Mechanical Engineering
University of Colorado Boulder

ROSEN AVIATION

Cessna | Beechcraft
BY TEXTRON AVIATION

*CU Boulder Team 10 | Textron Aviation | Design Center Colorado*

# Next Generation Cabin Windows Trade Study

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Project Whitepaper

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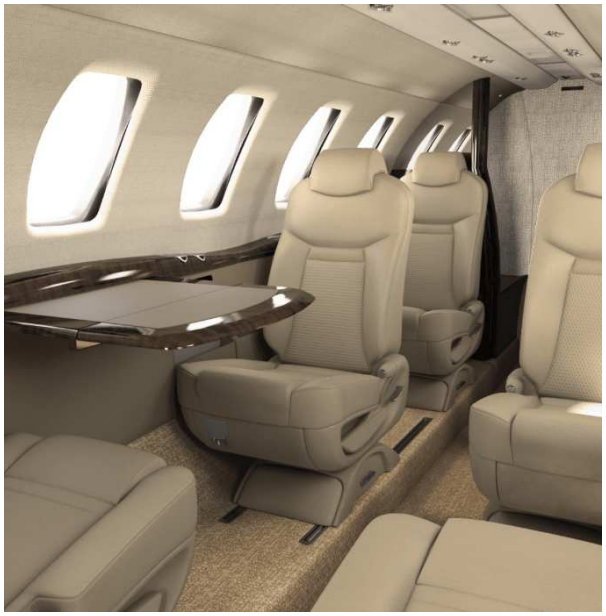
# 1 INTRODUCTION

## Background

Human centered design as a field focuses on the user experience and takes user's needs and feelings into account in the engineering design process. In this field, it is of utmost importance to make the user comfortable and relaxed. For the Business Jet Interior Design industry, human centered design is also about developing the best technology and overall experience so passengers enjoy the full potential of flying. In the world of business, this development must be paired with cost-saving measures.



Cessna Business Jet Club Seating Style with Traditional Glass Windows. Credit: Textron Aviation

For years, all passenger aircraft have used existing multi-layered glass windows to enhance user satisfaction and deter emotional and physical reactions such as motion sickness. To make planes lighter, stronger, and thereby less expensive, companies in the industry have begun researching implementation of screens, called virtual windows, to replace the existing glass windows for future passenger aircraft design. The questions that must be asked when considering human centered design are as follows:

**1. How will removing traditional aircraft cabin windows affect the passenger experience?**
**2. Will virtual windows simulate a similar positive response from passengers when compared to traditional windows?**

## Mission Statement

To design and construct a full-scale interior mockup of the club seating area based on the Cessna Citation CJ4 Business Jet, and produce behavioral study results from a human-centered psychological study examining implementation of virtual windows in a typical Textron business jet.

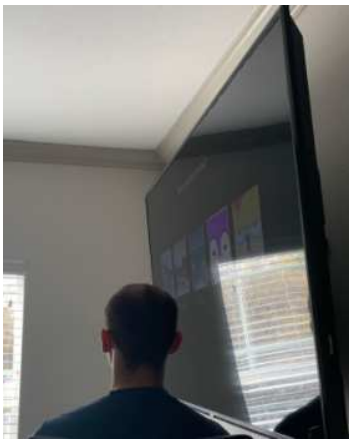
"Club Seating Area" that the mockup aims to replicate

## Disclosure

By going through the design, manufacturing and testing processes the team has provided Textron Aviation with the data and conclusions to understand the impacts of virtual windows and inform important engineering and business decisions for the company. **Because of the sensitivity of this information, no data or conclusions will be presented in this whitepaper due to IP considerations.**

