Martian Dust Storms Wind Load on Astronaut

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Abstract:

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Plain Language Summary

While watching the science fiction movie Martian Land (2015), an astronaut is blown away and carried off by a dust storm. I wondered if that's possible with Martian atmospheric low pressure and if so, what would be the minimum wind speed. This article explains the methods of wind speed measurement on earth and mars. The Martian wind velocity pressure is modified from Bernoulli's Law for Dynamic Pressure Equation. Both male and female astronauts in EVA (Extravehicular Activity) suits are evaluated for stability during Martian dust storms. For male astronauts to be blown away by Martian dust storms the wind speed must be greater than 342 mph.

Key words:

Martian dust storm, Mars Wind,

1. Introduction

Understanding the climate on Mars is essential to human colonization on the red planet. Since the1960s, forty-eight spacecraft missions (including unsuccessful ones) have been launched, mostly by NASA. In 1965, Mariner 4 returned the first close-up images of the Martian surface. The next breakthroughs in the exploration of Mars were the Mariner 9 mission which returned

7329 images in 1971. In 1975, Viking 1 was the first spacecraft to orbit and land on Mars; the orbiter returned over 36,000 images and the lander returned the first image of Mars surface. From 1975 to 1996 there was a slowdown period for Mars exploration (Martínez et al. 2017). 1996 began a new era in the exploration of Mars, starting with the Mars Global Surveyor and Mars Pathfinder and continued with the 2007 Phoenix Mars Lander which returned over 25 gigabits of data from Mars's north polar region. From 2007 to present, other countries have joined the exploration. NASA's Mars InSight Lander and Mars 2020 Perseverance Rover have returned an enormous amount of data from the planet surface such as wind and marsquakes.

In addition to the three biggest space agencies, NASA in the US, Roscosmos in Russia, and the ESA in Europe there are a number of private space agencies and other countries planning unmanned Mars missions for the near future and more aspiring missions to put humans on Mars.

The desire to go to Mars has made the race to red planet crowded. On July 19, 2022 two new space companies in California, Relativity Space and Impulse Space, announced that they are teaming up to launch the first commercial mission to Mars in 2024, this will be years before the first potential trip by the more established SpaceX (Brelt Tingley, 2019).

Table 1 is the list of historically successful missions to Mars.

Historical Log of Successful Missions			
Launch Date	Name	Country	Details
1964	Mariner 4	US	Returned 21 images
1969	Mariner 6	US	Returned 126 image
1969	Mariner 7	US	Returned 75 image
1971	Mars 3 Orbiter/Lander	USSR	Orbiter obtained approximately 8 months of data and lander landed safely, but only 20 seconds of data returned.
1971	Mariner 9	US	Returned 7,329 images
1973	Mars 5	USSR	Returned 60 images; only lasted 9 days
1973	Mars 6 Orbiter/Lander	USSR	Occultation experiment produced data and Lander failure on descent
1975	Viking 1 Orbiter/Lander	US	Orbiter returned over 36,000 images; lander returned first image from the surface of Mars and conducted soil experiments
1975	Viking 2 Orbiter/Lander	US	Returned 16,000 images and extensive atmospheric data and soil experiments
1996	Mars Global Surveyor	US	Mapped Mars and its topography; studied indications of Mars' wetter past
1996	Mars Pathfinder	US	Technology experiment lasting 5 times longer than warranty

2001	Mars Odyssey	US	High resolution images of Mars
2003	Mars Express Orbiter/Beagle 2 Lander	ESA	Orbiter imaging Mars in detail; lander appears to have landed intact but didn't communicate with Earth
2003	Mars Exploration Rover - Spirit	US	Operated for over 6 years on Mars, long past design life
2003	Mars Exploration Rover - Opportunity	US	Operated for nearly 15 years, roving a record 28 miles (45 km)
2005	Mars Reconnaissance Orbiter	US	Studying Mars in detail; has returned over 400 terabits of data (more than all other Mars missions combined)
2007	Phoenix Mars Lander	US	Returned more than 25 gigabits of data from its studies of Mars' north polar region
2011	Mars Science Laboratory	US	Exploring Mars' habitability
2011	Phobos-Grunt/Yinghuo-1	Russia/China	Stranded in Earth orbit
2013	Mars Atmosphere and Volatile Evolution	US	Studying the Martian atmosphere
2013	Mars Orbiter Mission (MOM)	India	Develop interplanetary technologies and explore Mars' surface features, mineralogy, and atmosphere
2016	ExoMars Orbiter/Schiaparelli EDL Demo Lander	ESA/Russia	Orbiter studying Martian atmosphere and EDL demo lander lost on arrival
2018	Mars InSight Lander	US	Measuring "marsquakes" and studying the planet's interior
2020	Hope Orbiter	UAE	Studying the Martian atmosphere
2020	Tianwen-1 Orbiter/Zhurong Rover	China	Orbiter arrived in Feb. 2021; released lander for successful touchdown and rover deployment in May 2021
2020	Mars 2020 Perseverance Rover	US	Searching for signs of ancient life and collecting samples for future return to Earth

Table 1 Historical Successful Missions to Mars. Reconfigured from NASA website.

