Virtual Reality in Aerospace Engineering - Literature Review

Leonardo Zhou

Abstract

Virtual reality (VR), an immersive technology that places users into a computer-generated virtual environment, has emerged as a promising tool with applications in various fields such as gaming, training, education, and social networks. In the aerospace engineering domain, VR has proven to be a valuable asset, providing them with multiple solutions to older problems with elegance. Therefore, this literature review will explore the expansive potential of VR, focusing on the aerospace engineering sector and highlighting what VR has already contributed to aerospace. It will also investigate proposed implementations of VR in aerospace companies and outline the most popular next steps. The review emphasizes the pursuit to solve the problem of cybersickness and promotes the further development and experimentation of VR in companies to advance the field of aerospace engineering.

Keywords: cybersickness, mental health, teleoperation, training, visualization

Introduction

Virtual reality (VR) is the technology of simulating another world in which a user that has been immersed into it can interact inside it. Tools such as controllers, 3D display headsets, and even full-body trackers are applied to provide the user with such an experience. The field started in 1968 when Ivan Sutherland created the first head-mounted display (HMD), and the field of VR has grown substantially to this day, evolving into five-hundred-dollar Oculus Quest and HTC Vive headsets supported by public-friendly software such as Unity or Unreal Engine.

However, it took around 30 years before virtual reality was seriously considered by marketers and engineers for different activities, such as education (Bricken 1991), gaming (Schroeder 1993), and social connections (Meleis 1996). Around the start of the new millennium, it was realized that virtual reality could act as a new type of computer-aided engineering (CAE) tool to help engineers with their designs and prototyping, although implementation at that stage was not possible, needing more research and development (Lu, Shpitalni, and Gadh 1999). Over the next two decades, VR has been fine-tuned to the needs of engineers and their design processes, and now aerospace engineers are leveraging this technology to enhance their design and development processes, to make dreams like space travel and the colonization of Mars come true.

Applications specifically for aerospace began just before the dawn of the new millennium when Loftin (1996) reflected on the Hubble Space Telescope repair in 1993. There, a group of engineers and computer scientists were told to develop virtual environments to enable flight team members to have a correct mental model of the telescope and to practice techniques necessary to replace the telescope elements beforehand. 105 flight members underwent training using these environments, and the Hubble Space Telescope was ultimately repaired successfully.

This being the start of the widespread applications of VR in aerospace engineering, this review will attempt to outline the major applications, as well as discuss the future potential of VR in this field.

Method

All sources in this literature review are all journal articles compiled from Google Scholar and the University of British Columbia's online library catalogue. Keywords such as "(virtual reality OR VR) AND engineering AND (aerospace OR aviation OR space OR flight)" provided the majority of these articles. A total of N = 21 journal articles were compiled from an initial scan of the abstract, and after assessing the quality of these journal articles, N = 13 journal articles ended up being used.

Results and Discussion

The most common application of VR in aerospace is the application of ISS model environments to train pre-flight astronauts. Both Laskey and Keebler (1990) as well as Liu, Jiang, Liu, and An (2016) have investigated this use, with functions similar to Loftin (1996) cataloguing the repair of the Hubble Space Telescope. Laskey and Keebler (1990) applied Game-Based Virtual Reality (GBVR) in spaceflight education and training and tested it on 10 university students about to graduate with a BSc in spaceflight operations. The simulation was found to be more useful for learning, slightly more enjoyable than the typical popular game, and was at an acceptable workload level, according to the perspective of the students (Laskey and Keebler 1990). Liu et al. (2016) reflected on the Astronaut Virtual Training System (AVTS), which simulated zero gravity and allowed users to explore the virtual ISS with six degrees of

freedom. They took 24 subjects with college-level education to test the AVTS out, and it was found that, compared to the mock-up where subjects simply stood upright under the influence of Earth's gravity, those using the AVTS to train and familiarize themselves with the ISS module were better at identifying the position and orientation of objects placed around the module than those training with the mock-up. Some problems identified with the AVTS system included the unnatural movement of using a 3D mouse, as well as VR sickness and dizziness (Liu et al. 2016).

Even after training, however, VR can still be applied to help astronauts maintain healthy mental states aboard the ISS and under heavy work schedules. Salamon et al. (2018) raises concern for the mental well-being of astronauts: although there are beautiful views and missions are in groups of around three astronauts, isolation can still set in and be damaging to the mental health of these astronauts. Thus, they raise the potential of VR in space, as mental therapy or even just a relaxing place for astronauts. By saving certain preferable locations or experiences, astronauts can retreat into immersive places they feel relaxed and comfortable in. This can help astronauts deal with the loneliness on the spacecraft.

But VR does not need to be limited to being in space. It can also be applied on the ground, where teleoperation's significant time delay makes operators inefficient. By using a VR model of where the teleoperation is taking place, this time delay can be partially eliminated, but errors in VR models like these are inevitable. Zainan et al. (2009) synthesized model matching and robot compliance, two of the most common techniques when correcting a VR model of teleoperation, to get rid of both large errors (using model matching) and smaller errors (using robot compliance). Model matching is using AR to superimpose the VR model with the actual robot arm to fix any large differences. Robot compliance uses the measurements of each arm

component's angle, velocity, and position to make sure that whatever commands the operator is sending are being followed by the arm.

VR can also help pilots of unmanned aerial vehicles (UAVs) envision what it is like to be right on the vehicle, while greatly expanding the range, accuracy, and efficiency of the UAV itself. Alce et al. (2022) outlines a potential user interface, consisting of a VR cockpit with 360º views coming from a camera attached to the top of the UAV, such that the pilot no longer needs to have the UAV directly in view, but then can pilot the UAV as if they were flying the vehicle in the first place. Also, an artificial intelligent object detection system can then use the data collected by the camera to detect any flying objects so that the pilot can be warned to avoid crashing right into them.

