IMMERSIVE MAINTENANCE REVIEW IN CUSTOMER CONFIGURATION INTEGRATED INTO THE SUPPORT & SERVICES 3D PRODUCTION CHAIN WITH A USER-CENTERED APPROACH: APPLICATION TO MAINTENANCE TOOLING REVIEW

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Abstract
Validation of the installation of maintenance tools on aircraft is often difficult, due to the downtime of the aircraft and prototypes that are not representative of the customer's configuration.
The objective of the study is to exploit the real-virtual coexistence specific to mixed reality, which is integrated here into the digital production chain of support & services to collect real data on the customer configuration in order to optimize the operational performance of maintenance by freeing itself from the removal of physical parts and the maturity of real aircraft.

1. INTRODUCTION

The Maintenance Program Engineering and the design office (GSE designers) qualify and validate the application of the maintenance tools (Ground Support Equipment) in operational conditions for each helicopter program in terms of ease of use and impact on the maintenance time leading to the immobilization of the aircraft.

To this end, a physical model of the maintenance tooling (GSE) is made from the 3D design to test the feasibility on prototypes (physical helicopters).
Unfortunately, some of these tests are not really representative because of the difference in configuration between the available prototypes and the "real" aircraft delivered to the customer. This difference, which increases over time, is mainly due to post-EIS improvements for which no representative physical prototype exists.

Finally, for some GSE validations, the parts to be disassembled previously to carry out the maintenance procedure are too important in terms of Aircraft downtime to allow a test on a prototype.

It is to answer this double challenge: the validation on Aircraft and the optimization of the operational maintenance that our study is part of the CORAC PLATFORM research project.

The objectives of this paper are: (1) to present our work on the review of GSE in mixed reality by support engineers in customer configuration; (2) to show the mixed reality interest for the validation on Aircraft; (3) to present the results of qualitative and quantitative analysis of this first ergonomic study on the usability, the acceptability of the mixed reality solutions to validate on Aircraft and in customer configuration, the feasibility of the installation procedure of GSE.

2. STUDY SCOPE : CORAC PLATFORM

This study is part of the CORAC PLATFORM research project led by the DGAC and the consortium made up of Daher, Latécoère, Segula, Fives and Airbus Helicopters. In this project, Airbus Helicopters was involved as a partner on stream 2.

2.1 Stream 2 “Digital continuity of the production system”

The objective of the stream is to implement the following key features of the digital continuity concept, and to validate them through concrete and representative application cases:

- A database of solutions for managing, exchanging and securing digital data (Daher, Airbus Helicopters, Latécoère)
- A demonstration of the benefits of mixed reality holographic experiences in real case reviews of maintenance analysis and maintenance task simulation for operational and economic maintenance optimization.

2.2 Compliance with customer requirements

Our reflexion is on compliance with customer requirements in order to improve the operational and economic performance of all maintenance activities by taking advantage of the collection of data on the whole chain to establish the real operational performance offered to our customers.

The objectives are:

- Increase **safety** thanks to the means of validation of the operational procedure and of maintenance tooling qualification in operational situations.
- Increase the **quality** of the maintenance procedure adapted to the customer's configuration and missions.
- Increase the **efficiency** of operational maintenance.

2.3 Architecture AND process

To achieve our goals, we have implemented a digital continuity architecture (see Figure 1).

This digital chain is made up of the Support Engineering 3D production platform which interoperates with immersive mixed reality and virtual reality solutions via an exposure layer.

The real production data consists of customer configuration data, maintenance tools, ILS (Integrated Logistics Support) business data and design modifications. The 3D data enriched with business and configuration data is collected, prepared and optimized on the ILS DIGITAL FACTORY platform and converted into a format that can be read by virtual reality and mixed reality glasses. We have implemented an innovative process centered on the customer in digital continuity that allows mixed reality simulation of operational conditions by feeding it with real production data, for an analysis of maintenance with regard to the benefits provided to customers (see Figure 2).