1.1 Wind Speed Measurement on Earth

Wind velocity is used in determining the maximum design wind loads that can be expected on a building or structure during its lifespan. (Fanella 2018). On earth, wind speed is the result of three forces; 1) The pressure gradient force (Pgf) which is the outcome of uneven heating of the Earth's surface creating different pressure in the atmosphere by moving from high-pressure to low-pressure regions, 2) Coriolis force which is caused by plant rotation and 3) Surface Friction. (NOAA, 2023)

The equipment used to measure wind is known as anemometers and can record wind direction, speed, and the strength of gusts. Wind direction is measured relative to true north (not magnetic north). Wind speed normally increases with height above the earth's surface and is much influenced by the roughness of the ground and the presence of buildings, trees, and other obstacles in the vicinity. Planetary Boundary Layer is the layer of the earth’s atmosphere which is located from the surface of the earth to approximately 3,300 feet above the surface. This layer has an important impact on the magnitude of wind loads on buildings and other structures. Wind speed naturally changes dramatically with time. The peaks in wind speed are called gusts, and these effects must be considered in design. Gust-effect factors are used in ASCE/SEI 7 to account for this phenomenon.

Here on earth, wind speed is routinely measured by a cup anemometer consisting of three or four cups, conical or hemispherical in shape, mounted symmetrically about a vertical spindle. The wind blowing into the cups causes the spindle to rotate. The design of the cups is such that the rate of rotation is proportional to the speed of the wind to a sufficiently close approximation. Anemometers are calibrated in a wind tunnel to find any variations in the connection between spindle rotation and wind speed specified by the manufacturer. Wind direction is measured by a vane containing a thin horizontal arm carrying a vertical flat plate at one end with its edge to the wind and at the other end a balance weight which also serves as a pointer. The anemometer and wind vane are each attached to a horizontal supporting arm located 33 feet above the ground in open terrain. The normal unit of wind speed is the knot (nautical mile per hour = 0.51 m/ sec = 1.15 mph).

In extreme weather conditions, to prevent damage to the instrument, a sonic anemometer is typically used. The instrument measures the speed of acoustic signals transmitted between two transducers located at the end of thin arms.

The hot-wire anemometer is another method to measure wind speed. This device uses a very fine wire electrically heated to a certain temperature above the ambience. Air flowing through the wire has a cooling effect on the wire. As the electrical resistance of most metals is dependent upon the temperature of the metal, a relationship can be obtained between the resistance of the wire and the flow speed.

1.2 Wind Speed Measurement on Mars

Unlike on earth, there is very limited wind speed data pertaining to the surface of Mars. Additional measurement of surface winds is essential since a single instrument in a given location is insufficient for representation of the entire planet (Viúdez-Moreiras et al., 2019a).

The measurements of Mars’ near-surface atmospheric properties (Martínez et al. 2017) were from Viking 1, Viking 2, Phoenix Lander, Pathfinder, and Curiosity. Mars Science Laboratory (MSL) meteorological measurements included surface pressure, atmospheric temperature, relative humidity, atmospheric opacity, wind speed, and direction. The Viking Lander meteorology instruments were designed to record atmospheric pressure, temperature, and wind speed. The wind velocity detector consists of a pair of hot film anemometers mounted on a boom 5.25 feet (1 .6 meters) above the surface to escape lander heat sources which could interfere with the wind flow, Figure 1. The speed and direction of the wind normal to each wire was specified from the power depletion required to hold the sensor at 100 C above the ambient atmosphere (Haslach, H. 1989).

Figure 1: Replica of a Viking Lander. The wind and air temperature sensors can be seen on the end of the boom at right. Photo from NASA's Mars Exploration

Viking 1 landed on Mars in the western slope Chryse Planitia on June 11, 1976. The surface weather report for the first 350 sols of pressure, temperature, wind speed, and direction based on hourly average are available on NASA's website (NASA Planetary Data System the maximum wind speed by Viking 1 recorded was 58 mph(25.9 m/s) with a temperature of -80.8 F (62.66 C) and atmospheric pressure of 0.114 psi (790 Pa) on sol 214 (Soureshjani,et al 2023).

Viking 2 landed on Mars west of the Mie Crater in Utopia Planitia on September 3, 1976 and operated for 1281 sols. Midlatitude baroclinic waves produced by the strong thermal contrasts around the northern seasonal polar cap's edge, created wind speeds to peak during northern fall and winter in both VL2 years. The maximum wind speed was at 52 mph (23.3 m/s) during first sol year ((Martínez et al. 2017). The second Viking 2-year data showed a drop in wind speed in the middle of the fall/winter period. This is known as the solstice pause when the sun appears to reach its most northerly or southerly excursion relative to the celestial equator on the celestial sphere (e.g.,Lewis et al. 2016).
The Phoenix lander landed May 25, 2008, on the Mars polar region and operated for 157 sols after its last communication in November 2008, when its solar panels ceased operating in the

dark Martian winter. The wind speeds and directions were recorded by the Phoenix Lander Telltale instrument, Figure 2. The Telltale is a joint Canadian/Danish instrument invented by the University of Alberta scientist Carlos Lange which provides a rough estimate of wind speed and direction. The speed is based on the amount of deflection from vertical that is observed, while the wind direction is provided by which way this deflection moves. The maximum wind speed was 37 mph (16.7 m/s).