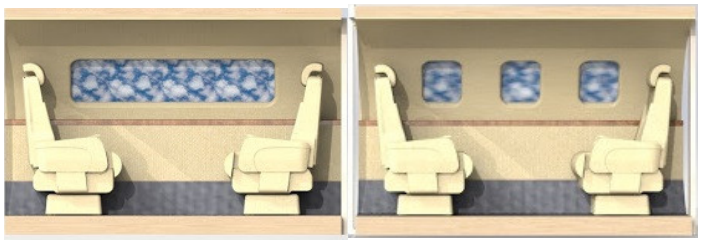
# PROJECT OVERVIEW

## Phase I : Research, Planning, and Prototyping



Bridger prototyping distance to LED screen and possible heat transfer effects

The team began by producing several iterative prototypes to learn more about project goals. This was done by creating prototype situations including replicating the size of the mockup or being seated next to screens for extended periods of time. These prototypes gave the team a sense of project scope be and what methodologies to use to design the mockup for full meaningful data potential in the psychological study. The study design centered around comparing club and traditional *window reveal* configurations, both paired with LED Screens, shown below. The greater team then divided into two sub-teams, the design sub-team and the test sub-team. While the design sub-team expanded upon and refined 3D models of the mockup in SolidWorks computer aided design software, the test sub-team devoted months to academic research on study design and psychological testing. Development of the study design was aided with consultation of industry experts.



Club (L) and Traditional (R) Virtual Window Reveal Configurations

Team 10 ensured the study plan was written and executed in line with industry standards, so consultation proved very useful. After numerous iterations, the test sub-team created a comprehensive Study Plan for implementation in March and concurrently the design sub-team was able to iterate design and manufacturing plans for implementation in January.

## Phase II: Manufacturing, Test Development, and Assembly

In January 2021, the team kicked off manufacturing and assembly and were able to cut all of the mockup frame sections from baltic birch plywood on a CNC machine and began assembly. The test sub-team continued refining study procedures while also devising and executing a recruitment plan to gain participants in a specific target demographic consistent with Textron's target customers.

## Phase III: Psychological Study Implementation and Data Analysis

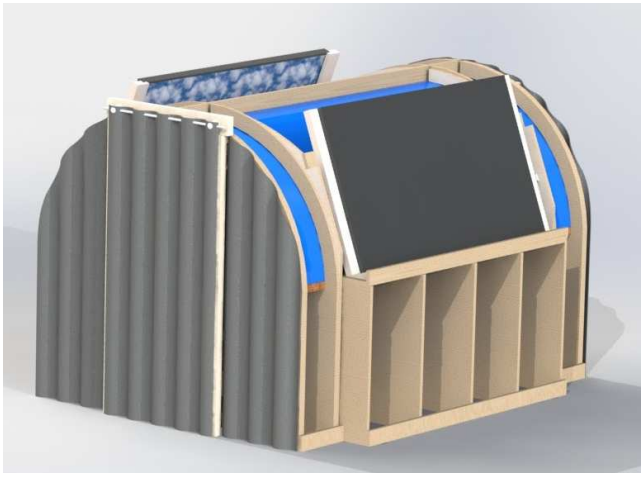
In March 2021, mockup construction was complete and the psychological study ran smoothly largely due to implementation of a test prototyping phase called a *Pilot Study*. With recruitment and testing ongoing throughout March and April, the test sub-team began data analysis and executed a plan to draw relevant conclusions for the client.

## Phase IV: Disassembly, Shipment, and Results and Conclusions

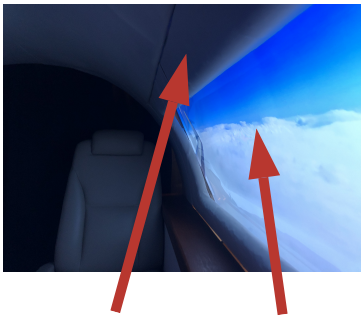
With the final report and presentation to Textron Aviation, our team disassembled the mockup and shipped the pieces to the Textron office for further use by their R&D teams. In addition to the physical mockup, the results and findings of the psychological study including raw data, data analysis results, and conclusions were delivered to the client through the final report and presentation.

