicle makers are examining the characteristics of drag or air resistance for different body forms at various operational situations in order to increase fuel efficiency, vehicle speed, reduce wind noise, and improvise road control and vehicle steadiness when moving. The study of the rigid body traveling across the atmosphere and the interactions among its surface and the atmospheric air with varying linear acceleration and air direction is called aerodynamics. Aerodynamic drag is generally insignificant at lower vehicle speeds, but as speed increases, the air resistance magnitude also increases. This chapter deals with the external properties design considerations and testing methods of road vehicle aerodynamics like drag force. Identifying the drag force by various methods like wind tunnel tests, coast down test, and computer fluid dynamics are explained to forecast the drag coefficient.

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Chapter 13

Study of Drag Reduction on a Hypersonic Vehicle Using Aerospike

Naren Shankar R.

Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Irish Angelin S.

Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, India

Vitalii Pertsevyi

Dnipro National University of Railway Transport, Ukraine

ABSTRACT

Humans longing to fly higher and quicker have prompted the improvement of hypersonic vehicles. Typically, hypersonic streams are described by high temperature fields and a thin layer of shock close to the object wall or the body surface. To ease the reduction of thermal loads, a blunt nose is forced in a hypersonic vehicle which is more imperative. In any case, increase in the wave drag is one of the quick outcomes of a constrained bluntness. Consequently, investigation in the hypersonic field is constantly fixated on the wave drag decrease. The flow features around the blunt body get changed because of the attachment of spike in front of the vehicle. This chapter aims to give a detailed review of a hypersonic vehicle that involves an aerospike design in front of the blunt body, which tends to reduce the drag at the forebody. Views of various researchers are investigated, and efforts are taken to summarize the reported results on how the drag has been reduced using aerospike technique.

INTRODUCTION

The speed of an aircraft is usually denoted in Mach Number, M . Based on the speed regime the aircraft can be classified into different types (i) $0 < M < 0.8$ subsonic, (ii) $0.8 < M < 1.2$ transonic, (iii) $1.2 < M < 4$ supersonic, (iv) $M \geq 5$ hypersonic. If $M = 1$ it is called as sonic condition. In hypersonic flows, the

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flow velocity is much greater than the sound velocity, which is the velocity of propagation of small disturbances. Hypersonic vehicles in general fly at higher altitudes where the density and Reynolds numbers are considered to be low and where the boundary layer formation is found to be thick. Reducing the drag and aerodynamic heating are the two main factors in critically designing a hypersonic vehicle. Reducing the drag in the hypersonic vehicle is necessary as it helps in saving the fuel, extending the range, simplifying the propulsion unit and increasing the payload to take-off the gross weight ratio. A hypersonic vehicle creates a bow shock in front of the blunt body which leads to a higher surface pressure load and aerodynamic drag. This surface pressure can be reduced if the conical shock wave is created rather than a bow shock wave. This can be achieved by using a spike in front of the blunt body. This chapter aims to review various papers related on drag reduction techniques by using aerospike passive method. The objects moving at high speed experience forces that will in general tend to slow objects down. This confrontation withinside the considered volume is named such as a drag that is a solitary significant concern throughout the time of planning in designing a high speed vehicle. Hypersonic vehicles are those that travel at Mach above 5. Usually, missiles, rockets, reentry vehicles travel at hypersonic speed. It is often planned to reduce surface heat flux by designing hypersonic space vehicles with blunt noses. By any means, this detached shock increases the wave drag, making space flights more expensive. Thus, the spaceship configuration should consider the best balance between wave drag and surface heat flux. Subsequently, in the future, there will be more development and improvement of the hypersonic drag reduction technique as it becomes a significant research area within the hypersonic field. A number of strategies have been put forth in this area.

The streamlined aerodynamic layout of hypersonic vehicles must be completed considering the intricacies associated with the hypersonic flow. Typically, hypersonic flows are described by high temperature field and a thin layer of shock close to the object wall or the body surface. Such shock and viscous dissemination came about raised temperature close to the space vehicle surface which led to inordinate warming of vehicles flying at speeds above Mach 5, which are considered as hypersonic speed regimes.

The nose area of a space vehicle which is considered as the most serious place of space vehicle that undergoes most noteworthy heat flux, blunt nosed plan of the equivalent design has been recognized as a powerful strategy to drive the shock layer away from the body, to lessen the surface heat flux. (John D Anderson, 1989). In the meantime, the aerodynamic heating appearing in the spot of stagnation changes conversely which is equal to the blunt nose radius root, possessing a huge blunt nose area is worthwhile all things considered. Besides this design measure improves the drag reduction. For space missions increase in drag makes higher fuel utilization and lesser payload limit. In this manner, the expense of space missions increments radically. Along these lines, the decrease of wave drag has stayed as a significant field of exploration in the field of hypersonics. Wave drag is triggered by the development of shock waves around the vehicle in supersonic flight and hypersonic flight. Also, to reduce fuel usage and to expand the payload limit of the space vehicle, decreased heat load or lower drag is required for a hypersonic flight or mission.

To ease the reduction of thermal loads, a blunt nose is forced in a hypersonic vehicle which is more imperative. In any case, improving the wave drag is a quick outcome of constrained blunt body. Consequently, investigation in hypersonic field is constantly fixated on the wave drag reduction. In order for hypersonic vehicles to succeed, reducing drag is a vital component. Extreme aerodynamic heating and aerodynamic forces are imposed at the blunt-nosed surface, owed to the drastic bow shock to be found at the forefront of the nose when a vehicle travels at hypersonic speed.

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