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Computational Fluid Analysis Of G-12 Parachute

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Dedication

This work is dedicated to my parents, my brother, and my friends.

COMPUTATIONAL FLUID ANALYSIS OF G-12 PARACHUTE

by

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THESIS

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I would like to extend my gratitude to my family because they were the one who allowed me what let me have the time to dedicate to the completion of this great challenge, but also the advice and confidence to continue and accomplish this great challenge.

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Abstract

The main focus is on the Computational fluid interaction of the effect of parachutes in use on stresses and forces in the material. Constant research is being done to understand how air behaves when it interacts with parachutes. Due to the high turbulence and chaotic air behavioral, it is difficult to predict the behavior of the parachute. The stresses and pressure measurements are nearly impossible to take when in actual use. By simulating such problem in a computer software major advancement is made. The measurements are now taken and the behavior of the parachute is obtained. Rather than having to physically experiment and conduct these experiments, time and a large amount of money is saved.

In this thesis problems are solved with the help of computer software. The main objective is to use example problems to learn how to use LS DYNA Pre-Post and Post Processor, and learn in order to work on problems of our own. The objective is to duplicate an army parachute and use results to create more efficient parachutes. LS DYNA only reads K files and K files are also covered in the report, these K files are automatically created when working on the Pre Post Processor. Projects covered are a beam problem as well as a cube problem.

The combination of various computer software's is used to solve parachute problems. The results are analyzed, interpreted and a conclusion is made. All scenarios are for actual parachutes. Parachutes include the G-12 a 64 foot diameter parachute, also included are the T-10 personal parachute. The T-10 parachute, is a 32 ft diameter parachute, all parachutes covered are those used by the ARMY.

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Introduction

Parachutes have been in use for many years. The first design was by Leonardo da Vinci in 1485 made of linden material. Fauste Veranzio constructed and tested a parachute similar to Vinci's design. The first parachute jump from an aerial craft was Andre Jacques Garnerin at a height of 3,200 ft (976 m). (parachutes) He continued to do this many times, at one point he jumped over England at a height of 8000 ft(2440m). The average speed at which a parachute descends is of 18 ft/s(5.5 m/s) Parachutes really took off after World War II they were used to deliver goods as well as troops and were also used by pilots to eject from their plane. (McGrath and Travers) Presently they are used for many applications. They go from being used for sky diving as a pastime to mission objective military use. Load applications can be food, space shuttle equipment, bombs as well as people use. Parachutes are used not only to transport people but also are used to transport cargo. Parachutes must be robust enough to withstand all types of weather conditions while also being able to be driven to a specific location. In addition to vertical descend parachutes, they are also used to slow down horizontal movement such as slow down a race car after a race. The discovery used parachutes after it landed to bring it to a stop. They are still very popular due to the relatively low cost as well as minimal maintenance cost. Currently the air force is using parachutes to remotely drop cargo such as food supplies to ground soldiers in Afghanistan, this as they state "is a cheap way of delivering (Brewin) goods as opposed to spending up to $40,000 on advance technology equipment to do the same thing". There are specific procedures taken to sky dive but can be learned by a professional. Classes are offered and once completed the person is free to sky dive using parachutes. This is done all over the United States and is very popular. The basic objective of a parachute is to create drag and the user be able to control at the rate at which it descends. In the U.S., a backup parachute is packed by professionals in case the parachute the user in use fails there is an extra chute to aid in landing, saving their life. It is important to focus on the research in parachutes because

this can prevent a injuries and worst case a possible death due to the wrong use or failure of parachutes. To date, the most common injury is the lower limb and vertebral column. This is due to the sudden force exerted when the paratrooper lands. (Whitting, Steele and Jaffrey) The parachutes focused on, will be personal parachutes. There are two main types of personal, use parachutes a square parachute is seen in Figure 1 and the other chute is a circular one (Gerhard, Wolfgang and Wallace). The main focus will be on circular type of parachutes. Also circular parachutes are used with remote control devices called unmanned slave parachute. (William M, Keeler and Tremayne) These types of parachutes are popular due to the control of the parachute being through a remote device controlled by someone on land.

Figure 1 Typical Personal Square parachute (Gerhard, Wolfgang and Wallace)

When a parachute is activated the strings are the first to pull out of the pack and the parachute opens. The parachute opens at a quicker rate in the vertical direction as opposed to the horizontal direction. It opens uniformly due to the symmetry of the parachute and the pressure and forces. Maximum pressure is at the center of the parachute called the apex. The rate at which the parachute exits is critical, if it is too fast this may damage the load at which it is attached. The material commonly used for the cloth is nylon but ongoing research is focusing in the creation of nylon that it stronger to support heavier payloads. The research is being done by Randolf Lewis at the University of Wyoming, Laramie supported and funded by the US Air force. Other research is being done on goat milk, which is being used to feed bacteria which in turn produce spider like silk proteins Figure 2 The-zipper like silk formed

by bacteria is a stronger material. (parachutes) This is proven to be a stronger material than the currently used nylon. (parachutes)

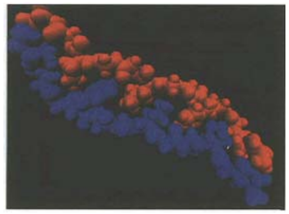

Figure 2 The-zipper like silk formed by bacteria is a stronger material. (parachutes)

The current way to analyze parachute behavior is in both actual experimentation and computation analysis. The cost and time needed to test an actual parachute is in the range of twenty thousand dollars. Not only is it expensive for the government but a whole crew of technicians is needed to conduct the experiment. On the other hand, computation analysis only takes a fraction of the cost saving time and money. Also, more information is able to be extracted from numerical analysis such as instant replay on behavior of parachute as well as pressure value concentration in specific areas. The numerical approach is being used for many different applications such as blood analysis flow, marine and water analysis. They all require specific boundary conditions as well as specific material parameters. This air becomes more accurate as time continues and more is reaming to be done. Confident results are in the stage it is now and are reliable.

The first chapter is parachute history and a timeline of how the parachute developed to this present day. Also covered is a parachute's definition as well as specifications on major parachute parts. In addition it also includes also problem statement the approach that is taken to solve the problem. Included is current methods to testing parachutes also different methods of testing and data obtained from such testing procedures.

Chapter 2 is focused on current research and how it is being done. This is also literature review covering the advancement being done. The results obtained and how it has helped for others to continue

the development of knowledge in parachutes which mostly covers research done at universities and research labs government funded.

Chapter 1

Currently there is need in methods to measure and simulate parachutes when in use. Not much is known about pressures, stresses and other factors when parachutes are in use. It is of great benefit to simulate and understand as much as possible about parachute behavior before testing. This is due tot he funding to government agencies being greatly reduced. Just recently the current president Barack Obama reduced the current yearly funding of 18 million to the NASA program. (James) This will directly effect testing sites such as Yuma Parachute Testing grounds. The objective is to research in the area when parachutes are in the air under various circumstances. The effect it has on the parachute when different designs are chosen or different material is used in the canopy. The approach to solving this problem is by simulating the parachutes in computer software such as LSDYNA. This software simulates similar scenarios and results are obtained that give us a base line to measure. Constant research has been done since the first recorded jump in 1617 done by Vinci. (parachutes)

1.1 Parachute History

As stated before Da Vinci is credited by having the design of the first parachute. Although he did not make the first parachute jump which is credited to Andrew Gernerin. This was the first parachute without a rigid frame. (Meyer) In one occasion when Gernerin jumped from an air balloon at 8,000 feet. A French astronomer, Lalandes observed with his telescope and noticed oscillation as he descended. At that point it was suggested to cut a hole at the center of the parachute to prevent the oscillation. This is presently known as the apex of the parachute. Presently all parachutes have the apex vent. This prove to indeed prevent oscillation and as a result a more stable decent is obtained.

When the parachutes inflated after going airborne it was very dangerous and risky until Captain Thomas Baldwin in 1887. He developed a parachute harness to strap to the person holding the parachute as a backpack. Next were Paul Lettman and Kathchen Paulus that came up with the concept of packing the parachute in a knapsack-like form. This is also the same concept as it is done presently. Also, the ring slot parachute what is now known as a cargo parachute used to transport goods and payloads was

developed by Knacke which was invented after World War II. This in turn is a less expensive parachute when compared to the personal ribbon parachute. (Meyer)

1.2 Problem Definition

The focus will be on circular 64 ft diameter G-12 parachutes, these are used by the army. These parachutes are used for payloads from 500lb to 3500lb. (TendersInfo) During Operation Provide Freedom 26 ft parachutes were used to drop Container Delivery System (CDS) as the demand increased, the load became too much for the parachutes. At that point an upgrade was necessary and this is when the G-12 parachute was introduced, it is nearly five times more expensive. The larger parachute was able to handle up to four times as much load compared to the smaller 26 ft parachutes. Slight modifications were needed to be done by the riggers in order to be able to be used. More time and effort is needed to pack the new G-12 parachutes, but also trained and certified instructors aided in teaching how to pack and use the new parachutes. The approach to solve the problem will be both in there as well as in computational fluid interaction. The governing equations will be those for incompressible and compressible flow. A parachute when in use undergoes many changes. From the inflation, to the descent, to the gliding on the ground and finally landing. The equations used are Navier-Stockes equations. The equations were derived by George S. Stokes (1819-1903) and C. H. Navier (1785-1836). (Kumar, Advanced Computational Techniques for Incompresible/compressible Fluid-Structure Interaction) much research is being done in the past, none the less, the major challenge is to understand the aerodynamics of parachutes. Currently in order, to explore this area air drop tests are being done as well as using wind tunnels to test the aerodynamics of parachutes. Numerical analysis helps to discover and simulate the aerodynamics of parachutes and are useful tools to this types of problem. It helps in predicting what a parachute will do under specified conditions, if results are satisfactory then a physical parachute drop test is done to confirm results. The Fluid Structure Interaction (FSI) software will be used to solve these type of problems. The mesh will be defined before the problem starts, then as the

parachute evolves or expands the mesh re-adjusts due to the turbulence and chaotic behavior. The problem involves nonlinear coupling between air fluid flow and the structural dynamics. (Accorsi, Leonard and Benney) In cargo parachutes numerical simulations is the only option to know how it behaves when in use due to not having a person on board.

1.3 Parachute Construction

Recently in Operation Ending Freedom the demand was so high that new parachutes were needed to be purchased. The G-12 parachute has 111 inch deployment line has a 68 inch diameter nylon pilot chute and a 15ft long static line. Strength is added to the parachute through bands, tapes as well as lines. The vent at the top of the parachute is the apex and it serves as a pressure relief. Maximum pressure is at the top center of the parachute area. The apex is a hole at the top of the parachute in the fabric through which air exits. It is important to have apex because if not the air would build such a high pressure that could rip the fabric apart resulting in a failure of the parachute. The major strength is through the radial lines of the parachute these also give shape to the parachute when fully expanded (Tezduyar, Sathe and Pausewang). Skirt bands are used to control the opening rate of the parachute and the suspension lines is what connect the parachute to the payload see Figure 3. The material used is nylon because it has low density value of 1E-8 kg/m^3 and modulus of elasticity of .21MPa and poisons ratio 3. Nylon is a porous material and this has an effect on the handling and performance of the parachute. The porosity is naturally of the material and can be controlled by the direction or orientation of the material as well as by controlling the temperature of the material. By having control on these factors, better guidance, navigation and control (GN&C0) can be achieved. The drag created by the parachute is then transferred to the payload and decelerated for a slower decent. These parachutes are in high demand and the U.S. army has bought new G-12 parachutes from Ballistic Recovery Systems (BRS) for a total of $4.1 million for 1,200 parachutes (TendersInfo). The company BPR is one of the leading providers for parachutes It alone has received $5.3 million for parachute production

(TendersInfo). Very little advancement in research has been made due to the difficulty of measuring data when parachutes are in use. Factors such as wind direction, turbulence make it difficult to take any valid measurement data. In the same manner it is difficult to make numerical calculations due to the instability of the air flow. Still research needed in the air flow is needed, as well as parachute opening, also the behavior of porosity of air on to the material, soft descent as well as control of parachute under harsh weather conditions. Much research has been done although the major challenge is to understand the aerodynamics of the parachutes.

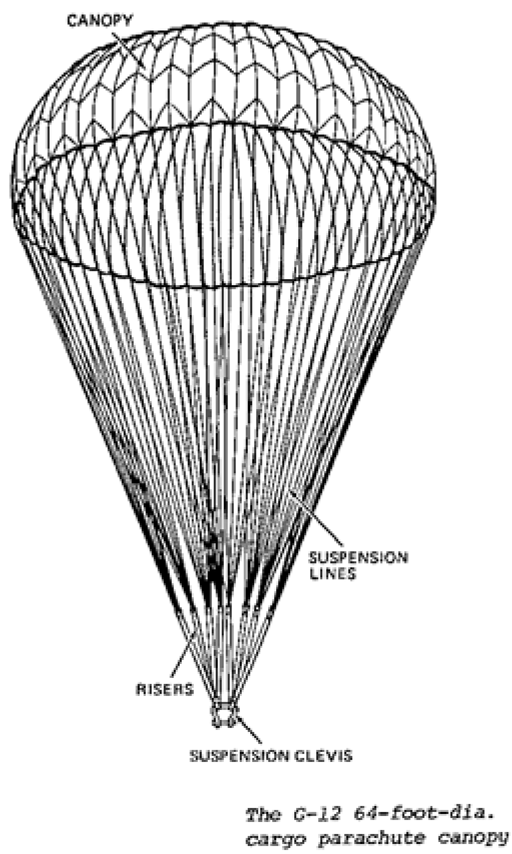

Figure 3 G-12 Cargo Canopy System

1.3.1 Parachute details

The cargo parachute is used for cargo and can support up to 2,200 lb (1,028 kg) additional parachutes can be added and supported load is increased as seen in the following table.

Table 1- G-12 parachute specifications. (millsmanufacturing)

Type	Parachute	Minimum (lb)	Maximum (lb)
G-12	1	501 (227kg)	2200(997.9 kg)
	2	2,270(1,029.7 kg)	3,500(1587.5 kg)

Table 2- G-12 Parachute series characteristics. (millsmanufacturing)

Shape	Flat Circular
Diameter	64 ft (19.5 m)
Gore material	2.25 oz, type 1, nylon parachute cloth
Suspension lines	64
Suspension line material	Type IV, PIA-7515, 1,000 lbs (450 kg) tensile strength
Length of suspension line	51 ft (15.5m)
Suspension Riser Assemblies	2
Suspension Riser Length	60 ft (18.28)
Complete Assembly Weight	125 lbs (57 kg)
Maximum Payload Capacity	2,200 lbs (997.6 kg)

Table 3- Pilot Chute

Shape	Flat Octagonal	
Diameter	68-in (1727mm)	
Canopy Material	1.1 oz PIA-C_7220, type I rispot nylon parachute cloth	

1.3.2 Parachute Schematics

The parachute image with dimensions can be seen in Figure 4. It has suspension 64 suspension lines and

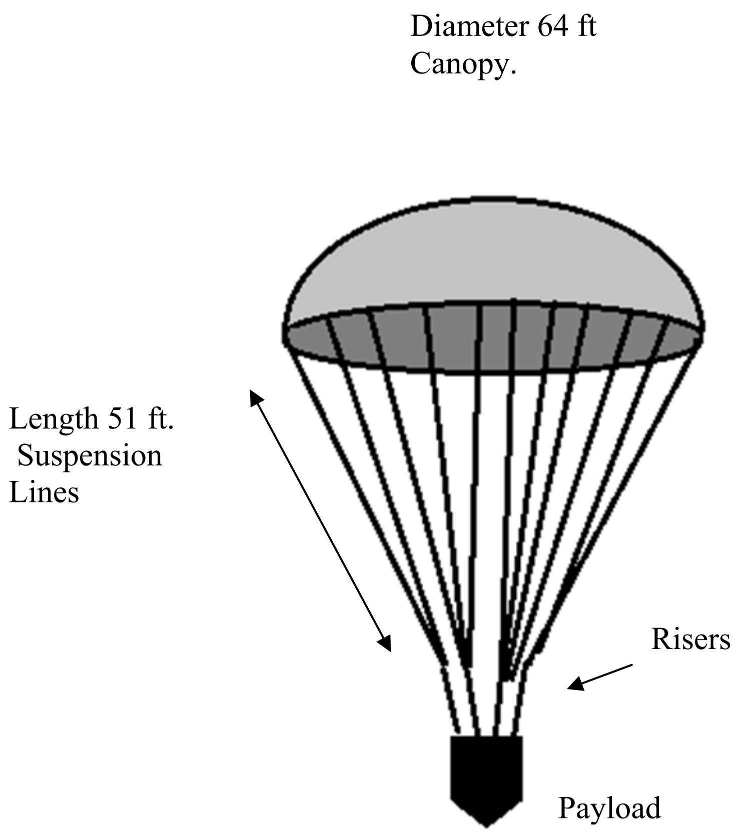

Figure 4 G-12 Parachute dimensions.

