ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

CFD Flow Analysis of a Reentry Space Vehicle with Wing and Without Wing

P.Chandra Shekar Rao
M.Tech Aerospace Engineering,
Institute of Aeronautical Engineering,
Hyderabad-500043, India.

K.Babitha
Assistant Professor,
Dept of Aeronautical Engineering,
Institute of Aeronautical Engineering,
Hyderabad-500043, India.

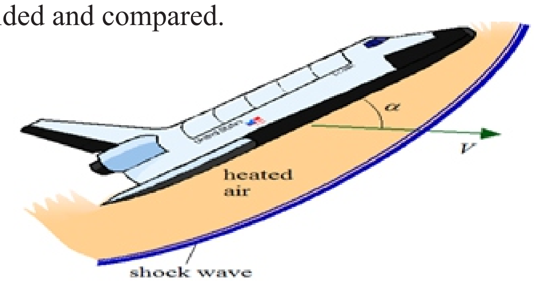
KopparapuVskc Mani Kumar
CAE Analyst,
General Motors Technical Centre,
India.

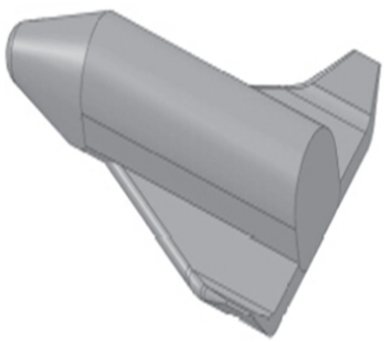
Abstract:
By adding thermodynamics to aerodynamics, one arrives at the notion of 'aerothermodynamics', in which those flow fields are considered, the analysis of which requires - beyond its use in classical aerodynamics - the consideration of special thermodynamic relations. Well-known examples are the hightemperature flows past re-entry vehicles, and flows in combustion chambers and in the nozzles of propulsion systems. Aerothermodynamics is a key technology for the design and optimization of space vehicles because it provides the necessary databases for, for example, the choice of trajectory, for guidance, navigation and control, as well as for the thermal-protection and propulsion systems. Computational aerothermodynamics, in particular, has become a powerful tool for improving our understanding of the physical phenomena that are at work. This project will present the design of Re-entry space vehicle and its analysis showing angle of attack with wing and without wing.

Key Words: CFD, Aerothermodynamics, Re-entry space vehicle, wing, angle of attack.

INTRODUCTION:
This study of Reentry Vehicle (RV) systems and their associated operations was conducted for the Department of Transportation/Office of Commercial Space Transportation. The purpose of the study was to investigate and present an overview of reentry vehicle systems and to identify differences in mission requirements and operations. This includes reentry vehicle system background, system design considerations, description of past/present/future reentry systems, and hazards associated with reentry vehicles that attain orbit, reenter, and are recovered. The Aerodynamic performance analysis at a phase design level of a reusable and unmanned flying laboratory designed to perform a high lift return from low earth orbit. The flying test bed aims to provide experimental data in the framework of re-entry technologies.

The vehicle concept is a wing body with rather sharp leading edges and slender aerodynamic configuration. Several design approaches, ranging from engineering-based to computational fluid dynamics analyses, have been addressed in this work. In particular vehicle aerodynamic performances for a wide range of free stream flow conditions hypersonic flow, including reacting and non-reacting flow and different angles of attack have been provided and compared.





(b)

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

An analysis of the longitudinal and lateral-directional static stability has been also provided together with same of main interesting features of the flow field past the concept vehicle at different Mach numbers. The vehicle configuration is the result of a trade-off study involving several vehicle aero shapes. The best aerodynamic and aero thermodynamic performances at the same time. The concept is wing flying test bed (FTB) that will re-enter the earth's atmosphere thus allowing the performing a number of experiments on critical re-entry technologies. Atmospheric entry is the movement of an object from outer space into and through the gases of an atmosphere of a planet, dwarf planetor natural satellite. There are two main types of atmospheric entry: uncontrolled entry, such as the entry of astronomical objects, space debris or bolides; and controlled entry (or reentry) of a spacecraft capable of being navigated or following a predetermined course. Technologies and procedures allowing the controlled atmospheric entry, descent and landing of spacecraft are collectively abbreviated as EDL.Atmospheric drag and aerodynamic heating can cause atmospheric breakup capable of completely disintegrating smaller objects. These forces may cause objects with lower compressive strength to explode. For Earth, atmospheric entry occurs above the Kármán line at an altitude of more than 100 km (62 mi.) above the surface, while at Venus atmospheric entry occurs at 250 km (155 mi.) and at Mars atmospheric entry at about 80 km (50 mi.). Uncontrolled, objects accelerate through the atmosphere at extreme velocities under the influence of Earth's gravity. Most controlled objects enter at hypersonic speeds due to their suborbital (e.g., intercontinental ballistic missile reentry vehicles), orbital (e.g., the Space Shuttle), or unbounded trajectories.Various advanced technologies have been developed to enable atmospheric reentry and flight at extreme velocities. An alternative low velocity method of controlled atmospheric entry is buoyancy which is suitable for planetary entry where thick atmospheres, strong gravity or both factors complicate high-velocity hyperbolic entry, such as the atmospheres of Venus, Titan and the gas giants.