## 3D Computer Aided Design and Material Choices

Using dimensions provided by Textron Aviation, the team was able to create a SolidWorks model representative of the CJ4 . The mockup needed to be structurally sound with a high quality finish, so Team 10 used a ribbed frame design made from high quality Baltic Birch plywood. This was chosen over other wood materials due to its structural integrity. Inside of the wood frame, thin sheets of ABS plastic were chosen to create solid walls that could also easily bend into the curvature that was required for the mockup. On top of this plastic, a layer of foam core board was added to make the walls slightly thicker and softer, similar to the interior surfaces that you would find in a business jet. The innermost layer of the mockup was covered in the same upholstery Textron often uses in their jets. This was chosen to keep the mockup as accurate as possible to the CJ4, so the test sub-team could minimize external variables other than the window reveals for the psychological study.



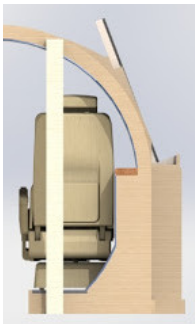
Final Mockup CAD Model



Window Reveal | TV Screen

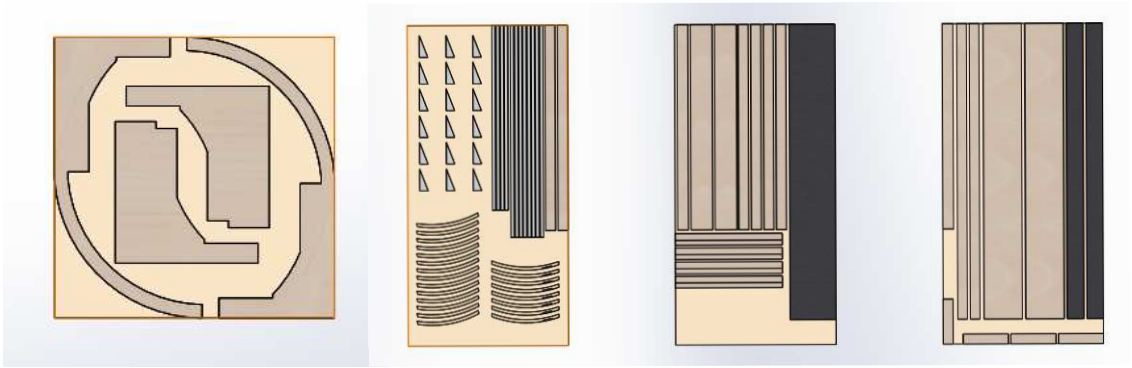
## Emphasis on Window Reveals

The most important aspect of this mockup was to create an environment for the passenger to imagine as if they are flying in a real jet. *Window reveals* are the actual window size cutouts, and Team 10 designed the club and traditional versions. To minimize the distance from the reveal to the TV screens, the TVs were mounted to the mockup so that they rested tangent to the reveals at their center point.



## Designed for Manufacturability

The mockup ribs were 5 feet tall which influenced the team's decision to order 5' x 5' x 3/4" plywood to minimize material waste. All other wood components shared the same 3/4" thickness so that parts could be cut from 4' x 8' x 3/4" plywood using a CNC machine. The majority of parts cut from the 4' x 8' sheets also included pre-cut pilot holes to aid in assembly.



## 1 CNC Wood Components

Since precision and detail are so important to a full-scale mockup, Team 10 had the main wood frame components cut on a CNC machine through a partnership with the CU SEEC LAB. This resulted in frame components that showed great repeatability and accuracy. These components were then delivered to the Idea Forge where the team would assemble the mockup.


## 2 Frame Assembly

Before beginning construction, the team counted and labeled all wooden parts. Most components had pre-piloted holes from the CNC process which reduced man-hours required for this stage of assembly. 3/4" wood construction screws were used alongside an impact driver to provide a rigid connection between parts.