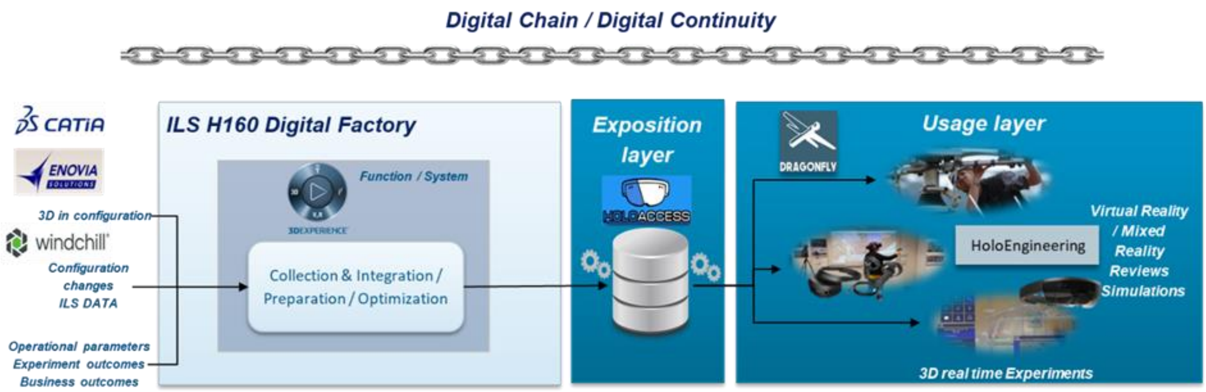

Figure 1: Architecture overview

GSE Analysis		Comment
Accessibility, feasibility	Verify the accessibility and feasibility of maintenance actions with the required amplitude to use the physical standard tools to simulate the task in mixed reality. Verify usability under operational conditions that are identical to real world activity. Identify contacts between the real environment such as hands, physical standard tools and the holographic 3D of GSE with its context in the virtual environment	Accessibility, feasibility checks enable the creation of the maintenance procedure that is right the first time
Identify the parts to be removed	Check the parts to be removed to establish the necessary removals before installing the GSE. Contribute to the job set-up definition of the GSE installation procedure	Avoids unnecessary disassembly of parts: time and cost savings. Reduces the potential risk of damage caused by unnecessary removal/replacement operations.
Determining the correct positioning of the operator	Check the gestures and positions to adopt for the installation of the GSE.	Allows the operation to be carried out more ergonomically and efficiently. Safety and working conditions are optimized.

Figure 2: The benefits of mixed reality for the validation of GSE on aircraft

This work targets internal Airbus Helicopters customers and in this study the Support Engineers of the Maintenance Program Engineering team.

3. MAINTENANCE REVIEW OF GSE IN OPERATION CONDITIONS

The GSE review in mixed reality aims to quickly identify the points of difficulty or vigilance in terms of accessibility, feasibility and to propose different solutions to optimize and facilitate the application of the maintenance procedure.
The aim is to give new means to the support engineers in charge of feasibility tests to validate and optimize the GSE installation procedure on Aircraft without physically removing parts
It is a decision aid for Maintenance Program Engineering to reinforce and target validation tests on Aircraft with the physical GSE.
We use mixed reality solutions integrated with the 3D digital production chain for ILS (Integrated Logistics Support) production with a user-centered approach.

This ergonomic approach consists in starting from the human to design mixed reality solutions that are as close as possible to the real activity of the support engineers and that are accepted by them. In our approach, the support engineers are co-designers of the mixed reality solutions implemented for them and with them.

4. WHY MIXED REALITY ?

Mixed reality is used to create interactive simulations. These simulations provide training at a lower material and human cost, even before carrying it out in real conditions. At the conceptual level, from the beginning of the development of interactive virtual environments, Milgram & Kishino [2] developed the idea of a continuum (mixed reality) between reality and "pure" virtual reality. The latter appeared indeed as an abstraction, in the sense that the presence of an operator interacting with a virtual environment necessarily creates a situation of mixed reality. It is different from the Augmented Reality describes by [7] as a superimposition of the real-environment-view with additional digital information. These pieces of information are presented as two-dimensional images that are generally either fixed in the field of view of the user or dynamically change location based on markers in the real environment.

We can then consider that we are always in a situation of mixed reality. This vision has the advantage of playing on the continuum proposed by Milgram & Kishino, with a variable weight of real and virtual environments, according to the needs of the application under study.

This concept has the advantage of trying to get the best of both worlds, for example by offering the operator haptic feedback from the real world, which is so difficult to reproduce in virtual reality (thus simplifying the behavioral interfaces). It also highlights the problems of spatial and temporal coherence between the virtual world and the real world, for example for the actions of manipulation and positioning of virtual objects, in reference to a real device. It is at this price that we will obtain guarantees of validity of the experiments carried out in mixed reality situations, in reference to the reality of the field.

5. EXPERIMENTAL PROTOCOL

The maintenance activity is mainly centered on the human factor. We have set up an experimental protocol to evaluate immersive experiments from a human factor point of view adapted to the needs of working on operational configurations not physically available.