Re-entry Vehicle:

A re-entry capsule is a part of the spacecraft that is designed to return through Earth's atmosphere. It is built to endure extreme heating during high-velocity flight through the atmosphere and to protect the crew and/or instruments until it brings them safely to Earth.The shape is determined partly by aerodynamics; a capsule is aerodynamically stable falling blunt end first, which allows only the blunt end to require a heat shield for atmospheric reentry. Its shape has also been compared to that of an old fashioned automobile's headlight. They are two types of reentry vehicles.

1. Manned
2. Unmanned.

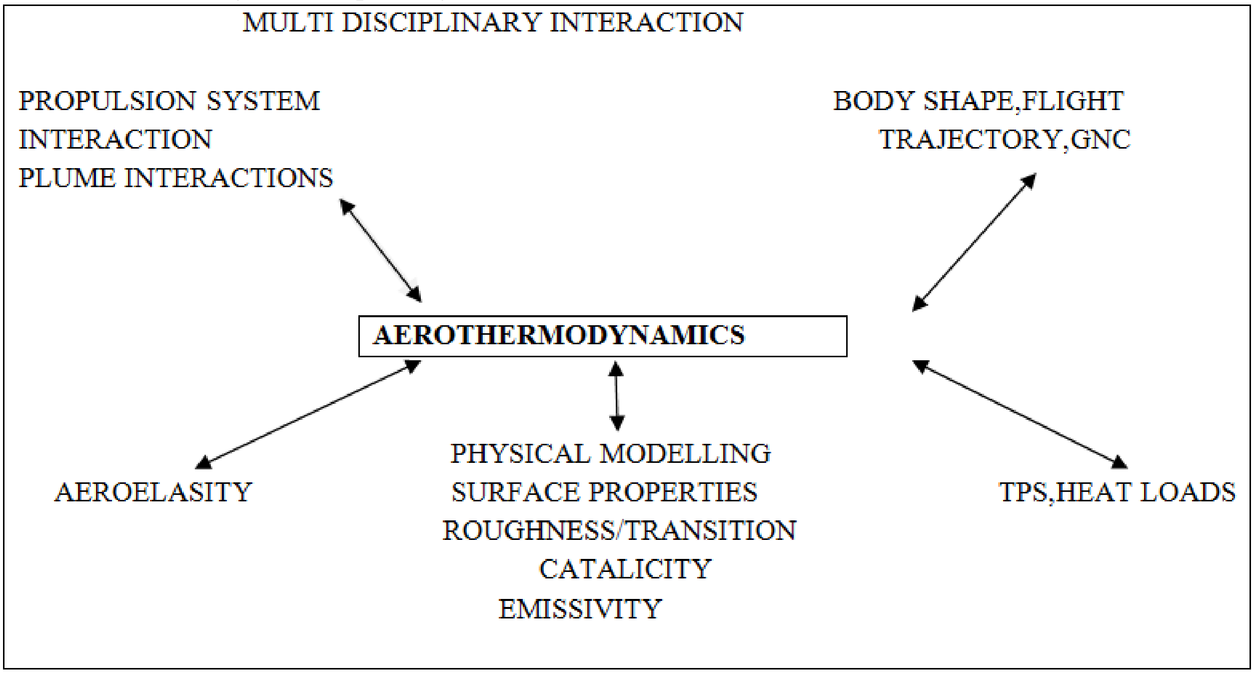
Manned reentry vehicles are designed to place the satellites into the orbit. A manned capsule contains the spacecraft's instrument panel, limited storage space, and seats for crew members. Because a capsule shape has little aerodynamic lift, the final descent is via parachute, either coming to rest on land, at sea, or by active capture by another aircraft.

Fundamentals Of Hypersonic Aerothermodynamics

Aerodynamic heating is one of the most critical design parameters when atmospheric entry of space vehicles is considered. A space vehicle enters +the atmosphere at a very high velocity, in the order of several kms per second. Aerodynamics heating, being one of the most critical design parameters when atmospheric reentry considered, can drastically be increased when the boundary layer is triggered from laminar to turbulent flow. Aerothermodynamics couples the disciplines of aerodynamics and thermodynamics. The flow field for a vehicle that flies at hypersonic speeds is one in which high temperature gas effects strongly influence the forces acting on the surface (the pressure and the skin friction) and the energy flux(the convective and the radiative heating).Hypersonic flows are usually characterized by the presence of strong shocks and equilibrium or non-equilibrium gas chemistry. Accurate prediction of this effects is critical to the design of any vehicles that flies at hypersonic velocities. The pressures and skin friction forces acting on the surface of the vehicle are integrated over the complete configurations to define the aerodynamic force and moment (e.g., lift, drag, pitching moment, control surface effectiveness) the peak heat –transfer rate and the heating load, which is the heating rate integrated over time, are mapped over the vehicle surface as part of the process to design the thermal protection system(TPS).Pressure distributions are required for assessing structural loads and venting environment. In the region between the shocks on the body surface, the flow is viscous and heat conducting. Physical and chemical effects the take place at hypersonic speeds are related to the fact that high Mach numbers the flow temperature increases rapidly behind the shock.

