Proceedings of the 10th World Congress on Mechanical, Chemical, and Material Engineering (MCM'24)
Barcelona, Spain –August 22-24, 2024
Paper No. HTFF 105
DOI: 10.11159/htff24.105

Design and Analysis of Drone for Foreign Object Debris (FOD) Detection in the Airport

Haifa El-Sadi*, Massimiliano Orfanini, Eleonora Orfanini
Wentworth Institute of Technology
550 Huntington, Boston, MA, USA 02115
*Corresponding author: elsadih@wit.edu

***Abstract* -** The Federal Aviation Administration (FAA) stated that Foreign Object Debris (FOD) is any object that is in an improper location in the airport setting that also has the potential to cause damage to equipment and personnel. There are an outstanding number of sources that could cause FOD to appear in operational areas, which makes prevention and detection very difficult and time consuming. These sources can come from the environment through wildlife and weather, operating equipment, and personnel on the runways, and even from the airport infrastructure itself. The aim of this project is to assist airports in enhancing runway safety by drones to improve the runway inspection process. SolidWorks, a computer-aided design (CAD) software, was used to create five designs, and the chosen design was subjected to Finite Element Analysis (FEA) to assess its strength performance. Given the high stresses that drones must endure during flight, it was decided to use onyx, a composite material made of nylon and carbon fiber, to construct the drone's chassis. Onyx has a strength of up to 40 MPa, which is more than sufficient based on FEA results that showed the highest stresses on the selected design to be just 2.5 MPa. The selection of SolidWorks Flow Simulation was employed as the method for conducting the CFD propeller analysis. Subsequent rounds of CFD testing led to the attainment of an average force value of 11.313 N. The outcome closely approximates the manually computed thrust value for the 7035 propellers at an RPM of 13000. The flow simulation findings represent the required thrust magnitude essential for operating the drone at the maximum permissible thrust limit.

***Keywords*:** Drone, CFD, Design, airport, Foreign Object Debris

1. Introduction

Runway inspections are regularly conducted by airports to identify and prevent foreign object debris (FOD) that can potentially cause significant damage and pose risks to aircraft. FOD refers to any unwanted objects present on the runway that can obstruct the path of airplanes, such as screws, bolts, or tire debris that may fall from a landing aircraft. According to the US Department of Transportation's one-year airport study, 60% of the detected FOD on runways consists of metal, while 18% is rubber [1]. According to the U.S. Department of Transportation, the expenses incurred by the airport inspection industry can reach as high as $13.9 billion annually [2].

As stated by the Federal Aviation Administration (FAA), Foreign Object Debris (FOD) is any object that is in an improper location in the airport setting that also has the potential to cause damage to equipment and personnel. There are an outstanding number of sources that could cause FOD to appear in operational areas, which makes prevention and detection very difficult and time consuming. These sources can come from the environment through wildlife and weather, operating equipment, and personnel on the runways, and even from the airport infrastructure itself. The unpredictable origins of FOD have led to a massive number of damaged items in the aerospace industry totaling upwards of $4 billion a year [3].

The aim of this project is to assist airports in enhancing runway safety by drones to improve the runway inspection process. Runway inspections are regularly conducted by airports to identify and prevent foreign object debris (FOD) that can potentially cause significant damage and pose risks to aircraft. FOD can originate from various sources, including weather conditions, fallen or misplaced aircraft components, and the degradation of pavement leading to rubble formation. If these objects remain undetected or are not promptly removed, they can pose serious hazards during takeoff or landing. Potential risks include damage to aircraft engines, exterior surfaces, and the surrounding areas affected by debris propelled by the engine during the operation of the planes.

2. Design and FEA Analysis of the Drone

SolidWorks, computer-aided design (CAD) software, was used to create all five designs, and the chosen design was subjected to Finite Element Analysis (FEA) to assess its strength performance. Given the high stresses that drones must endure during flight, it was decided to use onyx, a composite material made of nylon and carbon fiber, to construct the drone's chassis. Onyx has a strength of up to 40 MPa [4], which is more than sufficient based on FEA results that showed the highest stresses on the selected design to be just 2.5 MPa.