1.4 Parachute Testing

Testing methods are done with the use of wind tunnels and by Fluid Structure Interaction (FSI). Due to the large parachutes, a smaller scale is tested. Testing has been very difficult and requires adequate equipment. There are designated sites such as the Holloman High Speed Test Track(HHSTT) that specialize in testing parachutes as well as canopies, impact testing, weapon dispense testing and environmental testing (Truong, Weiss and Wang). The previous testing was done by NASA personnel to test parachutes for mars missions. The Army also uses drop indoor facilities to test parachutes. There are many factors ignored, the major one is cross winds. Previous testing have been done in the parachutes for missions. For example NASA, conducted numerous tests on a particular parachute used by Phoenix

before it was used in a mars exploration mission. Among some of the factors measured are drag and static stability (Cruz, Mineck and Keller). The force needed to hold the parachute in place while the wind is flowing is the principal force needed to determine the drag coefficient. A similar set up is used to calculate the static stability coefficient (O'connell). Once all simulations have taken place at some point it is time to test the parachute, this is what people like Richkster Powell do. He specializes in parachute testing, he has more than 20,000 jumps. The approximate deployment height is 13,000 ft for in order to have enough time to deploy the back up chutes if necessary. In order to capture the view of the user he also has a belly camera (Masamitsu). In case of an emergency and the test parachute fails he has 2 backup parachutes to use. In order to record data, Alti-2 digital altimeters are used. These record harnesses strain as well as barometric pressure when the parachute opens. If more measurements are needed, one of which is at the apex of the parachute as seen in Figure 5 Static stability coefficient laboratory test on mars parachute. .Figure 5 Static stability coefficient laboratory test on mars parachute.

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Figure 5 Static stability coefficient laboratory test on mars parachute. (Cruz, Mineck and Keller)

Current testing methods are through wind tunnels in a vertical guide wire. Also, tests are done through air drops being the most expensive and time consuming. Parachutes tested are those for NASA such as the gear used on the Discovery Space shuttle. The Discovery uses a drogue parachute to land and bring it to a stop due to it not having turbines. Also Test sites such as U.S. Army's Yuma Proving Ground near Yuma, AZ serves as a test site for the Ares rocket from NASA. This site test over 36,000 parachutes a year and flies over 6,000 aircraft missiles. (The military Standard-Army Bases) On Oct. 08,

2009 the heaviest load was successfully dropped from a moving aircraft at an altitude of 25,000 feet and a payload weight of 72,000 lb. Cites such as these source as testing and simulation before actual use. Paragraphs with the style applied can be extra (Tech Bastard)acted to appear in the table of contents as level 2 subsections. Testing site like these are becoming expensive to maintain. The cost for actual physical testing are becoming a larger part of the project budget. Testing is very important because it validates simulation results in addition to proof testing the actual hardware.

1.4.2 Vertical Guide Wire Drop

In this case, a secured area is used to descend a parachute that indoors to have an ideal parachute drop scenario. The test site is Space Power Facility (SPF) at the NASA Glen Research Center(GRC) Plum Brook Station in Sandusky, Ohio. The height of the drop is approximately of 120 ft. Minimal air current is achieved at .33 ft/s. No horizontal movement is permitted to be done to a piano cable serving as a guide running through the center of the parachute the wire only permitting the parachute to move in the vertical direction. (Desabrais, Lee and Buckley) In order to reduce the vertical movement, there is a cable pulling the pay load straight down. An electric winch is used to elevate the parachute to the drop height. With a remote activated mechanism the parachute is released. At the ground there is a landing safe zone. Foam and paper honeycombs are used for a safe landing on the payload. The testing procedure described is used for testing in an ideal scenario as this is not the case in real life. In real life there are cross winds and the user also maneuvers the parachute. This is done in order to simplify the problem and better understand how parachutes behave when in use. Paragraphs with the style applied can be extracted to appear in the table of contents as level 3 sub headings.

1.4.3 Payload

The payload is where the measurement devices are attached to. The instrumentation is composed of a tri-axial accelerometer, a descend velocity probe, and an onboard camera. Data and digital video recording systems are used, all used to record the most possible what’s and how’s a parachutes may behave when in use. This is when the actual parachute is tested. When this is simulated there is no need to include such devices. Refer to Table 1 to see details on capacity of G-12 parachutes in pay load capacity.

Payloads can be anything such as, cargo or merchandise, tools or machinery. The allowable load for a single G-12 parachute cannot exceed 2,200. In the case of Fluent Software the payload is fixed. As when parachutes are tested physically. Load is said to be pinned (Kumar, Advanced Computational Techniques for Incompresible/compressible Fluid-Structure Interaction) Wind-tunnel testing secures the payload and only the parachute deforms.

Chapter 2

Current Research And Methods

The current methods for solving parachute analysis problems, range from research to actual simulation experiment testing. Testing is costly and time consuming. Research is more common and is done more widely. Companies as well as government and educational universities conduct research. In this case the purpose is to research government based parachutes that are used by the army and use to results to save time and money as opposed to testing them unless necessary. The principals are the same for personal parachutes and airplane descending speed parachutes similar to those used by the shuttle discovery.

2.1 Current Research

Research is widely being done throughout the country. Research is mainly in universities and government labs. The University of Minnesota is doing research in Parallel Iterative Computational Methods for 3D Finite Element Flow Simulation. (Karlo and Tezduyar) Applications to Parallel Implementations are not only in parachutes but also in aircraft, automobile and sphere. All of which are meshed and parallel computing is used to solve as seen in Table 4.

Table 4- Description of meshes used for performance evaluation of parallel computing.

MESH	GEOMETRY	TYPE	NODES	ELEMENTS
1	AIRCRAFT	TET	192,595	1,110,046
2	AUTOMOBILE	TET	448,695	2,815,518
3	SPHERE	HEX	509,432	495,000
4	PARACHUTE	HEX	1,114,241	1,085,016

The research's main focus is in computing matrix-vector products using a sparse storage scheme.

Just like in our research computing is necessary using computer software. Parallel computing was not needed in this case due to the problem being capable of being solved by a single computer. Methods used to solve the complicated mesh are my matrix. The mesh is subdivided in to clusters and then solved with matrix manipulation as seen in the following equation.

$$Ax = b \quad \textbf{Equation 1}$$

This solution is done at each step of the Newton-Raphson method for iterative coupled solution and non linear equation system.

2.2 Current Parachutes

The Army just recently got an overhaul in their parachute equipment. In 2008, the parachutes got replaced with new current parachutes. The parachutes being used were old technology and there was no attention. The current parachutes were target to many complaints. The complaints were in the form of decent too fast, leading to injuries, parachute oscillation, and unstable. The reason the focus was aimed at parachutes is because the injuries increased, as the technology advanced the soldiers were better equipped. This increases the amount of equipment required, therefore increasing the weight of the soldiers. This puts more stress on the parachutes. Making the parachute less stable along with increasing the rate of decent.

The current parachutes replaced are the Mass tactical T-10 parachute with the T-11 Advanced Tactical Parachute system (ATPS). Also a maneuverable tactical operation parachute MC-1 with the MC-6. Special operation high altitude parachute MC-1 with MC-6 parachute. Also the MC-4 free fall parachute with the Advanced Ram Air Parachute System (ARAPS). According to MAJ T.J. Wright, Assistant Product Manager, personal airdrop system team the paratrooper can now jump with full equipment. The new parachutes are an improvement in oscillation to reduce entanglement. Larger canopy area increase force which in effect can support grater payload weight. Also is designed to reduce the parachute sudden pull this prevent possible cargo damage do to sudden force. (Wright)

By replacing parachutes, there were a reduction in personal injuries as stated by Modern Jumping SPC Richard Manley in the US Army Jumpmaster School in FT Benning, GA. (Crouse) As Manly also states, the descent is slower and the parachutes reject each other to prevent entanglement. All of these parachutes were tested in Yuma proving grounds in Yuma Arizona. The parachutes have a 28% larger canopy resulting in a slower rate of 4ft/s. This allows the paratroopers to absorb the landing and carryout its mission with no injuries. The reduction in landing impact was to 49% therefore also reducing the injuries to 73% (Jimenez)

Chapter 3

Mathematical Equations

The governing equations consist of the fluid dynamics aspect as well as the structure dynamics. The fluid dynamics consist of the Navier Stokes equations which are nonlinear time dependant advective diffusion equations. The structure dynamics equations are equilibrium equations of a “tension structure” apply to membranes point mass and cables.

3.1 Fluid Dynamics

The equations used are Navier Stokes (NS) equations for incompressible flow. For porosity in fabric homogeneous equations are used (Tezduyar, Sathe and Pausewang). Common values of porosity for nylon are in the range of 260 CFM. The amount of air that passes through the fabric has a big effect on the performance of the parachute and is taken into account through the numeric analysis. A low Reynolds number is chosen to simplify the calculations because at terminal velocity the air is in laminar flow. A low Reynolds number indicated laminar flow therefore justifying the reason for a low Reynolds number. Equations are reduced to a membrane shell theory form (Sheikhzadeh, Shanbeh and Semnani). The mesh parachute is fixed with respect to the air flowing through. Numerical simulations of the air is difficult due to the instability turbulence flow present at that time.

$$\Gamma \partial \frac{\partial}{\partial t} \int W \, d\,\Omega + \oint (F_c - F_v) dS = 0 \quad \text{Equation 2}$$

W is a vector variable, $\mathbf{F_c}$ convective flux vector, $\mathbf{F_v}$ viscous fluxes vector, ρ is density of air. **Γ** is the pre conditioned matrix. That is used to adjust stiffness due to low Mach number. After discretizing the N S equations the result is Equation 3 for a finite volume formula.

$$\Gamma \frac{d\,W_i}{dt} = -\frac{1}{\Omega_i}\left[\sum(F_c - F_v)_{ij} S_{ij}\right] = R_i \quad \text{Equation 3}$$

Where Ω_i is some controlled volume and $\mathbf{S_{ij}}$ is the vector with respect to *ij* (Sheikhzadeh, Shanbeh and Semnani)

The problem worked on is considered incompressible due to the fact that the Mach number is less than 0.3. When the Mach number is below 0.3, density varies only 5% therefore is negligible. Above 0.3 Mach number density is considered to de compressible using a different set of equations. For parachute cargo and personal parachute drops the mach numbers is below 0.3. Therefore incompressible mathematical equations are used. On the other hand, the space shuttle exceeds mach 0.3 when descending, in this case both compressible and incompressible solutions are necessary.

For the governing equations in $\Omega_t \subset \mathbb{R}^n$ within the (0,T) are the temporal and spatial domain, where n is the number of space dimensions, Γ_t is the boundary of Ω_t. The sub *t* represents the time-dependence of the governing equation of Navier Stokes equations for incompressible flow analysis. The equations are the continuous Equation 5 and conservation of mass Equation 4. The Navier-Stokes equation are non linear partial differential order equations. In some cases, can be reduced to linear when the problem is in one dimensional flow. The fact that it is non linear form makes it difficult to solve and becomes in some instances a turbulence problem. Where flow of air is chaotic.

$$\boldsymbol{\rho}\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} + \mathbf{f}\right) - \nabla \cdot \boldsymbol{\sigma} = \mathbf{0} \qquad \textbf{Equation 4}$$

In this case ρ is density, **u** is the velocity vector (*u*,*v*,*w*) and **f** is a external force acting on the body in this case it is gravity all are constant. The condition applies for a final constant terminal velocity.

$$\nabla \cdot \mathbf{u} = \mathbf{0} \ \ \textbf{for}\ \boldsymbol{\Omega} \qquad \textbf{Equation 5}$$

Equation 5 holds true at constant density and is referred to as the mass continuity equation. This is true for parachute deployment at final constant velocity approaching gravity value. (Brown, Cortez and Minion)

3.2 Computation Formulation

Fluid structure interaction is complicated and many articles have been published trying to further expand the knowledge and understanding in this area. Computer simulation helps parachute design because it has the ability to know how the parachute will perform before constructing it. By knowing how the parachute will perform using simulation the designer can make modifications if necessary based on the results obtained. This article prove that LSDYNA is a valid software to solve parachute problems. Previously LSDYNA has been used to simulate and analyze parachute conditions while in use when spacecrafts are landing. (Ma, Huang and Zhang) LSDYNA has a built in command ALE* represents arbitrary Lagrangian-Eulerian solver. This program uses a transient, LSDYNA is the software used to both create and solve the problems. It is used for the pre and post processors. Tension in suspension lines are measured by using a bi-axial tensile tester. (El Sherif, Fidanboylu and El Sherif). The material properties are shown in Table 5.

Table 5- Material properties for nylon.

Density (kg/m^3)	Modulus (GPa)	Poisson
0.0015	3	.3

The formulation used in FLUNET is time dependent in both steady and unsteady state. Time is important in the steady state due to time marching until a steady state is achieved. The solution to both is obtained through temporal discretization of both explicit and implicit time-marching algorithms.

3.3 Drag Coefficient

The drag coefficient is what is used to determine the parachute load to be used. Drag force is the force exerted by the parachute to reduce the speed at which the object is descending. The drag force equation is seen in Equation 6.

$$F = \frac{1}{2} C_d \rho V^2 s \qquad \text{Equation 6}$$

D= Total Drag (lb)

C_D=drag coefficient

P=air density (slugs/ft^3)

V= descent velocity

S= reference area

The drag force created is slight less ten the weight of the parachute total weight of the parachute including the payload. Newton's second law is shown in Equation 7.

$$F = ma \qquad \text{Equation 7}$$

m= mass of payload and parachute (slugs)

a_D= (a_m-a_D), a_m is acceleration from the double differentiation of the height-time span.

Velocity of the parachute can be calculated by using Equation 8. The velocity changes with the change in the drag coefficient. The drag coefficient ranges from 0.5 to 1.5. (Jian, Shuling and Yizhao)

$$V = \sqrt{\frac{W}{S_a * C_d * \rho}} \qquad \text{Equation 8}$$

S_a is surface area, C_d drag coefficient. Normal drag coefficients range from .5 to 1.5. Depending on material. Density is ρ, the total weight is W, total weight includes pay load with actual parachute weight.

3.4 Boundary Conditions

The problem is defined with a controlled system. Using walls inlets and outlets are what completes the problem. The parachute is simulates as it is tested experimentally. A 100 meter length and 50 meter height. The walls are set to be velocity to be zero at the walls as seen in Figure 6.

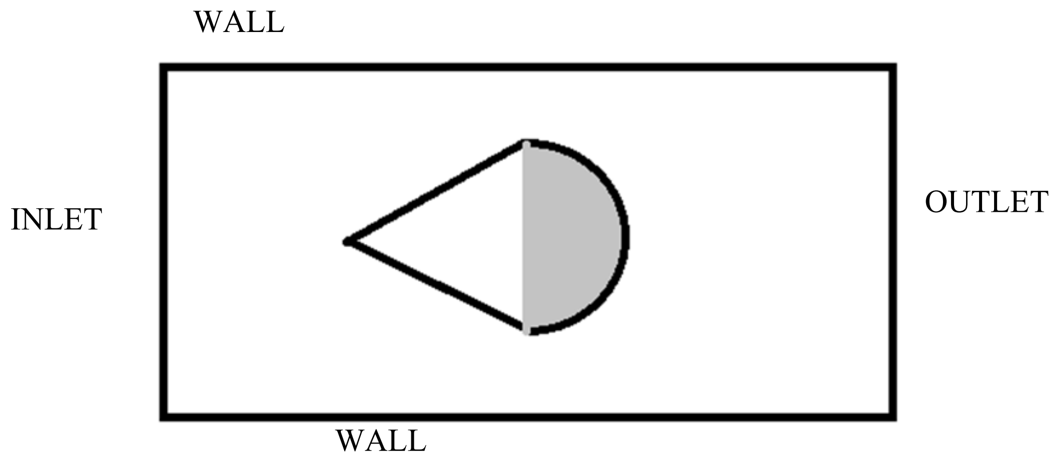

Figure 6 Boundary conditions for parachute analysis.

