Visualizations for simulation-based training

Enhancing the evaluation of missile launch events during after action reviews of air combat simulation

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Visualiseringar för simulatorbaserad utbildning
Förbättring av utvärderingen av robotskott under after-action reviews för luftstridssimulering

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Master Thesis in Interactive Media Technology

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SAMMANFATTNING
Detta examensarbete har haft som syfte att förbättra utvärderingen av luftstridssimuleringar som bedrivs vid det svenska flygvapnets luftstridssimuleringscentrum, FLSC. Inledande studier identifierade tre huvudsakliga behov för utvärderingen av flygplansburna robotskott avfyrade mot luftmål utom synhåll, på långa avstånd. Dessa behov inkluderar en förbättring när det gäller att upptäcka var och när i en simuleringsuppspelning som ett robotskott har skett, en samlad vy över flygparametrar för att förhindra förvirring och korsreferering mellan olika skärmar, samt möjligheten att utvärdera ett flygplans flygparametrar över tid för att kunna diskutera alternativa avfyrningsmöjligheter eller manövreringsmönster.

För att fylla dessa tre behov har iterativa designstudier utförts i samarbete med personalen på FLSC. Detta har resulterat i ett designförslag med en prototyp baserad på de designriktlinjer och rekommendationer som studiens deltagare delgett. Syftet med visualiseringen är att ge stöd till instruktörer och främja piloters individuella inlärning. Förhoppningsvis kan detta i slutändan bidra till att svara på frågan om varför en robot missade sitt mål. För instruktörer och flygförband kan ett sådant hjälpmedel underlätta identifiering av felmanövreringar och även ligga till grund för värdefulla diskussioner under analysen av genomförda luftsstridsimuleringar.
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ABSTRACT
This thesis work has been part of an effort to improve the after-action reviews of the air combat simulator training sessions conducted at the Swedish Air Force Combat Simulation Centre (FLSC). Initial studies identified three main needs regarding the evaluation of air-to-air missile shots during beyond-visual-range combat simulation. These needs included an improved detection of where and when in the simulation playback a missile shot took place, a collected view of flight parameters to prevent confusion and cross-referencing between the various displays, as well as the ability to review an aircraft’s flight parameters over time in order to discuss alternative shooting opportunities or maneuvering patterns.

To fulfill these three needs, design studies were performed iteratively in collaboration with staff at the FLSC. This work has resulted in a design proposal with a prototype based on the design guidelines and recommendations of the study's participants. The purpose of the visualization is to provide support for instructors and promote the individual learning of pilots. Hopefully, this can ultimately help in answering the question regarding why a missile missed its target. For instructors and air units such aids could mean that operating errors can be more easily identified and also form a basis for discussion during the assessment briefings.

Author Keywords
Simulation-based training, simulation, after-action review, AAR, FLSC, beyond-visual-range, BVR, air combat, visualization, flight parameters, air-to-air missile, UI, interface design, learning systems.

1. INTRODUCTION
For over half a century, aerial combat has been regarded as one of the most important aspects of modern warfare and defense. The Swedish Air Force (SwAF) has a long tradition of organizing and educating fighter pilots with a primary focus on safeguarding their own territorial boundaries or joining in UN-led support missions. By utilizing the multi-role JAS 39 Gripen fighter aircraft, SwAF pilots can perform an extensive range of air-to-air, air-to-surface and reconnaissance missions. While the aircraft itself might not be able to match the maximum speed and altitude of some of the competing aircraft models, SwAF units strive to overcome this by training to be the smartest, most maneuverable, flexible and tactical units in the world. In order to achieve this goal, a world-leading support, education and training system is required.

1.1 FLSC
The Swedish Air Force Combat Simulation Centre (FLSC) at the Swedish Defence Research Agency (FOI) is a world-leading simulation facility primarily used for the training of beyond-visual-range (BVR) manned aerial combat. What makes the facility unique is that it focuses on networked many-vs-many simulations, allowing up to eight pilots to simultaneously fly in different team constellations, typically 4v4 or 6v2. Both teams are usually accompanied by an arbitrary number of various computer-generated forces (CGF) such as other aircraft, air defense systems or ships. FLSC provides simulation support for a variety of areas, such as education and preparatory exercises or large scale distributed training sessions with foreign air force units. Since 1998 FLSC, together with the SwAF, has been implementing operational simulation for the training and education of pilots and ground controllers, as well as command and staff personnel (FOI, 2016).

1.2 After Action Review
Air force units visit FLSC frequently to train for one week at a time and conduct several combat simulation sessions per day. After each performed session, the unit is gathered to join the accompanied After Action Review (AAR). The AAR is a structured debriefing or assessment process that compares intended vs. actual results achieved. A typical scenario brought up during AARs includes missile launch events and the evaluation thereof. Currently, this evaluation is dependent on the experience and education of instructors to determine how detailed and comprehensive it will be. As the experience level of the instructors varies, there is a need to develop and introduce aiding tools to facilitate the evaluation of simulator sessions. This thesis intends to investigate the possibilities for how such visual aids should be designed in order to support and facilitate instructors and pilots when evaluating missile launch events during AARs.

