[ID 321997]

[Apollo's Legacy, NASA's Future: Leveraging Fusion 360 for Space-based Manufacturing]

[A Next Giant Leap: Using Fusion 360 for Returning To the Moon And On The Mars]

Dr. Patrick Suermann
Department Head, Construction Science at Texas A&M University

Learning Objectives

- [Learn how to conduct dynamic simulations in Fusion 360]
- [Learn about space-based projects using Fusion 360 for intermediate science and engineering]
- [Learn about other discrete element modeling (DEM) software]
- [Learn about a playbook for conducting low-gravity simulations for furthering Apollo's legacy and NASA's future]

Description

[NASA's work at the moon, which is pressing forward right now, is "preparing us for the next giant leap: challenging missions to Mars and other deep-space destinations"—NASA.gov. This class will help anyone looking for applying innovation for static stress analysis and finite element analysis via simulations and additive manufacturing. The presenters will show a case study where Fusion 360 software was used to accomplish the experiment when the competitive software platform failed to meet the expected results. Also, find out how Fusion 360 helped the Texas A&M University and the U.S. Air Force Academy teams conduct feasibility/benchmark tests on a mechanical drilling system and satellite mockup before their use in a Zero-G flight alongside NASA research. This session is a must for anyone who wants to learn about Fusion 360 for simulations, or for those interested in innovating with Fusion 360 for advancing the future of the built environment off-world.]

About the speaker

Patrick C. Suermann, PhD, PE, LEED AP is a graduate of the U.S. Air Force Academy with a B.S. in Civil Engineering. After serving as a combat and stateside engineer, he earned his M.S. in Construction Management from Texas A&M University and subsequently taught computer courses for engineers at the U.S. Air Force Academy. In the spring of 2009, he successfully earned his Ph.D. in Design, Construction, and Planning from the University of Florida. Later, he led numerous, large-scale military construction projects around the world and excelled as an educator during a distinguished 20-year career as a U.S. Air Force officer. He is now the head of the Texas A&M Department of Construction Science, the largest of its kind in the world. He is in constant pursuit of developing the best team with the most knowledge about the built environment.

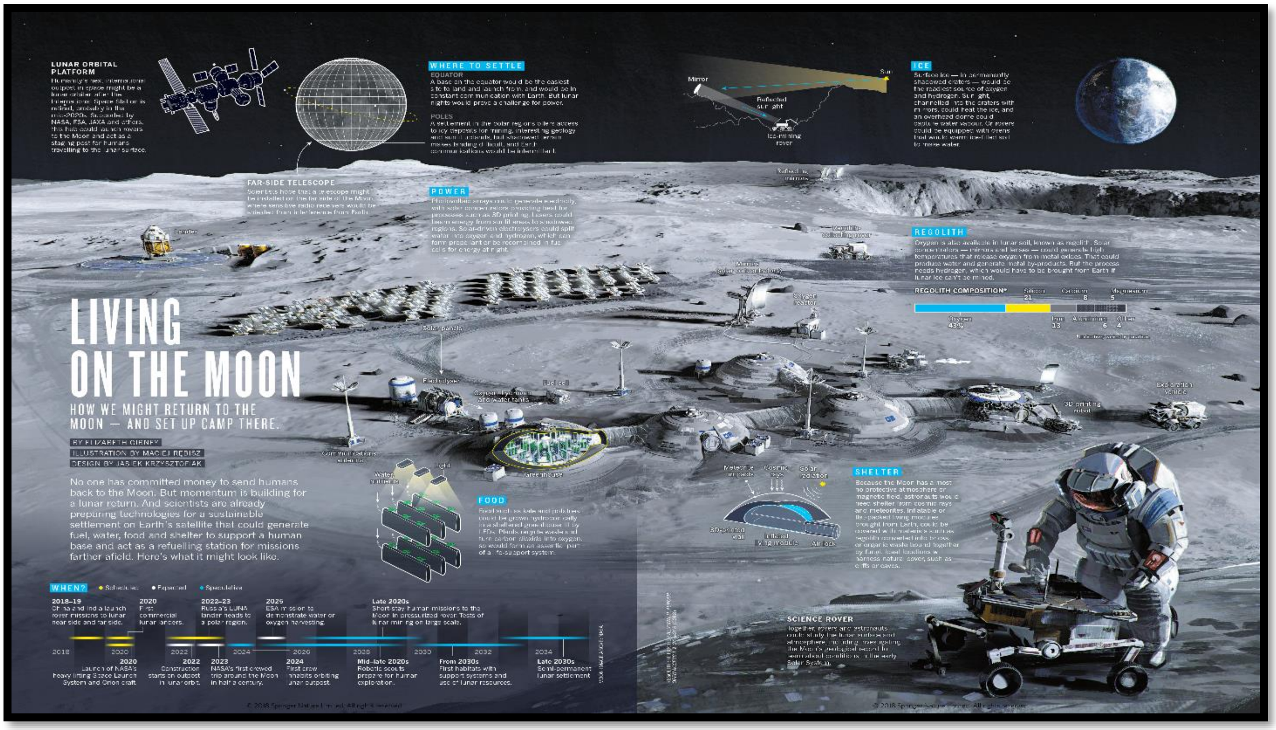
What is In Situ Resource Utilization?

