Determination of Minimum Descent Distance for Power Landing of Reentry Vehicle in The Mars Atmosphere

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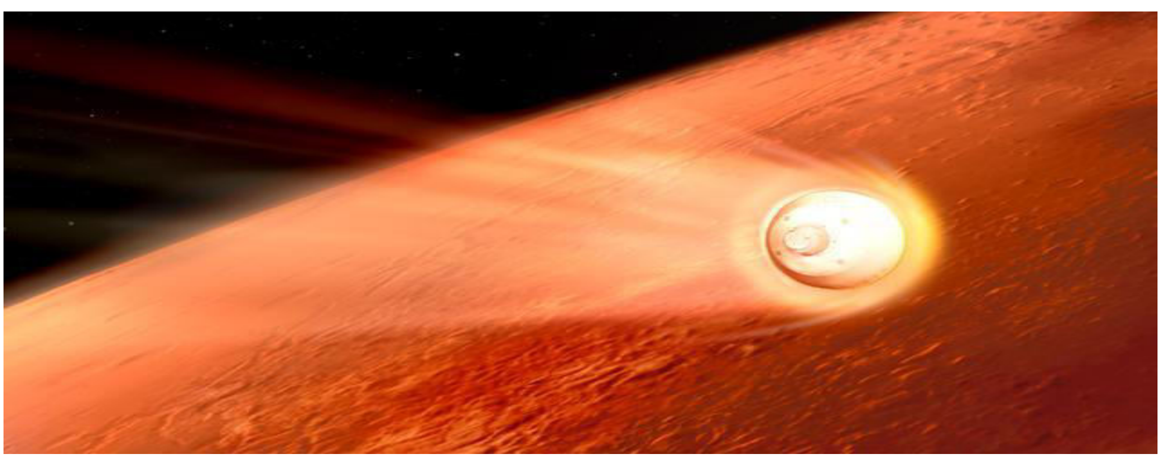


Abstract

Next-generation powered landing guidance for planetary soft landing needs multi-pointguidance capabilities. determination of minimum descent distance for power landing of reentry vehicle in the mars atmosphere presented in this study. First, the design of spacecraft by (the using of cad software- catia V5)optimization problem with threedimensional dynamics model,then the analysis of force with boundary conditions, and path constraints is formulated by the using of CAEsoftware - ANSYS.

Then, the minimum descent distance for landing on mars to the best landing aim point can be efficiently obtained based on the good initial value guess provided by the sensitivity analysis. Numerical results show that the proposed algorithm effectively and efficiently addresses the mars planet powered landing problem toachive minimum descent distance.

Keywords— Spacecraft, computational fluid dynamics method-ANSYS, Boundary condition ,Minimum descent distance for landing, power landing.

INTRODUCTION

The intense entry, descent, and landing (EDL) phase begins when the spacecraft reaches the top of the Martian atmosphere, traveling at about 12,100 mph (19,500 kmph). EDL ends about seven minutes later, with the rover stationary on the Martian surface. Many engineers refer to the time it takes to land on Mars as the "seven minutes of terror." Not only is the choreography of EDL complex, but the time delay involved in communicating with Earth means that the spacecraft has to accomplish this choreography all by itself. While all landings on Mars are difficult, Perseverance is landing in the most challenging terrain ever targeted.

Parameters of mars

	Mars	Earth	Ratio (Mars/Earth)
Mass (10^{24} kg)	0.64171	5.9724	0.107
Volume (10^{10} km^3)	16.318	108.321	0.151
Equatorial radius (km)	3396.2	6378.1	0.532
Polar radius (km)	3376.2	6356.8	0.531
Volumetric mean radius (km)	3389.5	6371.0	0.532
Core radius (km)	1700	3485	0.488
Ellipticity (Flattening)	0.00589	0.00335	1.76
Mean density (kg/m^3)	3933	5514	0.713
Surface gravity (m/s^2)	3.71	9.80	0.379
Surface acceleration (m/s^2)	3.69	9.78	0.377
Escape velocity (km/s)	5.03	11.19	0.450
GM (x 10^6 km^3/s^2)	0.042828	0.39860	0.107
Bond albedo	0.250	0.306	0.817
Geometric albedo	0.170	0.434	0.392
V-band magnitude V(1,0)	-1.60	-3.99	-
Solar irradiance (W/m^2)	586.2	1361.0	0.431
Black-body temperature (K)	209.8	254.0	0.826
Topographic range (km)	30	20	1.500
Moment of inertia (I/MR^2)	0.366	0.3308	1.106

J_2 (x 10^{-6})	1960.45	1082.63	1.811
Number of natural satellites	2	1	
Planetary ring system	No	No	

Martian Atmosphere

Surface pressure: 6.36 mili bar at mean radius (variable from 4.0 to 8.7 mili bar depending on season)
[6.9mili bar to 9 mili bar (Viking 1 Lander site)]

Surface density: ~0.020 kg/m^3

Scale height: 11.1 km

Total mass of atmosphere: ~2.5 x 10^{16} kg

Average temperature: ~210 K (-63 C)

Diurnal temperature range: 184 K to 242 K (-89 to -31 C) (Viking 1 Lander site)

Wind speeds: 2-7 m/s (summer), 5-10 m/s (fall), 17-30 m/s (dust storm) (Viking Lander sites)
Mean molecular weight: 43.34

Atmospheric composition (by volume):
Major : Carbon Dioxide (CO_2) - 95.1% ; Nitrogen (N_2) - 2.59%
Argon (Ar) - 1.94%; Oxygen (O_2) - 0.16%; Carbon Monoxide (CO) - 0.06%
Minor (ppm): Water (H_2O) - 210; Nitrogen Oxide (NO) - 100; Neon (Ne) - 2.5;
Hydrogen-Deuterium-Oxygen (HDO) - 0.85; Krypton (Kr) - 0.3;
Xenon (Xe) - 0.08

Entry, Descent, and Landing – often referred to as "EDL" – is the shortest and most intense phase of the Mars mission. It begins when the spacecraft reaches the top of the Martian atmosphere, travelling nearly 12,500 miles per hour (20,000 kilometers per hour). It ends about seven minutes later, with Perseverance stationary on the Martian surface. To safely go from those speeds down to zero, in that short amount of time, while hitting a narrow target on the surface, requires “slamming on the brakes” in a very careful, creative andchallenging way. Entry, Descent, and Landing – often referred to as "EDL" – is the shortest and most intense phase of the Mars mission.

Landing on Mars is hard. Only about 40 percent of the missions ever sent to Mars – by any space agency - have been successful. Hundreds of things have to go just right during this nail-biting drop. What's more, Perseverance has to handle everything by itself. During the landing, it takes more than 11 minutes to get a radio signal back from Mars, so by the time the mission team hears that the spacecraft has entered the atmosphere, in reality, the rover is already on the ground. So, Perseverance is designed to complete the entire EDL process by itself – autonomously

Powered Descent

In the thin Martian atmosphere, the parachute is only able to slow the vehicle to about 200 miles per hour (320 kilometers per hour). To get to its safe touchdown speed, Perseverance must cut itself free of the parachute, and ride the rest of the way down usingrockets.