The boundary values at the at the parachute are to be zero due to no fluid flowing at the surface of the material. The inlet boundary is set to enter air at a rate of 9.81 m/s. This velocity is set due to it being a terminal velocity of decent. The outlet is also set as one of the lines in the problem. This is where the air exits the system. The wall is set where no air enters nor exits. This problem is set for all the parachute simulation problems using fluent and gambit software's. The parachute is fixed and is not permitted to deflect in any axis.

Chapter 4

Computational Fluid Dynamics Parachute Simulation

Finite Element analysis is used to solve complicated problems in which common spectral or finite methods are too complex to apply. The idea is to obtain by computer help a solution given only limited boundary conditions and initial conditions. Finite element analysis solves the given problem involving differential order equations and by iteration approximates the solution and converges to a solution. Also Finite element analysis is a excellent tool due to the fact that initially a finite amount of degrees of freedom are possible and at the end a set number of degrees of freedom are determined and a solution is approximated by a number of unknowns. At the end a linear matrix is obtained when discretized it can be applied in both time and space. This formulation is defined as the space time finite element method. Also a dicretization can be done which is time only and this is called a semi discrete formulation this is proven in. (Tesduyar, Behr and Liou) The Lagrange-Galerkin method is used to solve convection through its numerical techniques. (E) Galerkin approximation is what is commonly used in the finite element analysis. Also Galerkin method is one of the most common methods for weighted residuals. Some other Common methods are Collocation method, Sub-Domain method, Least Squares Method and Methods of Moments. In Structural dynamics one of the areas of concentration is to minimize energy. By using Galerkin method a symmetrical matrix is obtained and we get “optimal” results. The meaning of “optimal” is that the solution is in the best approximation property method.

The parachute simulation for the fluid interaction is the main concentration. The objective is to analyze pressure concentration as well as velocity profile by using computer software to plot the solution. Parachute is a complicated unpredicted behavior and computer software such as Fluent, Gambit and LsDyna are used to solve the complex problems. LsDyna has both a pre processor as well as a post processor and is capable of solving general purpose transient dynamic finite element problems. The problem can be defined as well as solved without having to use a second program to solve the

problem. Also Gambit in conjunction with Fluent was used to solve other cases simulating parachute performance. In this case the problem is defined in Gambit then the problem is exported to Fluent where the problem is solved.

4.1 Parachute Solution LsDyna

The popular parachute analyzed is the G-12 army cargo canopy. The parachute is used to transport goods, and materials needed to build camps in needed areas. By simulating parachutes, it is possible to predict how a parachute will perform under certain conditions. It is costly and time consuming to go out and do this experimentally therefore computer simulation saves both time and money. LSDYNA is the computer software used to run the simulations and the results are presented in this report. Various simplifications are done in order to get results such as assuming the parachute will fall vertically down as opposed to falling at an angle due to wind. Also load is distributed evenly throughout the mesh although that may not be the case in real life. Many problems were solved previous to the results presented in order to understand how LSDYAN works. The problems covered are two, one is when a load of 300×10^{3} lb is applied and the second problem is when the mesh is expected to fail. The data will be presented for both scenarios and compared. The results will be analyzed and conclusions will be done and stated as well. Both problems are based on the same mesh and the change in load is the only difference. The future will be to attach a payload to the parachute as in real life. The parachute covered is a 64ft parachute and in the future different diameter parachutes will be analyzed and payloads with strings will be attached to the circular mesh.

4.2 Problem Statement

The circular plane is two dimensional plane and expands perpendicular to the plane as it would be in an ideal scenario. Initially the plane in a two dimensional plane and after the problem is solved it is

fully developed in to a parabolic shape. The circular plane is a of a 64ft diameter with a 3.2 ft diameter apex being 5% of the outer diameter. The pressure is perpendicular to the plane and is loaded at each element of the mesh. The outer nodes are fixed. The material properties used are those for nylon because nylon is the material used on the parachutes analyzed. Square elements are used and this mesh consists of 160 elements and 204 nodes. Different circumstances are analyzed by using the same mesh but the parameters are changed such as total time, load magnitude, constrains and material properties. The purpose of changing the parameters is to analyze the results and discover a better combination for the given problem of a 64ft parachute under different scenarios.

First scenario to be analyzed is the pressure distribution also maximum and minimum values of pressure. The data is analyzed as change in time occurs. The deflection of the parachute changes with respect to time and is plotted in x-y graph. The image in Figure 7 represents the body of the parachute before any load is applied, during a total running time of 0.5s.

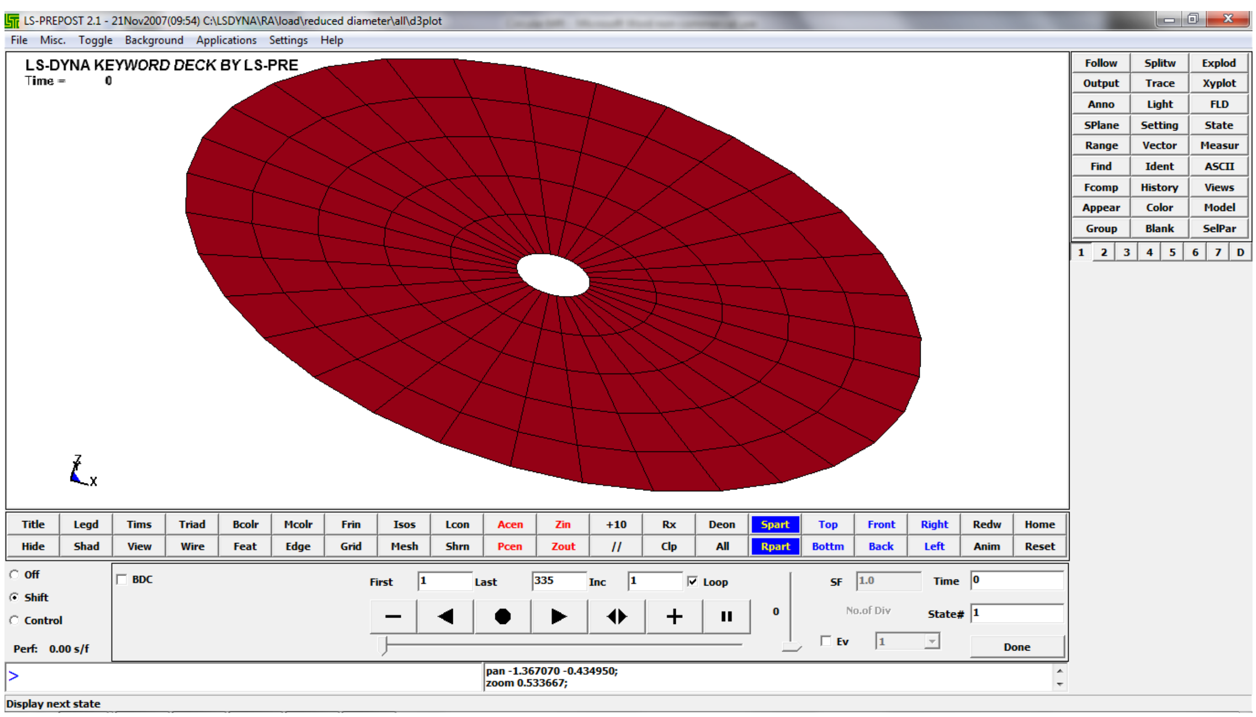

Figure 7 Two dimensional circular plane 64 ft diameter.

The outer 32 nodes are fixed in all directions preventing any type of movement when the load is applied. The inner hole serves as a bypass for the air in order to reduce the stress and pressure at the center of the parachute when in use. On the contrary of not having an apex relief, catastrophic failure is likely to occur because the stress and pressure would exceed the materials ultimate strength under light loads. Also, the Drag suddenly created can cause permanent damage to person operating the parachute. The load applied at each element is of 300 klb_f.

4.2.1 RESULTS

The maximum pressure and stress occurs in the *z* direction this is due to the direction of the load being on this axis. The results are presented in Table 6.

Table 6- The maximum values taken from LS-PREPOST.

Load	300 klbf
Z-Stress (kpsi)	76608
Pressure (kpsi)	25444.8
Max Shear stress (kpsi)	85060.8
Maximum in Plane Stress (kpsi)	13075.2
Min in Plane stress (kpsi)	106819.2

The values in Table 6 are the maximum values obtained. The values vary with respect to time and the exact values can be obtained from LSDYNA. Pressure is max at the outer edges because the outer nodes

are fixed. The load wants to pull away or stretch the material and the outer nodes are fixed so two opposing forces case the greatest stress at the edges. The deformation can be seen in Figure 8.

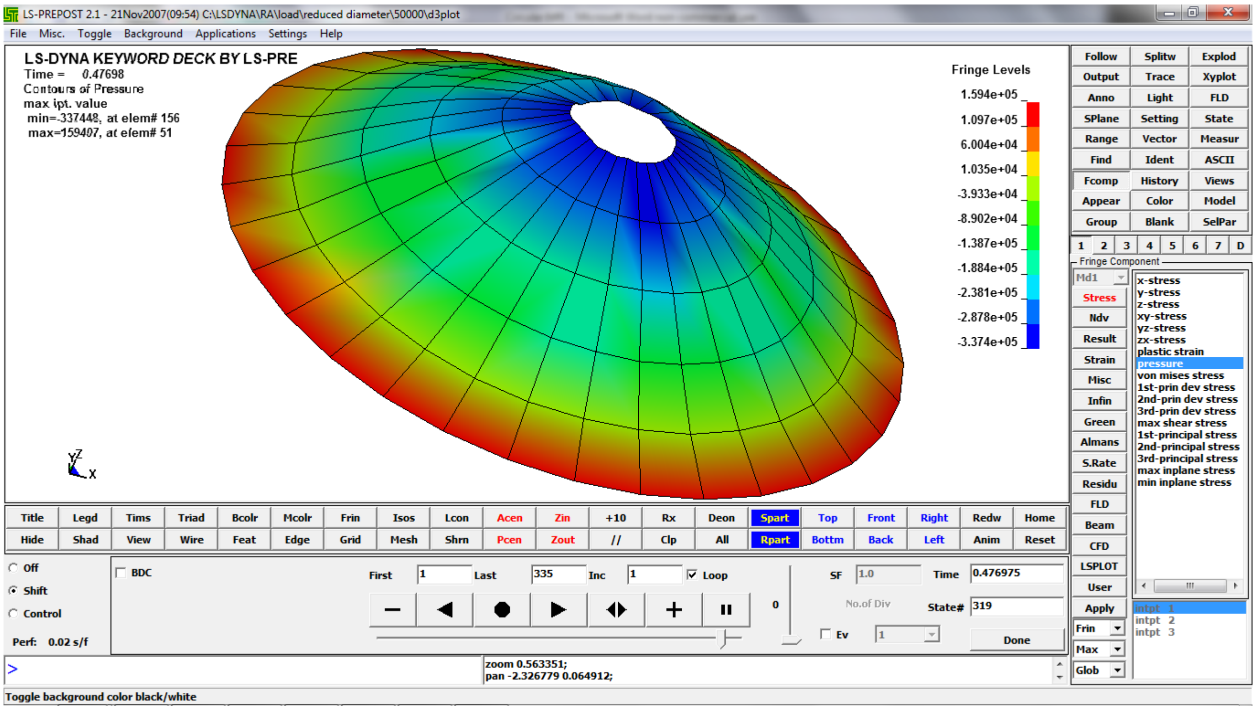

Figure 8 Pressure distribution at t=.47s.

The pressure is maximum at the outer nodes due to the fixed movement. The pressure is least at the center because there is free movement in any direction.

The displacement with respect to change in time is also important and LSDYAN provides the data to analyze the movement in all directions. The displacement of each node depends on the coordinate it has and varies with respect to time as well. The table in Figure 9 shows the displacement with respect to time.

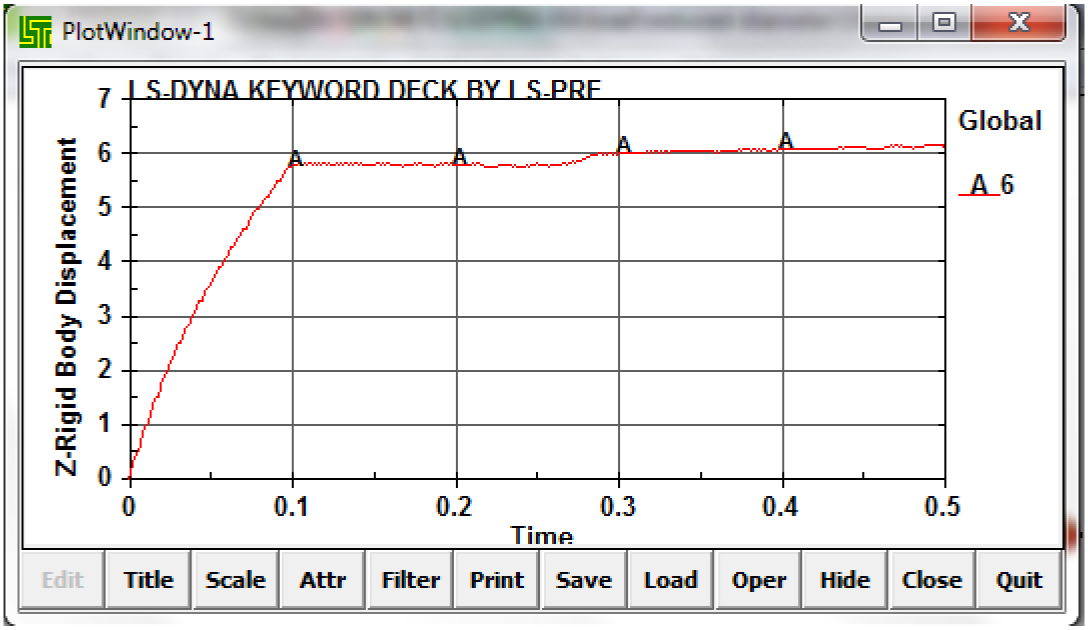

Figure 9- Displacement in the z axis perpendicular to the circular plane.

Maximum displacement occurs at 6ft and this value is achieved at after .1s. After .1s the displacement remains constant and steady state is achieved.

Results indicate that, under load of 300 klbf this problem will not fail. Future plans are to add strings that will have a payload attached. By attaching a payload it will simulate more accurately like a cargo army parachute. Also there is a need to take the parachute to a limit and test for failure. Increasing the load until the mesh fails is also done and is presented in the following problem. The Results can be compared to material limits and a decision can be made such as weather the material will fail or not. Results such as maximum pressure, displacement and minimum and maximum stresses are compared to actual material properties and a decision can be taken.

4.3 Failure Test

This case is done by increasing the load until the mesh fails. The purpose is to determine a maximum load that can be applied without failure. This will serve in order to establish a safety factor and can be used as a limit to not exceed. It is known that the results obtained are only an approximation

and are not actual values but they are relatively close and therefore are valid. The mesh and material properties are unchanged from the previous problem the only parameter changed is load. The initial problem is as seen in Figure 10. Based on previous results pressure should increase as well displacement. In general all results should increase and in fact did. Results can be seen in figure 10.

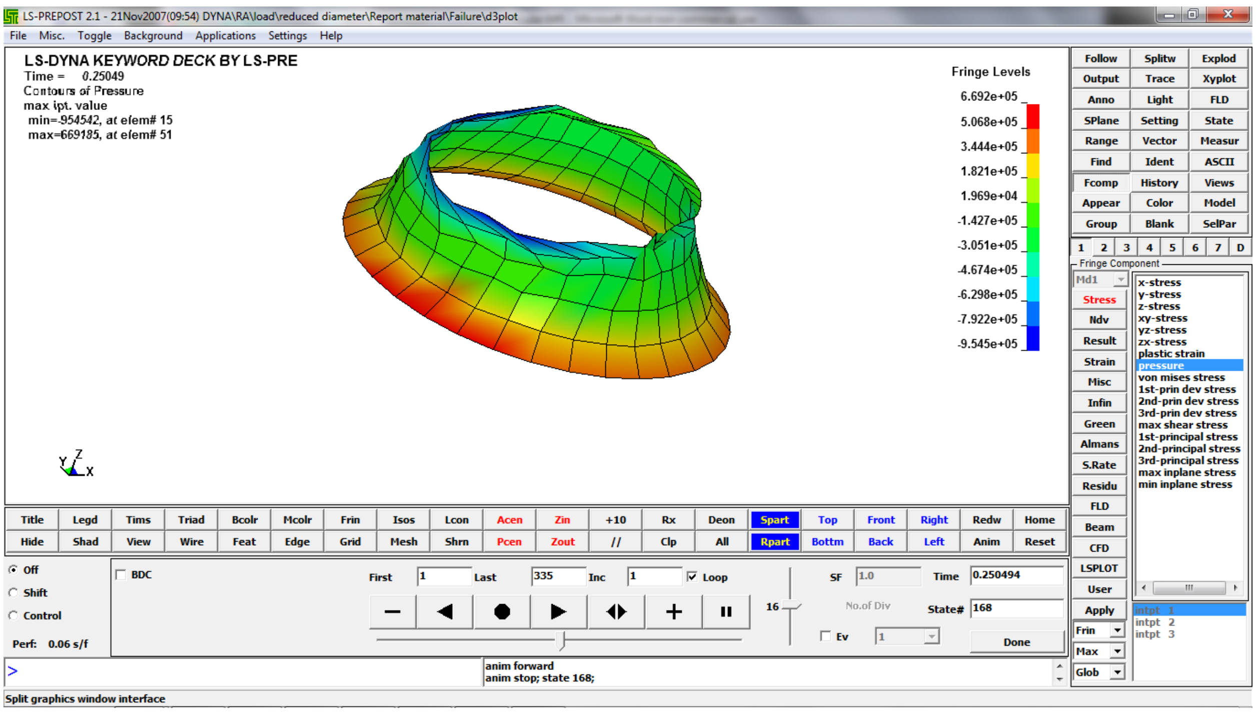

Figure 10 Failure mesh rupture under 500 klbf of load at 0.25s.