Transitioning to applications that help the aerospace engineers themselves, there are a few potential VR applications that can guide the design process of aircraft and spacecraft. Tadeja et al. (2020) created a VR data visualization tool that compresses N-dimensional ($N > 3$) data into 2D or 3D scatter plots. Using an Xbox controller to interact, aerospace engineers can visualize both the 3D model as well as data plots in real-time. Also, I. Moerland-Masic et al. (2022) proposed using VR as part of the design process of an aircraft cabin. By replicating the cabin design into a CAD model shown to potential air passengers through a VR headset, better reviews and feedback can aid the design process to produce a more successful design.

One of the major core issues VR is facing, as raised in Liu et al. (2016), is cybersickness. A good proportion of VR users feel similar symptoms to motion sickness in a car. A more formal definition is that

> "... cybersickness is a phenomenon involving nausea and discomfort that can last for hours after experimenting [with] VR applications, linked to the discrepancies of perceived motion between real and virtual worlds (Kemeny et al. 2020)."

Currently, the best ways of reducing cybersickness include physically creating movement in the real world, galvanic or auditory stimulation, changing the type of movement in the environment (such as teleportation), and reducing latency (Kemeny et al. 2020).

The other obstacle to VR in space is implementing new ideas. So far, NASA has only been able to implement VR in training astronauts. However, other possible applications of VR have not been tested yet. Economically, this should be possible for such a large and government-funded organization.

Conclusion

Virtual reality, being one of the most popular emerging fields of technology today, is becoming increasingly versatile in many ways, including in aerospace engineering. The original application of applying VR environments as training simulations for astronauts was limited by the technology at the time, but now VR may be able to help aerospace engineers much more. Such applications include preserving mental health aboard the ISS, decreasing the impact of the delay of teleoperations, flying UAVs remotely with object-detecting systems, providing a simple way to view N-dimensional plots as compressed 2D or 3D scatter plots, and CAD design to provide higher-quality feedback from users. Although there are a few obstacles that VR must jump over to be used effectively in some proposed applications like cybersickness, over time these problems will be solved, and eventually, VR will become one of the main components of everyday aerospace engineering.

References

Alce, G., et al. "Design and Evaluation of Three User Interfaces for Detecting Unmanned Aerial Vehicles using Virtual Reality." In 19th EuroXR International Conference, EuroXR 2022, Stuttgart, Germany, 2022-09-14 - 2022-09-16. Eds. G. Zachmann et al. Cham: Springer International Publishing, 2022, pp. 36-49. DOI: 10.1007/978-3-031-16234-3_3.

Bricken, M. "Virtual reality learning environments: Potentials and challenges." ACM SIGGRAPH Computer Graphics 25, no. 3 (1991): 178–184. DOI: 10.1145/126640.126657.

Jiang, G., Liu, Y., An, M., and Liu, P. "The utility evaluation of the astronaut virtual training system in layout familiarization training." In 2016 6th International Conference on IT Convergence and Security (ICITCS). IEEE, 2016, pp. 1–4. DOI: 10.1109/icitcs.2016.7740376.

Laskey, L., & Keebler, J. R. "Evaluating system usability, workload suitability, and user experience of game-based virtual reality in spaceflight education and training." The Journal of Aviation/Aerospace Education & Research, 1990. DOI: 10.15394/jaaer.2023.1948.

Liu, P., Jiang, G., Liu, Y., and An, M. "The utility evaluation of the astronaut virtual training system in layout familiarization training." In 2016 6th International Conference on IT Convergence and Security (ICITCS). IEEE, 2016, pp. 1–4. DOI: 10.1109/icitcs.2016.7740376.

Loftin, R. B. "Aerospace applications of virtual environment technology." ACM SIGGRAPH Computer Graphics 30, no. 4 (1996): 33–35. DOI: 10.1145/240806.240810.

Lu, S. C.-Y., Shpitalni, M., & Gadh, R. "Virtual and Augmented Reality Technologies for Product Realization." CIRP Annals 48, no. 2 (1999): 471–495. DOI: 10.1016/s0007-8506(07)63229-6.

Meleis, H. "Toward the Information Network." Computer 29, no. 10 (1996): 59–67. DOI: 10.1109/2.539723.

Moerland-Masic, I., et al. "Application of VR Technology in the Aircraft Cabin Design Process." CEAS Aeronautical Journal 13, no. 1 (2022): 127–136. DOI: 10.1007/s13272-021-00559-x.

Salamon, N., et al. "Application of Virtual Reality for Crew Mental Health in Extended-Duration Space Missions." Acta Astronautica 146 (2018): 117-122. DOI: 10.1016/j.actaastro.2018.02.034.

Schroeder, R. "Virtual Reality in the Real World." Futures 25, no. 9 (1993): 963–973. DOI: 10.1016/0016-3287(93)90062-x.

Tadeja, S. K., Seshadri, P., & Kristensson, P. O. "AeroVR: An Immersive Visualization System for Aerospace Design and Digital Twinning in Virtual Reality." Aeronautical Journal 124, no. 1280 (2020): 1615-1635. DOI: 10.1017/aer.2020.49.

Zainan, J., et al. "Virtual Reality-based Teleoperation with Robustness Against Modeling Errors." Chinese Journal of Aeronautics 22, no. 3 (2009): 325-333. DOI: 10.1016/s1000-9361(08)60106-5.