To live and work in deep space for months or years may mean crew members having less access to the life-sustaining elements and critical supplies readily available on Earth. The process to develop its own products with indigenous materials is a practice which is called In-situ resource utilization (ISRU). ISRU will become increasingly important as human space exploration evolves toward longer journeys farther from our home planet. Resupply missions are expensive, and as astronaut crews become more independent of Earth, sustained exploration becomes more viable. Future astronauts will require the ability to collect space-based resources and transform them into breathable air; water for drinking, hygiene, and plant growth; rocket propellants; building materials; and more. Mission capabilities and net value will multiply when useful products can be created from extraterrestrial resources. The image displayed shows the timeline overview for the Artemis missions planned by NASA to achieve by year 2030.

In Situ Construction

To manage and focus the wide range of possible ISRU applications and their development within NASA, NASA's Chief ISRU Engineer, Gerald Sanders, typically divides ISRU into six main areas of interest: Resource Assessment, Resource Acquisition, Resource Processing/Consumable Production, In Situ Manufacturing, In Situ Construction, and In Situ Energy (Sanders 2013). The development and flight of systems and capabilities in these six main ISRU areas requires expertise and knowledge from multiple science and engineering disciplines spread across three NASA Mission Directorates: Human Exploration and Operations, Science, and Space Technology (HEOMD, SMD and STMD). **I**n situ refers to construction which is carried ou**t using** raw materials at the building site. When you compare in situ construction with prefabricated construction in which building components are made *in* a factory and then transported to the building site for assembly, you will notice the difference in amount of embodied energy while working with both the processes. To realize the human colonization on the Moon, an imperative lunar base for sustainable long-term human presence must be established at first. However, it is too expensive to transport building materials from Earth; for example, it could cost up to $2 million to transport an ordinary brick to the Moon. (Duke, M.B. et al, 2003).

Understanding Artemis missions and the concept of Living on the moon



This image has been taken from a published article in Nature magazine.

Our moon makes Earth a more livable planet by moderating our home planet's wobble on its axis, leading to a relatively stable climate, and creating a tidal rhythm that has guided humans for thousands of years. The moon was likely formed after a Mars-sized body collided with Earth and the debris formed into the most prominent feature in our night sky. It is the only celestial body beyond Earth that has been visited by human beings. It's been 50 years since we first landed on the moon in July of 1969. Fast forward to 2019 and we are planning to return to the moon to stay.

NASA is planning to build a lunar orbiter like International Space Station (ISS) and the concept is called *Artemis*. The spaceship will be relatively smaller than the ISS and will be a temporary office and home for astronauts doing research on lunar surface. The orbiter has been named 'The Gateway'. The Gateway will have living quarters, laboratories for science and research, docking ports (like doors) for visiting spacecraft, and more. (Source- NASA)

NASA is committed to landing American astronauts, including the first woman and the next man, on the Moon by 2024. NASA's powerful new rocket, the Space Launch System (SLS), will send astronauts aboard the Orion spacecraft a quarter million miles from Earth to lunar orbit. Astronauts will live and work around the Moon as they dock Orion at the Gateway. The crew will make voyages from the Gateway to the surface of the Moon in a new landing system (proposed to NASA on the centennial challenges and UCF) before returning to the orbital outpost. Crew will ultimately return to Earth by boarding the Orion.