## 3 Plastic Base

Once the frame was complete, the team made cuts from the ABS plastic sheets. These were attached to the frame with a staple gun as to fill in the gaps in the ribbed frame to make solid walls. This allowed for the sheets of fabric to attach seamlessly to the inside of the structure.

## 4 Window Reveals

The window reveals featured a curved, wooden frame supported by ABS plastic along the curved back-edge. 3-D printed window frames allowed for the complex curvature required to accurately replicate the CJ4's window profiles. The team applied a spray foam insulation to create a smooth inner surface to give the windows a professional appearance.

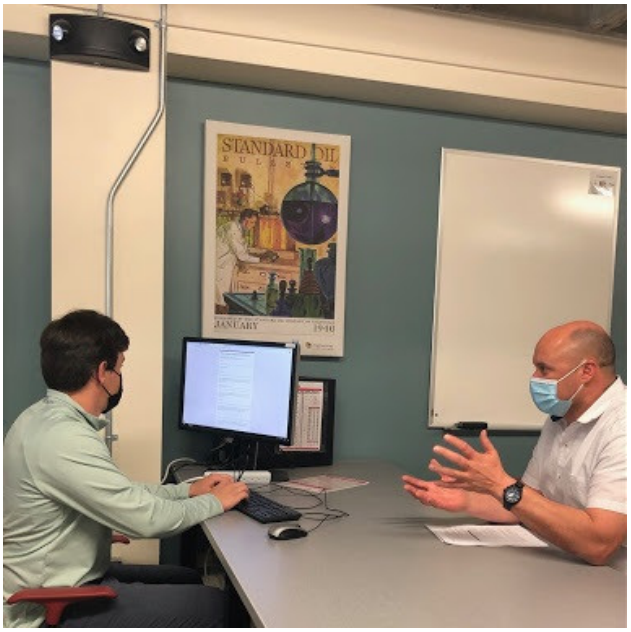
## 5 Upholstery & Finishing Touches

Grey carpet was installed on the floor and a faux leather fabric was applied to every other interior surface using a spray-adhesive. Blackout curtains were mounted to each end of the mockup and 65" OLED 4K TVs were mounted to each side of the mockup completely isolating the interior. Aviation-grade seats, provided by Textron, were bolted to the floor along with a finished and stained wood armrest spanning the length of the mockup.

## 1 Study Procedure Design

Because Team 10 had little prior experience in research study design, they used research skills and consultations with industry experts to develop a comprehensive study plan.

Team 10's in-person testing window is an analysis of what a passenger would experience in a typical flight with virtual windows, so it was determined that a 30 minute testing period was enough time to allow for the participant to adjust to mock flight and form concrete opinions about the virtual environment. In order to test both window reveals, two 30-minute tests were required.



Garrett Administering the interview-format Post Survey

From here, Team 10 developed a series of surveys to accurately collect data. These included two surveys the participant would take before the testing window administered with email to gain important flight-habit information. For the in-person portion, Team 10 developed a middle survey and an interview-format post testing survey.

| Survey Order | Task | Description | Location |
|---|---|---|---|
| 1 | Pre – Survey | Survey (Performed by Participant) | Off-Campus |
| 2 | Middle Survey | Survey (Performed by Participant) | Traditional Virtual Configuration |
| 3 | Middle Survey | Survey (Performed by Participant) | Traditional Virtual Configuration |
| 4 | Middle Survey | Survey (Performed by Participant) | Club Virtual Configuration |
| 5 | Middle Survey | Survey (Performed by Participant) | Club Virtual Configuration |
| 6 | Short Answer Post Survey | Survey (Performed by Interviewer) | Outside of mock-up |

Final Survey Testing Process

## 2 Surveys and Scheduling

The middle survey was developed to measure the attitudes and emotions of the participants while in the mockup. Here, participants rated words describing emotions such as "uncomfortable" or "safe" on a numeric scale. This survey design accomplished project goals in comparing club or traditional virtual window configurations on the passenger.