Directly above the rover, inside the backshell, is the rocket-powered descent stage. Think of it as a kind of jetpack with eight engines pointed down at the ground. Once it's about 6,900 feet (2,100 meters) above the surface, the rover separates from the backshell, and fires up the descent stage engines.
The descent stage quickly diverts to one side or the other, to avoid being impacted by the parachute and backshell coming down behind it. The direction of its divert maneuver is determined by the safe target selected by the computer that runs Terrain-Relative Navigation.

Method

This paper details the functionality of a software program used to space craft design, analysis and simulation effort. The program aids in aeroshell, chamber and high pressure gas bottle propulsion system design effort quickly and efficiently using a catia V5. Chamber dimensions, propellant selections, and injector selection between doublet or triplet allow for further refinement of the desired spacecraft design.

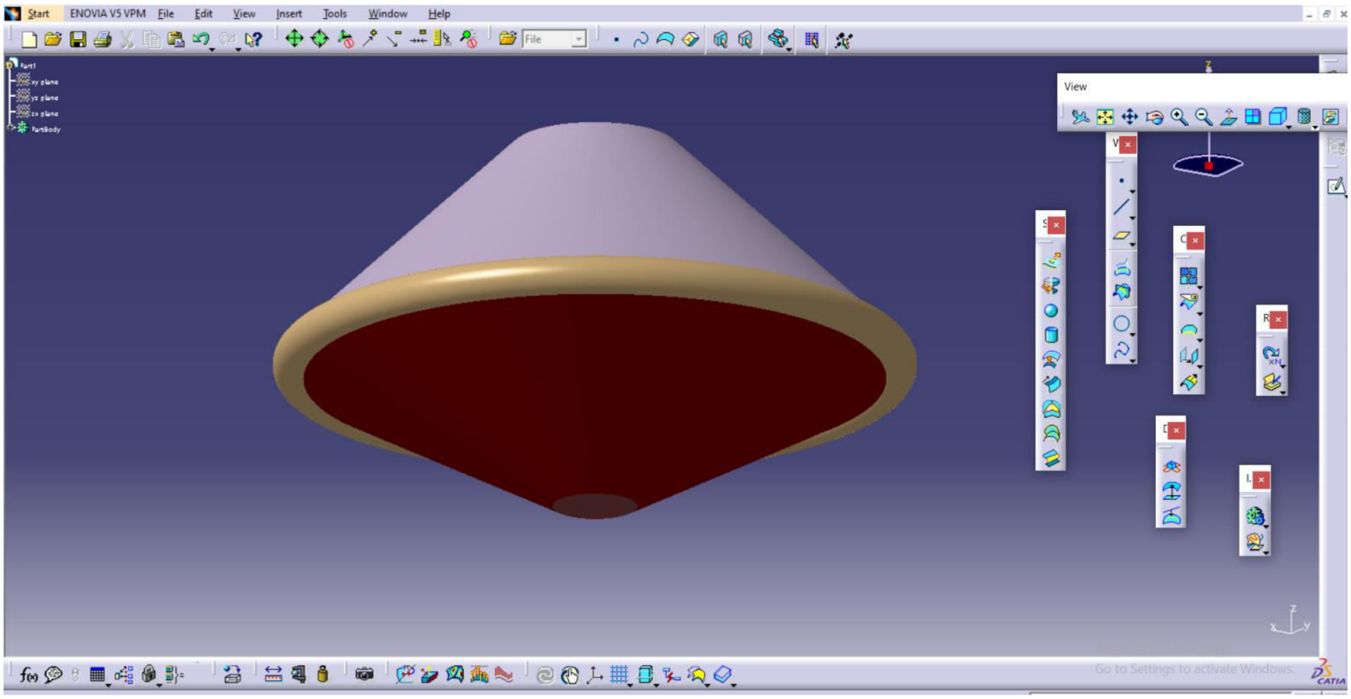
The program takes the available selections and specifications made by the user and outputs key design parameters calculated from the input variables. A 2-D design representation space craft chamber is plotted and coordinates of the plotted line are displayed.

The rocket propulsion system design coordinates are saved to a *data file which can be used in a CAD program to plot a 3-D model of the rocket propulsion system. The *data file is compatible for creating splines in Unigraphics NX, Catia, and SolidWorks. Coordinates of the injectors are saved to a *data file to be modeled in a CAD program as well.

The program currently provides a symbolic link in the form of a button on the output page which will open Unigraphicsansyscfxprogram.igesThe post-processing simulation of the space craft propulsion system is done in a computational fluid dynamics (CFD) program such as ANSYS ICEM CFD mesh generation software and ANSYS FLUENT CFD. The program provides a button on the output page which will open the ANSYS ICEM CFD mesh program and the ANSYS FLUENT CFD program. The user inputs the parasolid or IGES/STEP file of the CAD 3-D modeling of the rocket propulsion system into the ANSYS ICEM CFD meshing software.

The geometry tolerant mesher program produces a volume or surface mesh to be read into the ANSYS FLUENT CFD software. Using ANSYS FLUENT CFD software, we can choose to model the flow, turbulence, heat transfer, air flow over the space craft, combustion in the chamber, or various other options of the propulsion system.

DESIGN AND ANALYSIS

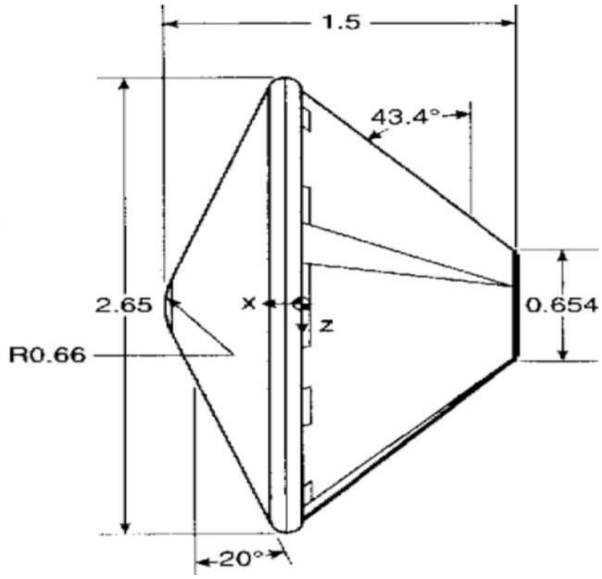


Spacecraft configuration:

1. Table: Satellite Details

Volume	$129.44m^3$
Mass	19582.43kg
Area	$13.025m^2$
Moment of Inertia	$I_{ox}G = 72.833kg.m^2$ $I_{oy}G = 72.833kg.m^2$, $I_{oz}G = 109.913kg.m^2$ $I_{xy}G = 0\ kg.m^2$, $I_{xz}G = 0kg.m^2$ $I_{yz}G = 0kg.m^2$
Centre of Mass	G_x=0mm, G_y=0mm, G_z= -730.013mm

