

Aircraft Design in Virtual Spaces

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Abstract

This paper aims to look at how virtual reality technologies can improve the aircraft design process. Virtual reality simulation can improve on costs and time savings with accuracy and efficiency. In addition, there are interaction and engagement benefits that provide more immersive experiences. The virtual reality method can also extend out further than the design process into manufacturing and assembly processes. Adding customization and future-casting of product manufacturing will ensure costs are kept to a minimum and ease-of-use is incorporated. Virtual reality can bring significant customer service value to a project with customization options that will be less timely and costly. Implementing a virtual reality process has great potential and can change how business is conducted in the aviation industry.

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The design process of an aircraft is complex, costly, and lengthy with many stakeholders involved. Incorporating virtual reality (VR) technology into this process can provide a better understanding of the final product by all stakeholders. There can also be assistance with post-design in the areas of manufacturing and assembly (Gudmundsson, 2016). This paper looks at the overarching process of designing aircraft and how VR improves engagement. It is important to see where VR fits within the overall operations, beginning with understanding the intention of the aircraft (Gudmundsson, 2016).

The Aircraft Design Process

The aircraft design process has five distinct steps; implementation of VR within several of these steps can help reduce time and costs to the overall project (Gudmundsson, 2016). The five distinct phases are the requirement phase, conceptual design phase, preliminary design phase, detail design phase, and proof-of-concept or construction phase (Gudmundsson, 2016). The requirements phase goes over the aircraft's main intentions and expectations (Gudmundsson, 2016). Having a clear understanding of how the aircraft will be used provides a path and prioritizes design aspects (Gudmundsson, 2016). It also allows for parameters giving designers the ability to turn down any project additions that do not contribute to the primary mission (Gudmundsson, 2016). Next in the process is the conceptual design phase providing an assessment of features such as performance, aesthetics, and labor requirements (Gudmundsson, 2016). Getting an understanding of the performance aspect, features such as cruise altitude, cruise range, or take-off distance are critical aspects of the mission but also introduce challenges (Gudmundsson, 2016). Deviations from the original plan can mean added time and cost to a project, managing through these types of obstacles is where VR can assist in reducing both costs and time (Gudmundsson, 2016). Another big-ticket item in this phase is manufacturing, thinking ahead to be economically viable while meeting primary objectives (Gudmundsson, 2016). Other portions of the conceptual design process include certification, initial cost, ergonomics, and technology (Gudmundsson, 2016). It is also important to note that VR can play a significant role within this stage of the process, providing cost and time savings along with other project benefits (Nath, Attarzadeh, Tiong, Chidambaram, & Yu, 2015). The benefits of incorporating VR within this stage will be presented later on in the paper.

The next phase is the preliminary design phase, where the project details begin to come together and presented for approval (Gudmundsson, 2016). This phase deals with project

features such as geometry development, loading paths, control, aerodynamics, maintainability, and cost estimations (Gudmundsson, 2016). Engineering and manufacturing should be made as efficient as possible, being cognizant of involving all stakeholders to avoid any hiccups down the road (Gudmundsson, 2016). In order to avoid an expensive aircraft part, a materials and manufacturing specialist should be involved (Gudmundsson, 2016). With complex projects such as aircraft design, integrated project teams are necessary for success; these key members are responsible for the success of carrying out the project. A team might consist of people like structural, and performance analysts, or powerplant, interior, systems, and electrical experts (Gudmundsson, 2016). Efforts of all stakeholders should aim to make the product viable while meeting expectations (Gudmundsson, 2016). When the preliminary design phase is approved, it is time to begin constructing and testing the aircraft to make sure all aspects of the project are working according to project specifications (Gudmundsson, 2016). Negotiations with outside vendors also take place within this stage, also making sure cost budgets are staying in line with expectations (Gudmundsson, 2016). This stage should also have VR involvement providing feedback on product and functionality before molds, or dies are created for internal review (Gudmundsson, 2016). When internal stakeholders are content with the product, a proof-of-concept is constructed and presented to the client in the final stage (Gudmundsson, 2016). Constructing a prototype can be expensive, and depending on client expectations or concerns could result in making revisions to original plans adding further costs to a project (Gudmundsson, 2016). Procedures and protocols are refined and provided, along with outside support in areas such as fabrication, structures, and tooling design (Gudmundsson, 2016). All having the possibility to exist within virtual application.