Rupture occurs at time of 0.12s and thereafter increases and propagates to failure which can be seen in Table 3. The results are shown in Table 7 and are as predicted (what increased) increased.

Table 7- Data comparison and difference in values for a load of 300 kbf and 500 klbf.

Comparison of Data			
Load	300 klbf	500 klbf	Difference
Z-Stress (kpsi)	532000	1040000	508000
Pressure (kpsi)	176700	697000	520300
Max Shear Stress (kpsi)	590700	1567000	976300
Maximum in Plane Stress (kpsi)	90800	3060000	2969200
Min in Plane Stress (kpsi)	741800	5260000	4518200

The results help in setting a limit to the load for this type of parachutes. The safety factor is set to 1.5 and the max load without failure is determined to be 333 klbf. In conclusion by solving this problem under different loads the maximum load at which there is no failure was determined. Results such as maximum stress values are also obtained and can be compared to material properties. Displacement also would be expected to increase and can be seen in Figure 11.

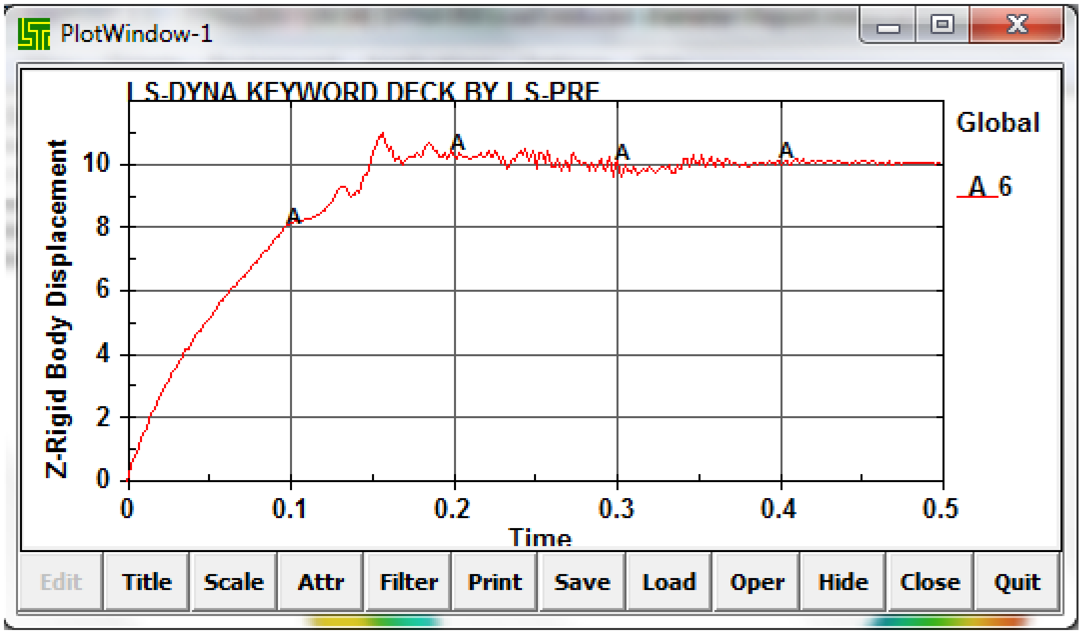

Figure 11- Z body displacement under a 500 klbf of load.

The displacement increased from 6 to 10 ft this is due to the increase in load. A conclusion can be made that the maximum value of displacement is of 10 ft and is achieved at approximately 0.2 seconds. By modifying the material properties a change in displacement can be achieved. Depending on what the objective is, the displacement can be controlled by changing the material properties such as density and modulus of elasticity. The material properties can be done in the material engineering area and is a option to improve the performance of parachutes.

5.4 Conclusion

This is an ongoing problem and further research is being done. The results indicate that a max load of 333 klb_f can be applied in order to have a safety factor of 1.5. The next step is to incorporate the strings that attach the payload to the parachute. This will simulate closer to the actual parachute in use. The same problem will be conducted under different diameters and finer meshes. By changing the diameter of the circle it will simulate different diameter parachutes and failure and maximum values will

be achieved. The results obtained will serve as a baseline to compare with and further deeper simulations will be conducted to achieve more accurate results.

Chapter 5

Fluent Results

Fluent program specializes in computation fluid dynamics (CFD) and is used for fluid flow simulation over parachute. Fluent uses a finite-volume method to solve the fluid flow problems using the governing equations. This program has the capability of solving compressible or incompressible fluid flow, turbulent or laminar, viscous or invicid flow. The software is only the post processor. It is used to solve the problems and define fluid type and properties as well as velocity values. Fluent works with Gambit as a package. Gambit is used as a preprocessor. This is where the geometry and mesh of the object is defined. Different cases will be solved starting with a single G-12 parachute and adding a second parachute. The addition of the second parachute is for heavier loads. The important factor here analyzed is the drag force. The drag force is the resistance and this is what is needed to bring the payload at a safe landing.

5.1 Pre Processor Problem Design

The problem was first designed in Gambit. This is where the problem was created and meshed. Once the problem was meshed and boundaries were set such as defining inlets outlets and walls then the file is exported. The file is exported to Fluent where the problem was solved. Gambit serves as computer software where the problem initiates. In the following figures, the images are of the mesh of two G-12 parachutes. The coordinates are inputted in to the Gambit where lines are connected. First a boundary rectangle is formed and inside a 2D arc to in the form of a parachute. The problem is divided in half and once the problem is solved then it is reflected. Due to the symmetry of the problem the results can be reflected in order to save computational memory and time. Makes problem simpler and at the end the same result is obtained. This can be seen in Figure 12.

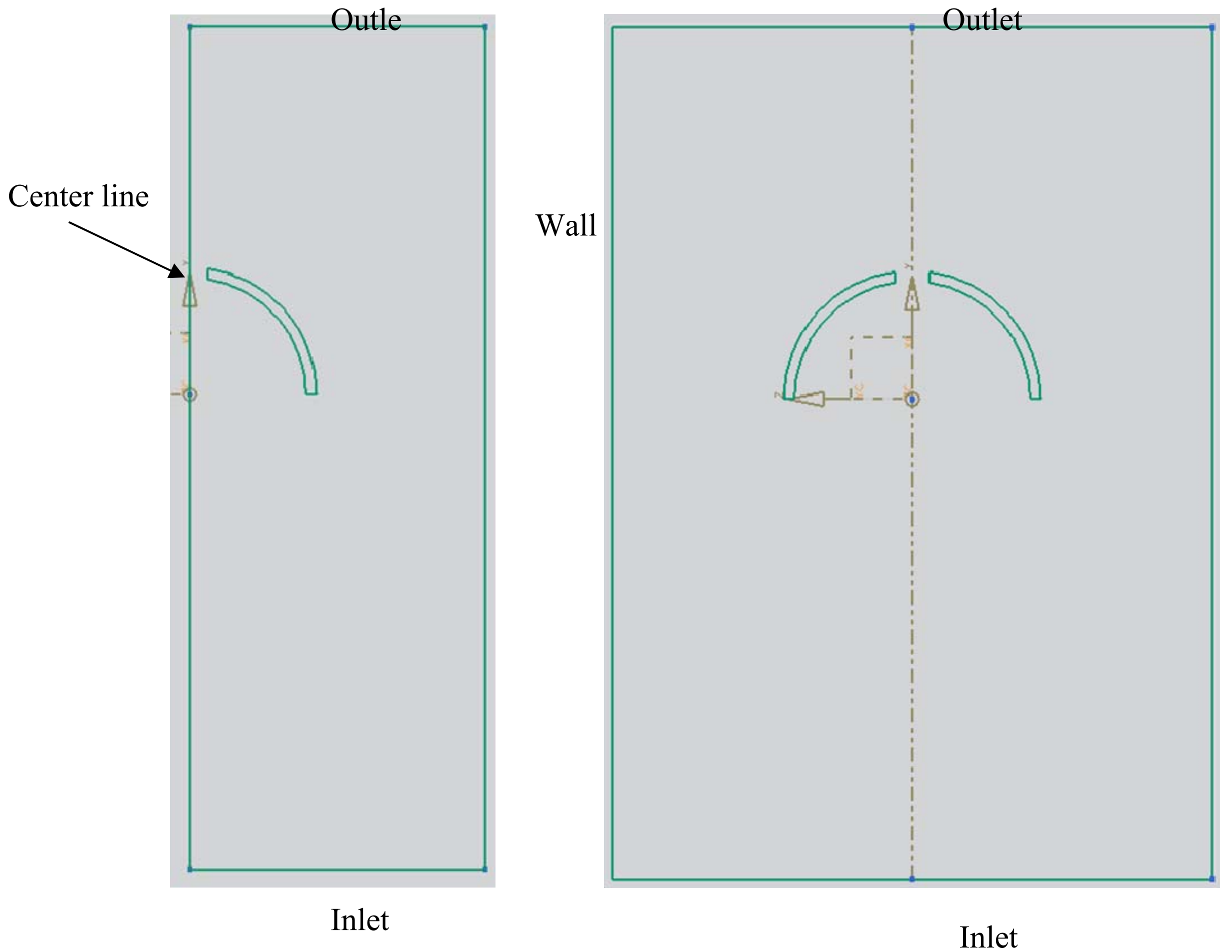

Figure 12 Parachute diagram in GAMBIT, second image illustrates single parachute after reflection.

Initially the problem starts as can be seen in Figure 12 and after reflection the parachute becomes complete. The reflection takes place at the end of the solved problem. Boundaries such as inlet and outlet flows are defined in the pre processor program. In this case it is inlet of air and outlet is defined. Also one line is defined as wall due to it not affecting the problem. No flow coming in or out of the system at that line. The remaining line is defined as a center line. This will let the software know that that will serve as a reflecting line. The parachute is initially started by points. The points are inputted as coordinates and are connected with arc lines. The material thickness is taken in to account ant the coordinate points reflect such a thickness from the material. In this case the material in nylon. Nylon is the parachute material used. After the boundaries are defined and the desired geometry is obtained the

object is meshed. This can be seen in figure 13. The mesh is composed of triangular elements and is meshed in the outer space where the fluid will flow. The suspension lines are added and are constructed with line elements.

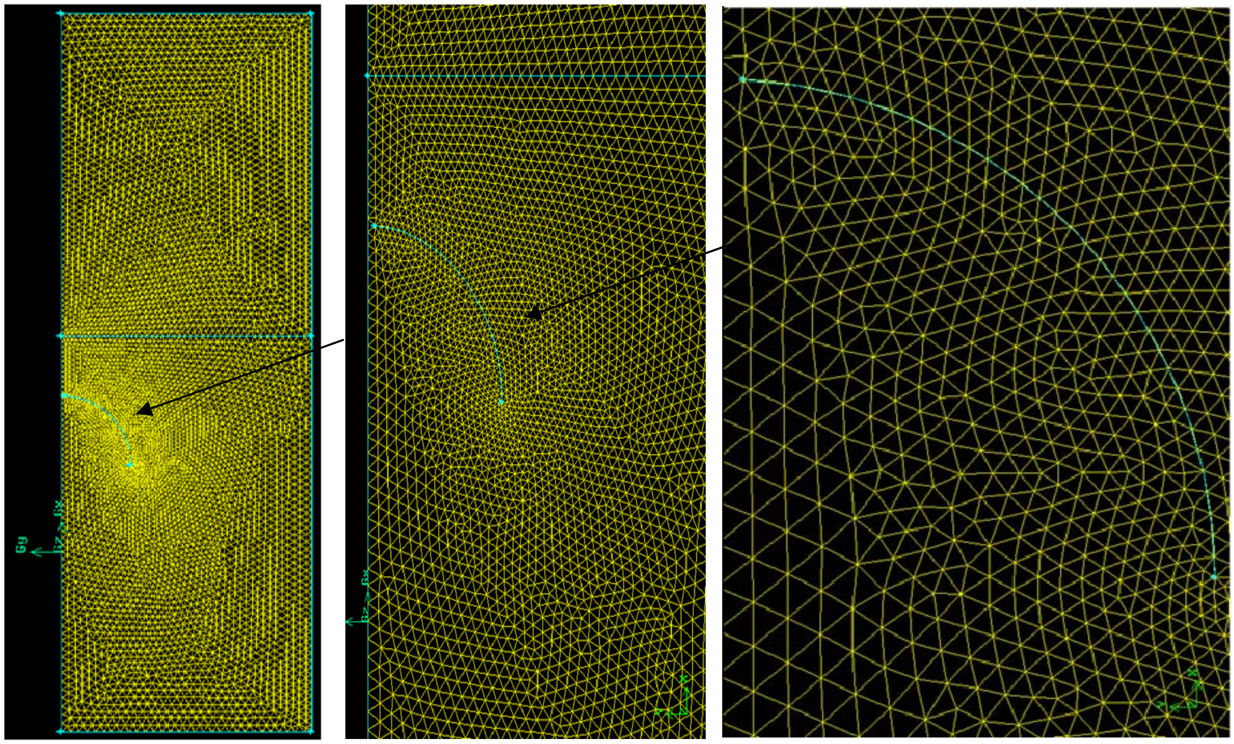

Figure 13 A single half G-12 parachute meshed with triangular nodes.

The mesh in Figure 13 represents a rectangular system of 100 m in length and 50 m in height. Figure 12 represents the original mesh and is zoomed in the parachute are of the mesh. The arc length is 14.78 m. The dimensions for the dual parachutes is the same as the single parachute. In order to eliminate element skewdness the points at the edges of the parachute material were united. This prevents from having non equal elements and distorted the mesh geometry.

5.2 Results

The results of interest are drag coefficient and drag force. The results are plotted in order to observe the behavior of the parachute with respect to time. From the results obtained in Fluent other factors such as drag coefficient can be obtained. The calculations for drag coefficient are done by using

Equation 9. Single values for both drag force and drag coefficient is calculated for each of the 1500 iterations. The result is plotted in an x-y graph. The results exported from the post processer software are in a table format. This is simply plotted in a graph as seen in Figure 14.

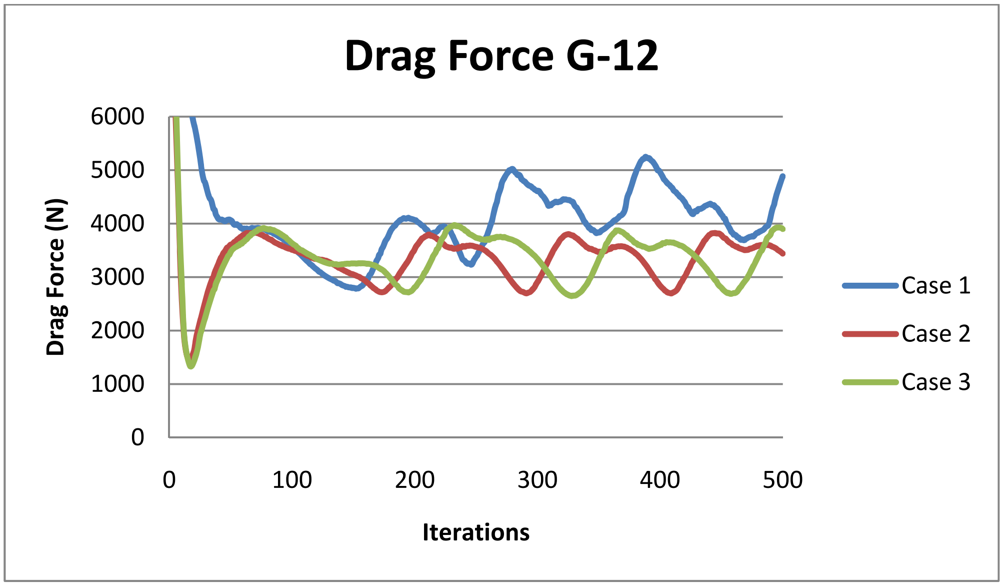

Figure 13- Single G-12 parachute Drag force for 3 mesh cases.