(a) (b) (c) (d) (e)

Fig. 1. Different Design of the Drones

A Finite Element Analysis (FEA) study of the model subject to the thrust forces by each propeller was performed. It is very important to understand the structural integrity of the design before spending money and time on 21 printing and developing a prototype. Deformation is a critical factor to consider when finalizing the design of a drone, as overlooking stress and deformation risks mechanical failure, and rendering the drone unable to support its load. The team subjected the new base plate design to an FEA simulation in SolidWorks, leveraging the calculated thrust required from each propeller to lift the drone and its total weight. The team analyzed the deformation results and generated two plots: one not-to-scale plot reflecting the microscopic-level stresses the model undergoes and a to-scale plot demonstrating that no damaging deformation will occur during the drone's regular operations.

Figures 2 and 3 show the deformation results from the not-to-scale and to-scale plot respectively. By simulating the stresses and safety of the acrylic base plate, it was important to demonstrate its viability as a reliable and sturdy alternative. In Figure 3 the to-scale FEA plot shows that little to no deformation occurs with the selected thrust forces applied to each of the four motor shafts. Based on this analysis, the laser cutting of the base plate was proceeded.

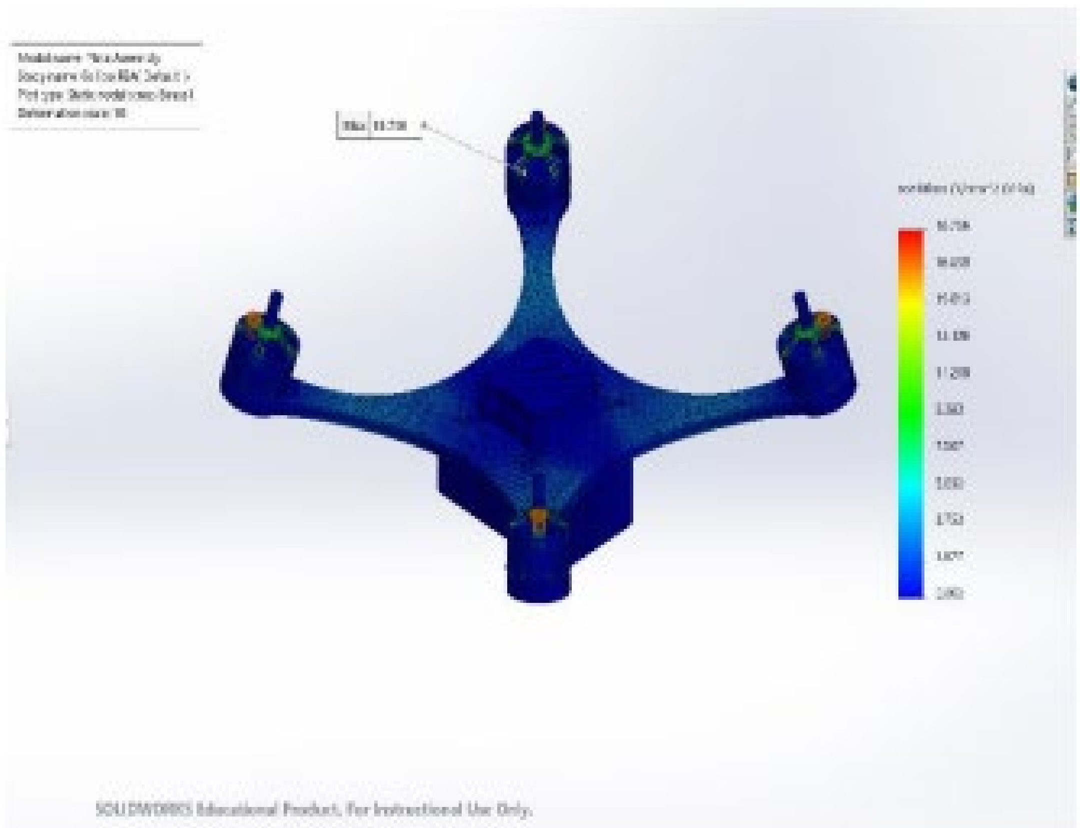


Fig. 2. FEA Stress Plot Not-To-Scale

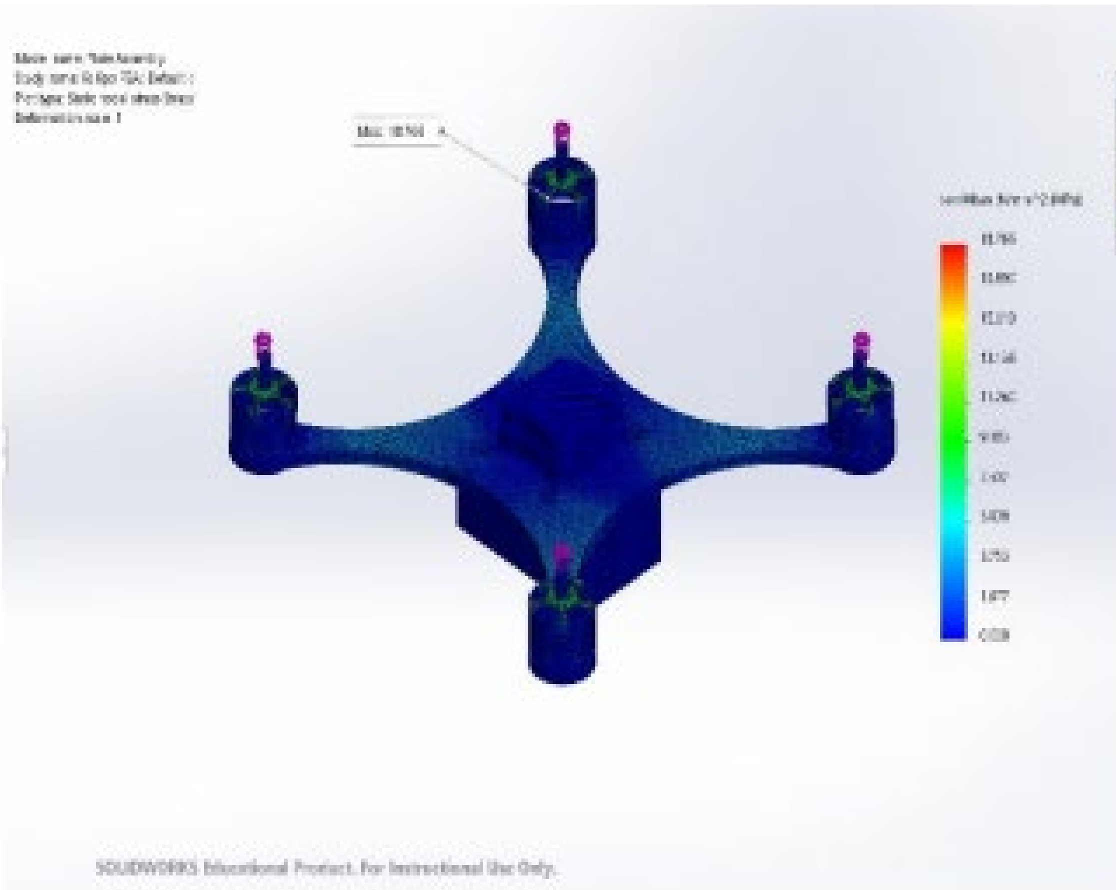


Fig. 3. FEA Stress Plot To-Scale

When designing a drone, one of the crucial areas to address is the propellers, which play a pivotal role in the drone's performance. The propellers, which rotate in tandem with the motor, generate the force needed to lift the drone off the ground. To ensure the correct propeller choice and optimal aerodynamic performance, it was employed a CFD analysis, with both results cross-verified for accuracy. Starting with hand calculations, our team relied on fundamental equations that are essential to understanding drone propeller dynamics, which were gathered through the MIT notes catalog website [5].