We have developed an iterative process of co-design of mixed reality solutions involving support engineers, developers and multidisciplinary researchers in human factors: cognitive neuroscience, behavioral biomechanics, and experimental psychology.

The evolutions are integrated and validated at each experimentation (weekly iteration frequency). An evaluation protocol for this user experience has been set up.

5.1 The experiment parts

The study focused on aircraft validation of the installation of "TGB (Tail Gear Box) input dynamic seal" tool.

The first part of experimentation consists in projecting the 3D hologram of the GSE in context, i.e. with the interfacing parts, on the physical helicopter to consider the general dimensions, the volumes and the good integration of the mixed reality solution in the customer configuration. This step allows to identify the parts to be removed before the operation on the helicopter to proceed to the installation of the GSE. In the case of our study the GSE is represented by the 3D hologram in yellow and the interfacing parts in blue and beige (see Figure 3).

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Figure 3: First part of the experiment on the identification of the parts to be removed

For the second part of experimentation, the 3D holographic GSE in context is projected alone at scale 1 (see Figure 5). The parts identified in the job set-up (first part) are hidden to perform the installation procedure of the GSE.

The actions to be performed with the standard physical tools for the installation of the GSE are simulated in mixed reality. The support engineer applies each step of the installation instructions (see Figure 4).

This allows the identification of possible contacts with the physical standard tools or the operator's hands and the 3D to verify the accessibility and feasibility of the procedure (see Figure 4 and Figure 5).

5.2 Equipment and measuring tools

HoloLens 2: The HoloLens is an augmented reality headset announced by Microsoft in January 2015. The device has all the components of a real computer to operate autonomously without connection to a computer or smartphone. Transparent high-definition lenses coupled with a spatialized sound system make it possible to view 3D images immersed in the environment. The principle is different from that of the virtual reality headset, with which the user is totally immersed in an artificial universe. Using motion sensors, HoloLens allows the user to not only see 3D objects as holograms in a physical space but also to manipulate them.
To complete the user analysis, 3 cameras and a timer were used to quantify the user's actions.

5.3 Selection of participants and experimental conditions

10 engineers aged 49.6±9.2 years participated in this review. These men have a professional experience in the field of 25.6±12.6 years.

Figure 4: Installation procedure document and the standard physical tools

Figure 5: Second part of experiment on GSE installation

They are novices or beginners in mixed/virtual reality. They have been trained in basic mixed reality on Hololens 2.
It is to be noted that the mixed solution has evolved with each experimentation in a continuous improvement approach that integrates the evolution requests coming from the participants' observations and feedback. This makes it possible to re-evaluate the integrated practices on a regular basis and to question the various developments in a co-design process with all the participants: support engineers, production and research team and development team.
This continuous improvement approach does not allow for statistical analysis as not everyone is testing the same version of the mixed reality solution.

5.4 Measured variables

To evaluate the mixed reality solution, the study uses both a qualitative and quantitative two-dimensional approach.
Among the variables, temporal data are measured, such as time to complete tasks, success/failure rate and number of interactions. In addition, there is other quantitative data collected through questionnaires: The SUS (System Usability Scale [2]) gives an index of the usability of the application, i.e. the performance in achieving the expected result, the satisfaction derived from its use and the ease with which one learns to use it, The TAM (Technology Acceptance Model [1]) assesses the degree to which the user will adopt and use the technology, le NASA TLX [4] which provides a workload index. In order to complete the quantitative and metrological approach, qualitative data from observation (movements, direction of gaze, verbal and non-verbal communication, postures, actions or information gathering, etc.) and exchanges around four open questions is also taken into account:

- Does this mixed reality tool meet your expectations?
- What are the benefits you have identified?
- What are the limitations of the solution? What difficulties have you encountered?
- What improvements would be interesting to implement?

6. EXPERIMENTAL RESULTS

6.1 Results of quantitative and qualitative analysis

6.1.1 Metrological analysis

On average, participants took 29 minutes and 52 seconds (± 19min 18s) to complete the tasks in both parts. The results show a high variability of times between participants due to the continuous improvement of the mixed reality solution (see Figure 6).