The results indicate that the average force converges to the same value range. The results validate each other. This is due to all the three cases coinciding in similar behavior at each single iteration corresponding to its force value. The graph is defined at 500 iterations. The graph is only focused on the first 500 iterations due to the results being repetitive in the remaining iterations. The same graph is plotted for average force. This can be seen in Figure 15.

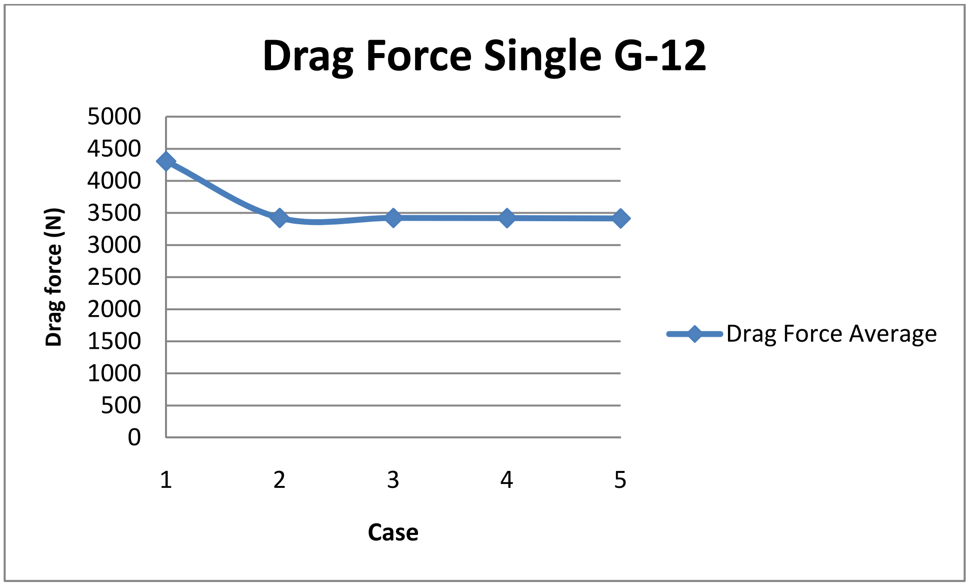

Figure 14 The plot for each case and its average Force value.

The results shown in Figure 15 indicate that there is a mesh independence. Mesh independence is what we want to obtain in order to do so additional case was done. The fourth case is within the constant value of 3,500 N. The drag force approaches 3,500 N. This is said to be a confident final constant value. Also obtained are drag coefficient it is also plotted in the same way as in Figure 14. The data is used from Figure 14 to calculate the drag coefficient. The calculations are done by using Equation 9 and results are shown in Figure 16.

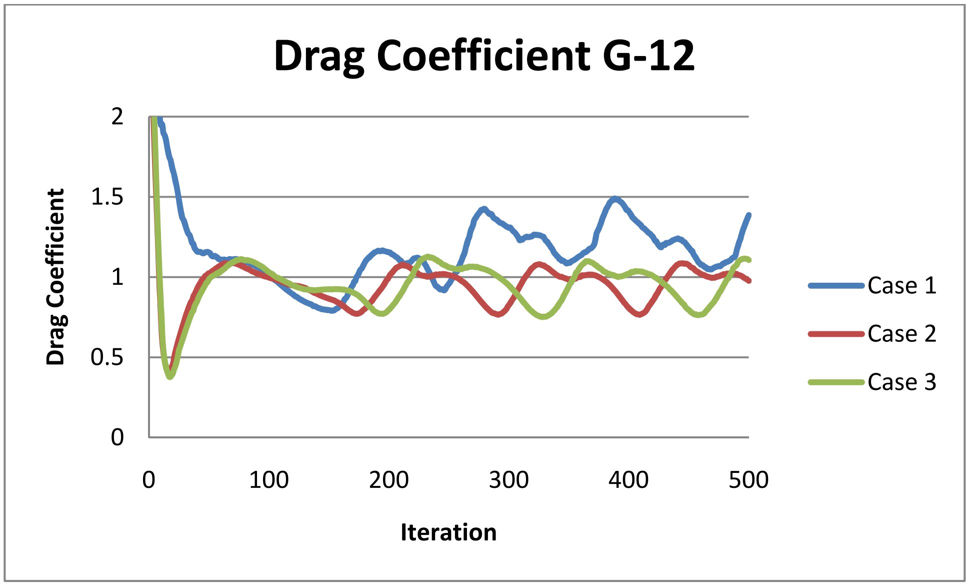

Figure 15 Drag force coefficient for 3 different mesh cases.

Results again converge to a single constant value. The data is said to be confident. The data after 500 repetitive. The results for all three cases are within range and are correct based on previous research from other universities and labs. (Parachute Decent Calculations) The average drag coefficient value is also plotted similar to Figure 14. This can be seen in figure 17, also mesh independence is desired. In this case you can see the average value for the drag coefficient.

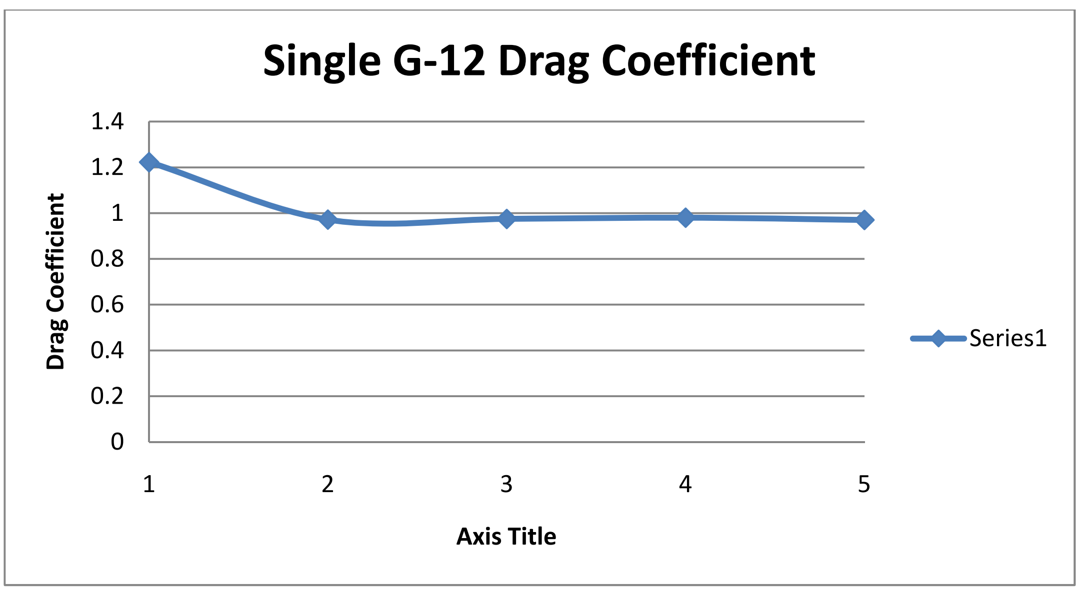

Figure 16 The results for 3 cases with corresponding average drag coefficient values.

5.3 Dual Parachute

In the following problem a dual parachute analysis is simulated. The angle is changed in order to determine the drag coefficient change. This is of interest due to drag coefficient being directly related to the maximum capable weight for the parachute. Cargo parachutes such as the G-12 are used for cargo and more than one parachute is required when a load greater than 2200 lbs. Two parachutes are used for load of up to a maximum load of 3500 lbs. There will be different angle separation and will be labeled as separate cases. The cases will be done at variable angle separation and the effect on angle separation will be analyzed. Also there are separate cases run with different meshes. Number of elements will range from a base starting mesh to a denser mesh with more elements and nodes for each parachute. This is to get better results and to check previous results.

5.4 Parachute Results Ten Degree

The distance from the parachutes are 10 degrees the drag force is expected to be greatest. This would be set for the grates loads or the slowest descending rate. Results analyzed will be drag force. Drag force is the force the parachute exerts on the payload. This is what is opposing the cargo weight and is resisting it from directly free falling. It is important to analyze a cluster of parachutes because it allows for more payload weight. A cluster is composed of 2 parachutes to 3 parachutes and the performance is affected. The problems solved consist of two parachute cluster. In the future a 3D case of 2 parachutes will be solved. The problem is constructed and solved in the same manner as the single parachute.

The problem is designed and set up in the in GAMBIT and solved in Fluent. The problem is constructed and solved in the same manner as the single parachute. The problem is set up and partialy designed in Gambit. Points are plotted in order to create the parachute arcs. Material thickness for the parachute is taken in to account and are reflected in the position of the points. The thickness is taken from nylon due to this being the material used for the parachutes. The problem is set up and designed and is seen in Figure 18.

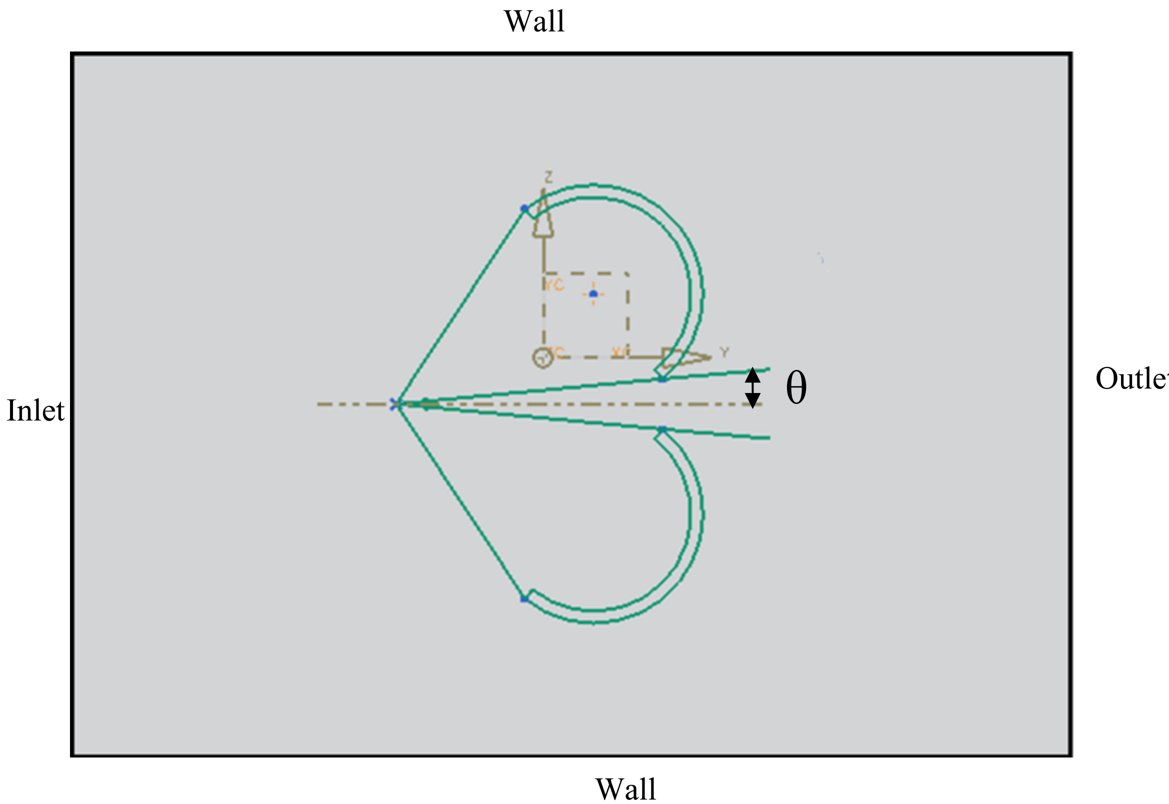

Figure 17 Dual G-12 Parachute in Gambit with a 10 Degree angle.

The drag force is what Fluent will provide from its direct results. For each time step a drag force is assigned. The drag force is expected to be erratic and eventually stabilize in to a final range of value. The results are to be plotted to evaluate the Drag parachute values with the corresponding time steps. The drag force for a ten degree separation parachute is plotted in Figure 19. There are 3 different solutions they vary in the number of elements in the mesh. The assigned values are in Table 8.

Table 8- Number of elements for each case for the 10 degree parachute separation

10 Degree for θ	Elements
1 Case	18598
2 Case	23524
3 Case	29158

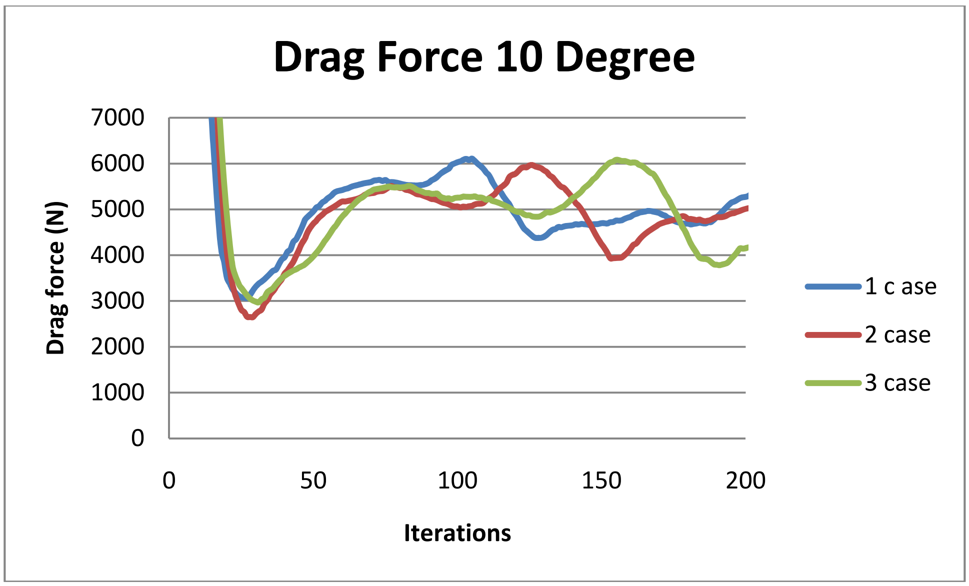

Figure 19 Drag force for ten degree separation parachute.

The results vary from a maximum of 6 kN to a minimum of 3 kN. The drag force converges to 5 kN. This is done after 50 iterations. The value of drag force after is oscillating at or within 5 kN with a plus or minus .5 kN. The results are expected to be steady and no more additional iterations are required due to having a stable steady result.

Each case follows the same path in Figure 19 therefore the results are dependable. The force is directly plotted from the values obtained in Fluent. Also of interest is the drag coefficient. This is obtained by using equation 9. Terminal velocity is set to 9.8 m/s this is due to final velocity of decent. The weight is the force value at each given point in time. The results are plotted in Figure 20.

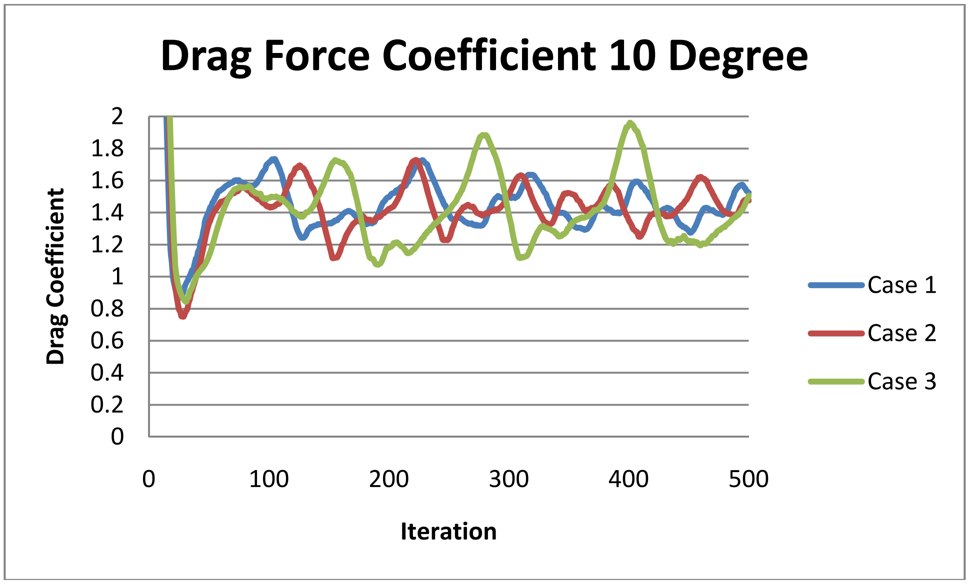

Figure 20 Drag force comparison with for 3 cases.