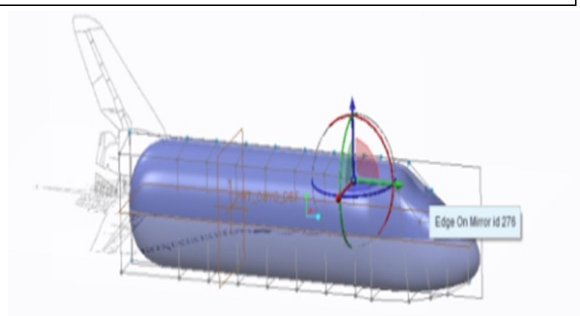
ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

It can reach high value when excitation of the molecular vibration decrease of freedom and chemical reactions occur, as well as ionization and radiation .Of course there is interconnection between the gas dynamic and physics of hypersonic flow, wherein each effects the other. In Earth's atmosphere of the outer atmosphere is quite low, so the sound speed is lower than at sea level and higher Mach numbers can be achieved there at lower speeds. A better measure is the speed itself, since it can also give an indication of the kinetic energy involved in the trajectory. For hypersonic craft, the flight enthalpy can usually be estimated very quickly from the speed as h=u/2. The amount of aerodynamic heating that the vehicle must deal with is linearly dependent on the kinematic energy of the vehicle. This is a very important aspects of hypersonic flight through planetary atmospheres. The vehicle encounters such severe heating that a significant part of the design and development effort is concerned with providing sufficient protection of the payload without using all capacity for doing this! Other general characteristics of hypersonic flows that are molecules behind a high-velocity shock wave become vibration ally excited, partially or completely dissociated depending on their bond energy, and, at very high speeds, partially ionized. These aspects of hypersonic flow are typically called "real gas" effects. This was especially true of the Development of the hypersonic high-enthalpy facilities, as well as for computational aerothermodynamics. Since then, aerothermodynamics has evolved to cover a wide field of applications and its use is becoming increasingly multidisciplinary. The design of space vehicles depends crucially upon databases providing the forces, moments, temperatures and heat fluxes along the chosen trajectories. These databases can be established for given shape and control surfaces, for an assumed center of gravity, where the shape and control surfaces of the space vehicle and to be determined in an iterative manner until stable and controllable flight is achieved. If the. Thermal-protection system chosen does not tolerate the loads encountered along the trajectory, the latter has to be adapted such that the flight remains controllable, by changing the space vehicle's shape and/or its control surfaces. In such multidisciplinary iterations, the available databases play a key role.

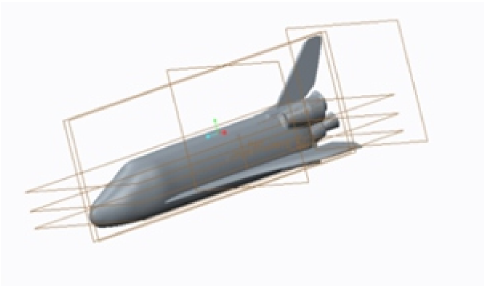


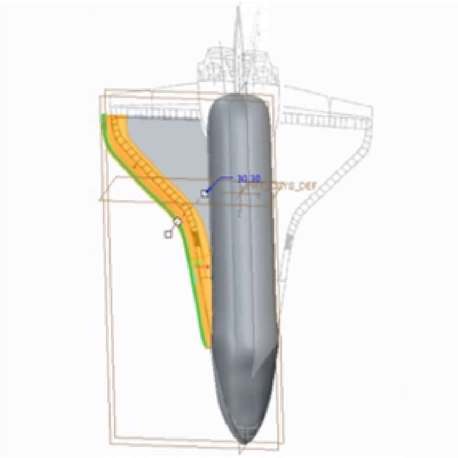
Design of Reentry Vehicle

Space shuttle was designed by NASA. The main purpose of this space shuttle is Earth to Orbit crew and Cargo Transport.The Dimensions of our current design was took from space shuttle. The dimensions are mentioned in the below Fig. The CAD model was done in Creosoftware and the same was imported in ANSYS for application of various materials and also for further processes.



ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal





Space craft Design by Creo software

BALLISTIC ENTRY

A ballistic entry is one in which the retarding force is always opposed to the line of flight, that is, a ”drag” force. The primary design parameter for ballistic entry ‘5 the Ballistic Coefficient β
Where
W is the Vehicle weight unit’s lbf
β = W/(C_D A)
C_Dis the drag coefficient and
A is the reference area used in the definition of the drag coefficient units Ft^2

Then β will have units of lbf/ft^2.