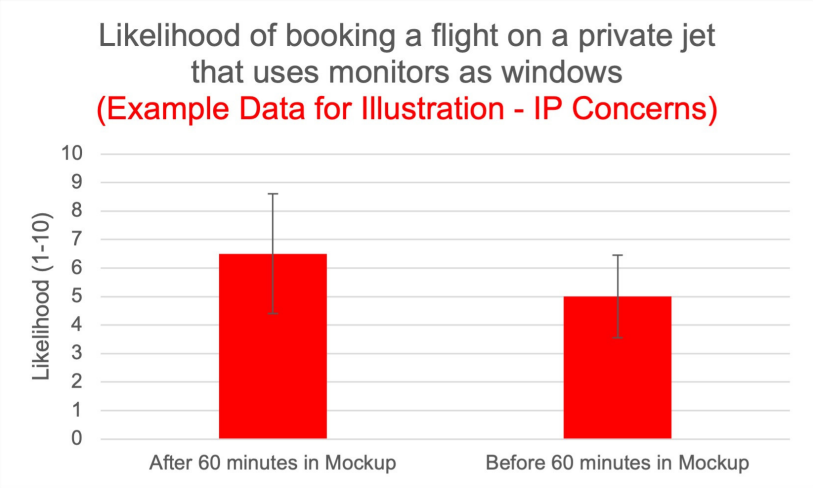
In order to accomplish the project goal of gaining insight on implementation of virtual windows versus traditional glass windows in general, a short post-survey interview was conducted. This utilized many open-ended questions, along with 1 to 10 style questions to give the participants the chance to voice their thoughts and opinions.

To effectively carry out the psychological study, a scheduling method was also developed utilizing Google Sheets and SignUp-Genius. Through Team 10's testing window, 29 total participants took part in the Psychological Study, allowing Team 10 to gain valuable data both for a deliverable for their client, and to use in subsequent data analysis.

# DATA ANALYSIS

After designing and throughout the implementation of the research study, Team 10 embarked on another vital segment of the project, the data analysis. Nearly the entire data analysis plan was developed along with the research study design, but development, and analysis took place simultaneously once data became available during the testing phase. Team 10 gained raw data from spreadsheet exports from all survey google forms, and used Microsoft Excel and Matlab softwares to parse through quantitative data, and make figures to later draw conclusions. From the survey design, both quantitative and qualitative data were gathered, and each presented unique opportunities to draw significant conclusions on implementation of virtual windows.

Team 10 embarked on the quantitative data analysis process by starting with the *Middle* survey data. From this data, they were able to calculate mean ratings for each word over time for each window type, as well as other descriptive statistics. Team 10 also utilized a technique called a one-way analysis of variance on these data to determine if descriptive statistic claims would hold for the greater population rather than the participant sample. Other quantitative data analysis centered around 1 to 10 style questions in the post survey and what the data meant for certain demographics or flying habits.




Example Data Analysis Figure
IP Concerns prohibit disclosure of collected data

An example of this data is shown comparing likelihood of booking a flight on a plane that uses virtual windows before Team 10's testing window and after it. **This was compiled using example data due to IP considerations.**

Team 10's qualitative data analysis was a very interesting part of this project. The process the team went through to go about this generally started with open-ended survey questions, with quotes and phrases. Team 10 also took detailed notes on body language of participants throughout their test window to gain insight beyond survey data gained from the participant themselves. The next step was to organize all of the open-ended data in once place and identify themes, patterns, and highlights. Team 10 even tied some of these patterns to demographic information or flight habit information gained in the pre-testing at-home survey. After much data organization and collaboration, Team 10 was able to use this process to arrive at noteworthy qualitative findings for the client, Textron Aviation.

During the initial design phase of the project, many challenges were due to the remote nature of many parts of this project. Remote design iterating and modeling software access were particular challenges. These fed into another challenge, which was meeting the client's expectations for the model on exact scale. Luckily, Team 10 was able to work through these challenges thanks to our extremely competent CAD Engineer, Eric Mann's, leadership. Eric used Kenesto, a product-data-management software as a repository for all of the team's SolidWorks files, allowing all team members to access the CAD model and enact version control.