Virtual Reality Technologies

Virtual reality can be described as an artificial depiction of an environment made up of three dimensions which are height, depth, and width (Vincenzi, 2009). These environments can contain multiple sensory inputs, including visual, auditory, tactile, and olfactory, which provide feedback with the idea of more modality information providing a richer experience (Vincenzi, 2009). The three different types of experiences within VR involve real-life environments, concept-based environments, and imaginary environments which can be experienced through non-immersive or immersive methods (Vincenzi, 2009). Non-immersive means the simulation is experienced on a 2D surface such as a computer screen and immersive means the user is surrounded by the simulation experience including multi-sensory information (Rangel, Guimarães, & Correa, 2003). These experiences are provided with the combination of software

and hardware systems through different types of virtual simulation formats utilizing head-mounted display (HMD) or a head-up display (HUD) and include HMDVR, augmented reality, and mixed reality, all of which share in VR benefits and challenges (Vincenzi, 2009).

There is a multitude of benefits when it comes to VR that correspond with human cognition combined with technological advancements which then translate into long-standing knowledge (Vincenzi, 2009). Perception of our environment is a complex top-down and bottom-up interaction which creates engagement because VR creates an enclosed multi-model virtual environment (VE) our perception is capturing more of this information as opposed to a 2D display surface (Vincenzi, 2009). For the most part, the higher the fidelity or detail of the environment, the greater the immersion and chance of information transfer (Vincenzi, 2009). In addition to an increase of immersion, VR can provide a natural way of directing a viewer to specific points of interest and create schemas for decision-making scenarios that most closely fit a real-life situation (Klein, 1993). The individual parts that contribute to making an environment more realistic are location, structural, behavioral, and procedural knowledge (Vincenzi, 2009). Location knowledge is learned or encoded differently when comparing 2D and 3D spatial recognition (Vincenzi, 2009). Cognitive maps are the internal understanding of the environment, and the three axes (x-width, y-height, z-depth) provide us with the landmark, route-road, and survey knowledge which is better understood through VR compared to traditional methods (Sternberg & Sternberg, 2017). When environments are complex and conveying detailed information, there is a reliance on landmarks for mapping where specific items are located, necessary for procedural knowledge (Vincenzi, 2009). Procedural knowledge is critical to following through a sequence of goal-oriented actions in order to accomplish a task (Sternberg & Sternberg, 2017). It is essential to understand how the complexity of the task or tasks affects cognitive functioning when VR is incorporated.

There are also non-cognitive benefits to using a VE, savings in costs, and time makes VR such an enticing method. A contributing factor to the savings is due to accurate project cost estimation (Nath, Attarzadeh, Tiong, Chidambaram, & Yu, 2015). For instance, flight simulators run 5%-20% the cost of aircraft, a significant amount of savings (Vincenzi, 2009). The time-savings portion has a lot to do with capabilities and methods. With the right technological tools, time can be saved equating to cost (Vincenzi, 2009). For example, an instructor with the capability of doing an after-action review (AAR) even though he/she is not at the same geographical location opens the doors to more resources with potential time and cost savings (Vincenzi, 2009). This capability paired with VE software systems such as CATIA part of the

Dassault Systèmes, there can be a greater potential for savings, especially within global team-oriented work processes (Vincenzi, 2009). CATIA is used in industries that deal with engineering, design, construction, and architecture, providing a collaborative setting that allows stakeholders to preview and contribute to design specifications on products (CATIA 3DEXPERIENCE, 2019). With everything just mentioned, there are still drawbacks and challenges ahead.

When it comes to cognitive obstacles, a major one is cybersickness, along with technological areas that still need some attention. Cybersickness can be caused by a combination of differences between real-world objects in comparison to virtual imaging (Nakajima, Ino, Yamashita, Sato, & Oyama, 2010). When 50% of individuals drop out after 20 minutes of use and 75% after 30 minutes, this can significantly impact VE project execution and make it harder to recruit more buy-in (Cobb, Nichols, Ramsey, & Wilson, 1999). There are efforts on improving factors such as exposure, duration, and movement, which are a few significant causes of cybersickness. (Stanney, Kingdon, & Kennedy, 2002). When looking at BIM-type VE, cybersickness is not an immediate concern due to the lack of stimulus and movement (Vincenzi, 2009). As the needs grow, a more immediate concern is meeting the technological and personnel needs, especially concerning integrated complex aircraft systems (Vincenzi, 2009). In order to keep viewers immersed, technological capabilities should focus on system consistency, update rates, and distortions (Uliano, Kennedy, and Lambert, 1986). Being able to have multiple connections that may be spread out over long distances, geographically is another vital need (Galambos, et al., 2015). If connections fail or information is lost, projects can encounter stalls and drop-outs.

In the following text, an analyzation on how VR can bring its benefits into the aircraft design process and add time and save on costs of a project while enhancing customer service. As more of the challenges are overcome, VR will become a more enticing and viable platform option that can provide a significant experience.