The Ballistic Coefficient β is the single most important parameter in controlling flight trajectory during entry. Heating and deceleration are less intense for a low β value (low weight and / or high drag and large frontal area) than for a high β value (high weight and I or low drag and small frontal area) since the entry occurs high in the atmosphere where the air is less dense. Early Inter-Continental Ballistic Missiles (ICBM) with highly blunted sphere-cone-cylinder-flare geometries utilized this reentry method.

RES-ENTRY MISSION PROFILE, CONSTRIAN’I‘S AND VEHICLE REQUIREMENTS:

The safe recovery of the spacecraft and its payloads is made possible by the re-entry mission. According to the different constraints the mission profile can be divided into three distinct flight segments:

» Deorbit and Descent to sensible atmosphere at an altitude of’ nearly 12Okms.
» Re-entry and hypersonic glide flight.
» Transition flight phase. Final approach and landing.

The unguided first flight segment (Keplarian trajectory) initiated by a rocket reboots maneuver at a specific orbital point determines the flight condition at re-entry. The second flight segment covers the atmospheric glide at an altitude of l20 km to 30 km during which the re-entry vehicle, has high initial kinetic energy is dissipated by atmospheric breaking. The third flight segment does the final approach and landing

The various forces acting on the re-entry vehicle are:

» Gravitational force acting towards the center of the planet
» Gas dynamic force opposite to the direction of motion of the vehicle
» Centrifugal and gas dynamic lift force acting normal to the direction of motion of the vehicle.

Along the re-entry flight several mission constraints much be imposed arising from the structural limit, crew comfort and control limits. These limits require the flight state of the vehicle to the constrained such that the:

» Load factor $n <= n_{max}$
» Dynamic pressure $q = 1/2 \rho V^2 <= q_{max}$
» Heat flux Q <= Q_max
» Heat load $Q1 = O.T\ Qdt <= Q1_{max}$
» Surface temperature $T <= T_{max}$

The maximum admissible values of these factors are highly depmdent on the state of the technology involved regarding heat resistant, lightweight materials and smtctures. The actual flight loads experienced by the vehicle depends upon:

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

» Local atmospheric environment (Eg: density, temperature)
» Current flight static conditions (Eg : velocity, angle of attack)
» Vehicle properties (Eg: geometry, weight, aerodynamics) and thus specific re-entry Miami "and design parameters.

Re-entry Design

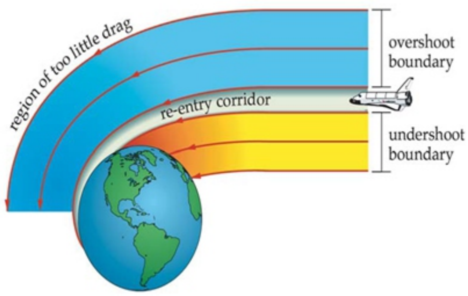
All space-mission planning begins with a set of requirements we must meet to achieve objectives. The re-entry phase of a mission is no different. We must delicately balance three, often competing, requirements

• Deceleration
• Heating
• Accuracy of landing or impact

The vehicle's structure and payload limit the maximum deceleration or"g's" it can withstand. (One "g" is the gravitational acceleration at Earth'ssurface—9.798 m/s2.) When subjected to enough g's, even steel andaluminum can crumple like paper. Fortunately, the structural g limits fora well-designed vehicle can be quite high, perhaps hundreds of g's. But a fragile human payload would be crushed to death long before reaching that level. Humans can withstand a maximum deceleration of about 12g's (about 12 times their weight) for only a few minutes at a time. Imagine eleven other people with your same weight all stacked on top of you. You'd be lucky to breathe! Just as a chain is only as strong as its weakest link, the maximum deceleration a vehicle experiences during re-entry must be low enough to prevent damage or injury to the weakest part of the vehicle.Another limitation during re-entry is heating. The fiery trail of a meteor streaking across the night sky shows that re-entry can get hot. This intense heat is a result of friction between the speeding meteor and the air. How hot can something get during re-entry? To find out, think about the energies involved. The Space Shuttle in orbit has a mass of 100,000 kg (220,000 lb.), an orbital velocity of 7700 m/s (17,225 m.p.h.),and an altitude of 300 km (186 mi.). In Section 4.1.3 we showed that an object's total mechanical energy depends on its kinetic energy (energy of motion) and its potential energy (energy of position)). If we were to get out our calculators and punch in the numbers for the Space Shuttle, we'd find that its total mechanical energy is E = 3.23 ×1012 joules = 3.06 ×109 Btu Let's put this number in perspective by recognizing that heating the average house in Colorado takes only about 73.4 × 107 Btu/year.