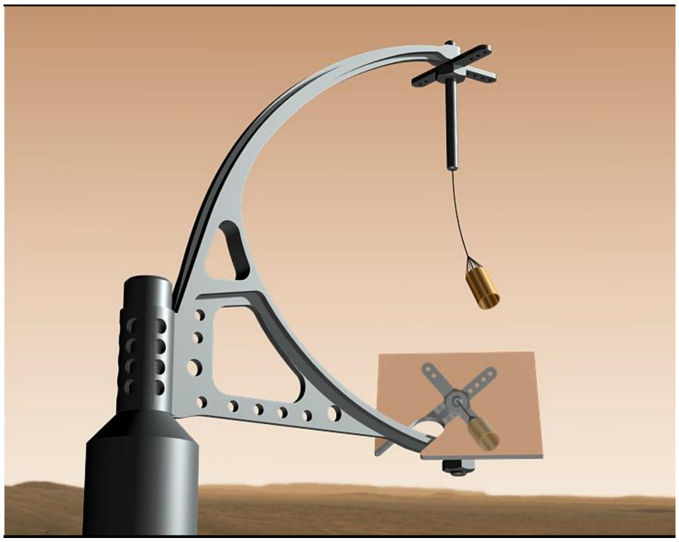

Figure 2: NASA's Phoenix Mars Lander Credit: NASA/JPL-Caltech/University of Arizona/Aarhus University/Niels Bohr Institute/Texas A&M University

Mars Curiosity Rover was launched from Cape Canaveral on November 26, 2011, and landed on Aeolis Palus inside Gale crater on August 6, 2012. The rover is still operating, as of July 28, 2023, Curiosity has been active on Mars for 3900 sols. The Rover Environmental Monitoring Station (REMS) has been designed to record six atmospheric parameters: wind speed/direction, pressure, relative humidity, air temperature, ground temperature, and ultraviolet radiation (Newman et al. 2017). All sensors are located around three elements: two booms attached to the Rover’s Remote Sensing Mast. Findings from the Curiosity Rover measurements on Mars dust storms, cloud movements, and wind streaks suggest that there are wind speeds up to 62 mph (ASU).

NASA’s InSight (Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport) mission lander launched on May 5, 2018, and landed on Mars on November 26, 2018 on Elysium Planitia, located in the Elysium and Aeolis quadrangles (Day 2019). Temperature and winds for InSight (TWINS), Figure 3, is a NASA meteorological suite of instruments. TWINS provides continuous wind and air temperature measurements to help understand the seismic data from the SEIS instrument (Velasco el al, 2015). InSight is equipped with two very sensitive sensors detecting wind vibrations, air pressure, and a seismometer on the robotic arm. This is similar to the meteorological package on the Curiosity Rover (Rover Environmental Monitoring Station) REMS (Gómez-Elvira et al. 2014). The seismometer records vibrations caused by the wind moving over the spacecraft's solar panels, which are each 7 feet (2.2 meters) in diameter.

The maximum wind speed recorded by TWINS is 62 mph, similar to the Curiosity Rover measurements.

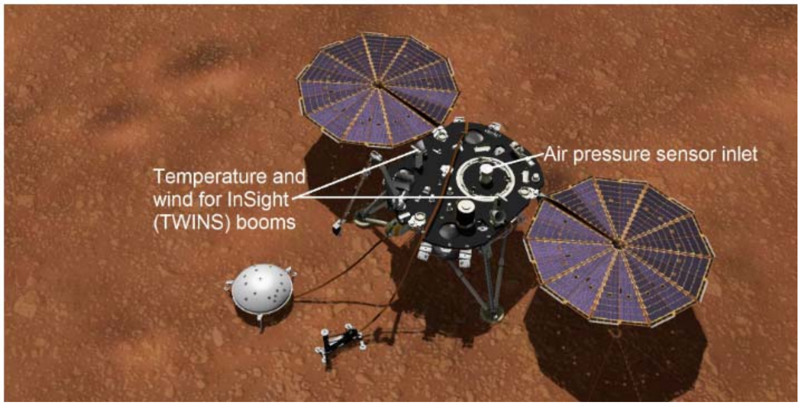

Figure 3 InSight's TWINS Instrument Credit NASA/JPL-Caltech

Mars 2020 mission Perseverance Rover is designed to explore the Jezero Crater on Mars. It was launched on July 30, 2020, and landed on Mars on February 18, 2021, (As of 27 July 2023, Perseverance has been active on Mars for 865 sol (Overbye, 21). The Perseverance Rover has a MEDA (Mars Environmental Dynamics Analyzer) which is designed to record six atmospheric parameters: wind speed/direction, pressure, relative humidity, air temperature, ground temperature, radiation, and dust optical properties. Attached to the Remote Sensing Mast (RSM), two wind sensors (WS) measure wind speed and direction. Wind Sensor 1 is 2 inches by 6.7 inches (5 by 17 centimeters). Wind Sensor 2 is 2 by 15.75 inches (5 by 40 centimeters), Fig. 1A. The combination of the 6 boards per boom provides wind speed, as well as pitch and yaw angle of each boom relative to the flow direction. The specification on horizontal wind speed has a 4.5 mph(2 m/sec) accuracy with speed limit up to 89.5 mph(40 m/sec)and the vertical wind, limit up to 22.3 mph (10 m/se) with the same accuracy (NASA). The wind speed recorded ranges from 0 to 45 mph (0 to 20 m/s) at the Jezero landing site (Viudez et al, 2022).

