CINNABAR PROJECT: EXAMINING REQUIREMENTS FOR USER ACCEPTANCE OF AIRCRAFT STRUCTURE INSPECTION IN AUGMENTED REALITY

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Abstract

The inspection of the outer skin of an aircraft is a crucial part of aircraft maintenance. Every dent or buckle must be inspected and cataloged to ensure continued airworthiness. This process is a lot of work for the inspector, especially when localizing and documenting damages. Finding already cataloged damages from the 2D documentation on the 3D surface is mentally demanding.
This paper examines whether an Augmented Reality approach is applicable to help overcome these challenges. For this reason, a HoloLens-based prototype of the dent and buckle chart is developed and tested in the field. This paper focuses on the methodology and execution of a user study to explore the Augmented Reality approach.
The study results show that maintainers appreciate the application as a solution to dent and buckle chart challenges. They suggest requirements for user acceptance and give insights into the current workflow. The main challenges for the application are the reliability of the system and the intuitive interaction with the application. Opportunities include better data consistency and faster execution of the task.
Establishing general requirements advances the digitalization of aircraft maintenance, as other use cases can utilize the study results.

Keywords: Aircraft Maintenance, Extended Reality Inspection, Human Factors, Technology Acceptance

1. Introduction

Thorough aircraft maintenance, repair, and overhaul (MRO) ensures safe flight operation. One major task is to inspect the fuselage for dents and buckles to assure airworthiness, as structural deficiency is one of the major causes of accidents [1]. The current Dent & Buckle (D&B) check is described in Figure 1. Workers inspect the aircraft's outer hull to find damages that need repair. Once they find a damage, they check if it is documented in the D&B chart or if it is new. New damages are measured, and their position and details are recorded. The differentiation between new and old dents can be very time-consuming, as certain areas on an aircraft are prone to having multiple dents in close proximity.
The D&B chart is also used to convey D&B information on working orders. Workers use the paper chart to find specific damages. Using the 2D schematic on the chart, workers must mentally convert these positions to 3D points on the aircraft. While the chart is divided into smaller sections, it is still a cognitive effort. Additionally, due to the rough estimation of positions, it is often hard to differentiate between multiple damages.
These problems are exacerbated by human error. Sometimes workers give only approximate locations or miscount the frames and stringers used for positioning. In that case, finding dents becomes more difficult, and data entries must be corrected.
New digitalization approaches, like structured light scanners or mobile applications, can support the workers in measuring the dents and can improve the economic factors of this task. They are further

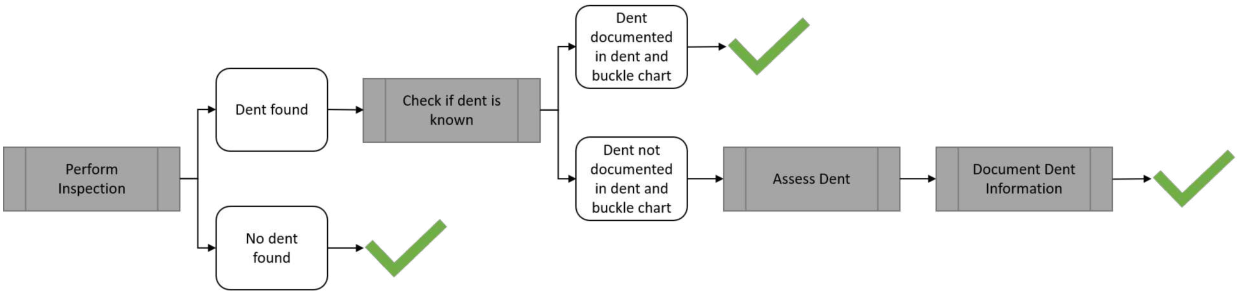

Figure 1 – Flowchart of the current Dent & Buckle inspection process from Aigner et. al. [2].

illustrated by Koschlik et al. [3]. These approaches often struggle to prevail permanently. If maintainers do not accept these systems, they will continue to use the conventional method, leading to unused potential.
Acceptance in this context describes the willingness of users to use the system in the intended way. It is a crucial factor in developing new applications, as rejection of new systems would result in losing valuable resources [4]. Examining acceptance of new technologies is often more complex than a cost-benefit analysis, and multiple factors play a role [5]. The users' involvement in the development process and consideration of their needs increases acceptance [6]. Further, if the system is forced upon the users, frustration and deterioration in performance could ensue [7]. The acceptance of new technology is entwined with the usability of a system. The term usability describes multiple concepts. The ease of use encapsulates the user's interaction with the system and can be measured by user performance and satisfaction [8, 9]. Factors affecting usability include style, interface properties, system reliability, and many more [8].
Next to usability other human factors play a role for handling technology. Human factors is a field of research that shapes human centered design. It encompasses human behavior, abilities, limitations and processes [10]. Workers are likelier to use a novel technology if it is learnable, useable, enjoyable, and supports being productive [4]. However, technology should also ensure that workers' performance does not suffer. User feedback can be measured in many ways, the most common being Think-Aloud, interviews, and surveys [11]. During Think-Aloud, participants comment on their experiences and describe their actions. While Think-Aloud gets many results about user interaction, semi-structured interviews allow for a broader reflection of the topic [11].
User studies can help integrate new technologies successfully. Through user studies, developers can understand the new approach's requirements, challenges, and possibilities at an early stage [12]. Early involvement of users also has financial benefits for the further development [13]. These initial reactions can give insights into the system's acceptance, assuming a new technology is not mandatory for the worker. The first few interactions with a system can hugely influence the decision to adopt the technology. Two critical aspects of technology acceptance are the perceived ease of use and the perceived usefulness [14]. If a newly introduced system can show how easy it can be used and how useful it is, the value of this system becomes apparent.
For aviation MRO, augmented reality (AR) has emerged as a promising new technology. AR technology couples virtual objects to the real world [15]. Hand-held devices like tablets or Head-Mounted Displays (HMD) like the Microsoft HoloLens 2 can visualize AR. Prior work shows that AR can lead to higher reliability and improved task performance [16, 17].
As a part of the CINNABAR project of the German Aerospace Center (DLR), this paper is an extensive analysis concerning the application of AR for the aircraft D&B check. The project is further illuminated in the next section, which integrates this paper into the CINNABAR context.