So, the Shuttle has enough energy during re-entry to heat the average home in Colorado for 41 years! The Shuttle has kinetic energy due to its speed of 7700 m/s and potential energy due to its altitude. It must lose all this energy in only about one-half hour to come to a full stop on the runway (at Earth's surface).But, remember, energy is conserved, so where does all the "lost" energy go? It converts to heat (from friction) caused by the atmosphere's molecules striking its leading edges. This heat makes the Shuttle's surfaces reach temperatures of up to 1477° C (2691° F). We must design the re-entry trajectory, and the vehicle, to withstand these high temperatures. As we'll see, we have to contend with the total heating and the peak heating rate. The third mission requirement is accuracy. Beginning its descent from more than 6440 km (4000 mi.) away, the Space Shuttle must land on a runway only 91 m (300 ft.) wide. The re-entry vehicle (RV) of an Intercontinental Ballistic Missile (ICBM) has even tighter accuracy requirements. To meet these constraints, we must again adjust the trajectory and vehicle design. On the other hand, if a vehicle can land in a larger area, the accuracy constraint becomes less important.

For example, the Apollo missions required the capsules to land in large areas in the Pacific Ocean much larger landing zones than for an ICBM's RV payload. Thus, the Apollo capsule was less streamlined and used a trajectory with a shallower reentry angle. n all cases, designers adjust the trajectory and vehicle shape to match the accuracy requirement as you can see from all these constraints, a re-entry vehicle must walk a tightrope between being squashed and skipping out, between fire and ice, and between hitting and missing the target. This tightrope is actually a three-dimensional which a re-entry vehicle must pass to avoid skipping out or burning up. The size of the corridor depends on the three competing constraints deceleration, heating, and accuracy. For example, if the vehicle strays below the lower boundary (undershoots), it will experience too much drag,



ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Re-entry Corridor

Slowing down rapidly and heating up too quickly. On the other hand, if the vehicle enters above the upper boundary (overshoots), it won't experience enough drag and may literally skip off the atmosphere, back into space. If designers aren't careful, these competing requirements may lead to a reentry corridor that's too narrow for the vehicle to steer through! Whereas the above three constraints determine the re-entry corridor's size, the vehicle's control system determines its ability to steer through the re-entry corridor.

Re-entry Motion

Imagine one of Earth's many small, celestial companions (say, an asteroid) wandering through space until it encounters Earth's atmosphere at more than 8 km/s, screaming in at a steep angle. Initially, in the upper reaches of the atmosphere, there is very little drag to slow down the massive chunk of rock. But as the meteor penetrates deeper, the drag force builds rapidly, causing it to slow down dramatically. This slowing is like the quick initial deceleration experienced by a rock hitting the surface of a pond. At this point in the meteor's trajectory, its heating rate is also highest, so it begins to glow with temperatures hot enough to melt the iron and nickel within. If anything is left of the meteor at this point, it will continue to slow down but at a more leisurely pace. Of course, most meteors burn up completely before reaching our planet's surface. The meteor's velocity stays nearly constant through the first ten seconds, when the meteor is still above most of the atmosphere. But things change rapidly over the next ten seconds. The meteor loses almost 90% of its velocity—almost like hitting a wall. With most of its velocity lost, the deceleration is much lower—it takes 20 seconds more to slow down by another 1000 m/s. Re-entry conditions for ICBM re-entry vehicles, depend on the velocity and flight-path angle of the booster at burnout. In either case, we must know how the re-entry trajectory affects a vehicle's maximum deceleration, heating, and accuracy, as well as the re-entry corridor's size. Depending on the mission and vehicle characteristics, planners can do only so much with the re-entry trajectory. For example, the amount of propellant the Space Shuttle can carry for the engines in its orbital maneuvering system (OMS) limits how much it can alter velocity and flight-path angle at re-entry. Re-entry conditions for ICBM re-entry vehicles, depend on the velocity and flight-path angle of the booster at burnout.

In either case, we must know how the re-entry trajectory affects a vehicle's maximum deceleration, heating, and accuracy, as well as the re-entry corridor's size.

Re-entry Motion Analysis in Action

To better understand re-entry motion, we need to understand how acceleration affects a vehicle's velocity and, in turn, its position during reentry. If we give an object a constant acceleration, we can determine its velocity after some time, t, from

Vfinal = Vinitial + at

Where

Vfinal= final velocity (m/s)

Vinitial= initial velocity (m/s)

a= acceleration (m/s2)

t= time (s)

To apply this method we assume that over some small time interval t, the acceleration is constant (a good assumption if Δt is small enough). This allows us to use the velocity and position equations for constant acceleration during that time interval. By adding the acceleration effects during each time interval, we can determine the cumulative effect on velocity and position. (Of course this means lots of calculations, so it's best to use a computer. We could either write a new computer program or use the built-in flexibility of a spreadsheet. Notice in the figure that the velocity stays nearly constant through the first ten seconds, when the meteor is still above most of the atmosphere. But conditions change rapidly over the next ten seconds. The meteor loses about 90% of its velocity—almost like hitting a wall. With v most of its velocity lost, the vehicle decelerates much more slowly—it takes20 seconds more to slow down by another 1000 m/s. We now have a precise mathematical tool to analyze re-entry characteristics.