The solution in Figure 22 for the drag coefficient average resulted to be 1.45 for case 1, 1.46 in case 2 and 1.5 in case 3. The data points are obtained from Fluent and the points are then plotted in Microsoft excel. In addition also average for each case is plotted in order to analyze the effect of mesh density on the average drag coefficient. The plot is shown in Figure 21.

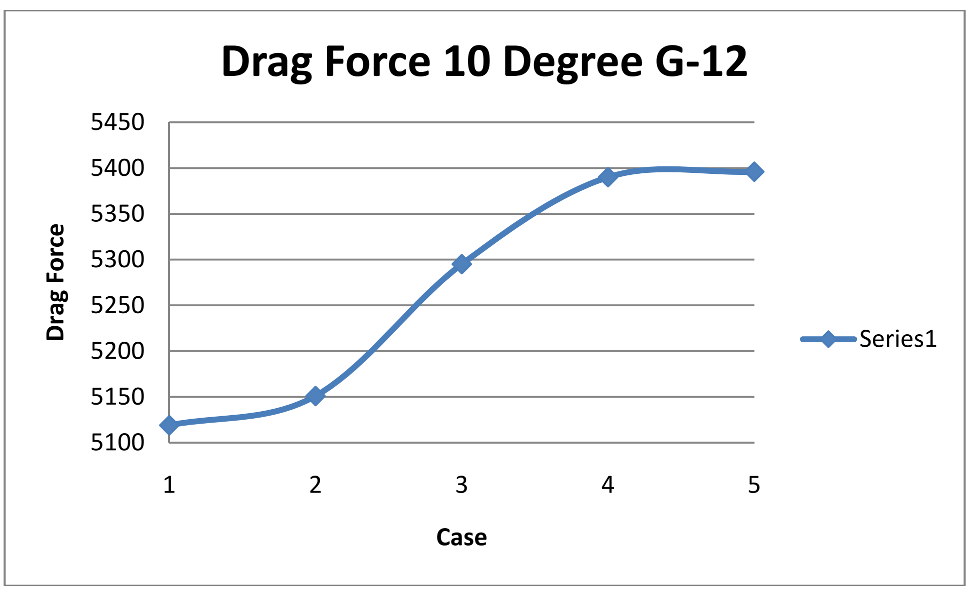

Figure 1821Average force for a G-12 parachute 10 degree angle.

The curve is starting to converge showing that there is mesh independence. This indicates that the force is in the same range and increases slightly to 5160 N. The results are said to be mesh independent due to the value of force not being affected regardless of the density of mesh. No matter how many elements there are the force approaches a constant value. Also in the same way the drag force coefficient can be compared to all the denser mesh cases. This is shown in Figure 22.

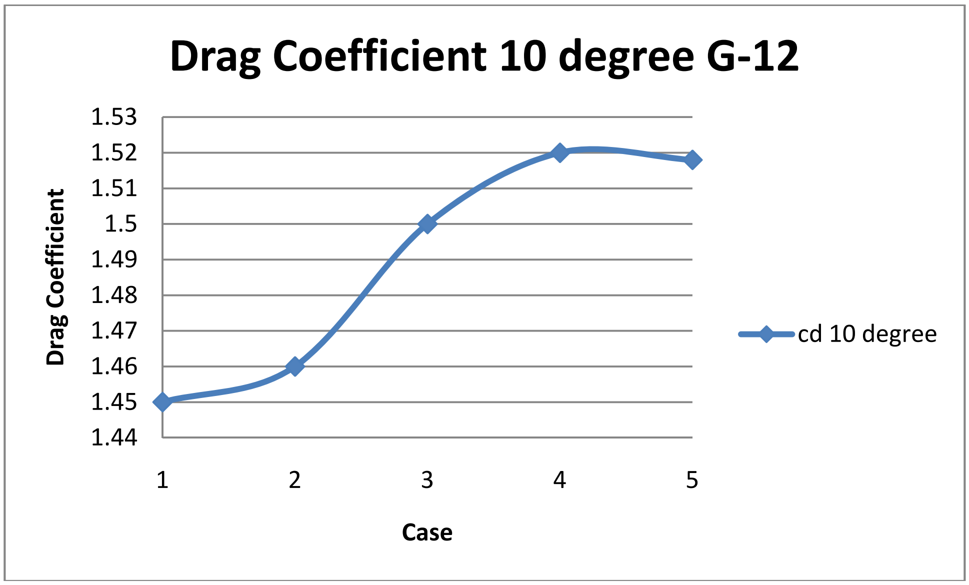

Figure 22 Drag coefficient incrementing to obtain mesh independence.

The results indicate that the mesh independence can be obtained and is in the following denser mesh solutions. At that point the ideal drag force is obtained. The same will be done for a 20 degree and 30 degree angle parachutes. This will determine the effect of increasing the number of elements has on drag coefficient drag force. By increasing the number of elements mesh independence is expected to be obtained.

5.5 Results Comparison

In order to understand the effect of increasing the angle of separation a comparison of the results is presented. Areas of interest are drag force, drag coefficient, pressure and velocity results.

The data will be presented in similar to the single parachute figure graphs. The same is done at 20 and 30 degree of separation. The effect of changing the angle of the parachute will be analyzed based on the results. This analysis is extremely useful due to better understand the how much the angle of separation has on the performance on the parachute. There are three cases for each angle of separation. Each case is identified by the following number of elements in Table 9 and Table 10.

Table 9- Case identification for 20 degree double G-12 parachute.

20 Degree	Elements
Case 1	18760
Case 2	23882
Case 3	29558

Table- 10- Case identification for 30 degree double G-12 parachute.

30 Degree	Elements
Case 1	19062
Case 2	24082
Case 3	29894

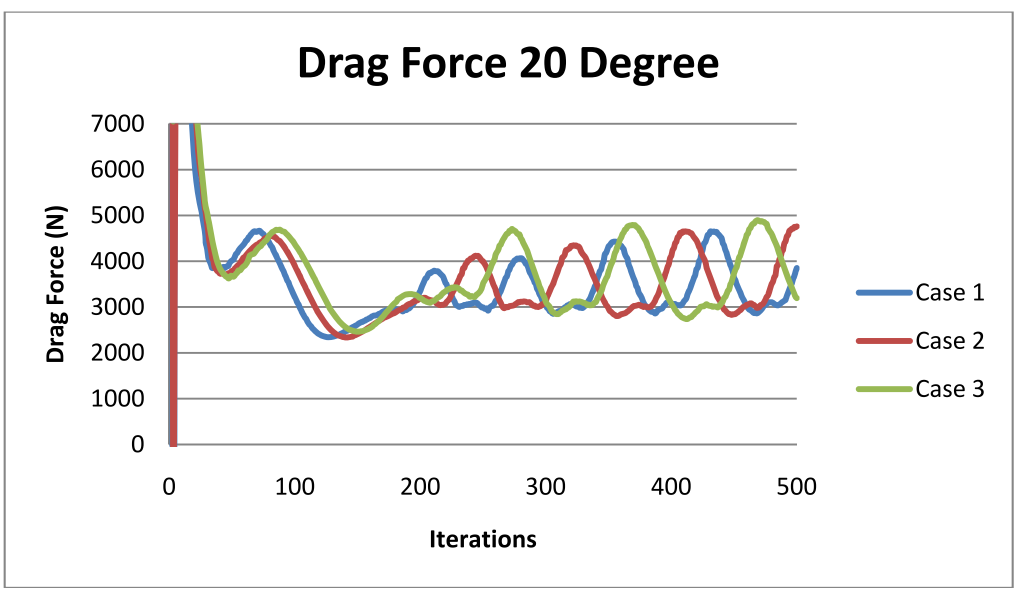

Figure 23 Drag force for dual G-12 parachute with 20 degree of separation.

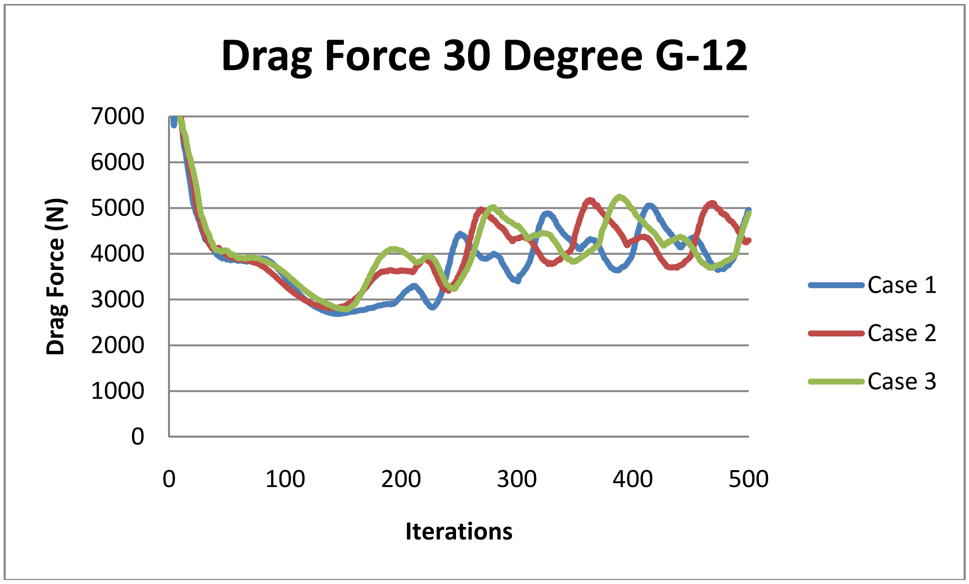

Figure 24 Drag force with 30 Degree of separation for two G-12 cargo parachutes.

The results in both Figure 20 and Figure 21 show the resulting force is in the same range. Both cases were solved for 3 separate times. Each case represents a number of different elements. Each case is identified in Table 11 and Table 12. The average drag coefficient and average drag force is plotted and Figure 25 and Figure 26.

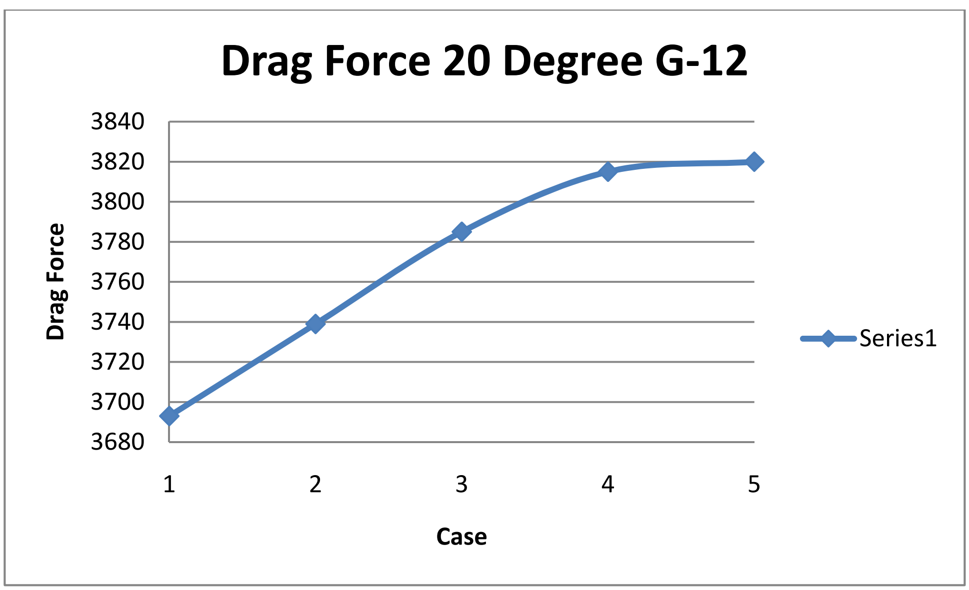

Figure 25 Drag force average for each case with a 20 degree angle separation for a two G-12 parachutes.

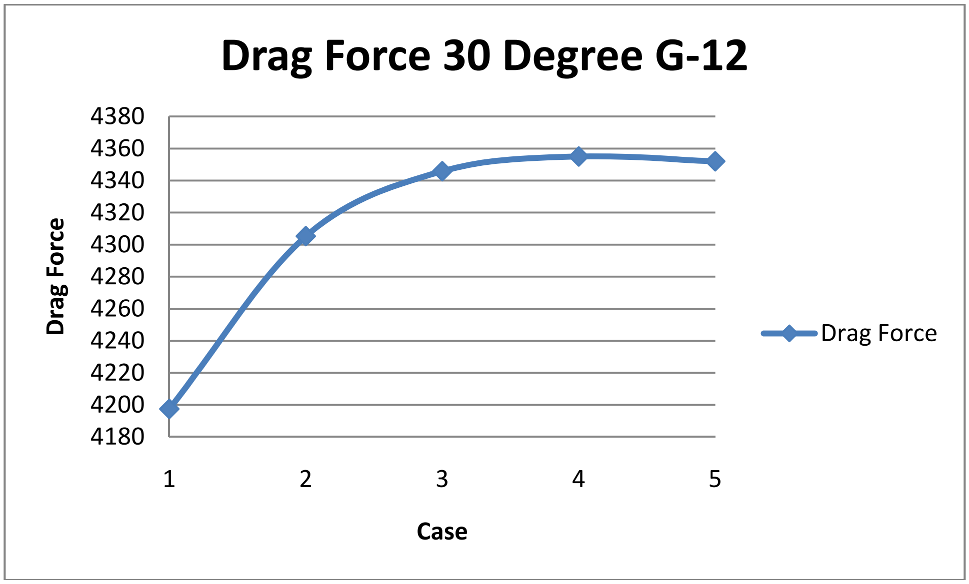

Figure 26 Drag force average for each case with a 30 degree angle separation for a two G-12 parachutes.

The conclusion is that mesh independence is obtained. This is the desired outcome. This indicates that the final drag force value is approaching 4360 N in a 30 degree angle separation. This is due to the graph reaching a constant value rather than continuing to change. No matter what the mesh size is based on the graph behavior it is concluded that a final constant value is obtained. The same is done with drag coefficient. This is calculated using Equation 9. From information obtained from Figure 27 and Figure 28. Drag coefficients range is from 0.7 to 1.5 this is the desired range. (Parachute Decent Calculations)

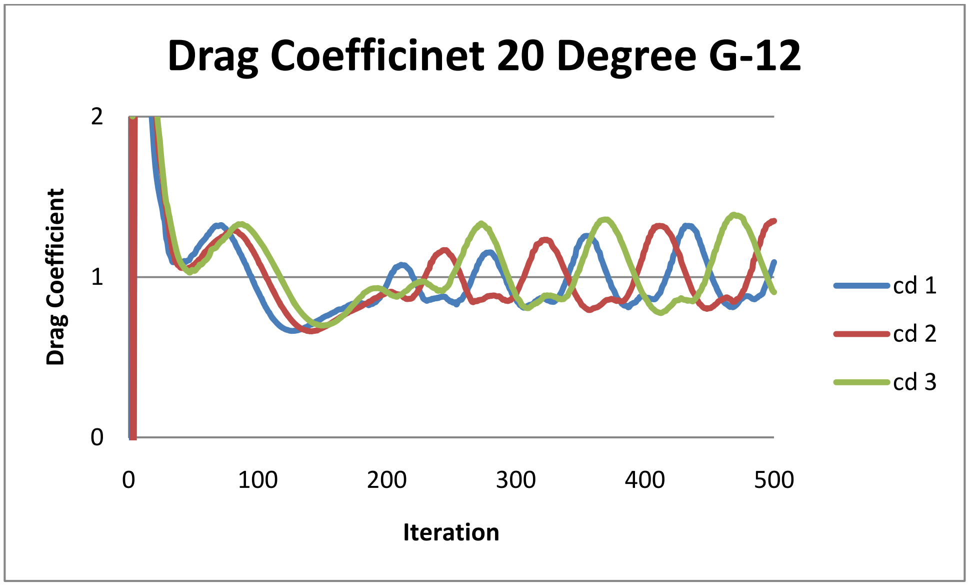

Figure 27 Drag coefficient for dual G-12 cargo parachutes with a 20 degree angle separation.