Missing Piece Rib Adjustment

The manufacturing phase also presented significant challenges that had to be overcome by the team members. Similar to the design phase, the remote nature of the semester made coordination with external vendors particularly difficult. Though the environmental design department internal to CU was massively helpful, Team 10 found it difficult to impart important technical details digitally. In the end, Team 10 members made a trip down to the manufacturing facility and were able to safely sort out the details in person. Another manufacturing challenge involved a mistake made by the vendor due to differences in 3D modeling softwares. This resulted in a missing structural wood piece. This was discovered as the mockup was assembled, and the team members had to make some adjustments to the ribs, shown above, in order to accomplish comparable results. Due to the robust nature of the original design, the changes did not affect the structural integrity of the mockup to a significant extent. This taught Team 10 that mistakes like this can be costly and time-consuming but with the right adjustments success can still be achieved.

The final major challenge during the manufacturing phase was upholstery application. Team 10 had little prior experience in this type of interior manufacturing, but were able to learn by doing and communicate with outside sources to produce an impressive upholstered finished product for psychological testing. The key pivot was the change in glue type to apply the upholstery to the reveals and aircraft interior. Originally, Team 10 used a combination of hot glue and staples, but research yielded a better method involving spray adhesive to create a more professional presentation.

Testing challenges included implementation of data analysis techniques and applying learned expertise in qualitative data analysis.

Final Upholstered Side-Ledge and Traditional Reveal

# CONCLUSION

The Next Generation Cabin Windows Study required the use of a wide array of technical skills. The scope of these ranged from carpentry, upholstery, survey design and data analysis, to 3D printing. Team 10's seven engineers were able to successfully coordinate the project in a timely manner with guidance from countless sources. Some to note are the project client Textron Aviation and direct manager of Team 10 Brad Guthrie, Design Center Colorado and specifically Dr. Daria Kotys-Schwartz, and Team 10's Project Faculty Director Katie Simon. The project was successfully completed and was a learning experience for Team 10. Textron Aviation received Team 10's mockup, raw psychological study data, and conclusions from data analysis on implementation of virtual windows. With these deliverables and due to the success of the project, Textron plans to develop further psychological studies in the future to inform engineering and business decisions in their industry.

# MEET THE TEAM

Alex Hermann -
Systems Engineer

Bridger Vallin -
Financial Manager

Spencer White -
Project Manager

Alden Burr -
Test Engineer

Eric Mann-
CAD Engineer

Jonathan Callan -
Manufacturing Engineer

Garrett Goulding -
Logistics Manager

Katie Simon -
Project Director

Brad Guthrie -
Project Client

## Team Bios

Bridger Vallin
Bridger is a Colorado Native and a former Marine Infantryman. He works for Northrop Grumman's Payload and Ground Systems Division in the SEIT department.

Spencer White
Spencer is an Eagle Scout from Golden, Colorado. He currently is the Project Manager for this project and plans to go into manufacturing engineering after graduation.

Garrett Goulding
Garrett is a Senior in Mechanical Engineering from Aurora, Colorado. When he's not golfing, he is spending time with friends and family. He plans to work in design engineering in the future.

Alex Hermann
Alex is a Senior Mechanical Engineering student from San Francisco, California. He is currently the Systems Engineer for this project and plans to work in product design after graduation.

Alden Burr
Alden is a Senior Mechanical Engineering student from Boulder Colorado and the Test Engineer for Team 10. After graduation he hopes to work in industrial design or design engineering.

Eric Mann
Eric is a Senior Mechanical Engineering student from Boulder Colorado and the CAD Engineer. After graduation he hopes to work with 3D modelling software in mechanical design field.

Jonathan Callan
Jonathan is an Eagle Scout who is operating as the manufacturing Engineer for this project. Looking to work in adjacent fields after graduation