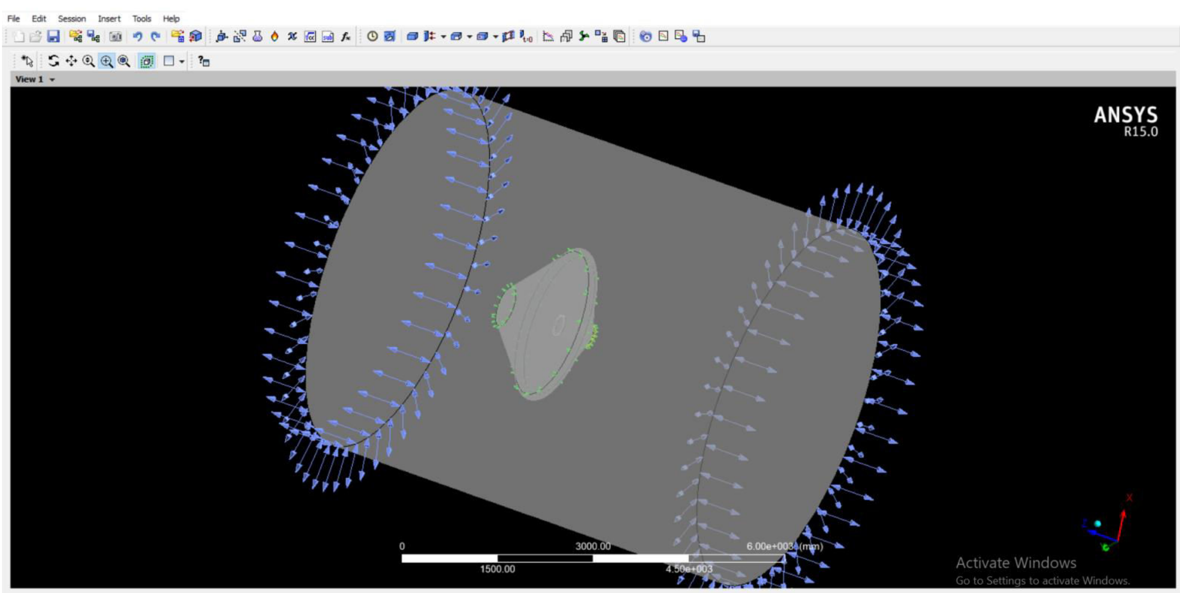
Primary Material	Aluminum



*All dimension in meters

Fig. craft dimension

Analysis



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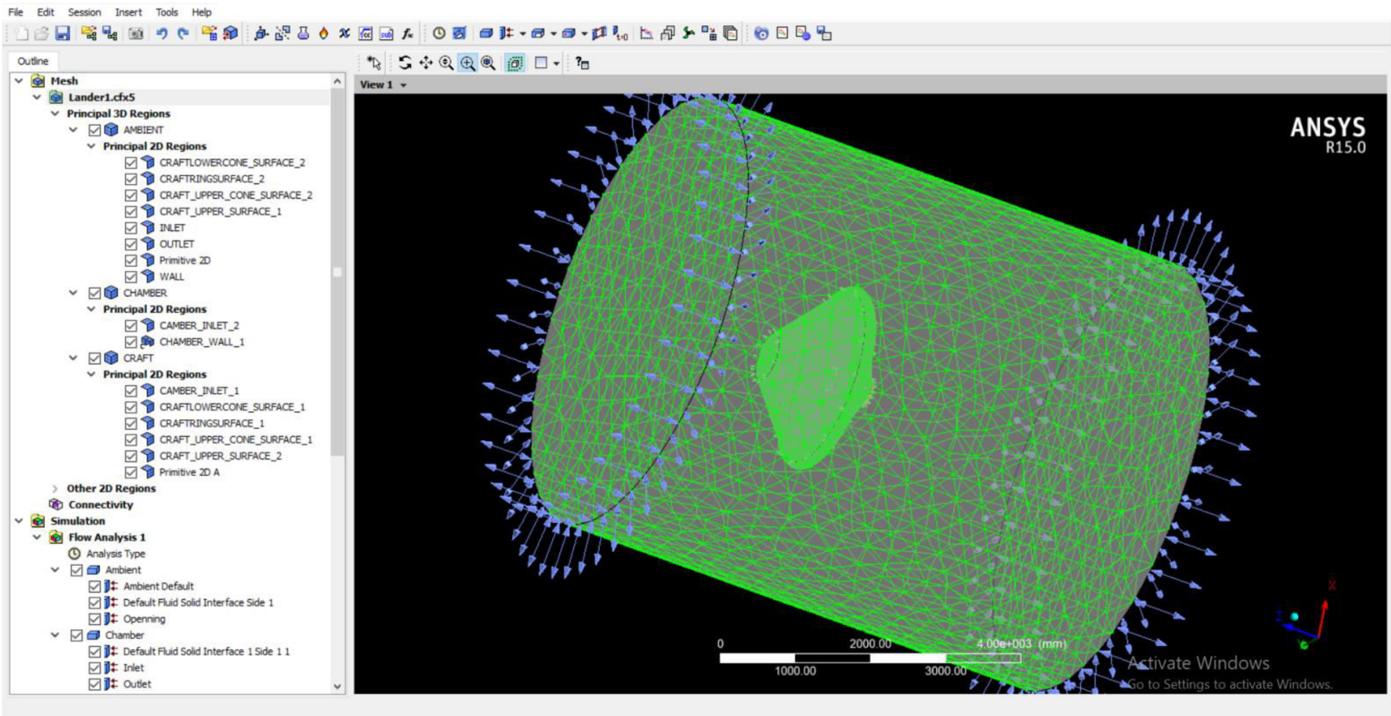


Boundary Conditions and analysis

3. Table: Mesh Information for Warhead Satellite

Domain	Nodes	Elements
Ambient	40869	208073
Chamber	1066	5134
Craft	24625	115828
All Domain	66560	329035