Gateway 2024 Concept (Credits: NASA)

To go further we must travel greater distance and more duration. We need to use the resources we find at our destination, we must overcome radiation, isolation, gravity and extreme environment like never before. These are the challenges we face to push the balance of humanity. We are going to the moon to stay by 2024.

What is Regolith? Why is it necessary for human inhabitation on moon?

Regolith is a highly abrasive material that has the potential to cause significant problems to engineered systems and human health during future exploration missions beyond Earth, especially those missions focused on high levels of interactions with the regolith of the target body (i.e. mining and construction). Understanding how regolith behaves during drilling processes in low-gravity environments of asteroids, the Moon, and Mars is a critical component in determining best-practices in dust mitigation and asset protection strategies.

The difference between the atmospheres on the inner planets and moons is enormous, which results into modifying processes on these planets surfaces varying from Earth. Chemical and physical processes on most extraterrestrial bodies in the Solar System are limited by the lack of water. Oxygen is available in lunar soil (regolith).It comprises of 43% of oxygen. Solar concentrators like mirrors or lenses could increase the amount of temperature that could release oxygen from metal oxides. This could produce ample amount of oxygen for the production of water by expediting transport of hydrogen from earth. Another source of oxygen can be lunar ice found on moon which could produce direct water if sunlight is concentrated on it.

Apart from producing oxygen and water, regolith particles could be used to amalgamate with geo-materials used for construction on earth. The 3d printing of the mixture could be developed as a building material which could provide a shield from radiation on moon and a sustainable way to provide human inhabitation.

Learn about space-based projects using Fusion 360 for intermediate science and engineering

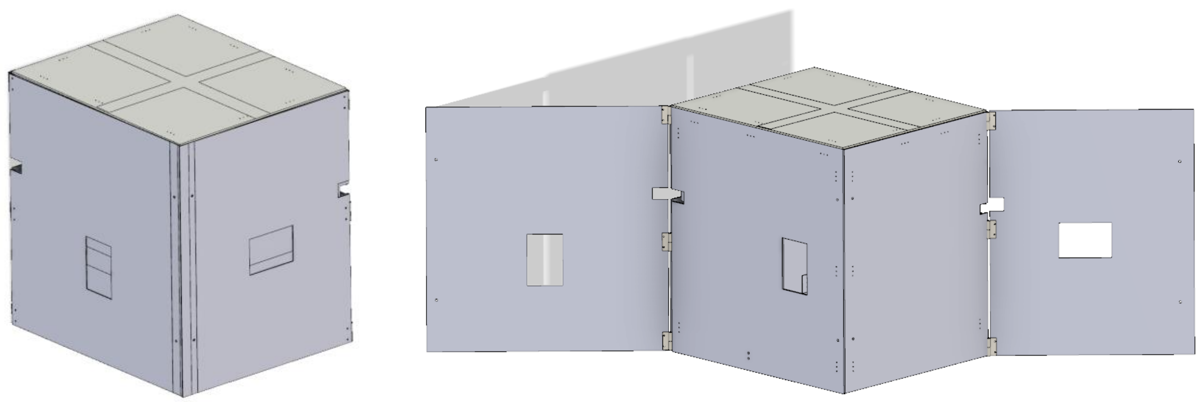
Experiments: The Zero G experiment

Zero G flight, November 12, 2018

In November 2018, a team from Crow Industries (CI), Texas A&M University's Department of Construction Science (TAMU), and the United States Air Force Academy Department of Astronautics (USAFA) conducted a series of low-gravity parabolas (three Martian, two lunar, and twenty-five microgravity) aboard a Zero-G research flight to evaluate regolith propagation during drilling in low-gravity environments. The experiment consisted of six regolith simulant types: two Martian, one lunar, and three asteroidal. The two Martian simulants were Exolith Lab's MGS-1 and NASA's MMS. The lunar simulant was CI's LMS-1, which is similar in structure and composition to NASA's BP-1. The asteroidal simulants were Exolith Lab's CR-1, CM-2, and CI-2. Predictive discrete element method modeling of the simulants' behavior was performed in partnership with Coupi, Inc. and presented in the Advances in Computational Design journal.
Researchers operated a hand drill in microgravity environment on samples that simulate rocks on the Moon and Mars. Wearable biometric monitors record data to test low to zero gravity's impact on human spatial cognition, a key factor in the ability to perform basic and high level tasks in space.