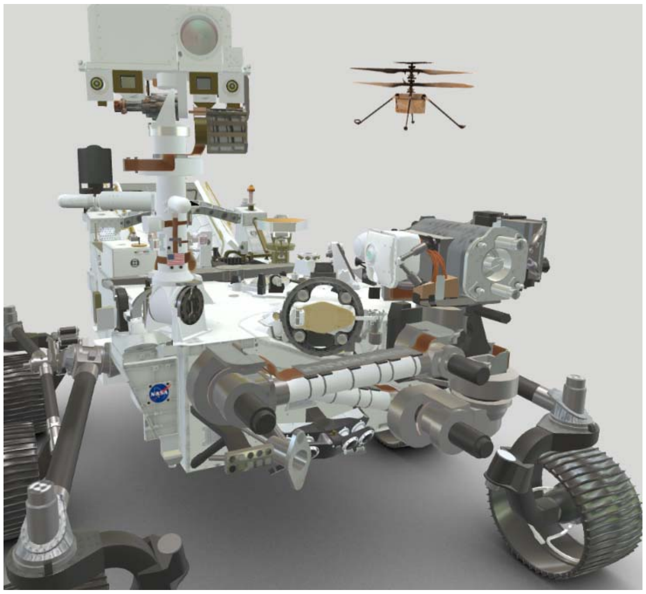

Figure 4 Mars 2020 Mission Perseverance Rover Credit NASA/JPL-Caltech

2. Wind Load

The surface of Mars exerts a horizontal drag force on wind, which impedes its flow. The more frictional resistance is applied, the closer the wind flow is to the surface; therefore, wind velocity is smaller at or near the ground level compared to levels above the surface. Correspondingly, at a given height above the surface, wind velocity is smaller over rougher surfaces compared to smoother ones due to friction. On earth, the basic wind speed is established at three-second gust speed at 33 ft (10 m) above the ground in open terrain (Section 1.1). However, on Mars the wind instrument is placed at an average distance of 5 feet above the ground. From the Mars 2020 Perseverance Rover to the Viking 1 Lander (Section 1.2), the maximum Martian wind speed is about 62 mph which is considered for this study.

When wind encounters a structure or object, two different types of pressures are created: external pressures, which act on all exterior surfaces, and internal pressures which act on all interior surfaces. Internal pressures are due to leakage of air through the exterior surface to the interior space. However, in this study, only external pressure is evaluated since the pressure suit is completely sealed.

Wind pressure is directly proportional to the square of wind velocity using Bernoulli's Law for Dynamic Pressure Equation.

$$P = \frac{1}{2}\rho V^2 \qquad (1)$$

ρ is the atmospheric air density and V is the wind velocity

Several methods are used for calculating wind load on an object or a structure. American Society of Civil Engineers (ASCE 7) has the one of the most detailed methods of calculating wind load on a structure defined within five chapters which has been adopted by many other organizations around the world. On earth, the velocity pressure q_z at height z above the ground surface is determined by ASCE Equation 27.3-1 ASCE/SEI 7-22 (American Society of Civil Engineers).

$$q_z = 0.00256 K_z K_{zt} K_d \, K_e V^2 \qquad (2)$$

Where:

K_d = wind directionality factor-- This factor is for the statistical nature of wind flow and the probability of the maximum effects happening at any specific time for any given wind direction.

Kz = velocity pressure exposure coefficient-- This factor modifies the velocity pressure with respect to exposure and height above ground.

Kzt = topographic factor--This factor modifies the velocity pressure exposure coefficients for structures located on the upper half of an isolated hill or escarpment.

Ke = ground elevation factor--This factor adjusts the velocity pressure, qz , based on the reduced mass density of air at elevations above sea level.

V = basic wind speed

q_z = velocity pressure

This is basically Bernoulli's Equation, and it converts the basic wind speed V to a velocity pressure based on the mass density of air for the standard atmosphere, which is defined at the temperature of 59°F and a sea level pressure of 29.92 inches of mercury (0.0765 lb/cf). The constant 0.00256 in ASCE equation is computed using Bernoulli's Law for Dynamic Pressure, which is equal to one-half times the density of air times the velocity squared, where the velocity is in miles per hour and the pressure is in pounds per square foot:

Constant = 0.5*x* [(0.0765 lb/ft^3)/(32.147 ft/S^2)*x*(1 mi/hr *x* 5280 ft/mi *x* 1 hr/3600 sec)$^{\mathbf{2}}$ =0.00256

Where: 0.0765 lb/ft^3 is the density of the air and 32.147 ft/S^2 is the gravitational accelerations of earth.