4. Table: Physics Report

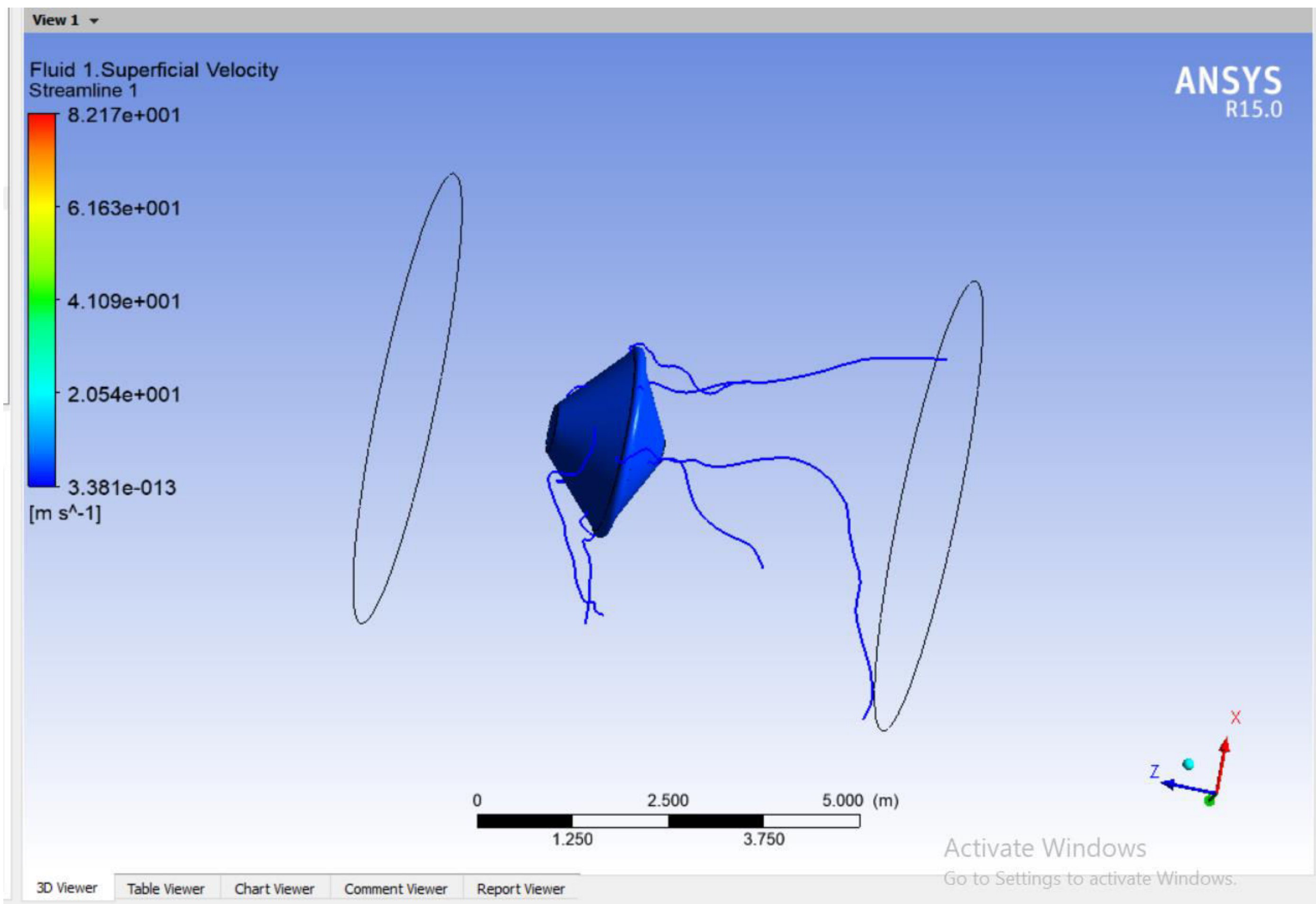
Domain Ambient	
Type	Fluid
Reference pressure	1 [atm]
Heat transfer	Total Energy
Domain Craft	
Type	Solid
Morphology	Continuous Solid
Heat transfer	Thermal Energy
Domain Craft	
Type	Solid
Domain Motion	Stationary
Domain Interface- Default Fluid Solid Interface	
Boundary list 1	Default Fluid Solid Interface Side 1
Boundary list 2	Default Fluid Solid Interface Side 2
Interface Type	Fluid Solid

5.Table:Boundary Physics for Warhead Satellite

Domain	Boundary Opening	
Ambient	Flow Regime	Subsonic

	Opening temperature	210.372 [K]
	Relative Pressure	0.0061 bar
Chamber	Boundary Inlet	
	Heat transfer	Static Temperature
	Static Temperature	450 [K]

	Normal Speed Static pressure	89,85,80,75,70,65,60,55,50,45 [m/s] 3,2.5,2.2,2,1.8,1.5,1.2,1,0.9,0.8 [bar]
	Boundary Outlet	
	Flow Regime	Subsonic
	Relative Pressure	0.007 bar