Experiment 2: USAFA FalconSAT Engineering Model: Stress Analysis

Computational stress analysis was used to provide evidence that a structure meets g-load requirements set for by Zero Gravity Corporation and the Federal Aviation Administration to allow in flight experimentation on the structure to occur within Zero Gravity Corporation's aircraft. The computer based nature of the analysis allowed the solution to be found through successive simulation model alterations and subsequent solves as hand calculations would have proven cumbersome and unrealistic to attempt. The model greatly exceeded some requirements set forth and marginally passed others. Ultimately, the model was cleared to fly aboard Zero Gravity Corporation's aircraft to conduct research.



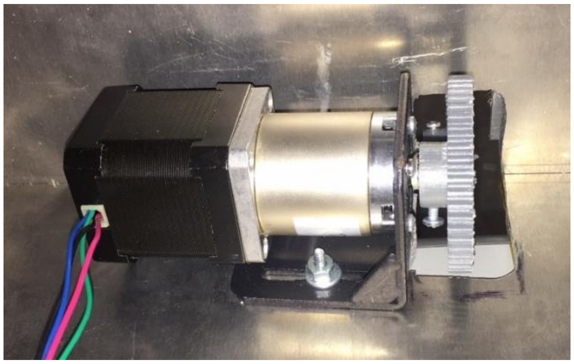
9 g load configuration (left) and 3 g load "free-float" configuration (right)

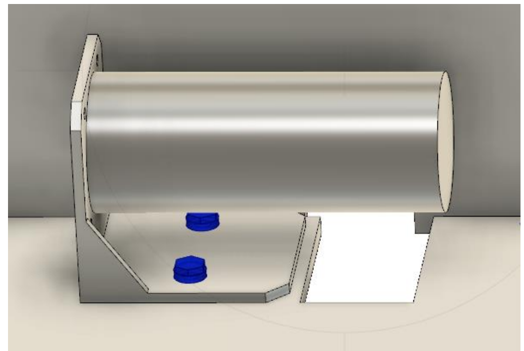
The CAD model was created in Solidworks due to a higher level of familiarization with the modeling software and then was uploaded to Fusion 360 for stress analysis. Fusion's modeling software uses the proven NASTRAN code to compute the EM's factor of safety. About Nastran code: NASTRAN is a finite element analysis (FEA) program that was originally developed for NASA in the late 1960s under United States government funding for the aerospace industry. (Source: Nasa)

Learn how to conduct dynamic simulations in Fusion 360

Issues faced:

The panel actuators are simulated with a solid zinc cylinder, which has an accurate CG location relative to the bracket and a higher mass than necessary to allow for a conservative stress simulation, as shown in Fig below. Zinc is chosen due to its closeness to the actuator's mass and the exact average density of the actuators not being available in the Fusion materials library. The EM and modeled actuators are mirrored due to error on behalf of the model designer. The effects to the stress analysis are negligible.



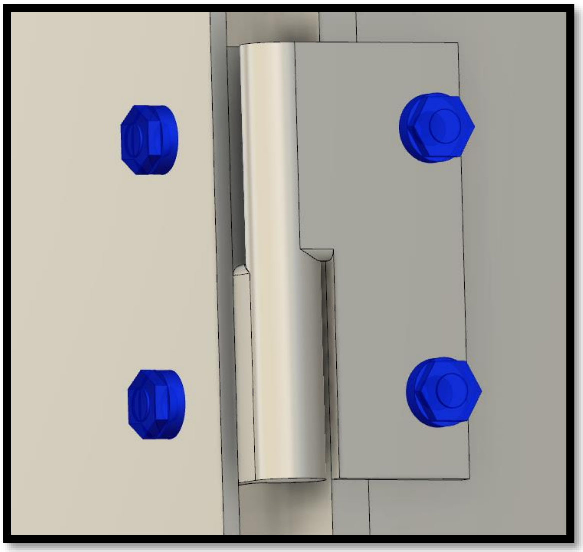


EM’s panel actuators and simulated counterpart

The aforementioned simulation considerations produce an abnormally low factor of safety once the simulation is solved. Even during the 3g load it results in a FoS of approximately 0.1. The low FoS is found in the hinges near the pin. This leads to the assumption that there is a simulation or modeling error within that part. This error most likely comes from the contact between the sharp edges of the hinge leaves. This normally produces inaccurate results.