2. Background

Koschlik et al. examine the current process and introduce a novel framework exploring digitalization opportunities of the D&B check [3]. The framework proposes using AR to digitalize multiple process steps, such as measuring, localization, and decision-making. Finding dents and localizing them in AR can be achieved using retro-reflective markers as described by Keser et al. [18], who illustrates

the technical implementation of the AR process. Utilizing the virtual overlay over real-life objects could reduce the cognitive effort of the workers as they do not have to infer 3D locations from the 2D schematic [19]. The viability of the workflow is discussed by Aigner et al. [2], where the financial factors and potentials in terms of time, labor, and quality are explored.
Koschlik et al. and Keser et al. conducted a preliminary study to get initial reactions and see if the idea is beneficial [3, 18]. The feedback was positive, with the subjects recognizing the potential benefits for the inspection process.

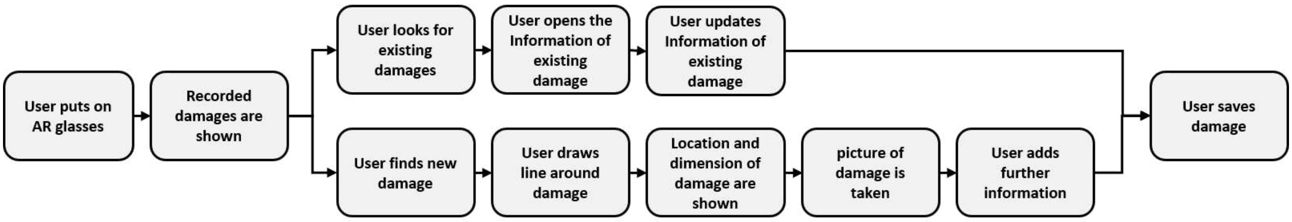

Figure 2 – Flowchart describing the AR-adapted Dent & Buckle application.

The AR workflow is broken down in Figure 2. The user starts the D&B inspection process wearing an AR HMD (here: HoloLens 2). The application uses retro-reflective markers to detect the aircraft's position, and the user can begin looking for dents. The application visualizes existing damages, so it is immediately clear if a damage is already documented or if it is new. In case of an old damage, users can select it and see the corresponding information. If it is new, the user can mark the position using their finger to draw a virtual circle around the damage. The Location is automatically detected, and the initial measurements are calculated using the drawing. The damage is photographed with the HoloLens 2, which automatically overlays the virtual drawings. After confirming that the picture is sufficient, the user can input detailing information as asked in the D&B chart (e.g. damage type, status, and performed action). In the final step, the user saves the damage, and the information becomes persistent.
Using a prototype of the application, this paper will expand on the initial proof-of-concept, focusing on the methodology and the execution of an in-depth user study to examine the approach's opportunities and challenges for maintenance personnel.
The paper will explore the research question: What are the requirements for user acceptance when developing systems for aircraft maintenance? This research question will be explored from two different angles. On is concerned about broader requirements for systems in general, the other with the specific use case of AR support for the D&B inspection.
The remainder of this work is structured as follows. The next section examines the proposed method to answer the research question. Subsequent, the user study results are shown and discussed.

3. Method

The user study was conducted during a C-Check of the DLR D-ATRA Airbus A320 aircraft in the spring of 2024. An in-depth qualitative analysis with trained personnel allows for valuable insights and a thorough investigation of the presented system.
To draw relevant conclusions, the conventional D&B check played a huge role. Before introducing new technologies, one must familiarize oneself with the current process. One can improve the workflow by knowing the pain points of the methods and systems. The goal is to assess the factors influencing the user's acceptance of the new system and examine options to integrate it into their work successfully. This study is split into multiple segments. In the conventional segment, workers approach the D&B inspection tasks using pen and paper, as currently performed. Equivalent tasks are done in the AR segment using the virtual support application.