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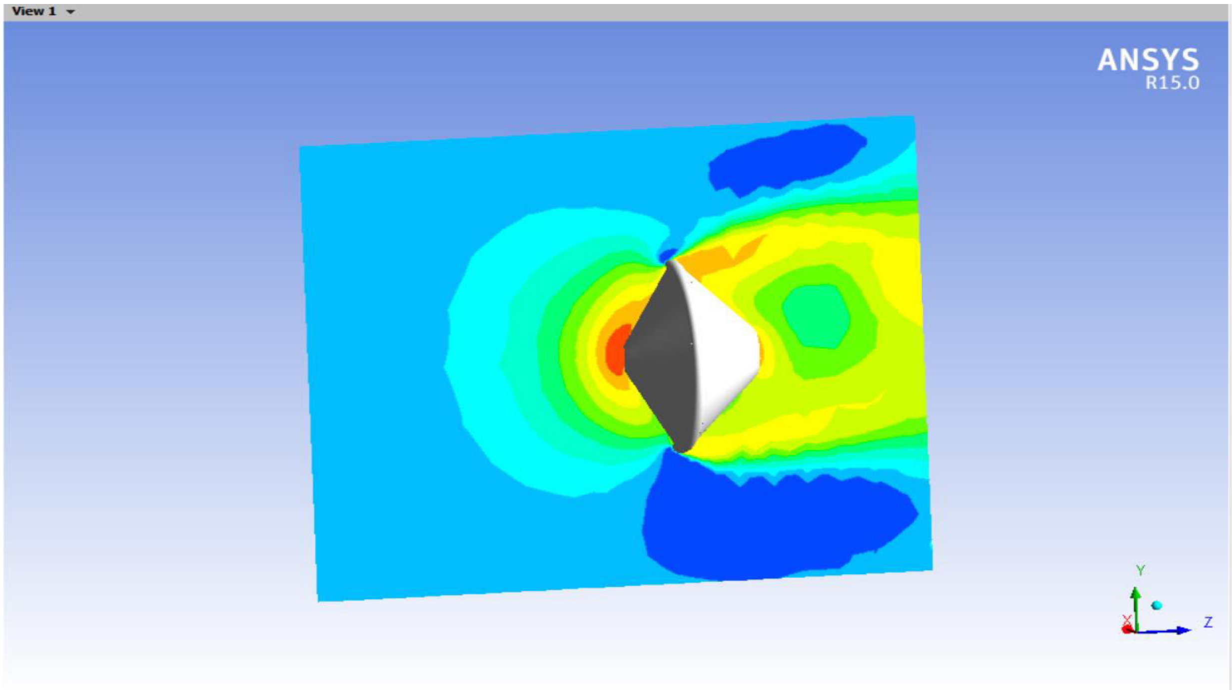
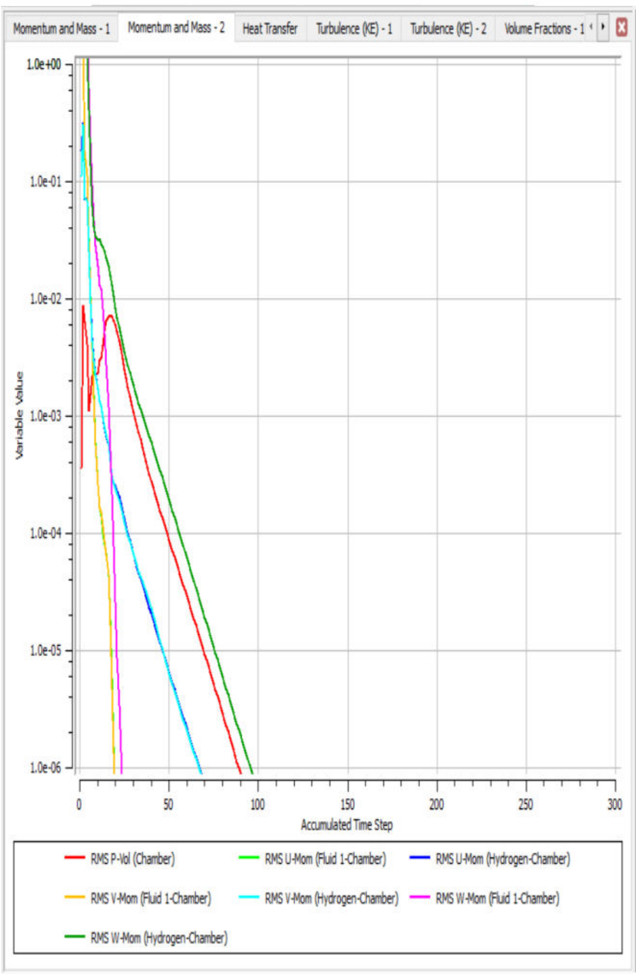
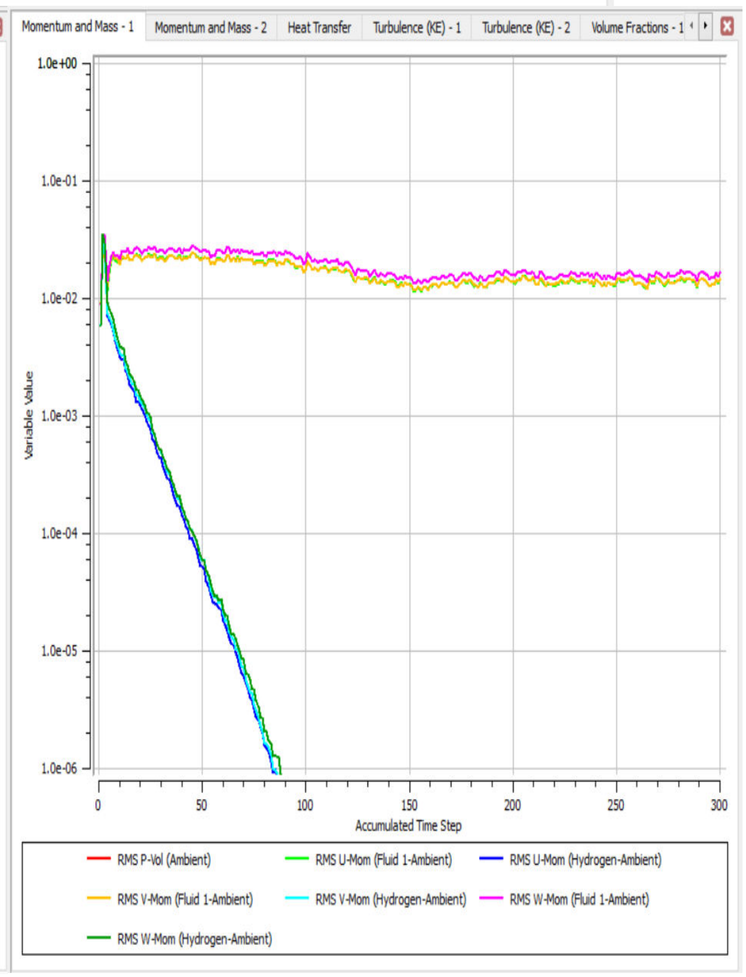
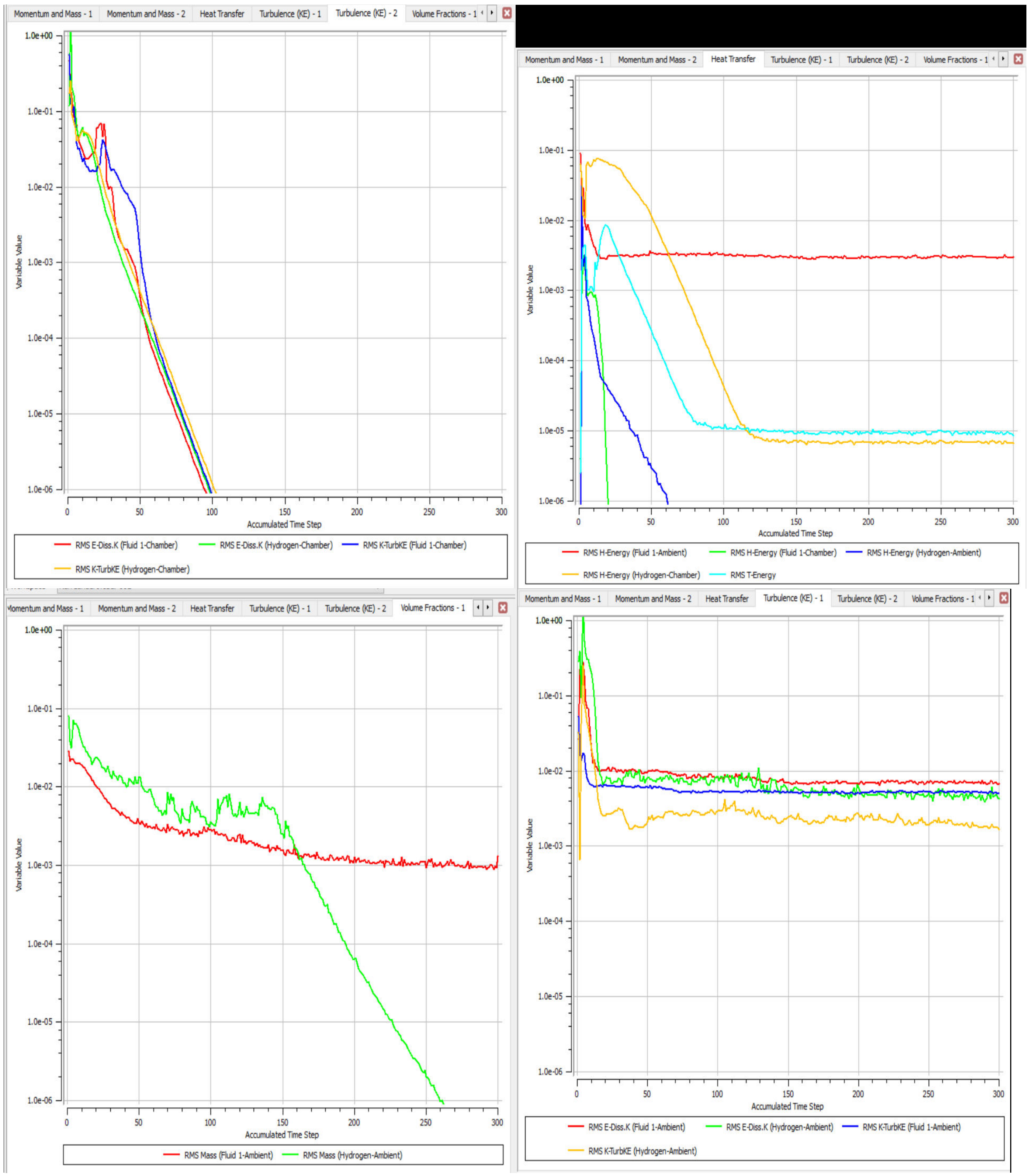
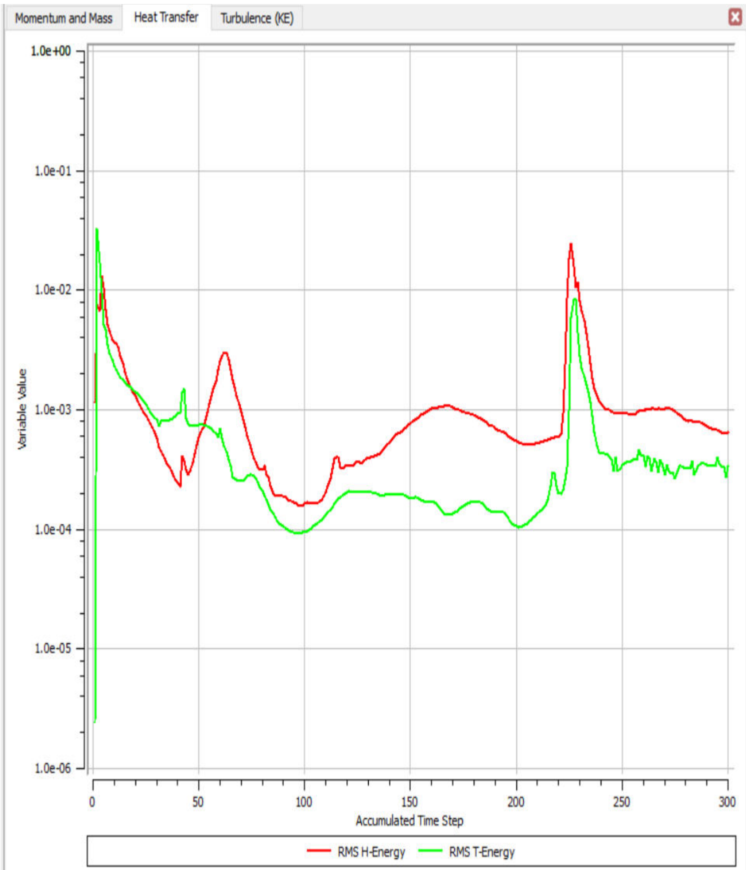
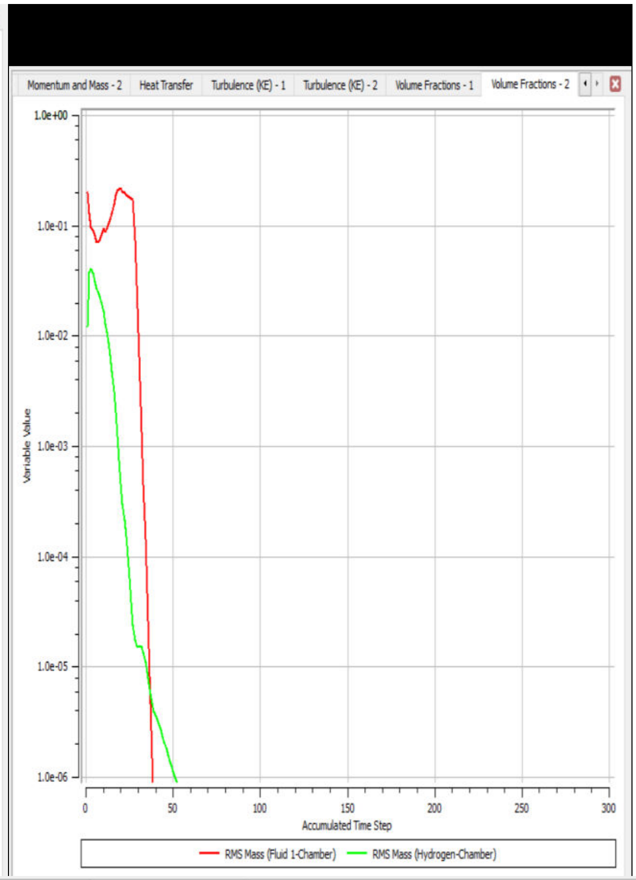