Iterations of Modeling:

In order to remedy this issue the solar array’s piano hinges are treated as solid bodies to increase the accuracy of the simulation (Figure below). In addition to eliminating the sharp contact points, it simplifies the model and marginally decreases the simulation time. When this iteration failed, the edges of the hinges were filleted to further reduce stress concentrations caused by those sharp corners. The changes created by this were negligible but alterations were preserved to retain any benefits. Once the solve is run with the solid piano hinges, the point of failure shifts to a seemingly arbitrary bolt hole in an l-bracket. This indicates an improvement in modeling as the failure has moved from a simulation error to failure on behalf of the bracket or the shear with in the bolt connector (the simulation does not specify failure type). A third bolt connector is added to each pair of connectors on the l-brackets in the model. This is implemented physically in the EM via the addition of a third rivet to each rivet pair.



CubeSat Hinges Modeled in Fusion360

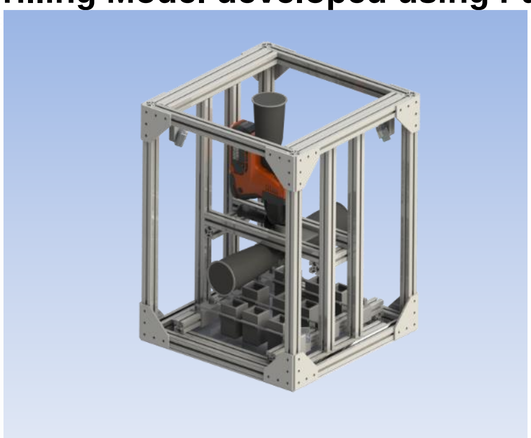
Results and how usage of Fusion 360 helped with the model's pretesting before the crucial Zero G flight:

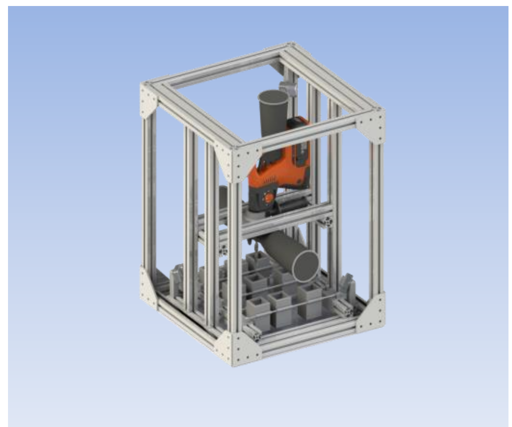
Through a great deal of iteration, the model is able to successfully reach passing FoS. Initially, the model did not pass the FoS requirements due to simulation problems regarding Fusion/NASTRAN's treatment of sharp corners and contact between sharp bodies. A potential cause is investigated with respect to stress concentrations in sharp edges and the selection of small surfaces for fixed constraints. Special types of contact sets are strategically used to simulate certain constraints accurately without greatly increasing computation time or work load; specifically the use of the "offset bonded" contact to simulate the ratchet strap across the surface of the solar panels. The zinc panel actuator mass simulator is a sufficient choice for modeling the panel actuators. Reaching the final model could not have been done if a timely fashion without the aid of CAD simulation software. Iterating through the engineering process via hand calculations would have proven herculean in nature given the project timeline. A possible source of error in the FoS is the mirrored nature of this part in the simulation versus the EM.

Finite Element Analysis through Fusion 360's static stress analysis tool is chosen as the best option to prove the Engineering Model's viability due to the complex nature of the structure and loads. Through many iterations of model modifications and analysis, the Engineering Model is expected to pass the g-load requirements and subsequently be permitted to fly.