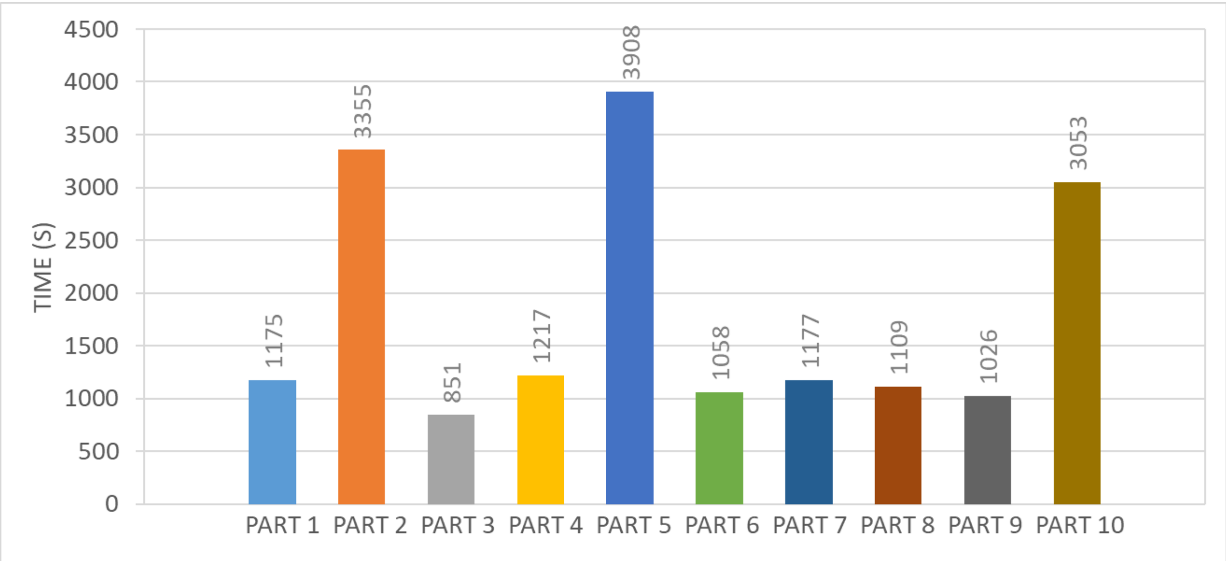


Figure 6: Total execution time for part 2 of the experiment

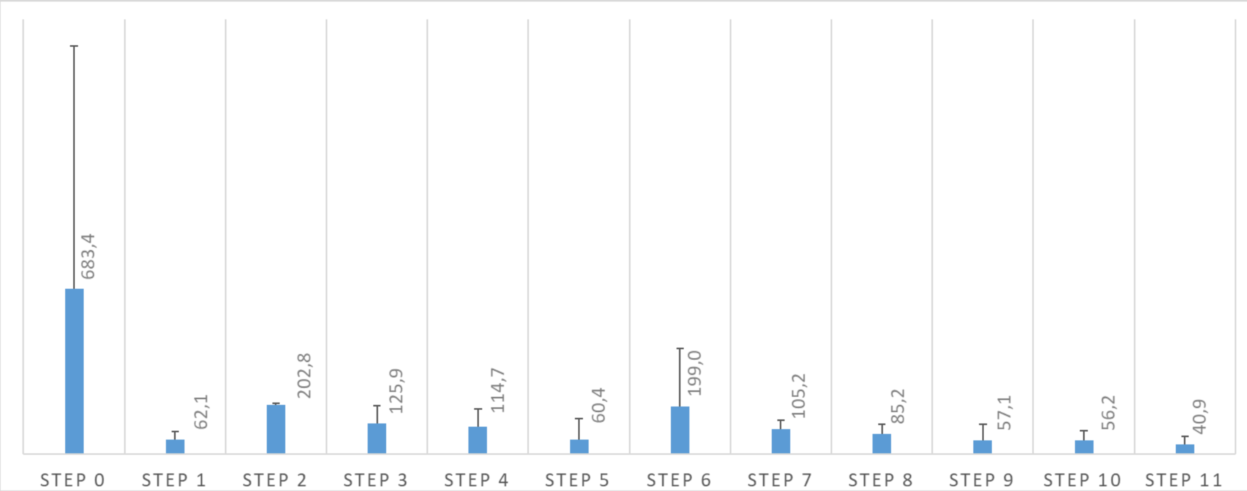


Figure 7: Mean time (in seconds) to complete each of the 11 steps required to install the GSE

Two main stages can be observed in the second part with strong variability between participants (see Figure 7). The first concerns the hiding stage (i.e. Step0). The improvements made to the mixed reality solution mainly concern this stage. A trend of time reduction is observed except for some enhancements that are too CAD and too far from the field (see Figure 6).

The second step (i.e. Step 6) is the tightening of the captive screws, where the engineers identified an accessibility problem in the installation procedure. They tested different strategies.