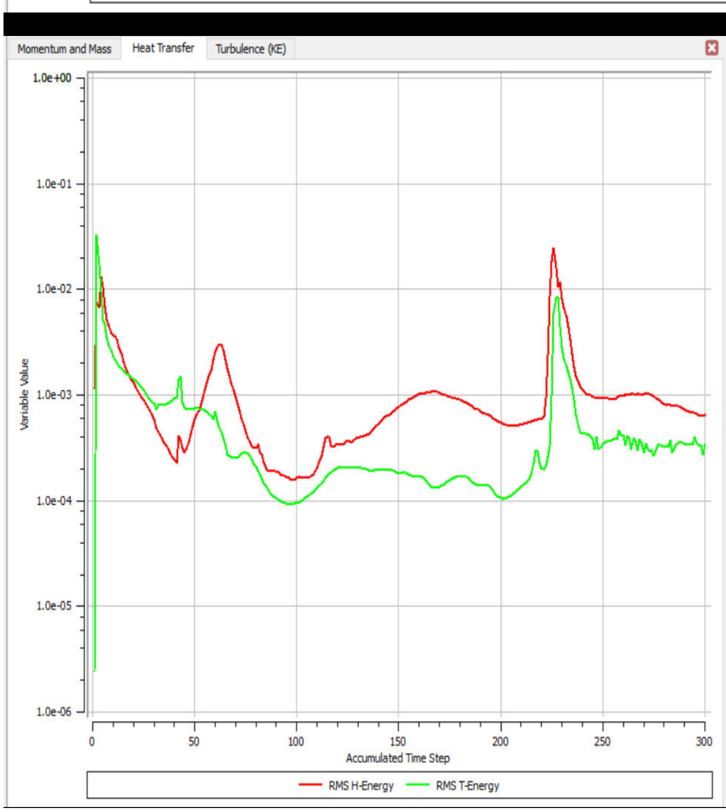


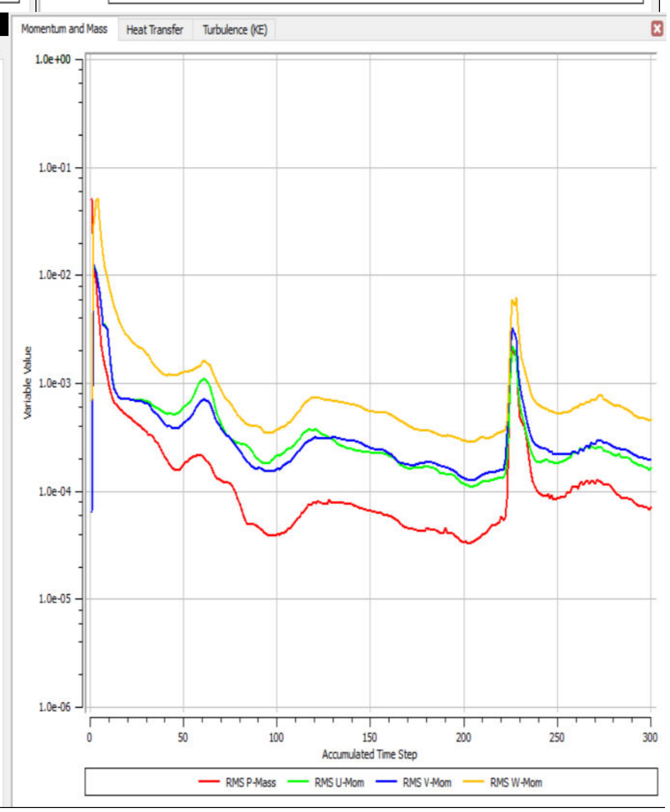



Momentum and Mass - 1
Momentum and Mass - 2
Heat Transfer
Turbulence (KE) - 1
Turbulence (KE) - 2
Volume Fractions - 1
Variable Value
Accumulated Time Step
RMS E-Diss.K (Fluid 1-Chamber)
RMS E-Diss.K (Hydrogen-Chamber)
RMS K-TurbKE (Fluid 1-Chamber)
RMS K-TurbKE (Hydrogen-Chamber)
RMS H-Energy (Fluid 1-Ambient)
RMS H-Energy (Fluid 1-Chamber)
RMS H-Energy (Hydrogen-Ambient)
RMS H-Energy (Hydrogen-Chamber)
RMS T-Energy
RMS Mass (Fluid 1-Ambient)
RMS Mass (Hydrogen-Ambient)
RMS E-Diss.K (Fluid 1-Ambient)
RMS E-Diss.K (Hydrogen-Ambient)
RMS K-TurbKE (Fluid 1-Ambient)
RMS K-TurbKE (Hydrogen-Ambient)