3.1 Study Design

This paper focuses on the system's general viability and how it fits the current working environment. Thus, a combination of think-aloud and semi-structured interviews is the preferred choice for this

study. Qualitative research has the advantage that even smaller groups can bring considerable insights and diverse results.
Figure 3 shows the general approach of the study. In an initial interview, the participants are introduced to the study and the concept. Then, the participants measured a dent in the conventional way to outline the current process and highlight the advantages and disadvantages of manual measurement. This helps to get the participants into the right mindset and allows for a more direct comparison between the systems. Next, participants are introduced to the AR application in an explorative way. With limited cues from the interviewer, the participants could freely choose a damage and register it with the help of the application. They were encouraged to share their thoughts during the process (to "think aloud") and were able to immerse themselves in the experience without the pressure of performing.
This first impression is collected using a semi-structured interview, after at least one damage was recorded. The interview focuses on the users' experiences during usage, the learnability of the system, the challenges, and the main opportunities of the application. The interviews also capture the users' overall experience and any further comments they might have.

Figure 3 – Study design (dark-blue: semistructured interviews, light-blue: think-aloud).

3.2 Evaluation

The evaluation was done using audio recordings of the interviews. The recordings were transcribed and separated into small statements. Using a variation of the contextual design method [20], the statements were first categorized into broader subjects, and then wishes and beliefs were extrapolated. After clustering these wishes, the requirements become visually clear. This allows for connections to be drawn between different wishes, opinions, and ideas.

4. Results

The study was conducted with 11 workers (ages $23 - 57$), three of whom regularly conduct the D&B check (ranging from $1 - 37$ years of work experience), and one who works as an engineer. The other 7 were neglected in this result section as they did not participate in all the study parts and lacked in-depth knowledge about the current process. However, the feedback was positive from all 11 participants, who saw the potential in AR technology for aircraft maintenance.
While multiple other topics were mentioned in the interviews, this paper focuses on results concerning the usability and acceptance of the new AR workflow. The results are sectioned into *general requirements*, which are not specific to the use case and potentially applicable for similar systems, and *system requirements*, which are given by the nature of the task and the actual needs in the D&B check.
The researchers translated any quotes in the following section as the interviews were conducted in German, and the participants were handled anonymously and noted in Roman literals. Further, any mention of company names is redacted; the used alternative damage measuring system is denoted as an "alternative system" in the following results sections.
For easier readability the thematically connected requirements are collected in subsections. The order of mention is not reflecting the importance of the requirements.

4.1 General Requirements

This section describes the general requirements which resulted from the assessment of the AR application, these can also be applied to other domains in aviation research.

Reliability & Validity

The needs in Table 1 all refer to the broad idea of a correctly functioning application. This includes the system working when needed (see requirement R1), having no ambivalence in the results (R2), and coming to the correct results (R3). These requirements work as a fundamental prerequisite, which needs to be met for the other requirements.

Table 1 – Reliability & Validity

No.	**Requirement** (System needs to...)	**Description**	**Example Quotes**
1	be dependable	The System should work if needed. Some alternative systems are not often used due to their undependable nature.	"The System needs to be dependable" (I) "If everthing would work, I would use the system" (III) "[Alternative System] often does not work as it should" (III)
2	always come to the same result	In decision-making, localization, or measurement, human error plays a role. The system should make the same choice every time. For example, the often-used flowchart in the SRM can lead to ambivalent results, depending on personal judgment.	"The flowcharts can lead 3 collegues to 3 different results" (III) "Different people measure differently" (IV)
3	be valid	Information from measuring, localization, and decision-making must be correct.	"[With the system] we could avoid measuring mistakes" (III) "There is no flexibility wanted. There should only be valid results" (IV)

Integration into workflow

MRO processes are often complex and interconnected. Strict guidelines like the Software Repair Manual (SRM) are crucial for providing safe air travel. The safety and care of work should be at no time at risk. Apart from ensuring airworthiness, the interviews showed some concerns about integrating new technologies (see Table 2). These concerns range from the general difficulty of changing to new systems (R4) to removing critical dependent features (R5). Also, the interaction with existing workflows, like the documentation in a management tool (R6) or the SRM (R7), was mentioned, especially with the regular updates of the SRM in mind (R8).

Table 2 – Integration into workflow

No.	**Requirement** (System needs to...)	**Description**	**Example Quotes**
4	allow for an easy transition	The transition to the new system should be lossless, and the system should be integrated well into the current process. It needs to be compatible with the current IT infrastructure and work with the provided prerequisites	"Changing systems is difficult" (III) "When a new system is introduced, everyone is excited, and then something always goes wrong" (II)
5	understand all the attached processes	For example, reflective silver stickers marking documented damages, support the conventional visual inspection. An easy method requiring little extra effort. The process needs to be fully understood so the new system does not make a depending process harder.	"The stickers make it easier for the crew" (I) "The stickers work very well" (III) "I don't think it's a hard task to stick the dots" (III)