6.1.2 Technology Acceptance Model (TAM) Questionnaire

To explain user behaviour, the TAM (Technology Acceptance Model) adapted from the questionnaires of Davis [1], Venkatesh [5] and Venkatesh and Davis [6] includes 4 sub-scales: **Ease of Use** (EoU)**, Perceived Utility** (PU), **Intention to Use the technology** (INT) **and Attitude towards the device** (ATT)**.** The TAM is based on a Likert scale that allows the user to answer on a 5-point scale from "strongly disagree" to "strongly agree". The overall results are summarized in the table below (see Table 1):

TAM	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10	Average score per component
Perceived Utility (PU)	4,0	4,3	5,0	5,0	3,8	3,5	4,0	3,3	2,0	3,0	3,8
Ease of Use (EoU)	2,8	3,6	3,9	3,8	3,4	4,0	4,6	3,0	2,6	3,2	3,5
INTent to use (INT)	4,0	4,5	3,0	3,0	2,5	3,0	3,5	3,0	3,5	3,0	3,3
ATTitude towards the device (ATT)	4,0	4,0	3,0	3,7	3,3	3,3	3,7	3,3	3,7	3,3	3,5

Table 1: Results of the Technology Adoption Questionnaire of the different components

In the table above (see Table 1), scores in **green (around 4)** are the preferred scores and tend towards the "ideal" result. The components in **blue (around 3)** are relatively positive and fulfil their objectives without having a negative impact. However, improvements on these aspects are possible and recommended. A score with a majority of **orange (around 2)** highlights more pronounced weaknesses that require improvement. A **red score (around 1)** reflects a real problem that requires a redesign.

In conclusion, the result of this questionnaire highlights **many positive points regarding the perceived utility of the technology.** Engineers see a **real potential that can bring added value to their work**. However, some **improvements have to be done to make the tool easier to use.**

6.1.3 System Usability Scale (SUS) questionnaire

The notion of usability includes both: the performance of the task, the satisfaction of using the object, and the ease with which one learns to use it. The notion of ease is directly related to that of efficiency or the achievement of a result with less effort or time.

The System Usability Scale (SUS) **is a measure of perceived usability**. This is a questionnaire consisting of ten questions that collect the user's subjective view of a system or service. The SUS is based on a Likert scale that allows the user to answer on a 5-point scale from "strongly disagree" to "strongly agree". The end result of the questionnaire is a score out of 100 which gives **a measure of a user's feeling about the usability of a "system"** (see Table 2)**.**

The raw SUS scores can be converted into percentile ranks (see Table 2). The average score obtained (at the 50th percentile) is 68.

SUS	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10	Average score by item
1 : I think that I would like to use this system frequently	3	4	4	4	2	3	3	2	2	2	3,75
2 : I found the system unnecessarily complex	2	3	3	4	3	3	4	3	2	3	3
3. I thought the system was easy to use	3	2	3	3	1	3	3	3	2	3	2,75
4 : I think that I would need the support of a technical person to be able to use this system	1	1	1	1	1	2	1	1	1	1	1
5 : I found the various functions in this system were well integrated	2	2	3	4	3	3	4	2	1	1	2,75
6. I thought there was too much inconsistency in this system	3	4	3	4	3	3	4	2	3	3	3,5
7. I would imagine that most people would learn to use this system very quickly	1	3	2	4	3	2	3	2	2	3	2,5
8. I found the system very cumbersome to use	2	3	3	4	3	3	4	3	2	2	3
9. I felt very confident using the system	2	2	3	4	3	3	3	2	2	2	2,75
10. I needed to learn a lot of things before I could get going with this system	3	4	3	4	3	3	4	2	2	3	3,5
SCORE SUS	55	70	70	90	62,5	70	82,5	55	47,5	57,5	71,25

Table 2: Results of the SUS Questionnaire / Overall Score

This means that a gross SUS above 68 is above average and below 68 is below average. The results (see Table 2) show that the participants have some reservations about **the ease of use (2.75)**. These results are in line with the initial results obtained from the technology adoption questionnaire.

6.1.4 Questionnaire NASA TLX (National Aeronautics and Space Administration Task Load Index)

The analysis of the subjective data was based on direct measurements of the six NASA-TLX workload criteria (Mental Demand, Physical Demand, Time Demand, Effort, Performance and Frustration) and on the workload index calculated from the scores obtained for these six criteria.

In the present study we find a relatively low workload score. If we take into consideration all the sub-scales, we can observe that the mental load score is the highest. In contrast, the physical component and the frustration component scored the lowest. This first remark highlights the fact that the installation task in mixed reality does not require a great deal of physical effort and causes little frustration, which is rather positive because this is a determining factor in the future use of an application.