We can use this tool to balance all the competing mission requirements by approaching them on two broad fronts • Trajectory design, which includes changes to– Re-entry velocity, V re-entry– Re-entry flight-path angle, γ

• Vehicle design, which includes changes to
– Vehicle size and shape (BC)
– Thermal-protection systems (TPS)

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

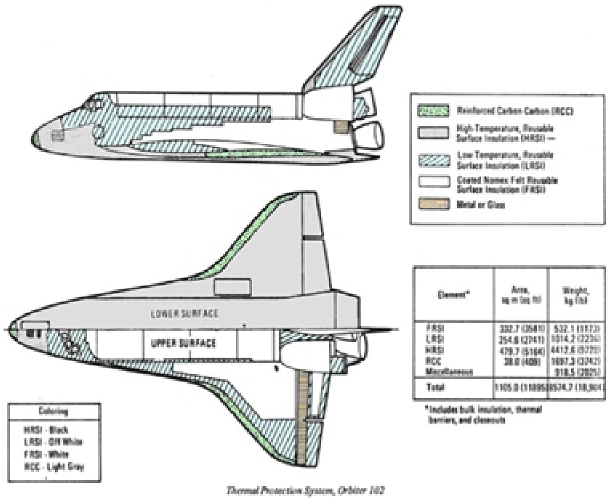
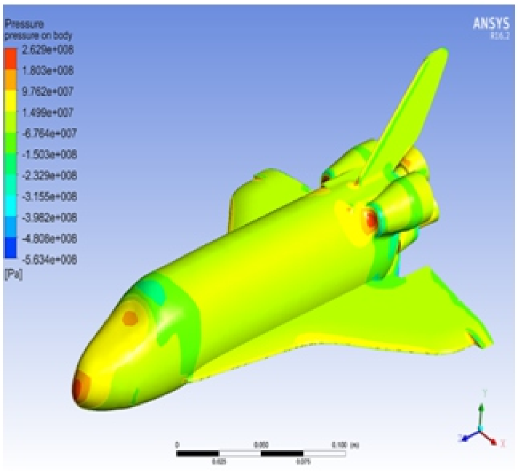


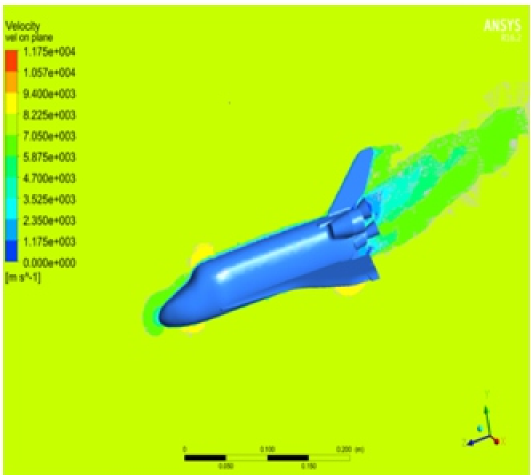
Fig.Thermal protective system of Apollo Space shuttle
CFD Analysis in Ansys

With wing:

Case 1)Zero degree angle of attack

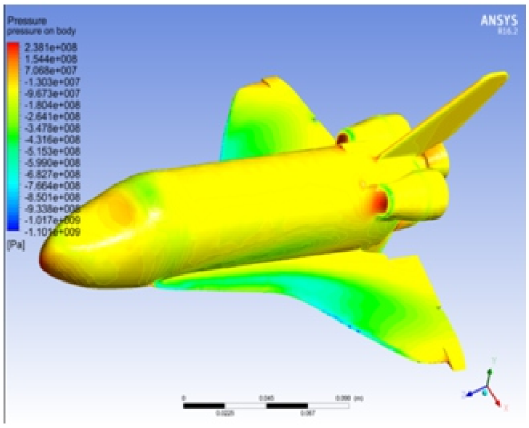


Pressure distribution

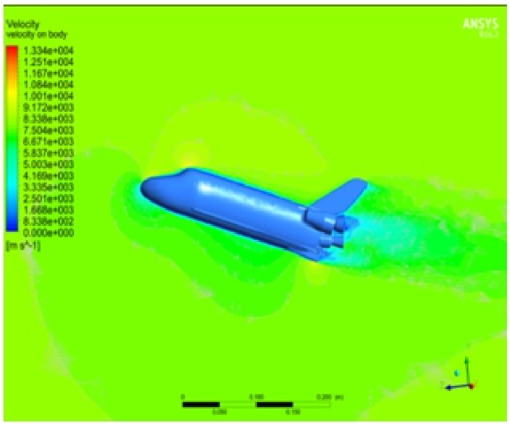


Velocity distribution

Case 2) 22.5 degree angle of attack

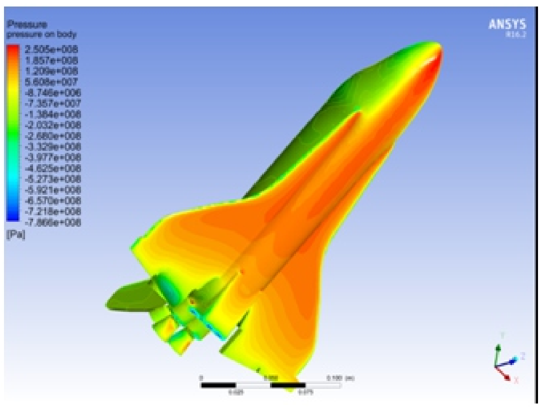


Pressure distribution



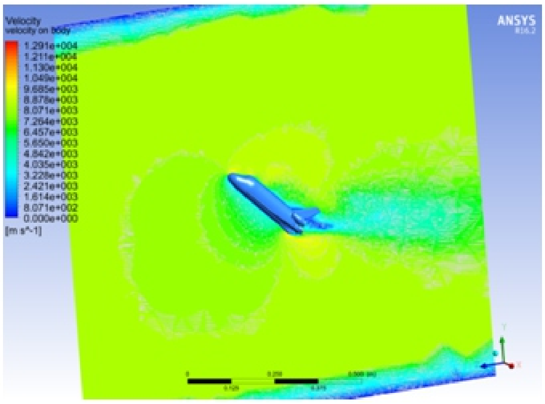
Velocity distribution

Case 3)45degree angle of attack



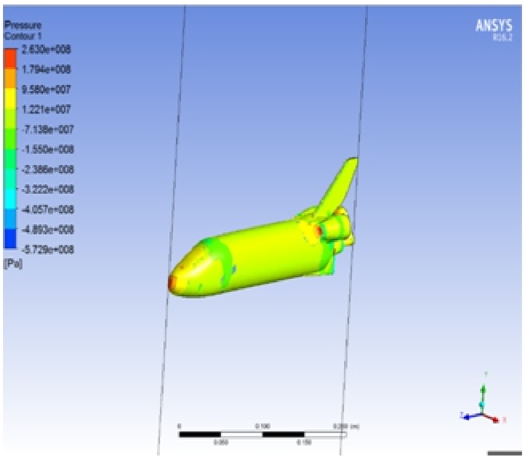
Pressure distribution

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

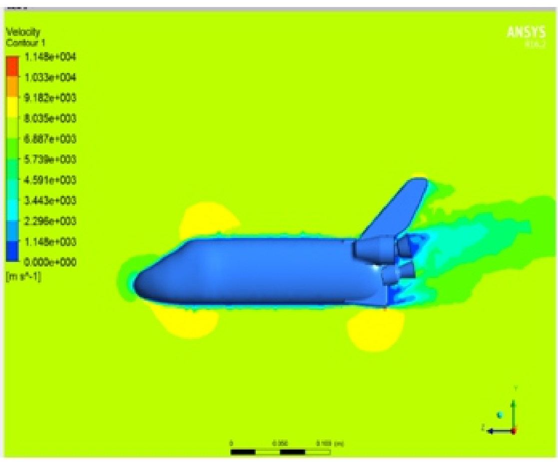


Velocity distribution

Without Wing:
Case 1) Zero degree angle of attack

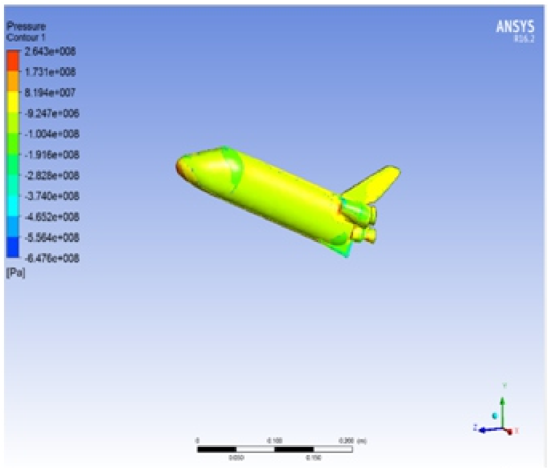


Pressure distribution

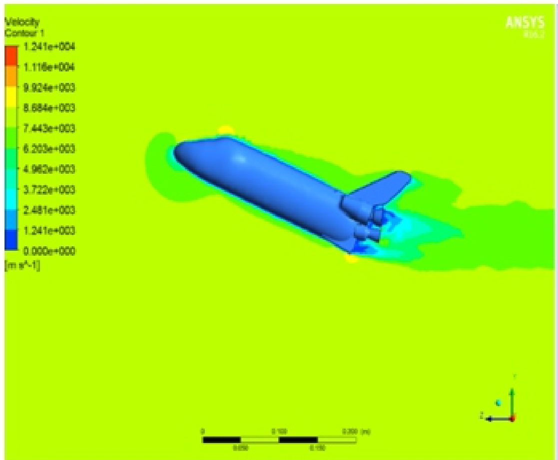


Velocity distribution

Case 2) 22.5 degree angle of attack

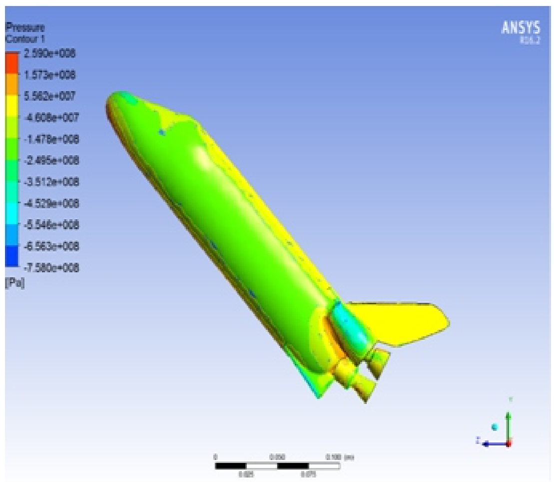


Pressure distribution



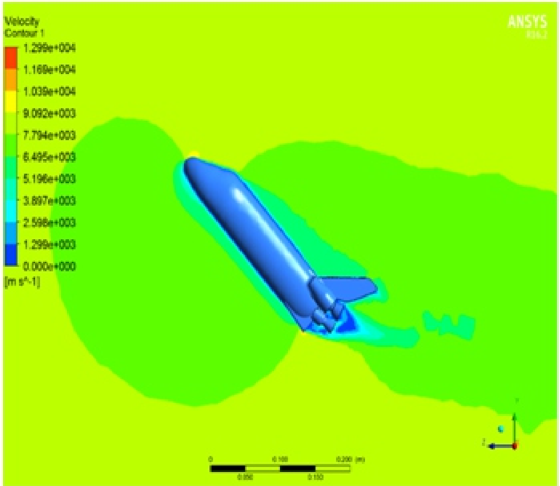
Velocity distribution

Case 3) 45 degree angle of attack



Pressure distribution

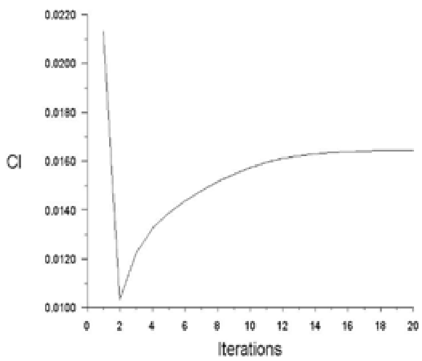
ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal



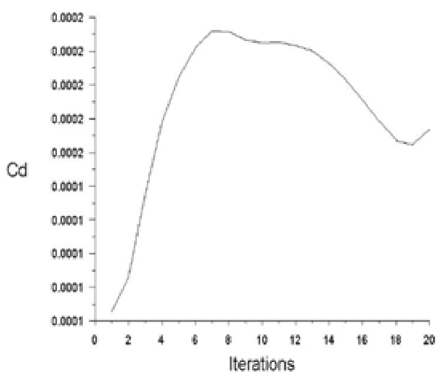
Velocity distribution

Conclusion:

By considering the pressure and velocity distributions of all the results the space shuttle with wing at AOA22.5deg gives the safe angle of reentry into the earth's atmosphere



Coefficient of Lift



Coefficient of Drag

References:

[1] "Developmental Testing of Ablative TPS for Orion Heat Shield", USACA 32nd Composites Materials and Structures Conference/JANNAF ITAR session, Jan 2008.