6	be linked to managment tool	Workers use an MRO management tool for documentation containing detailed information and pictures. A link would be helpful to avoid having to transfer the data manually.	"We used to have an app, where pictures were send into the network directly. That was very handy" (III) "Connecting the [MRO managment tool] to the glasses would be great" (I)
7	be linked to SRM	The system could be linked to the SRM, providing the user with the correct ATA chapter and aiding with searching for the right chapter, and the decision-making process.	"A link to the SRM while being at the damage would be useful" (II)
8	work well with revisions	The SRM is updated regularly. It is used to make critical decisions and needs to be up to date without much effort and cost, which could be done with an automated update system.	"We have to change stuff all the time" (IV) "Who would want to update this every 3 months? " (II) "Software needs to allow updates" (I)

Resources

Aircraft maintenance is an expensive undertaking. The time in the hangar is limited, and any prolongation is costly. Thus, resources like time and money must be dealt with cautionary (see Table 3). Saving time is desirable (R10), which includes preparation for tasks (R11) and documentation processes (R12). Overall, new technologies should be worth the investment, and running costs (e.g. through updates) must be considered (R9).

Table 3 – Resources

No.	**Requirement** (System needs to...)	**Description**	**Example Quotes**
9	be financially viable	The cost of new systems must be related to the provided usage.	"We look at the cost of systems and the use they have."(I) "We don't get updates for the [alternative system], since they are to expensive."(II)
10	save time/speed up the process	To complement the conventional method, the system needs to improve the efficiency of the process. This can be done in multiple ways, such as by reducing the time of the whole process or aspects like measurements, finding old and new damages, or tending data entries.	"Correction [of data] takes a lot of time" (I) "[Alternative system] is good because of time and accuracy" (IV) "I think the system reduces the needed time and work" (III)
11	take little preparation time	Alternative systems are criticized because they need a long preparation time.	"[The system] is very easy. You turn it on and it starts immediately." (I) "The calibration of [alternative system] is difficult." (I) "[Alternative System] is never charged" (III) "With a normal dent you are a lot faster manually." (I)
12	should improve the documentation process	Improvement of the documentation process would allow workers to focus on more practical work.	"You spend half the shift to look up the documentation for damages" (III) "I want to start the practical work quickly" (I)

Human Factors

In Table 4, the aspect of the end user is explored further. Humans are a crucial part of the process, and the interview shows that they all wish for the new system to be easy to learn (R13). Ideas for achieving this were having instructions (R14) or courses to work confidently with the system, as well as having a simple (R15) and intuitive (R16) structure. Other wishes were a user interface (UI) that makes sense (R18) and having the whole system accessible to different workers (R17). These factors could be achieved by including users in the development process (R19) and designing with their perspective.

Table 4 – Human Factors

No.	Requirement (The system needs to...)	Description	Example Quotes
13	be easy to learn	Learning to use the system should be quick and not require much effort.	"It was hard to get started with [the system] but you get into it." (II) "After 1, 2 times everyone knows what they need to do" (I)
14	have instructions available	Learning should be facilitated by instructions, with potential training courses being available.	"We do not use [alternative system] a lot because people are not trained correctly for it." (III)
15	be simple	The system should focus on the fundamental aspects and functions rather than adding nonessential features. Interactions and functionality should be clear so people can operate it efficiently.	"Don't over-complicate" (II) "It should be as easy to use as an iPhone" (I) "Software needs to be uncomplicated" (I)
16	have intuitive interactions	Interactions with the system, like drawing and using the UI (via, e.g. buttons), should not need much explanation	"The buttons are difficult to press" (I) "I always press through it" (III) "How do I mark the damage? (III)
17	be accessible	People from different backgrounds use the system, so easy language and different language alternatives could be an option.	"You also have to be prepared for simpler people" (II) "Every system is only as good as its user" (IV)
18	have a intelligible user interface (UI)	The UI should avoid unnecessary displays and use clear icons and language.	"Suddenly there is a line" - confused (I) Observation: Participant pressed cancel instead of redo (II)
19	focus on end-user	Users want to be included in the development process and their individual preferences taken into account.	"The engineers don't take the usefulness for the workers into account." (III) "Many developers forget the user and lose the usefulness" (I)

Environmental Aspects

The introduced technology plans to improve maintenance, thus the working environment was mentioned in the user study as well. The requirements can be seen in Table 5, including the AR headset's easy wearability (R20) and a positive mention of the hands-free interaction (R21).

Table 5 – Environmental Aspects

No.	Requirement (The system needs to...)	Description	Example Quotes
20	be easily wearable	The new system should work with long hair, as well as glasses. Further, it should not cause feelings of unwellness.	"Is it okay with my hair?" (III) "Do I need to remove my glasses" (II) "I get a bit of a headache" (III) "Do people see the real world with the glasses? Not that they trip." (IV)
21	allow hands free interaction	Workers often have tools, so another thing to carry would exclude possible interactions.	"It's good that the hands are free" (I)

4.2 System Requirements

While the above section describes requirements that can be more broadly applied, this section looks at the D&B process specifically and aims to collect the feedback for the AR application.

Localization

The D&B process begins with an aircraft inspection where new damages are to be found. Localization requirements are collected in Table 6. The new tool could support this initial searching procedure (R25) but also help automatically (R23) determine the accurate position of the damage (R24). This position (either through manual input or automatically by the tool) should be saved in relation to the aircraft (R22). This helps to find old damages again. To inspect these older damages, workers want to have an overview from the ground and not make all the effort to climb to the needed position for a quick inspection (R26). To inspect these older damages, workers want to have an overview from the ground and only inspect the damage more closely if needed (R26).