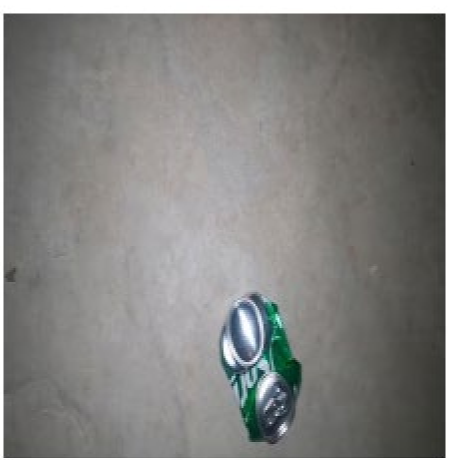
The primary objective is to detect the presence of Foreign Object Debris (FOD) on airport runways. In order to achieve this, it was crucial to develop a convolutional neural network (CNN) algorithm. The CNN algorithm was trained to recognize a clean runway, which serves as a reference point to identify any foreign objects present on the runway. This approach was suggested by industry expert Barry Bratton, as it is difficult to train the model to recognize every type of FOD that may exist on the runway. The CNN algorithm was trained using a dataset consisting of images of clean runways as well as images containing FOD. CNNs use layers of interconnected nodes to analyze and identify patterns in images. The initial layers of the CNN detect simple patterns, such as edges and curves, while deeper layers detect more complex features. The output of the final layer represents the probability of the input image belonging to each category. During testing, the CNN algorithm processes images captured by the drone's camera and provides a prediction on the presence of FOD on the runway. The accuracy of the algorithm is evaluated by comparing its predictions with ground truth labels assigned to each image. Through this iterative process, the CNN algorithm is optimized to achieve higher accuracy in detecting FOD on airport runways. . A dataset of FOD acquired through GitHub [6] and a clear pavement image dataset acquired through Kaggle [7], were used as part of the training. As debris detection is performed by the drone, various images taken in real-time may not match the images the model is trained on.