The velocity pressure equation can be modified for the Martian atmospheric condition.

Mars gravitational accelerations = 12.23 ft/S$^{2.}$ However, the Martian atmospheric density shows more daily and seasonal variation; the average is 0.00124 lb/ft^3 (0.020 kg/m^3).

Constant = 0.5*x*(0.00124 lb/ft^3) / (12.23 ft/S^2) *x*(1 mi/hr *x* 5280 ft/mi *x* 1 hr/3600 sec)$^{\mathbf{2}}$ =0.000108

Therefore, the velocity pressure in pounds per square foot on Mars is given by

$$q = 0.000108V^2 \qquad (3)$$

On earth, assuming all velocity pressure coefficient equal to 1(open terrain and worst-case scenario) the earth velocity pressure would be

$$q_z = 0.00256V^2 \quad (4)$$

From the previous section, the maximum wind speed on Mars is around 62-mph at 5 feet above the ground.

$$q(Mars) = 0.000108(62)^2 = 0.415\,psf \quad (5)$$

$$q(Earth) = 0.00256(62)^2 = 9.84\,psf \quad (6)$$

At this wind speed and elevation on earth, the velocity pressure would be equal to 9.84 pounds per square foot while on Mars it would have a pressure of 0.415 pounds per square foot. Here on earth, the wind velocity pressure of 0.415 psf (pounds per square foot) would result from 12.7 mph wind speed. To put this in perspective, if a human was standing on the surface of Mars, the 62-mph wind would feel more like a light breeze than a tropical storm.

Next section evaluates the impact of wind velocity pressure on humans in a Mars suit in a Martian dust storm.

Pressure

The Martian atmospheric pressure shows more daily and seasonal variation with elevation, but there is not enough pressure to sustain life without a pressure suit. The lowest pressure the human body can tolerate, known as the Armstrong Limit, is at 0.91 psi. Water boils (vaporizes) at the temperature of a human body (98.6 F). The average surface pressure on Mars is 0.088 psi and the highest pressure, at the lowest surface elevation, at the bottom of Hellas Basin, is 0.180 psi (Freudenrich et al, 2023). Current space suits are pressurized to 4.3 psi. This is below the usual atmospheric pressure on Earth (14.7 psi at sea level). Higher pressure in the suit creates resistance for every movement which can be physically exhausting during long activities. However, a lower pressurized environment allows astronauts to move around with better mobility (Hsu on July 17, 2009).

A number of space organizations including NASA, Axiom Space, and Collins Aerospace are designing a new space suit for Mars and the Moon (O'Callaghan, 2022). The existing Extravehicular Mobility Unit (EMU) space suit which is used on the International Space Station (ISS) is too bulky and rigid for the Mars surface. The new suit will be designed for walking including an abrasion resistance against high-speed winds filled with abrasive Mars dust, low temperatures, radiation, and micrometeorite strikes. It will also have better mobility than its predecessor.

NASA has performed many experiments aimed at understanding the physiological and biomechanical effects of space suits under numerous different conditions (Sridhar et al. 2017). The first use of EVA space suit was in 1960 by Alexei Leonov and there have been many developments by United States, Russia, and recently by private industries. Russia's current EVA suit Sokol pressure suit was first worn by Soviet cosmonauts in 1973 and the current US suit is the Extravehicular Mobility Unit (EMU) which provides environmental protection, mobility, life support, and communications for astronauts performing extravehicular activity (EVA). NASA has conducted a test on EVA suit's alignment and the system's center of gravity (CG), and the difference between the system CG and the human CG. (Sridhar et al. 2017). The composite CG will be used in this study to examine the horizontal wind load on the occupied EVA suit and its stability during a Martian dust storm.

For wind load determination, wind must be assumed to come from any horizontal direction, eight wind directions are shown in Figure 5. Four that are perpendicular to the main axes of the space suit and four that are at 45-degree angles to the main axes.