Table 6 – Localization

No.	Requirement (The system needs to...)	Description	Example Quotes
22	localize damages in relation to the aircraft	The position should not need conversion and work well with digital models of the plane.	"It's like GPS on the plane and the colleague can see it too" (I) "It's saved in relation to the aircraft" (II)
23	automatically position damages	The system should know where it is and calculate the position automatically.	"I think it's good that the system recognizes the location of stringers and frames by itself" (III) "The localization would make it a lot easier" (I)
24	localize validly	Searching for damages that are documented incorrectly is time-consuming, and it could lead to missing the correct damage.	"The HoloLens could avoid incorrect information" (II) "We need good information to actually localize damages" (I) "We often have to search for the damages in the working orders" (III) "Sometimes people miscount and then the frames and stringers are wrong" (III)
25	help find damages	Using, e.g. drones, damage locations can be found automatically and saved for human inspection. This could apply to areas that are hard to reach (e.g. the top of the fuselage) or damages that are difficult to spot.	"You could send a drone around the aircraft" (II) "It would be cool if a drone would fly around the aircraft and send the data to the HoloLens" (I) "Lightning strikes are hard to find" (III) "Sometimes we look at a damage from 30 different angles" (III)
26	work well without being close to the aircraft	It would be good if information about damages could be seen from the ground and dent selection worked without needing to be physically close.	"It would be great if you could select damages from further away too" (I) "To select things from a distance would be nice" (III)

Measuring

After finding new damages, they need to be measured (requirements for measuring in Table 7). The system should make correct (R30) and automatic (R29) measurements of the found area while still allowing manual correction (R27). This could be helpful, especially in crucial areas where manual measurement is complex (R28).

Table 7 – Measuring

No.	Requirement (The system needs to...)	Description	Example Quotes
27	allow for correction	If the measurement needs to be corrected, manual input should be available.	"You can put in manual measurements, right?" (II)
28	work for complicated areas as well	Certain aircraft parts are more challenging to measure (e.g. strongly curved parts of the wings).	"Curvature is complicated for the conventional method" (IV) "In some areas the measurement with the ruler is difficult" (I)
29	measure automatically	Automatic measurements would eliminate the process of conventional measuring, and the worker could see dimension information straight on the HoloLens.	"It would be nice if the glasses could meaure as well" (II) "If surfaces would be recognized directly, it would be great I only would have to click on a damage to select it" (III)
30	make valid measurements	As a crucial part of damage assessment, measurements must be correct and sufficiently detailed.	"I would need to draw very accurately" (I) "There is no flexibility wanted. There should only be valid results" (IV)

Input

The measured damage must be further described for the documentation (e.g., damage type, status, and performed action). The available choices for these descriptions produced differing opinions of the participants (see Table 8). While some focused more on the need for more specific options or a multi-select (R33), others saw some choices that are not used much in practice. Thus, the input must align more with the process, showing just the right amount of information (R31). A companion tool for further entries was suggested (R32), or a general option for manual input (R34).

Table 8 – Input

No.	Requirement (The system needs to...)	Description	Example Quotes
31	have as much as necessary, but as little as possible	There were varying opinions on how much information there should be. Some people wanted to have even fewer selection options, while others were satisfied or wanted more possibilities.	"Too much choices in the HoloLens Menu" (II) "The words did not describe the damages sufficiently" (III)
32	link to a companion tool	Input limitations of the HoloLens could be balanced by introducing a companion tool where more input and interaction options are possible.	"Connection of laptop/tablet to glasses with mirrored information" (I) "Connect with laptop/tablet for more selection choices" (I) "One could do only the localization and a dummy entry and do the rest with the PC" (II)
33	allow multiselect	Sometimes a damage can not be put into set categories but meets intersecting criteria.	"Multi-select for type" (I) "Can you select two things?" (III)
34	allow manual inputs	Sometimes additional input is required, e.g. if a damage fits in none of the categories or something noteworthy needs to be documented.	"I would have entered everything straight away out of reflex." (III) "Manual entry with HoloLens must be possible" (I)

Additional Requirements

The needs in Table 9 are additional steps that were extracted in the interview process. For the visualization, limit information and distances to relevant structures should be shown next to the damage (R35). These distances should also be present in the taken picture. The picture is helpful for the documentation and is required to be of good quality (R36). Participants also noted that they need to measure some dents repeatedly (R37) and that dents have different statuses (e.g. permanent or temporary) (R38).