A source of difficulty is the massive number of simulated bolted connections required to construct the simulation model as it causes incredibly time consuming model construction, manipulation and solves that last upwards of ten hours. This hurts the iterative engineering process greatly and inhibits innovation and improvement. In order to improve the model and results further, a method should be devised to test pieces of the model individually. In order to remedy the potential stiffness cause by the "offset bonded" contact sets, a 2 inch strap width section could be extruded on the back on the panel and selected as opposed to the panels' entire back face. This would more accurately simulate the effects of the circumferential strap. Additionally, an investigation can be launched into the large deviation between the 9 g +X and +Y FoS. Due to the similarity between the load cases, there is the potential for a simulation error to exist. Validating this will require further investigation mediated by the accelerated testing mentioned above. Ultimately, achieving the objective was not possible without the convenience and flexibility that the computational analysis provides.

Drilling Model developed using Fusion 360 and SolidWorks





Drill Rig Sectional view from SolidWorks model

The purpose of these experiments was to gain more knowledge about space effects on in-situ construction techniques. Initially, the drill rig model parts were designed in Solid works software. The Solidworks™ file was imported to Fusion 360™ for the stress analysis and simulations. These analyses were done to achieve accurate propagation flow of the dust regolith when drilled in low to zero gravity, amount of stress induced on the model when it is utilized and the stability of the model when used in Zero G flight under extreme conditions. Static Stress analysis is done on the drill with gravitational acceleration acting in Earth, Mars and Moon. The handle of the drill is locked and the force is applied on the stress pressure points, highlighted in figure given below to develop the stress analysis in Fusion 360™. The issue which was faced in the initial stages of assembling the solidworks file in Fusion 360. The smaller parts designed separately in Solidworks went all over the plane when tried to transfer in Fusion. Solidworks is an assembly-driven software. That means it builds parts individually before assembling them in a separate file. This is advantageous when parts are used in many assemblies as well as for documentation purposes. Although Solidworks does have the option to create multibody parts, this feature does not provide the same amount of flexibility as Fusion 360's process. (Source: the playergroup, scribd)

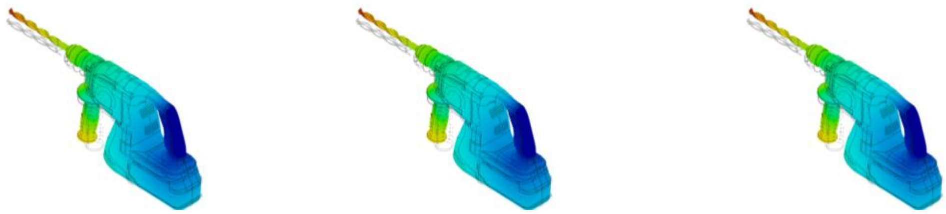
Fusion 360's solution is to use a multi-component part system, where components of an assembly are built and assembled in the same file. This makes it easier for engineers and designers to reference other components and build off of them within an assembly. Unlike Solidworks, Fusion 360 does not need to reference multiple files when building an assembly, although larger assemblies in Fusion can cause issues. Fusion 360 excels with smaller assemblies with many cross-referenced parts.

All the components had to be hinged down to the surface in order to function for the collective stress analysis.

Drill with highlighted stress points

Calculation of Forces acting in low gravity environments and Stress analysis by Fusion 360

The drill model was tested by different forces acting on it on different gravitational conditions. The points where the static stress will be prevailing maximum were kept as the principal axis of the drill and the drill handle. The principal axis is where each of three mutually perpendicular axes in a body about which the moment of inertia is at a maximum. The gravitational acceleration of the different conditions and different simulants used on the flight were considered to determine the factors of safety. The gravitational acceleration of 1.62 m/s^2, 3.711 m/s^2 and 9.807 m/s^2 for moon, mars and earth were multiplied with the actual forces to get the static stress on the drill. The fusion 360 report was then developed to observe the changes on the drill when operated in low gravity environments. The report showed changes but passed the feasibility tests since it didn't pass the breaking point when simulating.