The second highest value is the notion of effort. The latter indicates that the participants spent relatively large amounts of effort (mainly mental) in order to achieve the goal of the task. These difficulties are to be considered in conjunction with the previous results, particularly concerning ease of use. However, and referring to the "frustration" component, it can be noted that despite the difficulties experienced by the users, they feel little or no frustration with the task. This shows that the participants are highly motivated and have a real interest in the innovation that has been presented to them.

The result of the performance index seems to be in line with this idea, as the participants considered their performance to be significant despite the effort expended to perform the task. The latter did not have a direct impact on performance, but only on workload.

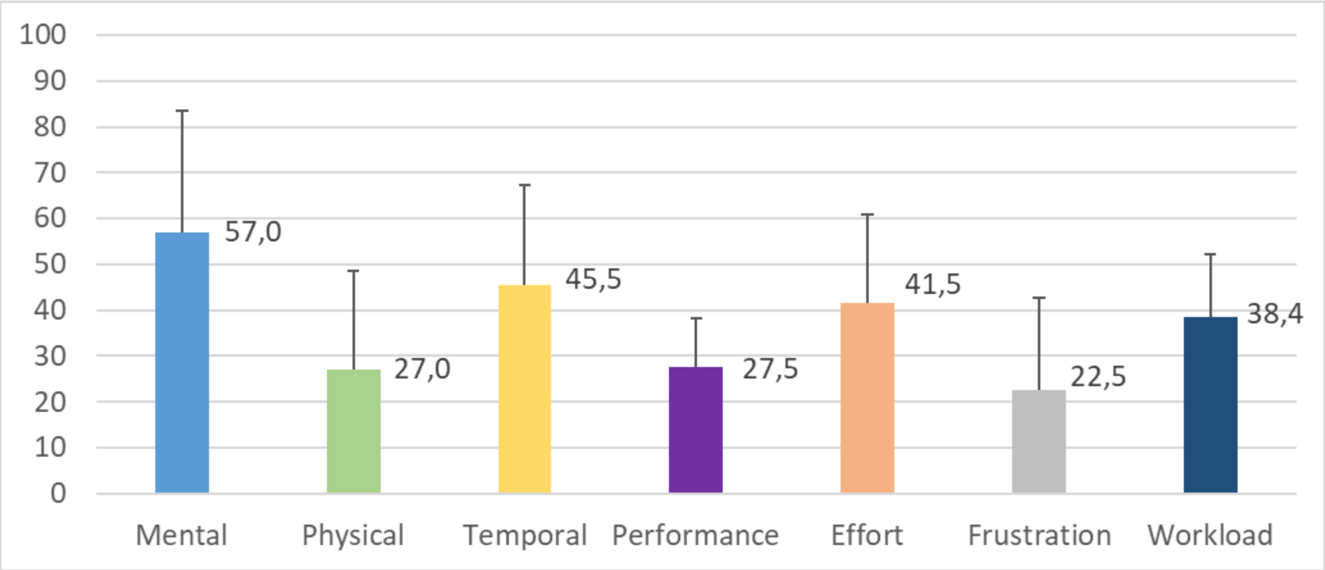


Figure 9: Results of the NASA-TLX Questionnaire / Score of the different components according to their weight

6.2 The improvement axis

6.2.1 Navigation and removal of parts

In early versions, navigating from the product structure to hide parts is too time consuming. Scrolling through the product structure is not easy in a dedicated window (see Figure 10).

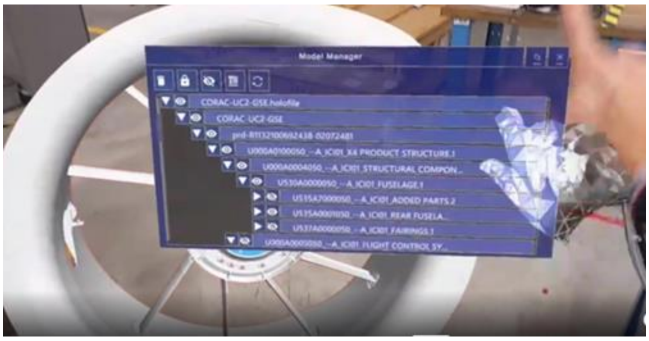


Figure 10: Model Manager of Hololens 2 to navigate from the Digital Mock-up Product

A first evolution was implemented following proposals and exchanges with the support engineers: Selection by level and hide/show directly in the 3D scene as in CAD (see Figures 11 & 12).

In this solution, the parts to be removed are in position in the no-show space.