[2] 'Ablation Studies on Re-entry Capsule': Sponsored by Advanced Naval System Program (ANSP), Defense Research and Development Organization (2009-2010).

[3]David E. Glass, Ceramic Matrix Composite (CMC) Thermal Protection Systems (TPS) and Hot Structures for Hypersonic Vehicles,NASA Langley Research Center, Hampton,Virginia 23681,AIAA-2008-2682.

[4]Tian, "Anisotropic Thermal Property Measurement of Carbon-fiber/Epoxy Composite Materials" (2011). Mechanical (and Materials) Engineering -- Dissertations, Theses,StudentResearch.Paper 27.

[5] U. Trabandt, T. Schmid, and E. Werth, "CMC and Metallic Hot Structure Hybrid Components for RLV," 54th International Astronautical Congress, Bremen, Germany, 2003

[6]. David M. Kendall, KazNiemiec, and Richard A. Harrison, TRW Systems, A Modeling and Simulation Approach for Reentry Vehicle Aero shell Structural Assessment,MissileDefense Division, Technology review journal spring/summer 2002.

[7]. High-Performance Heat Shields for Planetary Entry Systems R. RouméasStructures and Mechanisms Division, ESA Directorate for Technical and OperationalSupport, ESTEC, Noordwijk, the Netherlands, EASA Bulletin 94-May1998.

[8] John M. Kennedy, Helen H. Moeller , Thermal and Mechanical Behavior of Metal Matrix and Ceramic Matrix Composites, Volume 1080 of ASTM special technical publication, ISSN 0066-0558.

[9] R.Rolfes, High performance 3D-analysis of thermomechanically loaded composite structures, Elsevier science Ltd Composite structures 49(1991)367-379