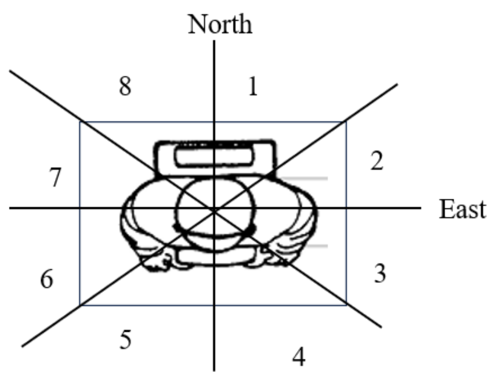

Figure 5: Wind Directions

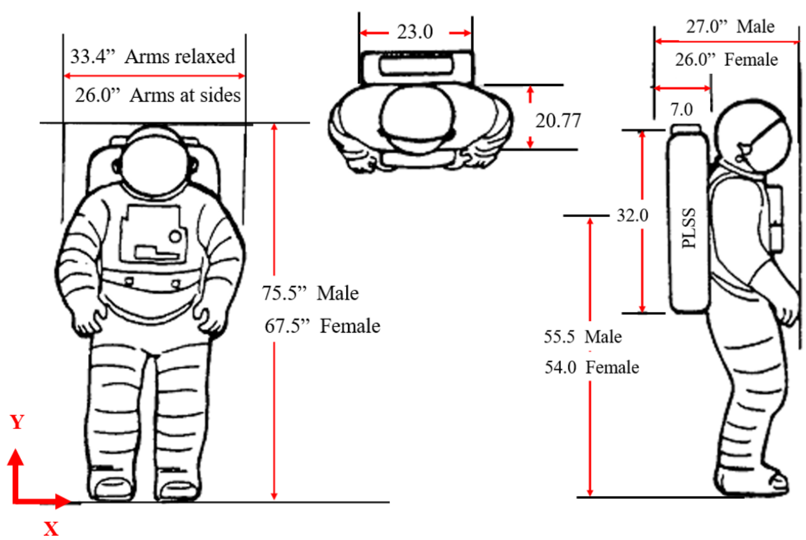

Figure 6: EVA(Extravehicular Activity) Suit Position Reconfigured from NASA's MAN-Systems Integration Standards Volume 1, Section 14.

The forces generated from wind velocity pressure are a function of the shape and size of the object. Naturally, large transverse surfaces generate a larger pressure force due to the Bernoulli Effect. The highest surface area of the space suit is the function of position and wind direction on the suit. The front and back would generate the highest surface area. Figure 6 shows the dimensions of the EVA suit.

EVA suit						
	Earth	**Mars**	**Male**		**Female**	
Gravity	100%	37.90%	Y	wy	Y	wy
Suit(lb)	78	29.56	42.28	1249.88	37.80	1117.44
PLSS(lb)	93	35.25	55.50	1956.21	54.00	1903.34
OPS(lb)	41	15.54	56.50	877.95	55.00	854.65
Astronaut(lb)M	180	68.22	39.20	2674.22		
Astronaut(lb)F	120	45.48			35.00	1591.80
Total Male	392	148.57		6758.27		
Total Female	332	125.83				5467.23

Table 2 Combined Space Suit and Astronaut CG Measurements.

To determine the effect of wind on the EVA suit, the composite Center of Gravity (CG) and the Centroids of the EVA suit should be computed. The center of gravity (c.g.) of an erect person with arms at the side is at approximately 56% of the person's height measured from the soles of the feet (Davidovits, 2019). Table 2 is based on Figure 6 assuming a male astronaut at 5 feet 10 inches180 pounds and female astronaut at 5 feet 2 inches 120 pounds. In general, astronauts should weigh between 110 and 209 pounds and height should be no more than 5 feet 11 inches (National Aeronautics and Space Administration).

The location of the center of gravity in Y direction is given by:

$$Y_M = \frac{\sum wy}{W} = \frac{6758.27}{148.57} = 45.5\ inch \qquad (7)$$

$$Y_F = \frac{\sum wy}{W} = \frac{5467.23}{125.83} = 43.4\ inch \qquad (8)$$

The CG for a male astronaut is 45.5 inches and female astronaut is 43.45 inches from the soles of the feet. This is well above the natural human CG. A male astronaut's natural CG is 6.3 inches and a female astronaut's natural CG is 8.4 inches below composite CG of the EVA suit. The location of the center of gravity of an object affects its stability. The lower the center of gravity (CG) is, the more stable the object. However, the higher it is, the more likely the object is to tip over if it is pushed. The high CG of EVA suit may cause an issue during a Martian windstorm.

The EVA suit centroid is computed based on Figure 7 with an approximate front surface area of 1881 inch square (Table 3). The front and back side of the suit has maximum surface area.

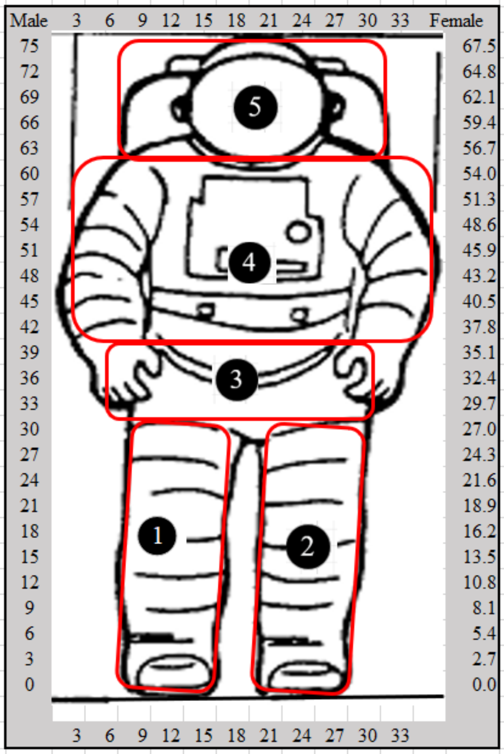

Figure 7: EVA(Extravehicular Activity) Suit Front Position Reconfigured from NASA's MAN-Systems Integration Standards Volume 1 Section 14.