Virtual Reality Incorporation

The incorporation of VR has four significant areas that impact aircraft design, and those are expression, interaction, authoring, and collaboration. All areas have to do with the balance of tools in order to provide a VE that can effectively and efficiently carry out project objectives. Creating an immersive experience is critical to executing a project with a successful outcome

because it creates the best chance for the transfer of information (Vincenzi, 2009). Expression of material is the first area that is analyzed.

When expressing VR information in product design, virtual prototyping (VP) provides an alternative to traditional methods which save on costs, time, and provides added customer service value (Sá & Zachmann, 1999). The main objective to VP is to eliminate the need to spend the added time and costs into building a physical mockup and ultimately get approval on moving forward (Sá & Zachmann, 1999). For instance, the assembly process can drive the majority of product costs, and up to 70% of life-cycle costs can come from the design cycle (Sá & Zachmann, 1999). The amount of realism involved in the project depends on the ultimate goal of the project and will be the deciding factor on the where and what of the simulation also dictating how detailed simulation fidelity should be (Morrow, et al., 2011). Highly detailed referents can be demanding on resources for generating high-fidelity simulations and defeat the purpose of utilizing VR due to overspending on time and costs (Roza, Voogd, & Va, 2000). For example, a task displaying function might not require high-fidelity in order to convey information to the viewer (Alessi, 1988). If the viewer can understand the information and utilize the device accurately, then low fidelity is the best strategy due to its low use of resources (Alessi, 1988). When it comes to aircraft design, the three significant areas of expressive fidelity that must be attended to are task-related, personal, and device utilization (Hays & Singer, 1989). In addition to expression, interaction is another component that makes the VR design process promising.

The VR interaction component allows for more natural behavior which equates to an improved experience (Vincenzi, 2009). This experience does come with some technological and cognitive challenges, such as ensuring information is steady, and cybersickness is kept to a minimum. Natural motions, combined with multimodal engagement, allows for a deeper understanding of the aircraft material (Hale & Stanney, 2014). The gesture-based engagement method has shown to improve attentive and visuospatial perception, carrying this over to the aircraft design process would lead to better attention to detail and understanding of the product (Alkemade, Verbeek, & Lukosch, 2017). Haptic devices such as gloves and bracelets also make it possible for tactile feedback with force or vibrational signals (Gavish, et al., 2013). Because aircraft are complex, there are obstacles to overcome, such as keeping a steady stream of data flowing to avoid immersive conflicts (Vincenzi, 2009). A helpful strategy is to balance the fidelity of the simulation, so connectivity is sufficient (Vincenzi, 2009). On the cognitive end, issues like cybersickness have a direct negative effect on experiences with VR (Ray, 2000). With bodily discomfort equating to 50% dropouts occurring within the first 20 minutes and 75% after

30 minutes, these challenges may be few but their significant (Vincenzi, 2009). As it relates to aircraft design, cybersickness should not be a significant concern due to low movement within the VE. Other solution methods can involve how the simulation is built and presented in order to assist these with these challenges.

Authoring VR material in aircraft design should be templated and as accessible as possible while meeting performance, aesthetic, and labor requirements (Neumeyer, Exner, Kind, Hayka, & Stark, 2017). Creating VE should have the ability to recycle or interexchange components in real-time if necessary, providing service value and saving on costs due to not having to recast parts (Nath et al., 2015). Performance levels should be sufficient enough to run both the input and output of data simultaneously, regardless of distance separation (Vincenzi, 2009). Providing an interface that is easily understood and to maneuver in VR is critical, and if there is confusion by the viewer, there should be assistance available within the VE (Galambos, et al., 2015). Creating material should go beyond the design aspect, continuing into manufacturing and assembly (Neumeyer, Exner, Kind, Hayka, & Stark, 2017). Building parts should be cost-efficient and manageable, VR manufacturing combinations can be provided to the client to serve their unique needs with minimum costs (Neumeyer, Exner, Kind, Hayka, & Stark, 2017). A big part of working through these customizable and involved processes involves seamless collaboration between stakeholders.

Communication within any project is critical to its success, and the VR aircraft design process offers an improved method compared to traditional means (Galambos, et al., 2015). Offering a client, the opportunity to review a project without having to leave the comfort of their current location can be a significant added value both financially and timely (Vincenzi, 2009). In addition to human interaction, there might be a third-party logical AI system that provides feedback when social cues are recognized or engaged through the interface, which could provide further assistance or information (Morrow, et al, 2011). As mentioned earlier, VR also offers gesture-based controls or movements, using our hands to communicate is a big part of our social being and makes for a better connection with other stakeholders (Alkemade, Verbeek, & Lukosch, 2017). Multimodal communication within VR goes beyond traditional reading, and auditory methods and contributes to the immersive experience of aircraft design.