Therefore, when dealing with a small dataset, it is important to augment the data as it makes some modifications to the existing images and allows the model to learn from a wider variety of images. That way, as different scenarios are encountered, the model will be able to make better predictions. The final prototype was assembled, as shown in Figure 4

Fig. 4. prototype design

2.1. Camera FOD Detection Algorithm

The pictures taken by the drone will be transmitted to the operator via a receiver on their computer. The operators will then run the images sent by the drones through coded software that will be able to tell whether the runway is safe for flight. Additionally, the group will try to code a live image version of this software. This code is just an initial proof that this method exists. With further research and work this technology can give more accurate and faster results. The code was developed using a combination of Python, Tensor Flow libraries, NumPy, and Matplot. Python was used for debugging and running the code. Tensor flow libraries were used to get a pre-trained CNN model. NumPy and Matplot functions were used to process the code. NumPy provided support for numerical operations and Matplot enabled the visualization of data.



(a)

(b)

Fig. 5. (a) Object Debris, (b) Clear Pavement

There are 2 different data sets. One data set is to verify and detect debris and the other is used to verify a clear runway as shown in Figure 5.a and 5.b respectively. This will help the software navigate between whether the runway is clear or needs to be cleaned up.

4. Conclusion

The proposed drone system offers significant advantages over human inspection, as it can scan larger areas at higher speeds and with greater accuracy. This efficiency translates into saved time and energy for personnel currently conducting manual pavement inspections. Furthermore, maintenance of the drone system is simpler, less time-consuming, and more cost-effective compared to the maintenance of automated FOD detection systems like the X-Sight used in Boston. The estimated maintenance cost for our design is approximately $50 a year per drone. The largest and most impactful benefit of an unmanned aerial vehicle for the use of detection of FOD objects is its ability to ensure runway safety. Whether it is used as an initial detection device or as a secondary verification detection device, a drone utilizing machine learning algorithms can accurately detect FOD in operational areas.

References

[1] U.S. Department of Transportation. (2009). *Airport Foreign Object Debris (FOD) Detection Equipment*. Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5220-24.pdf

[2] Transportation Research Board. (2011). Read "Current Airport Inspection Practices Regarding FOD (Foreign Object Debris/Damage)" at NAP.edu. In *nap.nationalacademies.org*. Airport Cooperative Research Program. Retrieved from https://nap.nationalacademies.org/read/14572/chapter/1

[3] Bachtel, B. (n.d.). Foreign Object Debris and Damage Prevention. https://www.boeing.com/commercial/aeromagazine/aero_01/textonly/s01txt.html#:~:text=Foreign%20object%20debris%20(FOD)%20at%20airports%20includes%20any%20object%20found,industry%20%244%20billion%20a%20year.

[4] Markforged. "Onyx." *Markforged Support Portal*, 17 Oct. 2022, https://support.markforged.com/portal/s/article/Onyx.

[5] Performance of Propellers. *11.7 Performance of Propellers*, web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node86.html. Accessed 12 May 2023.

[6] FOD-UNOmaha. (2023, April 24). Foreign Object Debris in Airports (FOD-A) Dataset Overview. Retrieved May 12, 2023, from GitHub website: https://github.com/FOD-UNOmaha/FOD-data.

[7] Kaggle. (2023). Pavement Image Datasets. Retrieved May 12, 2023, from www.kaggle.com website: https://www.kaggle.com/datasets/augustineheng/pavement-image-datasets.