Momentum and Mass
Heat Transfer
Turbulence (KE)
Variable Value
Accumulated Time Step
RMS H-Energy
RMS T-Energy


Momentum and Mass - 2
Heat Transfer
Turbulence (KE) - 1
Turbulence (KE) - 2
Volume Fractions - 1
Volume Fractions - 2
Variable Value
Accumulated Time Step
RMS Mass (Fluid 1-Chamber)
RMS Mass (Hydrogen-Chamber)


Momentum and Mass
Heat Transfer
Turbulence (KE)
Variable Value
Accumulated Time Step
RMS H-Energy
RMS T-Energy


Momentum and Mass
Heat Transfer
Turbulence (KE)
Variable Value
Accumulated Time Step
RMS P-Mass
RMS U-Mom
RMS V-Mom
RMS W-Mom

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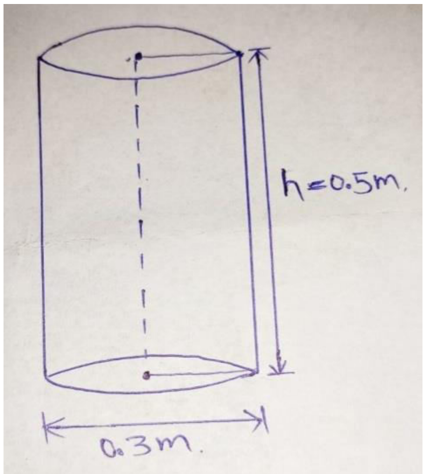
NUMERICAL CALCULATION

We need to project device -**HIGH PRESSURE GAS BOTTLE**, assume inert gas argon, then find mass flow rate (dm/dt)=ṁ
mass flow rate =mass/time (kg/s)
time= m/ṁ
mass =density*volume
And , distance = velocity*time

Graph intersecting at 1.0.9 bar,50.2 m/sec
2.1.22 bar,60 m/sec

High pressure gas bottle-



V = π *(r^2)h
V=0.035325 m^3

For finding area (A) =(2* π *r*h+2* π *(r^2))
A= 0.6123m^2

Po =chamber pressure =0.9bar
Velocity=50.2 m/sec

Mass flow rate(ṁ) = Area * sqrt[(2γ/γ-1) ((P_o^2)/R T_o) {1- (P_a/P_o)^((γ-1)/ γ)} {(P_a/ P_o)^(1/ γ)}]

Here

γfor argon = monoatomic (1.667)
A= area of high gas pressure bottle
Po= Chamber pressure =0.9 bar
To= Chamber Temp = 450 K
Pa = Ambient pressure = 0.0061 bar at mars
R = gas constant

Now,
R=[R universal/molar mass of argon]*1000
R=[8.314/39.948]*1000
Aftercalculating we get ,**R**= 208.13 J/kg. K

For 1.0.9 bar,50.2 m/sec

Mass flow rate(ṁ) = Area * sqrt[(2γ/γ-1) ((P_o^2)/R T_o) {1- (P_a/P_o)^((γ-1)/ γ)} {(P_a/ P_o)^(1/ γ)}]
=57.0703467 kg/ sec

For Calculating mass ,
M= ρ* v=0.0566 kg
Time taken = Mass /(ṁ) = 0.00099221 sec
Distance = Velocity * Time = 49.8m

NOW,
2. Po= 1.22 bar and Velocity = 60 m/sec

Mass flow rate(ṁ) = Area * sqrt[(2γ/γ-1) ((P₀^2)/R T₀) {1- (Pₐ/P₀)^((γ-1)/ γ)} {(Pₐ/ P₀)^(1/ γ)}]

$$\dot{m} = Area \cdot \sqrt{\left(\frac{2\gamma}{\gamma-1}\right)\left(\frac{P_o^2}{R T_o}\right)\left\{1-\left(\frac{P_a}{P_o}\right)^{\frac{\gamma-1}{\gamma}}\right\}\left\{\left(\frac{P_a}{P_o}\right)^{\frac{1}{\gamma}}\right\}}$$

= 94.5914 kg/sec

M= ρ* v=0.0566 kg
Time taken = Mass /(ṁ) = 0.0005986373 sec
Distance = Velocity * Time = 35.91m

RESULT

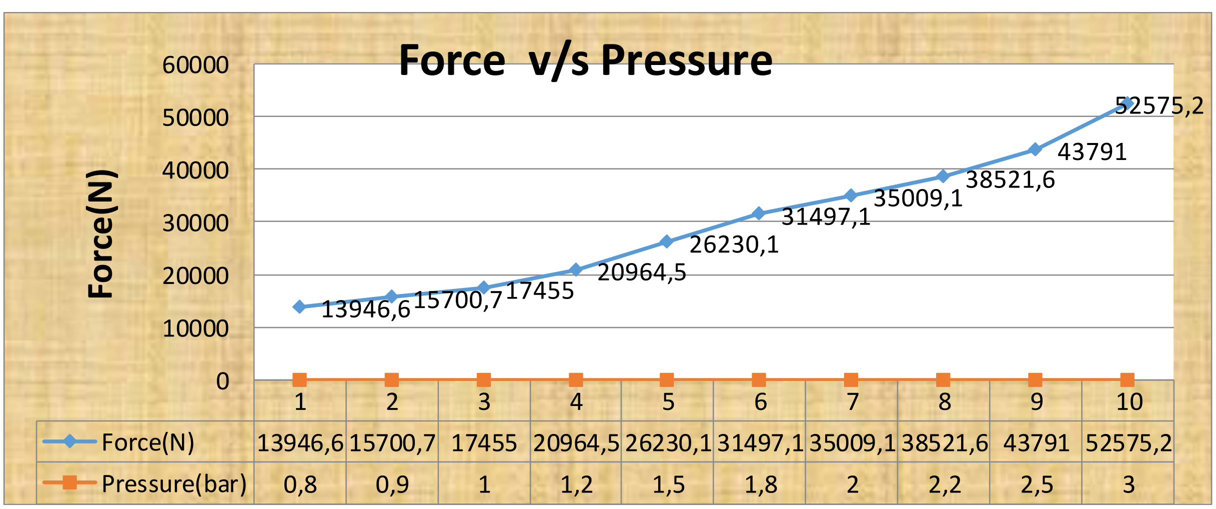
This paper presents the results of numerical investigations of the interaction with the Mars surface landing platform propulsion system and between minimum descent distance for landing. The cases of impingement of spacecraft are considered depending on the values of propulsion system thrust. According to the results of numerical studies are obtained the values of minimum descent landing distance on the surface of Mars at altitudes of 35.91 and 49.80 meter to the surface of the landing. The estimates are consistent with the available data from previous Mars missions 2020.