	Male			Female		
Component	**Area(in^2)**	**Y (in)**	**AY**	**Area**	**Y**	**AY**
1	320	16	5120	270	13.5	3645.0
2	320	16	5120	270	13.5	3645.0
3	195	36	7020	186.3	32.2	5998.9
4	701.4	51	35771.4	628.4	44.2	27775.3
5	345	69	23805	310.5	62.1	19282.1
Total	1881.4		76836.4	1665.2		60346.2

Table 3 Surface Areas of Front Position and Y Distances Measured from the Reference Axes.

$$Y_{cM} = \frac{\sum Ay}{\sum A} = \frac{76836.4}{1881.4} = 40.8\ inch \qquad (9)$$

$$Y_{cf} = \frac{\sum Ay}{\sum A} = \frac{60346.2}{1665.2} = 36.2\ inch \qquad (10)$$

Center of gravity is the point where the total weight of the body acts while centroid is the geometric center of the shape. When an object has a perfectly uniform density these two centers are exactly the same. However, when additional weight is added to the object, in this case

PLSS(Portable Life Support System) and OPS (Oxygen Purge System), the two centers can be at different locations, as shown in Figure 9.

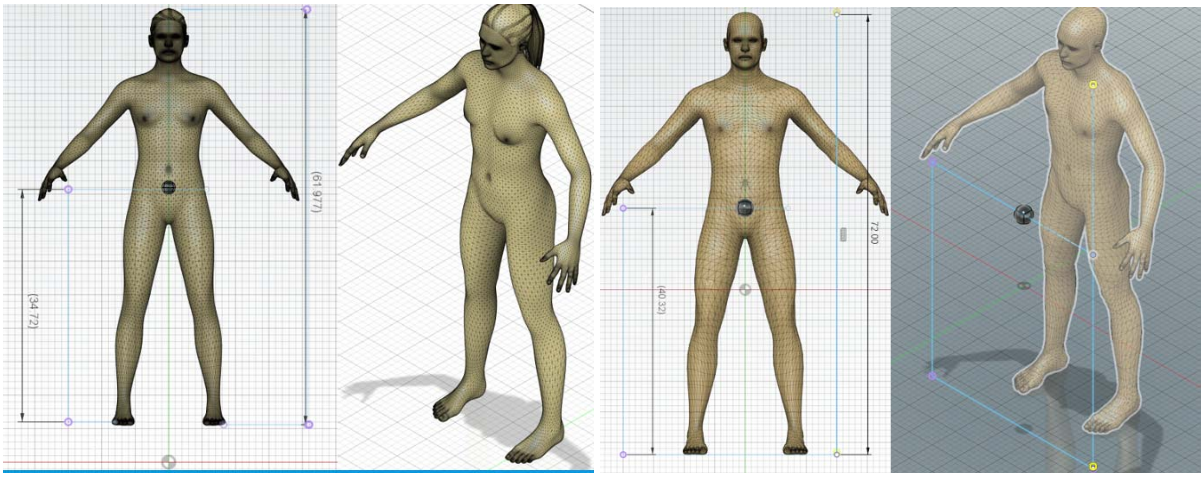

Figure 8: : 3 D Model of Male and Female Astronaut in Autodesk Fusion 360.

Modeling 3 D in Autodesk Fusion 360, Figure 8, female astronaut at 62 inches tall with CG at 34.72 and male astronaut at 72 inches tall with CG at 40.32 inches from the soles of the feet.

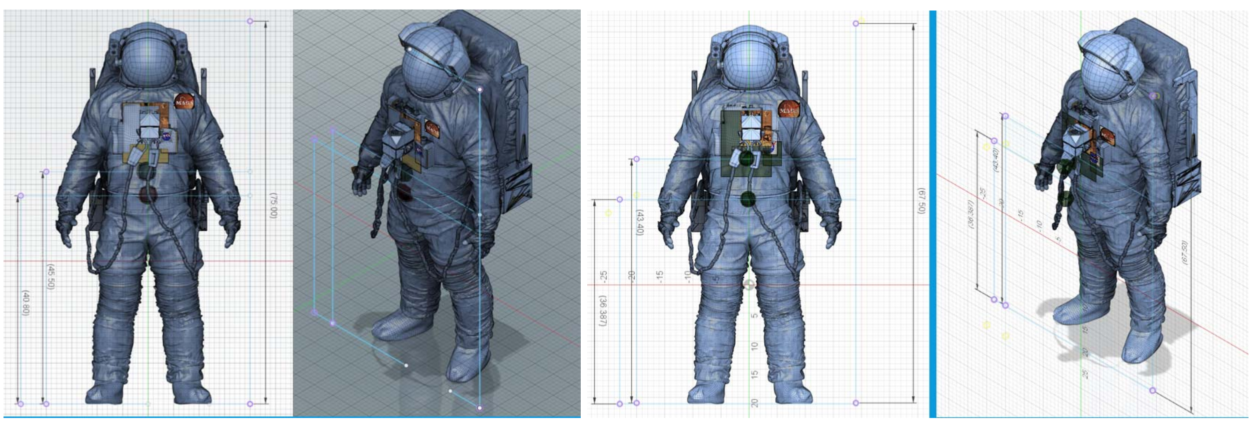

Figure 9: 3 D Model of Male and Female Astronaut in EVA Suit in Autodesk Fusion 360