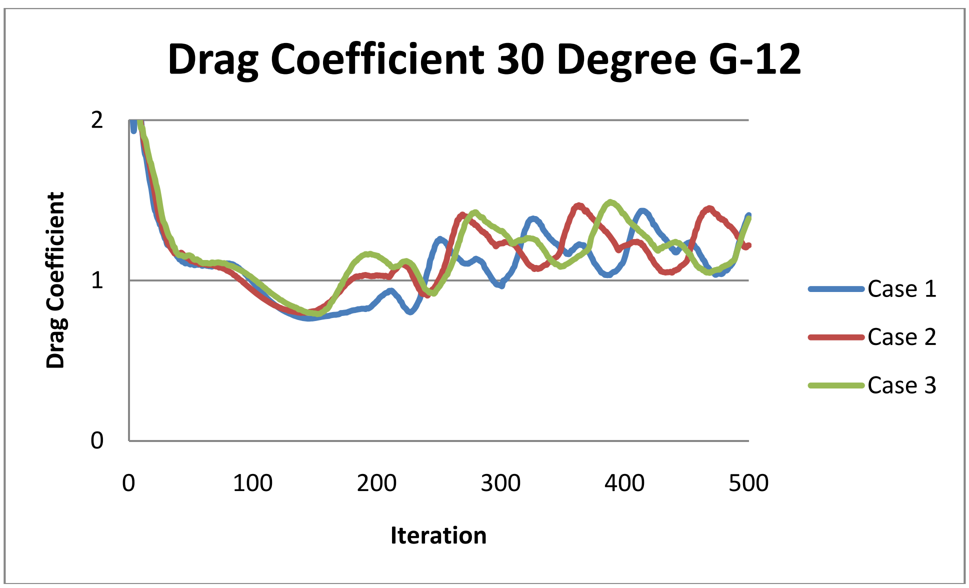

Figure 28 Drag coefficient for dual G-12 cargo parachutes with a 30 degree angle separation.

The results indicate that both drag coefficients are in the same range for each of the given cases. Both Figure 29 and Figure 30 have a Drag coefficient within the valid range. The average drag coefficients for each case can be seen in figures 29 and Figures 30.

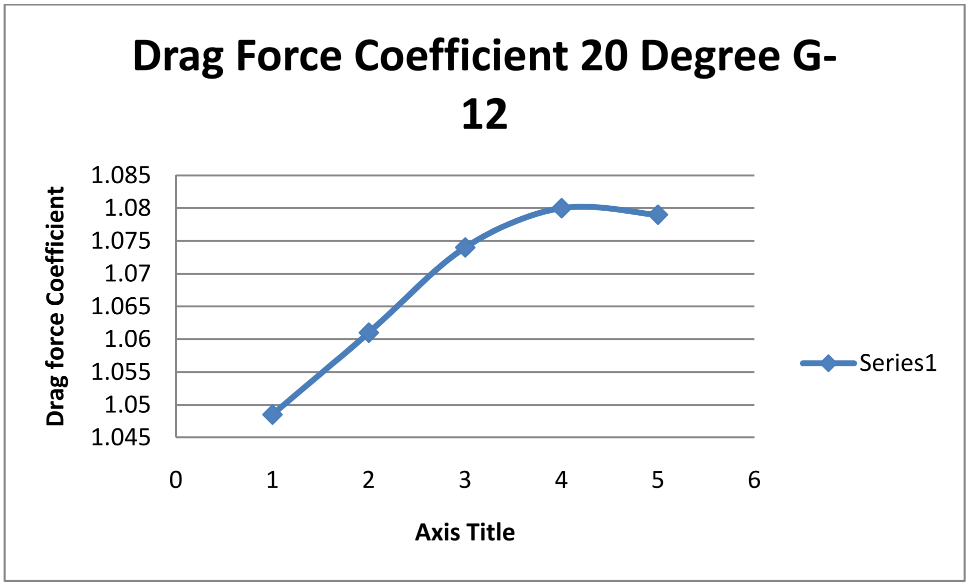

Figure 29 Average Drag coefficients for each case at a 20 degree angle of separation for 2 parachutes.

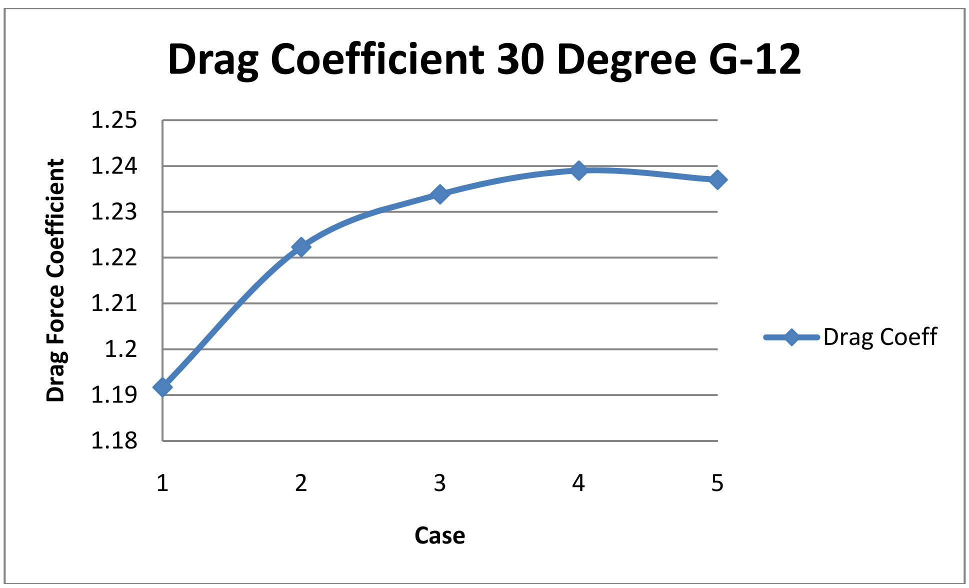

Figure 30-19 Average drag coefficient for each case at a 30 degree angle of separation for 2 parachutes.

The results show mesh independence similar to the previous 10 degree angle and single parachute results. Additional two cases were done in order to revalidate the results. The additional solutions contribute to the mesh independent conclusion.

5.6 Pressure and Velocity Comparison

Also of interest are pressure and velocity results. The velocity is of great interest due to it having a major effect in the performance of the parachute. Factors affected are stability of parachute and control of the direction while in descent. Pressure concentration is also important. This is due to the fact that the pressure has to be below the maximum limit. If the maximum pressure is exceeded catastrophic failure would be the end result. The pressure results for each angle of separation are presented and can be seen in the following figures.

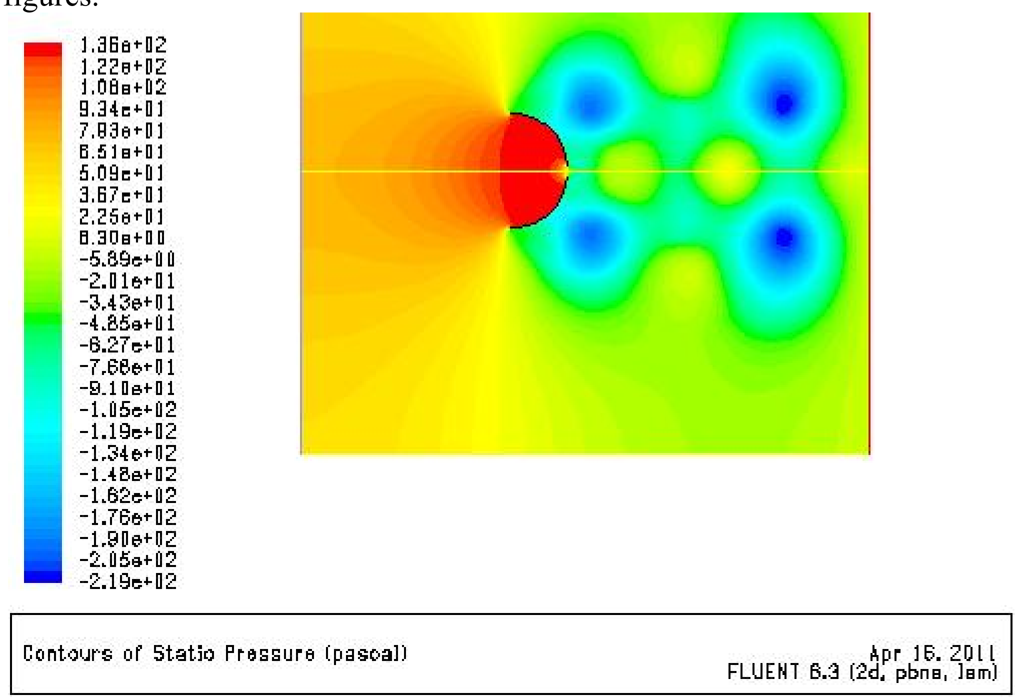

Figure 31 Single G-12 parachutes Pressure results obtained from Fluent software.

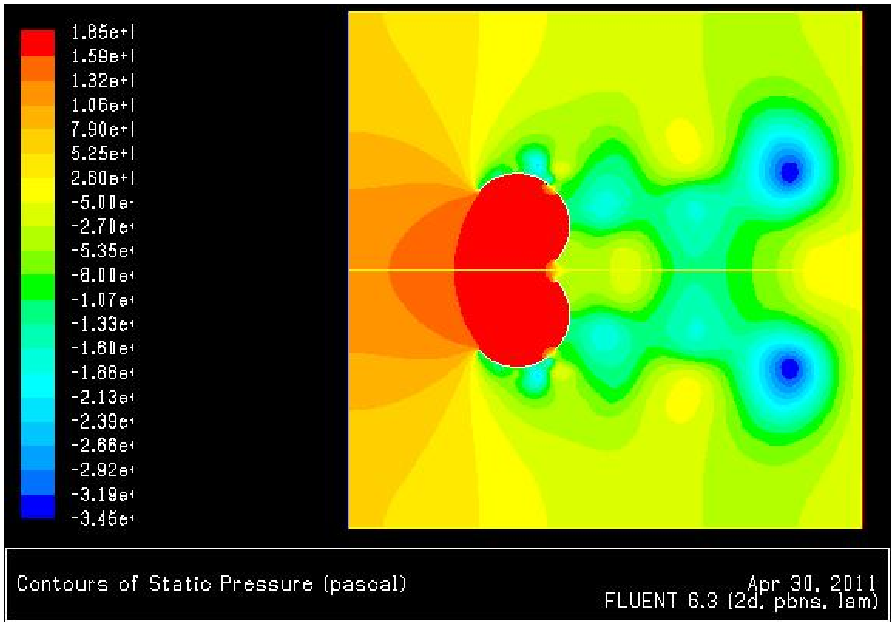

Figure 32 Dual G-12 parachute pressure results obtained from Fluent at a 10 degree angle separation.

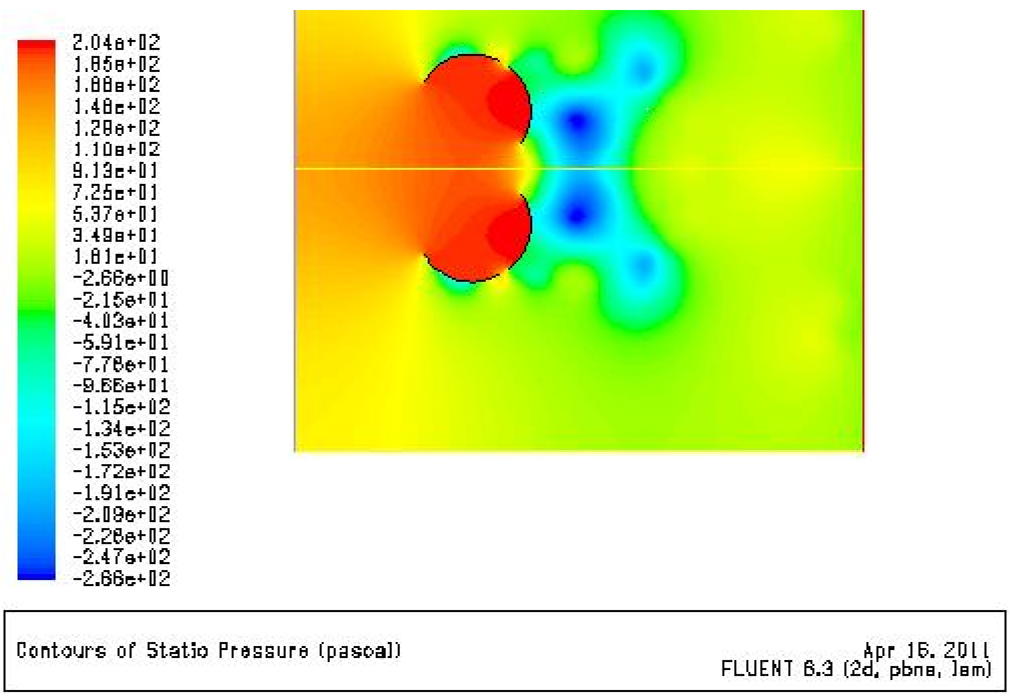

Figure 33 Dual G-12 parachute pressure results obtained from Fluent at a 20 degree angle separation.

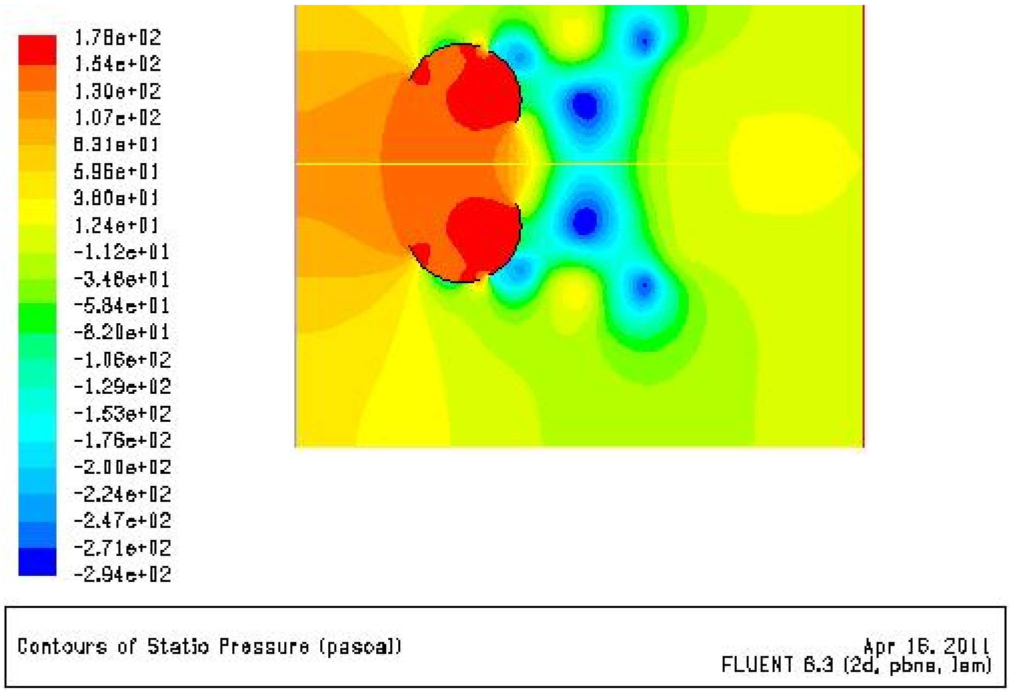

Figure 34 Dual G-12 parachute pressure results obtained from Fluent at a 30 degree angle separation.