Table 9 – Additional Requirements

No.	**Requirement** (The system needs to...)	**Description**	**Example Quotes**
35	show limit information	Visualization of restricted areas, the thickness of materials, distances to components, and other information necessary to assess if a damage is in limit could facilitate decision-making.	"Show restricted areas. 'Here should not be a damage'" (II) "Show hints about metal thickness" (II) "Can you overlay frames and stringers?" (II)
36	take pictures (of good quality)	Pictures with distances to components can be saved directly in the MRO management tool and support documentation. They need to be of sufficient quality so they are meaningful.	"Pictures including distances to rivets and joints" (III) "Put measurements onto picture" (III) "You take a picture of the damage" (I)
37	measure damages repeatedly	Deferred damages are measured again after a set amount of time. Changes within dents need to be recorded.	"Deferred dents have to be measured again" (I) "We always update existing damages" (II)
38	classify different damage types	Damages can be displayed according to damage type or status in varying ways.	"*Permanent* and *temporary* could be displayed differently" (III) "Show lightning strike with small icon or with a red dot" (III)

5. Discussion

The dent and buckle inspection is complex and time-consuming. Thus, it is an area with great potential for improvement. The general feedback during the user study was encouraging. Through intensive analysis of the user interviews, feedback concerning the AR application was collected, and valuable requirements were found.

5.1 General Requirements

The requirements were separated into general requirements and specific requirements. All requirements are built on the following prerequisites, which must be met for the system to function in a meaningful way. Participants were reluctant throughout the user study, saying the system would be great "provided it works" (III). Due to alternative systems often failing to function, participants doubted new technology. A high level of dependability of the system is necessary to fully utilize it and take advantage of its possibilities (R1). This is interconnected to requirement R3, which states that the system needs to be valid as part of the general functioning of the system. Multiple steps of the D&B check are exposed to human error, which is why it is related to many specific requirements. Like, Errors should be avoided during the initial recording of the damages' location (R24) and measurement (R30), the decision-making using the SRM flowchart (R2), and finding already documented damages with the D&B chart (R24). If the system works, it allows for correct and objective results. The system should not fluctuate in its results but always come to the same outcome (R2). Aircraft maintenance is a safety-critical procedure with no room for uncertainty and errors.
With the initial requirement established the functioning systems needs to be integrated in the existing process. It is crucial to understand the process completely, with all involved participants and attached processes (R5). This can be seen clearly when looking at the usage of reflective sticker dots to mark damages. One could assume the stickers will become obsolete with the introduction of the new

system, but they are not only for the maintenance workers in the hangar but also helpful for any ground crew or the pilots conducting visual inspections. While they could also use the HoloLens, it would change their processes greatly and influence the cost of the systems. Thus, it needs to be carefully considered how to integrate new technology into multi-dimensional processes.

A thorough understanding of this process further helps to smooth the transition (R4). Participants stated that the move towards a new system should occur without loss and integrate easily into the current IT infrastructure. Current tools like their MRO management tool could be linked to the new system to improve data consistency (R6). This would avoid the need for an extra data transfer and would store the data in one location. Additionally, a link to the SRM was discussed, which directly shows the connected SRM chapter (R7). Due to the regular updates in the SRM, the system would need to be adaptable to change (R8), updates should be financially sustainable, and revisions should be smoothly integrated. Independently of a direct link, it is crucial that the system works in combination with the SRM, as having the most recent information on how to assess damages is a safety factor.

It is in the interest of the airlines and manufacturers that the D&B check runs smoothly and safely. C-Check maintenance is costly for the airlines; thus, saving time and resources is a priority for airlines and workers alike. The new systems must be financially viable (R9). By addressing needs and improving processes, this viability can be demonstrated. Speeding up parts of the process (R10) while maintaining the quality of work would benefit all stakeholders. Participants mentioned that finding incorrectly documented damages and correcting wrong data entries is especially time-consuming. The validity of the new application would solve this. The HoloLens 2 (R11) preparation time was also often noted. Participants liked that no complex setup and calibration were required and that they could immediately start the application. Alongside preparation time, the workers noted that documentation often takes longer than their practical work on the aircraft. Improving their documentation process could shift time distribution towards repairs (R12).

Figure 4 – Testing of the AR application on the aircraft surface.

There are varying opinions when analyzing processes, as the perceived ease depends on individual needs. The users want to be included in the process, and have their individual preferences considered (R19). As the workers are the ones using the technology, their acceptance is crucial. It is important that the system works for the users and does not try to replace them.

In all interviews, the learnability was discussed. The system should be easy to learn (R13) or should provide instructions on how to use it (R14). Mandatory courses or certifications can limit the use of technologies because if only some people can operate a system, others will stay with the manual methods or lose time waiting for an expert. Therefore, the steps of the approach should be easy to understand and operate. Easy learning is facilitated by keeping it simple (R15). Focusing on the important functions makes the training phase shorter while making it more accessible for everyone. Having a simple application negates the need for deep technical knowledge.

Accessibility, as practice of making the system usable by as many people as possible, is crucial for technology. Users of all backgrounds should be able to interact with the system. By using uncomplicated language, the system is more inclusive, and by including multiple languages, people of all backgrounds can fully utilize the system (R17). The study found that the user interface (UI) needs to be clear (R18). Unnecessary information and transitions should be avoided, and distinct icons and language are helpful. Next to language, familiarity with other technologies plays a role. Having intuitive interactions can foster the learning process (R16).