The overturning moment and sliding of the stability of the astronauts due to the wind load is determined by:

For male astronauts from Table 1 computation (7) and Figure 9:

The overturning moment of the base of the feet due to astronaut weight is

$$Moment = (148.57lb)x(45.5\ inch) = 6760\ in - lb \qquad (11)$$

From computation (5) for 62 mph wind on Mars with the velocity pressure of 0.415 psf will produce an overturning moment of

$$M = \left(\frac{0.415}{144}\right)(1881.4)(40.8) = 221.2\ in - lb \qquad (12)$$

Which is far less than moment due to the male astronaut's weight. To determine the overturning wind velocity, the following equation will be used (Figure 10)

$$R = qSC_d \qquad (13)$$

R= resulting force acting on centroid of EVA suit in pound force

q= velocity pressure in pounds per square foot

S = EVA surface area

C_d = drag coefficient (unitless) assuming C_d=1

Overturning moment due to the wind on EVA is given by

$$M = RC \qquad (14)$$

C = distance from the bottom of the feet to the centroid of the EVA in inches

From equation 3 and 13

$$M = 0.000108V^2SC \qquad (15)$$

Setting M equal to 6760 in-lbs, results in the wind speed of 342 mph. Consequently, for male astronaut to be blown away by Martian dust storms the wind speed has to be greater than 342 mph.

or greater to move the

$$6760 = 0.000108V^2(1881.4)(40.8) \qquad (15)$$

$$q = \frac{\frac{6760}{40.8}}{\frac{1881.4}{144}} = 12.68\ psf \qquad (16)$$

$$V = \sqrt{\frac{12.68}{0.000108}} = 342\ mph \qquad (17)$$

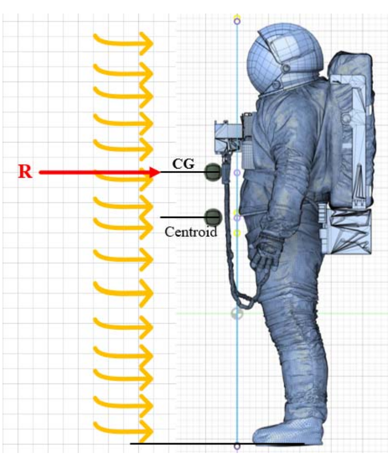

Figure 10: Wind Pressure of Front Surface of the EVA Suit

Similarly for female astronauts, the overturning wind velocity is 347.6 mph.

$$Moment = (125.83lb)x(43.4\ inch) = 5461in - lb$$

$$M = \left(\frac{0.415}{144}\right)(1665.2)(36.2) = 173.7\ in - lb$$

$$5461 = 0.000108V^2(1665.2)(36.2)$$

$$q = \frac{\frac{5461}{36.2}}{\frac{1665.2}{144}} = 13.05\ psf$$

$$V = \sqrt{\frac{13.05}{0.000108}} = 347.6\ mph$$

Conclusion

We have seen in science fiction movies in which the astronaut is blown away and carried by a Martian dust storm. In this article, the wind velocity pressure on a male and female astronaut is evaluated. On earth, the equipment used to measure wind is known as anemometers and can record wind speed, direction, and the strength of gusts. The anemometer and wind vane are each attached to a horizontal supporting arm located 33 feet above the ground in open terrain. Since wind varies rapidly over very short periods of time, it is sampled at high frequency (every 0.25 sec) to capture the intensity of gusts, or short-lived peaks in speed, which cause the greatest damage during a storm. The gust speed and direction are defined by the maximum three second average wind speed occurring in any period. ASCE/SEI 7 provide basic wind speeds based on 3-second gusts at 33 feet above ground for Exposure C which is "Open terrain with scattered obstructions including surface undulations or other irregularities having height generally less than 30 feet extending more than 1500 feet from the building site in any quadrant."(ASCE/SEI 7) However, on Mars the wind speed measurement device like hot film anemometers or a Telltale instrument which are mounted on a boom an average distance of 5 feet above the surface. Based on data from NASA's landers, the highest wind speeds are correlated to global dust storms with speeds up to 62 mph. From NASA's MAN-Systems Integration Standards Volume 1, Section 14 the dimensions for a EVA(Extravehicular Activity) space suit is used to determine the center of gravity and centroid of the EVA. Bernoulli's Equation was modified based on Martian atmospheric density to determine velocity pressure in pounds per square foot (Equation 3). Contrary to science fiction movies, the maximum wind speed on Mars (62 mph) would feel more like a light breeze than a tropical storm. The wind speed must be in excess of 342 mph for a male astronaut and 348 mph for a female astronaut to cause instability.

Further data is needed to measure and evaluate available wind more accurately, predict and measure wind speed, wind direction, and ambient turbulence. Placing wind speed measurement instruments similar to earth across large portions of the Mars' surface will provide valuable data that could be used for Wind energy.

Open Research

The data that support the finding of this study is publicly available in NASA's MAN-Systems Integration Standards Volume 1, Section 14.. https://msis.jsc.nasa.gov/sections/section14.htm

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