Parachute deployment occurred 134 sec before landing, only 6 s later than the a priori predicted time at an altitude of 9.4 km. All subsequent events including heat shield separation and lander bridle deployment occurred at the predicted times relative to parachute deployment. The lander took 10 s to descend on the descent rate limiter to the point that the bridle was fully extended and loaded. Radar data were acquired 1.6 km above the surface, 28.7 s before landing. The terminal descent rate just prior to rocket ignition from minimum descent distance for landing 35.91 m and 49.80 above the ground, is velocity at 50.2 m/s and 60 m/s well within design tolerances.

From Graph (1 and 2) we found that:

1. With the increasing Pressure the Force Value will increases.
2. As the velocity increases the Force value also increases.

Graphs



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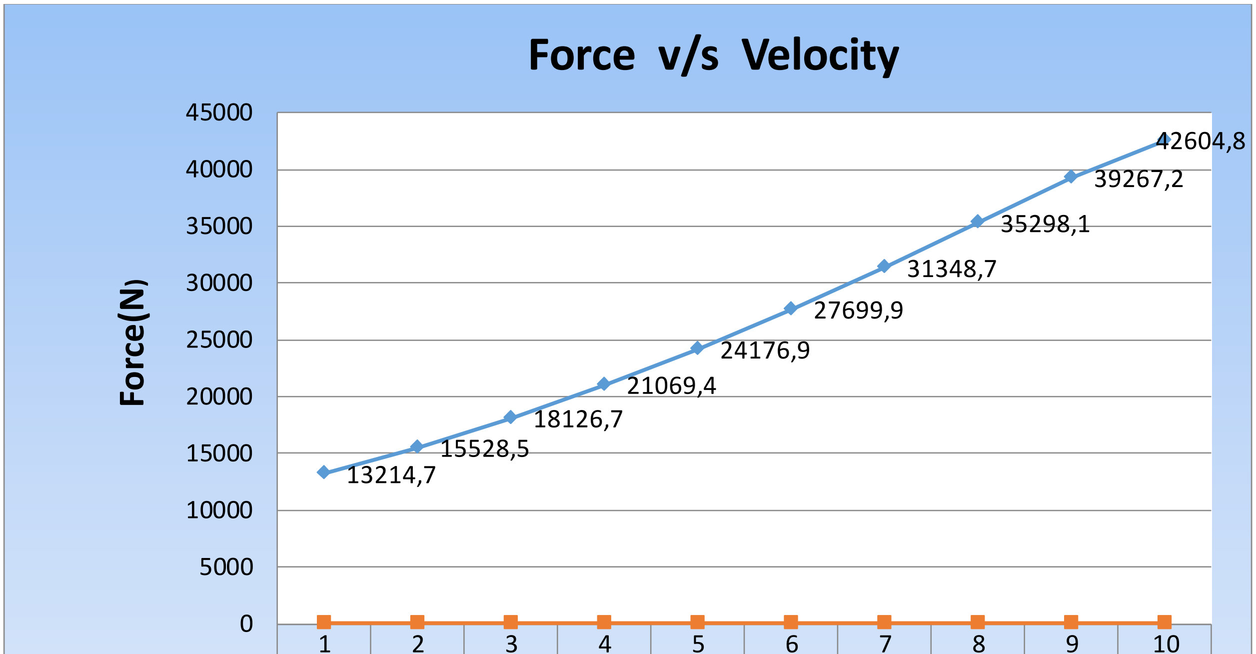
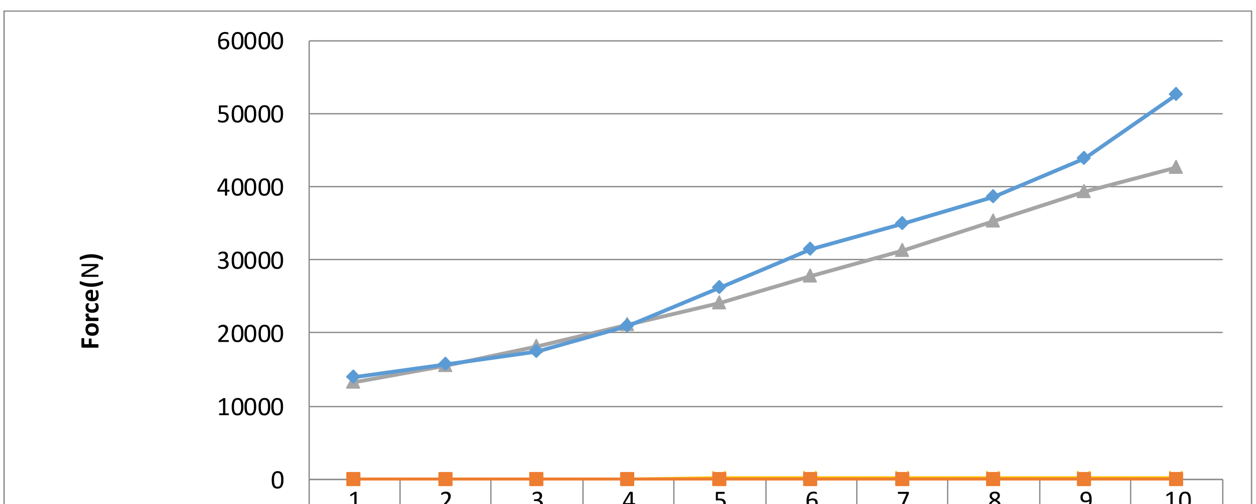


	1	2	3	4	5	6	7	8	9	10
Force(N)	13214,7	15528,5	18126,7	21069,4	24176,9	27699,9	31348,7	35298,1	39267,2	42604,8
Velocity(m/sec)	45	50	55	60	65	70	75	80	85	89



	1	2	3	4	5	6	7	8	9	10
Force(N) 13214.7	13214,7	15528,5	18126,7	21069,4	24176,9	27699,9	31348,7	35298,1	39267,2	42604,8
Velocity(m/sec)	45	50	55	60	65	70	75	80	85	89
Force(N)	13946,6	15700,7	17455	20964,5	26230,1	31497,1	35009,1	38521,6	43791	52575,2
Pressure(bar)	0,8	0,9	1	1,2	1,5	1,8	2	2,2	2,5	3

CONCLUSION

This study presents the minimum descent distance for landing on mars to the best landing aim point can be efficiently obtained based on the good initial value guess provided by the sensitivity analysis. Numerical results show that the proposed algorithm effectively and efficiently addresses the mars planet powered landing problem to achive minimum descent distance.

The best landing aim point from the candidate landing aim points can be efficiently and accurately obtained by optimal sensitivity analysis based on computation fluid dynamics and numerical method, which only needs one optimization computation. Then another optimization computation is implemented to obtain the minimum descent distance for landing from the initial position of the lander to the selected best landing aim point, whose computation cost is quite low because of the good initial value guess provided by the sensitivity analysis.

Therefore, only two optimization computations are required to obtain the minimum descent distance for landing to the best landing aim point, which is quite efficient. Thus, the proposed approach has the potential for powered landing missions. For the proposed algorithm, the estimation error will increase as the distance from the candidate point to the defined midpoint increases. Therefore, designing the space craft for powered landing algorithm when the candidate landing aim points are located in large landing region will be the future work

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