It was observed that many people had problems pressing the virtual buttons. This was due to a lack of understanding of how interactions in AR work, which was made more difficult by a lack of haptic feedback. Similarly, the drawing interaction proved to be difficult for some people. In the implementation, users needed to touch the airplane fuselage to start the drawing process and then use their fingers to draw a circle around the dent. Some participants only hovered over the airplane part or had difficulty drawing a closed circle. With the participants' lack of experience with AR interactions and the limited time during the study, it is yet to be seen how well they learn the interactions and how well they work during a longer period.

A more extended study would also allow further exploration of the environmental aspects. However, by conducting this user study inside the hangar, specific needs could already be identified. The HMD should be wearable regardless of whether users wear glasses or have a ponytail (R20). Further, the system must be mindful of cybersickness symptoms, which can occur in some users when using extended reality. Often the symptoms span headaches, tired eyes and nausea. In the final implementation, one must be mindful of the chosen AR medium and the visualizations to reduce the symptoms. One of the advantages of the HoloLens 2 is the hands-free interaction (R21). Especially in the D&B Check and other maintenance tasks, workers might need to operate tools, which makes hands-free AR useful.

The most important general requirements are the ones that are crucial for introducing the technology. Firstly, the system needs to be well-functioning and correct (R1, R2, R3). Then, it is vital to know the process and what the change will entail (R5). It needs to be financially viable (R9) and improve the process before it is considered for introduction. In this scenario, improvement can be mainly done by saving time (R10). As for human factors, the main point is that the system should be simple (R15) and intuitive (R16). Knowing the end-user (R19) and making it accessible to all potential users (R17) is essential to consider, as the use should be facilitating and not frustrating. This is also reflected in the wearability of the system (R20), which needs to be sustainable for the hangar environment. In the study the application is used directly in this environment as can be seen in Figure 4.

5.2 System Requirements

While the above section describes requirements that can be used for different use cases, one of the aims of this paper is to explore the extent of acceptance and usability for the D&B chart.

The user starts with finding a new damage. One challenge with this is determining if a damage is new or already documented. Due to data consistency, all documented damages are saved in the application, so quickly looking through the HMD makes it clear if the damage already exists. For this to work, the localization needs to be valid (R24) and automatic (R23). Through the localization with the markers of Keser et al. [18], the HoloLens 2 knows where it is, so the position of the dents can be calculated easily. Saving this position in relation to the aircraft (R22) then allows for a straightforward visualization pipeline. All the damages are exactly where they were placed by the workers and not described only by frames and stringers. This accurate input can also help find specific damages for work orders later. Localizing and navigating to existing damages would be easier, and work orders could be executed faster. The overview of all damages on the plane from the ground and the selection of damages from farther away would make discussing damages on site more tangible (R26). Many participants also inquired about automatically detecting damages (R25) using sensors on top of the HoloLens or drones that scan the whole airplane. Drones would be especially useful for areas that

are hard to access, such as the top of the aircraft. However, it could also facilitate with damages that are hard to identify visually.
After finding a new dent, the length, width, and depth are measured. Participants criticized the measurement implemented in the prototype. The calculations from the drawing needed to be more accurate, as the manual measurement is more detailed (see Figure 5). Since valid measurements are important for decision-making (R30), a different method for measuring automatically (R28) would need to be implemented. As the workers are highly trained in manual measurement, they are often faster using the conventional method than getting and setting up more advanced measurement technologies. The new system should be as good as the conventional measurement, time-wise and accuracy-wise. Especially in special cases (e.g. high curvature at the wings) or critical areas, the system could improve the process, as manual measurement in these areas can be time-intensive (R28). With the measurement not being certified, manual correction must be possible, as safety depends on accurate measurements (R27). This manual correction could be done with conventional measuring but also integrate alternative superior scanning technology and possibly a measurement by the HoloLens.
After putting in correct measurements, the participants noted it would be beneficial if the system could display the distances to the closest relevant structures (e.g. lap/butt joint, windows), as well as visualize critical areas where limits are calculated differently or where there are no damages allowed (R35). This could assist the users in the decision making process. Further, the distances are necessary for the documentation and workers often draw them with whiteboard markers on the plane, before taking a picture of it (R36). The picture is helpful for documentation, localization, change management, and is sometimes required by the manufacturer. The photo feature of the prototype was commented as having sufficient quality (picture can be seen in Figure 5).