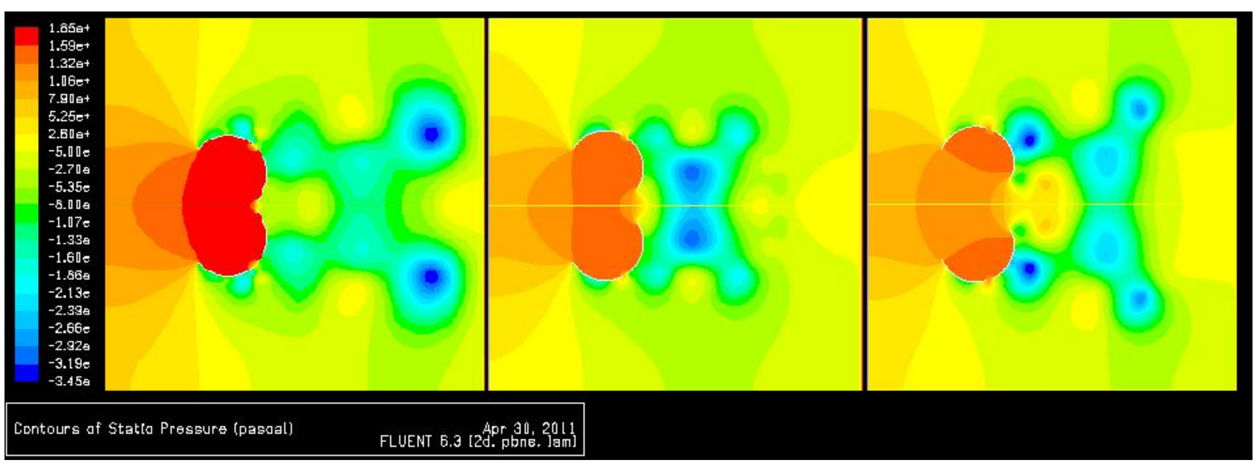

Figure 35 Pressure for 2 G-12 parachute comparison with increasing angle in separation.

The Results indicate that that pressure is maximum at the inner parachute and is minimum at outside behind the parachute for all cases. Same is done with velocity. The following figures will show how velocity changes with increasing angle.

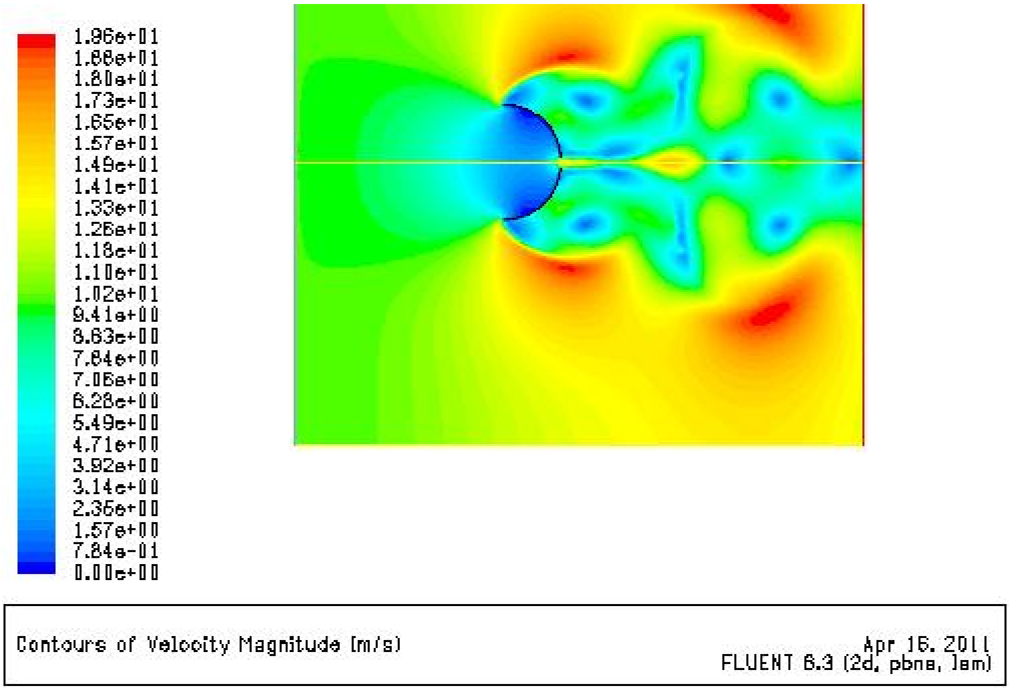

Figure 36 Single Velocity results for a G-12 cargo parachute.

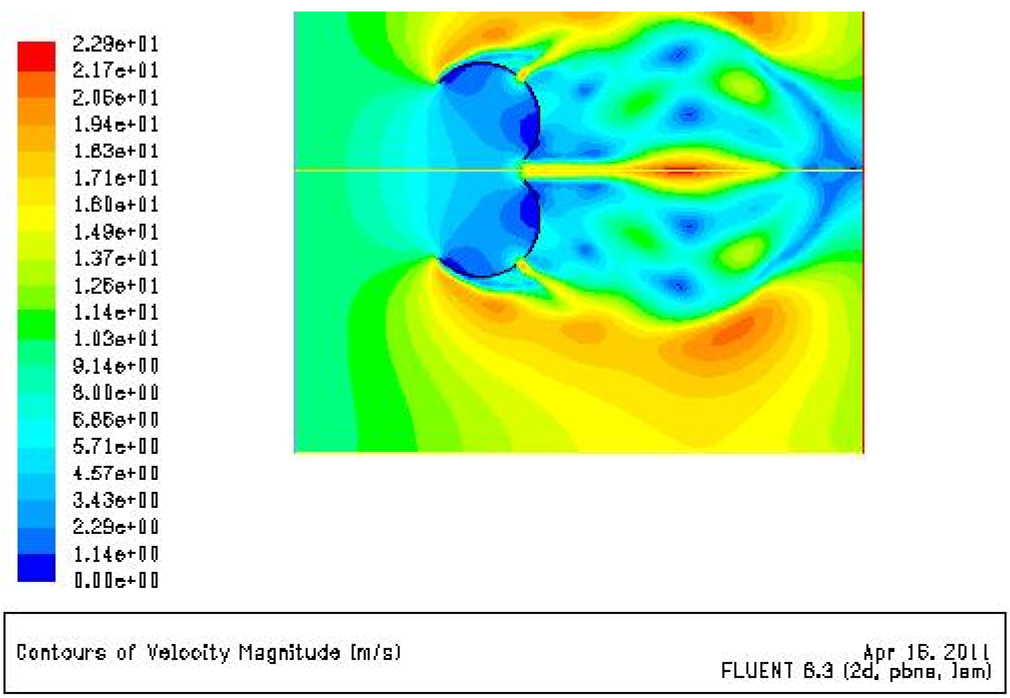

Figure 37 Dual G-12 parachute velocity results obtained from Fluent with 10 degree of angle separation.

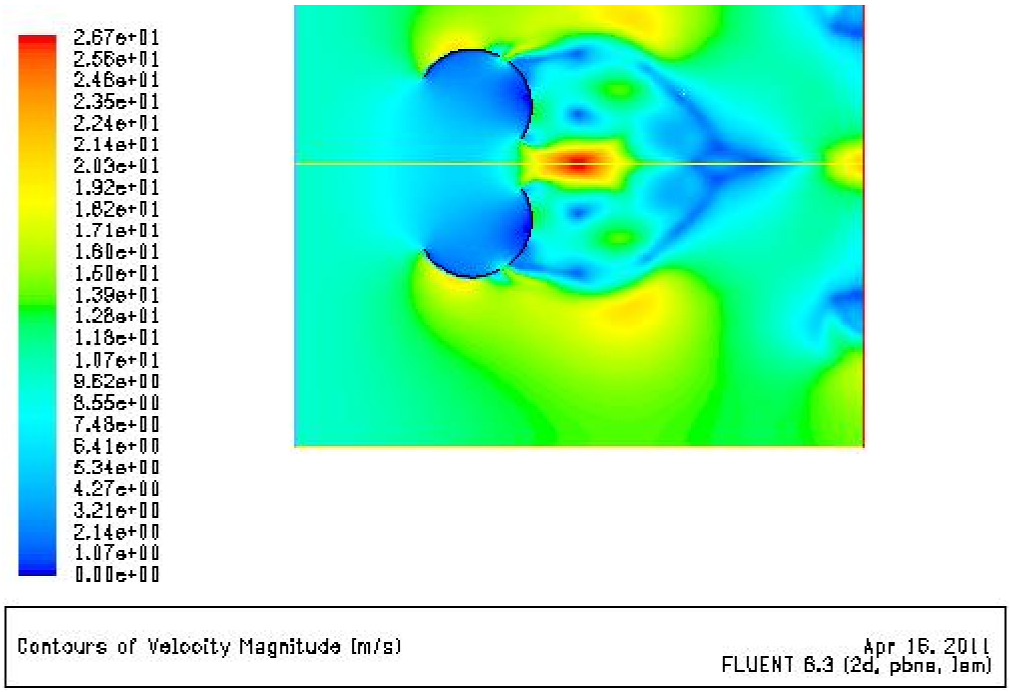

Figure 38 Dual G-12 parachute velocity results obtained from Fluent with 20 degrees of angle. .

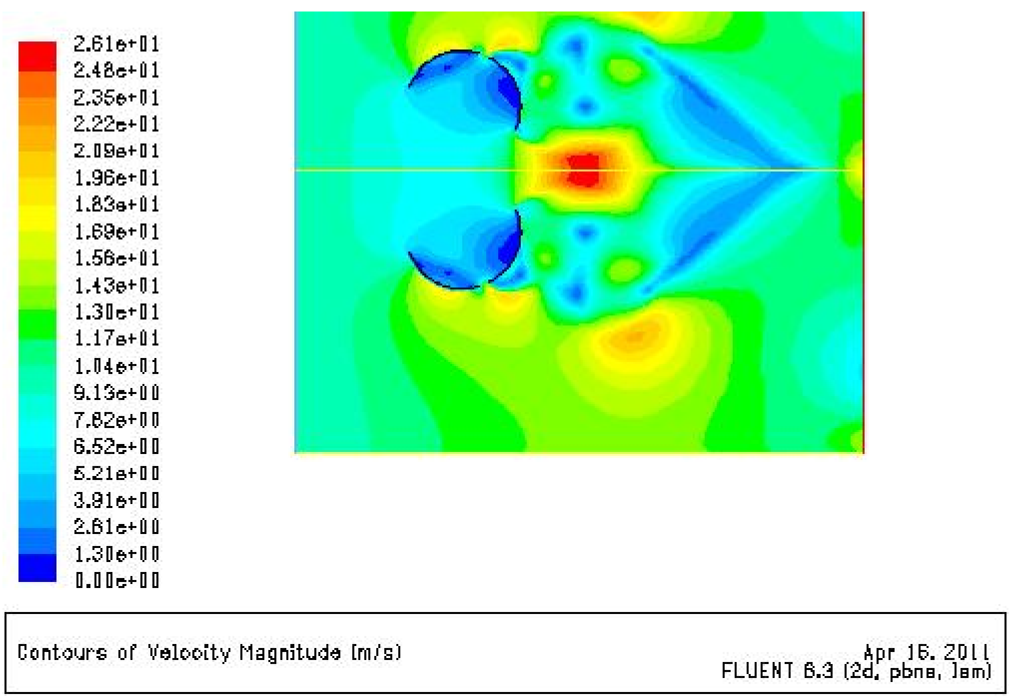

Figure 39 Dual G-12 parachute velocity results obtained from Fluent with 30 degrees of angle.

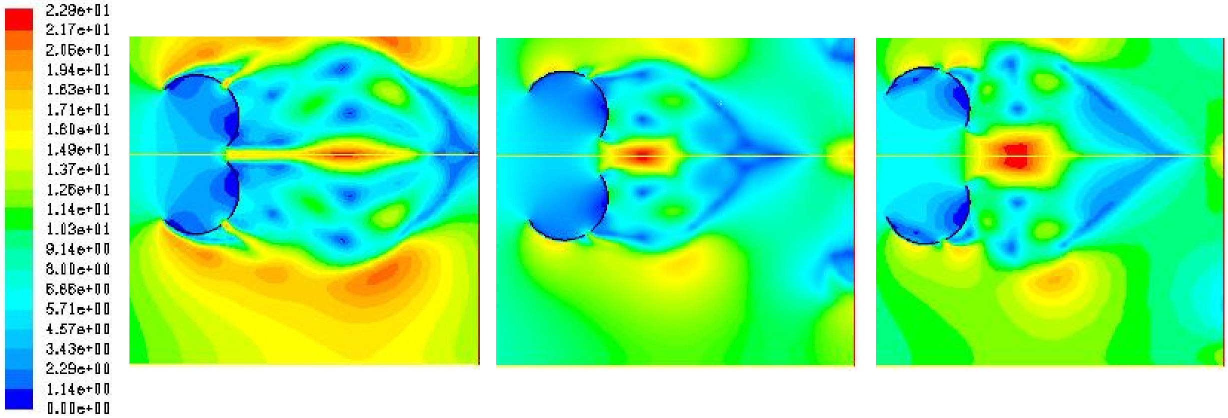

Figure 40 Velocity for 2 G-12 parachute comparison with increasing angle in separation.

The velocity results indicate the maximum values at the center. This is due to the reduced diameter apex relief. This serves to reduce the pressure inside the parachute and the sudden lift force when the parachute is deployed.

Chapter 6.0

Conclusion

Although the research has been very extensive due to the complexity of the problem there is more to be done. From Leonardo Da Vinci who designed the first parachute in 1485 to this date much advancement have been made parachutes. Those advancement include the development of various types of parachutes. Each parachute has a specific task as is the case of the parachute analyzed in this case which is the G-12 parachute. The main focus in this research is to analyze the effect of increasing the angle of separation of a two G-12 cargo parachutes. A comparison of results were done to conclude on the effect of changing angle. The Parachute simulation is very complicated and the results presented are only in the drag force area. The results indicate that the drag force decrease in the increase in angle. This is due to the less perpendicular area. Force is greatest at 5 kN when angle is ten degrees. Force decreases at each angle until angle is at 30 degrees. The pressure is greatest at when angle is ten degrees. The max pressure is found to be 205 Pa. The velocity is also shown in the picture images and are useful as well. The images capture the value of the velocity at each pint as the problem is being solved.

Velocity behavior is unpredicted and chaotic. This is due to the shape of the parachute. It drastically affects the flow of the air and causes turbulence from the parachute opening. The values at the walls are set to zero due to the no slip condition. The air velocity is maximum at the apex and this is due to the reduced diameter. Air flows at greater speed at the outer edges of the parachute. This is due to the resistance the parachute to let air flow through it. Velocity is zero at the parachute wall this is due to the no slip condition. The behavior of the velocity can be seen in Figure 40 the maximum is at 30 m/s. One of the many factors that effect is the turbulence and this occurs at the rear of the parachute. The reason is because of the low pressure. Due to the chaotic velocity behavior it directly affects the overall performance of the parachute. In order to increase the stability of the parachute this turbulence behavior

needs to be reduced because it is nearly impossible to completely eliminate. Pressure behaves in the same manner as velocity.

Pressure is maximum at the inner of the parachute just as it is shown in Figure 35. This is what causes the parachute to glide down at a steady rate. If this pressure is in excess of the limit of the material limits it can fail. The apex serves as a pressure relief. This reduces the sudden force exerted when the parachute opens reducing the possible payload damage. In the case of personal parachutes the apex is necessary and prevents the user of the parachute to suffer permanent injuries. Pressure is decreases in the same way as velocity decreases behind the parachute. This also has a major effect in stability and control. The maximum pressure is found to be 204 kPa at a 20 degree separation. Simulation permits us to know how pressure behaves and where the pressure is concentrated. This permits us to do changes and view the outcome of such modifications. Future problem plans are to model the same problem in a 3 dimensional state. This will have better overall results due to the simulation being closer to real life scenario. The end simulation is results in the true overall parachute compared to a 2 dimensional problem.

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Curriculum Vita

Jesus Lucio Valles was born in Santa Maria, California. The first son of Maria Teresa Valles Castillo and Gabriel Valles, he graduated from Clint High School, Clint, Texas, in spring of 2002. He received a scholarship upon graduation from high school to attended Western Technical College in fall of 2002 majoring in Combination Welding, graduated in fall of 2003. Worked building houses while attending college and started a welding job upon graduation building and customizing street rod vehicles. Started El Paso Community College (EPCC) in Fall 2003 received a Associates of Arts in 2007 while working as math Tutor at Mission Del Paso Campus at EPCC. Started Working for Dr. Kumar in the Computation Lab in 2008 after taking Advanced Fluid class as a Jr. in Mechanical Engineering at University of Texas at el Paso (UTEP) Presented numerous research results at carious conferences in and out of town. Graduated with Bachelors of Science in Mechanical Engineering in fall of 2009 while working as a Research assistance under the guidance of Dr. Kumar. Area of research was Computation fluid interaction with parachute dynamics for G-12 parachutes used by the army as cargo parachutes. Started Masters program in Mechanical Engineering in Spring 2010 and continued to work on parachute research project under the guidance of Dr. Kumar. Graduated in spring 2011with BS in Mechanical engineering.

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