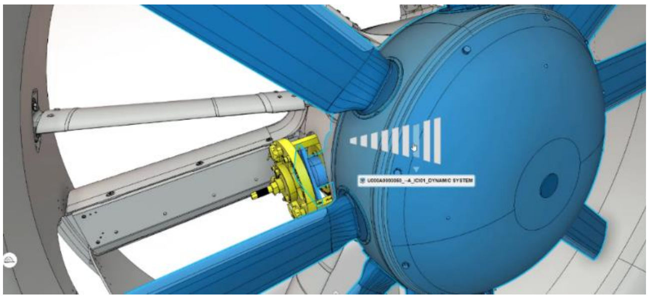


Figure 11: level selector in 3DX (CAO)

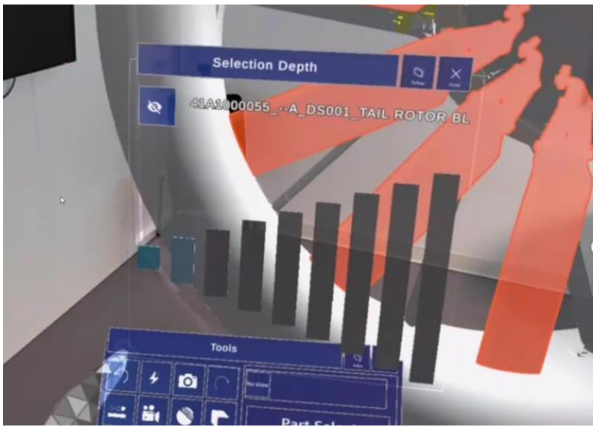


Figure 12: select parts in mixed-reality from level selector to navigate on the Digital Mockup

Successive experiments to test this evolution have shown mixed results: the support engineers, although CAD users, are disturbed by the display of the no-show with parts in position in the real environment (see Figure 13).

The coexistence of the hidden parts with the real visible environment requires an effort of abstraction and creates an inconsistency. This solution is too far away from their real activity on the Aircraft. The new solution currently being developed is to place the part on a simulated physical surface as they do in reality. This solution will be evaluated in future experiments.

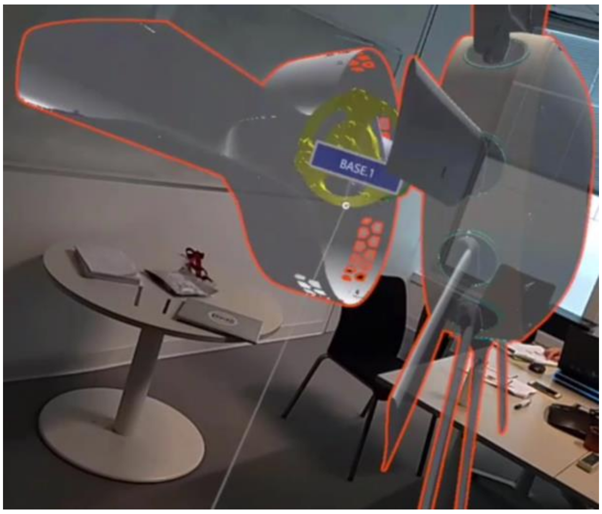


Figure 13: the parts to be removed are hidden in the no-show space but in the assembly position as they are in the visible space

6.2.2 Managing the transparency between the real and the virtual

The 3D hologram of the projected parts is of very good quality but does not offer the expected transparency to see precisely the physical elements interacting with the 3D, such as the hands (even with the hand mesh), the body and the standards physical tools (see Figure 14).

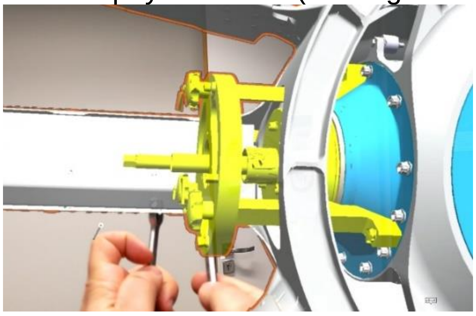


Figure 14: Two illustrations of holographic opacity

6.2.3 The accuracy of the hand mesh.

The hand mesh is stable over time but there is a latency in the movements and interactions with the 3D (see Figure 15).