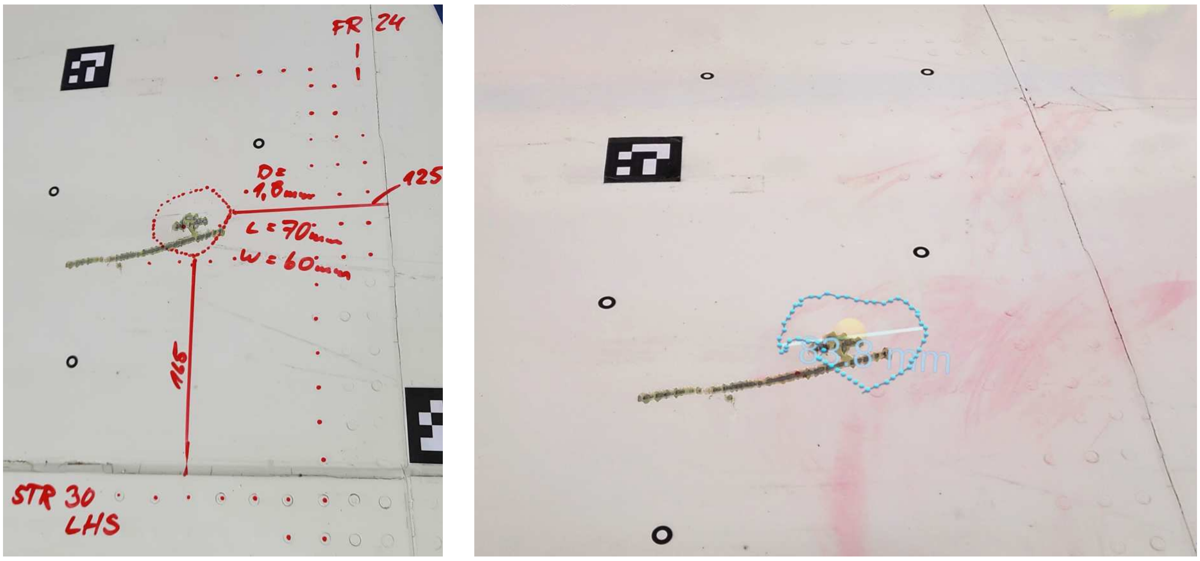

Figure 5 – Left: Manual dent measurement Right: Photo taken by a participant using the AR application.

Documentation requires not only photos but also additional information, which workers can fill out using suggested input in the application. The conflicting opinions about the amount of presented information were discussed in detail. Participants criticizing the lack of information missed necessary input options, while participants who wanted less information commented on unnecessary elements. Thus, the requirement is to have as much as necessary and as little as possible for its input options (R31). One needs to avoid a myriad of unwanted options while still allowing the needed information to come across. A further user study is needed to extract the required information. A different solution for more Input could be a companion tool on a tablet, phone, or PC where more detailed input is allowed to expand the HoloLens 2 interface (R32). It further emerged that some damages are not distinctly classifiable. Some participants suggested a multi-select option (R33) or the possibility of

manual inputs (R34).
Damages saved in the system can be re-inspected. In the prototype, the information could only be seen and not changed. However, sometimes damages are measured repeatedly to document whether a dent has changed between checks (R37). This is a relevant use case for change management that still needs to be implemented. Further, participants asked for different visualizations in the overview. Deferred damages that need to be inspected again could be displayed differently (R38). Similarly, different damage types could be visualized.
Overall, the prototype already fulfills some necessary system requirements. Through Keser et al.'s work [18], the position of the HMD is calculated automatically (R23). Thus, damages are saved in relation to the aircraft (R22). The validity of this method (R24) needs to be tested more intensively before, but the initial prototype is promising [18]. The measurement, while allowing manual correction (R27), is not yet at a point where the measurements are accurate enough for use (R30). Alternative measurement methods should be explored while the application is evaluated for this specific part of the process. Supporting tasks like picture-taking were already working well (R36). Also, the general idea of input using the HoloLens 2 was received positively, with further work needed to determine the amount of information (R31). It is important to note that this prototype combines multiple parts of the D&B process. Smaller use cases, such as localization, would already greatly facilitate the work. Participants were excited about the localization possibilities, mainly as alternative scanners are available for measuring, but there are few alternatives for localization.

5.3 Limitations

The found requirements are helpful for the future of aviation research, however it needs to be considered that the method in itself has limitations. Qualitative research is inherently subjective and especially with a small group of people conclusions drawn from the participants might not mirror the general population. Further, their opinions were interpreted by the research team to get to tangible requirements. While both these factors influence the repeatability of the results, the researchers, as well as the participants agreed with each other almost always. By repeating the study with different participants, the results could be expanded.
The time frame of the study is another factor to consider when looking at the acceptance of the system. Controlled study environments don't account for the long-term usage of the system and how it integrates into their daily work. A repeated review at a later time could confirm the positive attitude towards the new system and explore the actual acceptance. This is especially interesting once the system is developed with all functionality.
Even with those limitations the results can be of great value, as they show the potential of the introduced work and what the system needs to fulfill to be of value for the workers. The general requirements not only apply to the D&B check but can also be a starting point for technological advancement.

6. Conclusion

User studies are critical to ensure that the implementation is acceptable, usable, and functions correctly. A lot of new technologies in the aircraft sector, while intensively tested, need to utilize in-depth user studies. A rare research opportunity presented itself with the C-Check of the DLR-ATRA. The study was conducted with trained professionals at the maintenance hangar. Conducting a study with these characteristics is often challenging, as this process is too expensive and time-consuming for most airlines.
The study found among other things requirements for reliability, integration into the workflow, sustainability of resources, and human factors. Participants appreciated being asked for their needs and opinions and were able to voice concerns and hopes. Especially when asked about the D&B check, many system-specific requirements were established for measuring, localization, visualization, and input. The user study provides insights about the next iteration phase of development and shows that the system is worth continued evolution. Early signs of acceptance and a need for the digitalization of the D&B process allows researchers to put more time and resources into this project. This shows the many advantages of user studies and underlines their value for aircraft maintenance research.

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