Overall Final Aspects

Looking through the aircraft design process, it is evident that the inclusion of VR would save time, costs, and provide client-centered value. Because aircraft are very complex and

involve many stakeholders, the challenges are sizable but manageable (Vincenzi, 2009). As VR-related human factors, knowledge increases executing projects in a VE will become more comfortable and practical (Alkemade, Verbeek, & Lukosch, 2017). Compelling, immersive experiences lead to a better understanding of material cognitively and enhance the project process throughout (Vincenzi, 2009). As technological improvements increase, the VR process will become more accessible and a reliable means of accomplishing complex project goals that involve many stakeholders (Vincenzi, 2009). Moving forward, smarter integration of systems will pave the way for more automation further increasing the benefits of VR-based project processes (Galambos, et al., 2015). The aircraft design process can significantly benefit from VR and set the course for smarter design methods.

References

- (2019). CATIA™ 3DEXPERIENCE® - Dassault Systèmes® 3D Software. Retrieved from <https://www.3ds.com/products-services/catia/>
- Alkemade, R., Verbeek, F. J., & Lukosch, S. G. (2017). On the Efficiency of a VR Hand Gesture-Based Interface for 3D Object Manipulations in Conceptual Design. *International Journal of Human-Computer Interaction*, 33(11), 882–901. doi: 10.1080/10447318.2017.1296074
- Alessi, S.M., 1988, Fidelity in the design of instructional simulations, *J. Comp.-Based Instruction*, 15(2), 40–47.
- Cobb, S. V. G., Nichols, S., Ramsey, A., & Wilson, J. R. (1999). Virtual Reality-Induced Symptoms and Effects (VRISE). *Presence: Teleoperators and Virtual Environments*, 8(2), 169–186. doi: 10.1162/105474699566152
- Gavish, N., Gutiérrez, T., Webel, S., Rodríguez, J., Peveri, M., Bockholt, U., & Tecchia, F. (2013). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments*, 23(6), 778–798. doi:10.1080/10494820.2013.815221
- Gudmundsson, S. (2016). *General aviation aircraft design: applied methods and procedures*. Amsterdam: Butterworth-Heinemann.
- Hale, K. S., & Stanney, K. M. (2014). *Handbook of Virtual Environments: Design, Implementation, and Applications*, Second Edition. CRC Press.
- Klein, G. A. (1993). *A recognition-primed decision (Rpd) model of rapid decision making*. Norwood, NJ: Ablex Publishing Corp.
- Nath, T., Attarzadeh, M., Tiong, R. L., Chidambaram, C., & Yu, Z. (2015). Productivity improvement of precast shop drawings generation through BIM-based process re-engineering. *Automation in Construction*, 54, 54–68. doi: 10.1016/j.autcon.2015.03.014

- Neumeyer, S., Exner, K., Kind, S., Hayka, H., & Stark, R. (2017). Virtual Prototyping and Validation of Cpps within a New Software Framework. *Computation*, 5(4), 10. doi: 10.3390/computation5010010
- Rangel, R. K., Guimarães, L. N., & Correa, F. D. A. (2003). Development of a Virtual Flight Simulator. SAE Technical Paper Series. doi: 10.4271/2003-01-3744
- Ray, P.A., 2000, Is today's flight simulator prepared for tomorrow's requirements? Flight simulation—the next decade, *Proceedings of the Royal Aeronautical Society*, May 10–12.
- Roza, M., Voogd, J., & Va, P. (2000). Fidelity considerations for civil aviation distributed simulations. *Modeling and Simulation Technologies Conference*. doi: 10.2514/6.2000-4397
- Stanney, K. M., Kingdon, K. S., & Kennedy, R. S. (2002). Dropouts and Aftereffects: Examining General Accessibility to Virtual Environment Technology. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 46(26), 2114–2118. doi: 10.1177/154193120204602603
- Sternberg, R.J., & Sternberg, K. (2017). *Cognitive psychology* (7th ed.). Boston, MA: Cengage
- Vincenzi, D. A. (2009). *Human factors in simulation and training*. Boca Raton, FL: CRC Press.
- Uliano, K. C., Kennedy, R. S., & Lambert, E. Y. 1986. Asynchronous visual delays and the development of simulator sickness. *Proceedings of the Human Factors Society 30th Annual Meeting* (pp. 422–426). Dayton, OH: Human Factors Society.