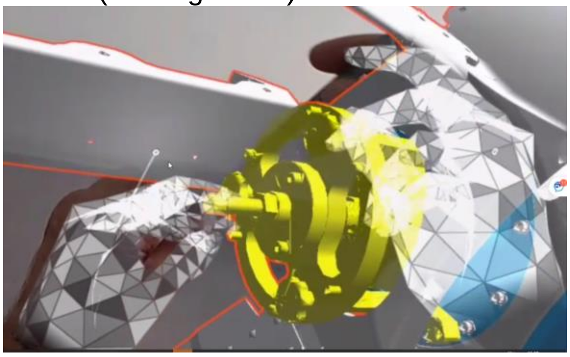
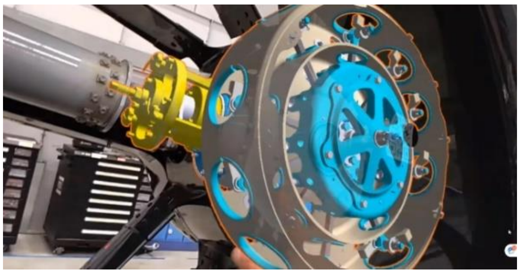


Figure 15 : Hand mesh

6.3 The main positive points

6.3.1 Good spatial perception of the 3D volume at scale 1 and of the interactions with the physical helicopter or the standard physical tools (see Figure 16).



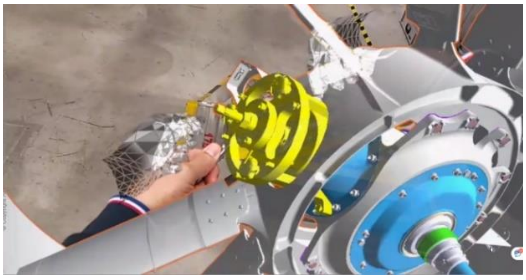


Figure 16a & 16b: Good quality of 3D hologram and interactions with the real environment

6.3.2 The mixed reality validation of the installation procedure in client configuration.

The mixed reality review highlighted the unfeasibility of the installation procedure as written without removing the fairing cover to tighten the third flange behind the fairing. Different strategies were proposed by the support engineers (see Figure 17).

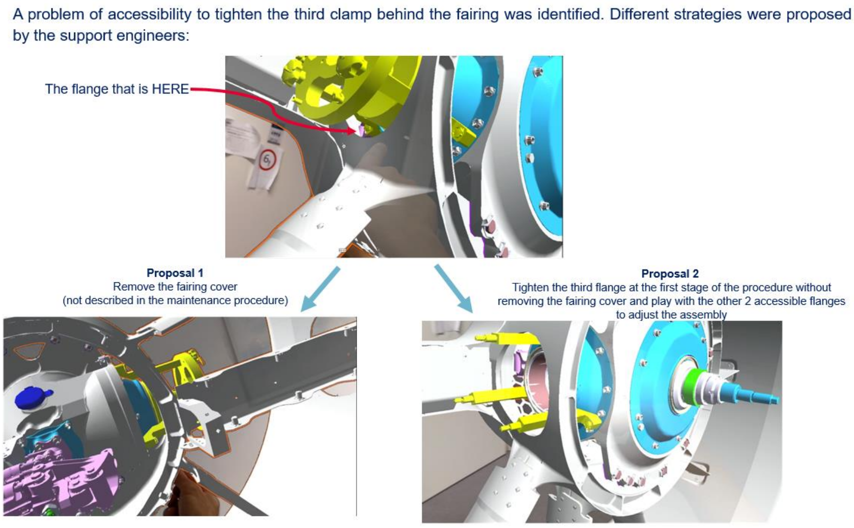


Figure 17: several proposals to solve the unfeasibility of the installation procedure

7. CONCLUSION

On the help of observations, feedback from the field and quantitative measurements, we were able to formulate hypotheses and collect the first results.

The first results show that the review of the GSEs in a mixed reality simulated work situation allowed us to anticipate feasibility problems in operational maintenance conditions and in customer configuration and also to propose new strategies in the maintenance procedure to avoid the removal of parts.

The main advantage of our approach is that no physical disassembly of parts is required (reduction of downtime) thanks to this hybrid model, using a physical prototype, less mature than the helicopter delivered to the customer, but augmented by the projection of the 3D digital model of the GSE in customer configuration.

This approach teaches us a lot and leads us to improve the realism of the interactions to be closer to the real maintenance activity. CAD type interactions are not the right ones.

We are continuing to work on the accuracy of hand/finger tracking in mixed reality in order to be as close as possible to the real gesture made by the operator and to follow the interactions between the user, the standard physical tools and the virtual objects.

We enrich the study with new quantitative methods, new tools for capturing movements and interactions in physical space in order to implement immersive review solutions better adapted to the maintenance situation.

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