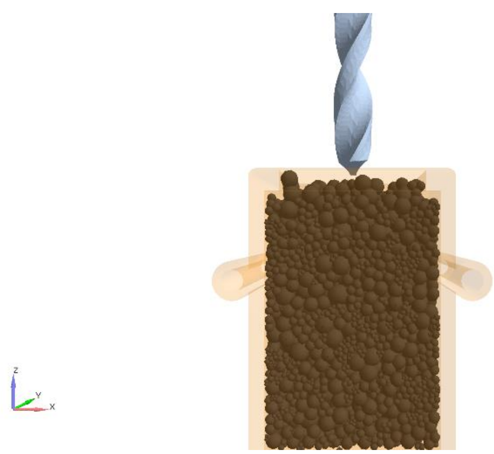
Earth 0 0.003846 | Mars 0 0.001456 | Moon 0 6.356E-04

Total displacement on the drill in inches after stress applied

Learn about other discrete element modeling (DEM) software

DEM Modelling, Shortcomings of Fusion 360 and Use of Coupi

The stress analyses were conducted in Fusion 360™. Due to Fusion 360's inability to develop simulations of dust propagation, software like Coupi™ software and Autodesk CFD were considered for the process. Finally, Coupi™ (Controlled Objects Unbound Particles Interaction) was considered to develop simulations of the dust propagation by the drilling process via discrete element modeling (DEM).



Coupi Video snapshot of drilling

The above shown draft video snapshot is of drilling with 300 rpm in Martian gravity. Coupi used constant velocity control while developing the drilling simulation.

Drill simulation still done in Coupi

DEM is a first principle computational method to simulate the behavior of solids, individual particles, and particle aggregates (bulk solids) using physical interaction rules between the particles. The DEM is extensively used for modeling of granular materials and powder technology. The actual particle count involved in the process of dust propagation during drilling exceeds the capability of any model to track each particle individually by many orders of magnitude. To address this issue, larger particles that represent the group of actual particles need to be used. The size of the particles in DEM analysis can be considered as a "resolution" of the model. To achieve the correct results of bulk behavior, contact mechanics laws between these large particles used in simulations need to be adjusted. The post analysis of the results also needs to include the micro-macro transition from modeled particle parameters to the actual particles behavior. This multi-scale approach is known as "coarse-graining" and is widely used.

The drilling simulation include the following stages:

1. Particle bed creation. At this stage the CAD triangulated model of the experimental container is imported and filled with the particles. The particle linear size varied from 100 micron to 2 mm. Each particle is represented by three partially overlapping equal spheres with their centers forming an equilateral triangle and all three spheres have a single common point – the center of the particle. Using such tri-spherical particle shape instead of spheres allows taking into account a possible particle interlocking process while keeping the

shapes simple enough to avoid too much computational overhead. Particles are gravitationally deposited under normal Earth gravity with no cohesion into the container.
2. Particle bed adjustment. At this stage some particles are removed from the top of the container to create an even surface. Then, the particle properties are adjusted by adding cohesion and adjusting friction between particles to the desired value.
3. Gravity adjustment. At this stage gravity is gradually linearly by time reduced to the target values such as Mars, Moon, Asteroid or 0 gravity.
4. Drilling. The tip of the drill is imported from the CAD triangulated model. The constant angular velocity and constant drilling velocity is applied to the drill to allow it to move into the particle bed.

After the last stage is completed, the results are analyzed to restore the velocity field of the particles that left the container. The stress within the material, the stress evolution on the container walls, and forces and torques applied to the drill tip are restored.

Conclusion

The DEM analysis is another backdrop of Fusion 360 which was further tested on another competitive platform Coupi. This can be a new business line for Autodesk as they approach a smoother cloud design process as DEM and FEM in one platform could be a turning point in simulation. The cloud design has bested its rival Solidworks for our project. Although, this was another take on the software use as it has been used in a pioneering way for space exploration and experiments with similar extraterrestrial value. This shows us a wider usage of Autodesk products for further usage than the pre-existing modelling patterns experienced in the manufacturing and construction industry.

VR machine learning experiment of Dr. Dixit can be added in conclusion and ending point as offered in a similar Autodesk platforms as the company is now moving swiftly towards VR and Augmented reality.