1.3 Goal of the thesis study
For over 10 years, simulator based research and development (R&D) has been conducted at FLSC. This research is largely about the learning process and how to improve and evaluate the training of fighter pilots. In the publication Towards the Learning Organization (Artman et al., 2013) it is described that evaluation of simulator sessions is key in the process of improving the training and learning of fighter pilots. The publication also stresses the need for tools that visualize the actual flight process of individual pilots. For instructors and pilots, such aids might mean that operating errors can be more easily identified and
provide input to the evaluation. Borgvall et al. (2011) did a study regarding enhancing the scenario visualization for simulated-based training at FLSC. By investigating using the in-house developed simulator system HawkEye, a discovered common need among user groups was the visualization of non-physical parameters and composed measures. Many of the underlying parameters exist within the simulator system; for instance: flight parameters, weapons- and sensor systems as well as data regarding the missile’s predicted intercept or impact point (PIP/PRIMP). Currently, flight parameters such as heading, distance-to-target and PIP are mainly displayed in the cockpit view of the simulator system. Visualizations of composed measures and parameters over time or in relation to each other are currently lacking. In the future development section, Borgvall et al. suggests development of visualizations of individual pilot performance with comparative visualizations of spatial and temporal deviations.

With this in mind, the goal of this thesis is to improve AARs by exploring and conceptualizing design suggestions that could serve as aids to instructors and facilitate in evaluating missile launch scenarios, ultimately resulting in the development of a prototype. In order to accomplish this goal, the following research question was formulated:

“When compared with current practices, during After-Action Reviews of aerial combat simulation, what are the most relevant visual mappings and structures of aircraft flight parameters that support instructors and pilots evaluating missile launch scenarios?”

The research question was divided into three sub-questions:

- What are the limitations of the current evaluation procedure?
- What individual flight parameters are deemed relevant to visualize?
- What are the needs for improving the evaluation?

1.4 Delimitations

A full implementation of the prototype as a plug-in to the existing simulator system is outside the scope of this thesis. Statistical analysis and calculations regarding data from measurements and underlying flight parameters will be a delimitation due to time limits and that the data is considered classified information. A complete and thorough quantitative evaluation of the finished product will thereby be outside the thesis time frame. Since the end user group consists mainly of experienced fighter pilots and instructors, whose availability was deemed scarce, a quantitative design study is beyond the scope of this thesis.

2. RELATED WORK

In the report conducted by Artman et al. (2013) about the process of improving learning, the performance measurement tool PETS and its usage for gathering and parameterizing values of maneuvering and weapon systems, is discussed. The tool, developed by the US Air Force Research Lab, was a proof-of-concept human performance measurement system that could collect 80-100 ‘core’ combat performance measures in real-time, for instance the underlying flight parameters of the shooter. It has since its original design been developed into the Coalition PETS (CPETS), which is a shell for logging and analyzing air combat related variables.

In 2004 Grandt et al. introduced a concept for an enhanced knowledge-based, human-machine interface for future combat direction systems of naval ships. This is presented as a visualization model for a Command Control Information System (CCIS) with the purpose of providing real-time computer-based decision-support and control for naval operators during non-simulated events of a variety of defensive combat scenarios. While the CCIS focuses on threat levels and recognizing suddenly deviating tracked object behavior, this thesis focuses on concepts for visualizing information from past simulations as a learning aid during after action reviews of offensive scenarios in air-to-air combat. Despite the differences, there are some similarities that make the work of Grandt et al. related to this thesis. Both concepts aim to visualize larger quantities of information that is otherwise difficult for users to grasp. Grandt et al. suggests a Tactical Situation Display (TSD) system that is similar to HawkEye but has a larger focus on displaying individual events and object movements in real-time, showing historic information and positions of objects augmented over the current display. On the left side of TSD there is a column of radar chart displays featuring data of tracked objects which are implemented in order to integrate hundreds of parameters within one multidimensional display. The resulting shape pattern assists the operator in noticing momentary changes in tracked object behavior. This, according to Grandt et al., is facilitated by the innate human ability for pattern recognition. One of the five branches in the radar charts consists of object kinematics, such as velocity, acceleration, altitude, climb rate, turn rate; some of which are relatable to this thesis.

On a second visual display terminal, detailed track data can be accessed. Grandt et al. deemed this necessary, as using an easy perceptible radar chart might encounter difficulties if object evaluation requires knowledge of specific parameters. The track detail display features multiple representations of different parameters. Speed, altitude and distance to object are visualized separately, with views displaying the respective parameter graphically in regard to tolerance ranges. Underneath the three parameter-views, a graphical area displays parameters as a function over time or distance. These views all lack the option to visualize the parameters with respect to each other over time or reference ranges. Grandt et al. decided which information should be shown where and in what interface by categorizing information into groups of “need-to-know” (overview) or “nice-to-know” (on-demand basis). This is comparable to Shneiderman’s (1996) Visual Information-Seeking Mantra: “Overview first, zoom and filter, then details-on-demand”.

Riveiro et al. (2014) discusses threat evaluation; the process of assessing how much threat an object poses against a defended asset (DA) (Roy et al., cited by Erlandsson, 2013). The authors present a design proposal for making threat evaluation more transparent. A proof-of-concept prototype is designed, which has an interactive map in the center of the interface, with sensor readings to the left and prioritized targets to the right. When objects appear on the map they are identified and their kinematic values over time
can be seen in separated simulator views. Using initial values together with input parameters from the human operator, threat values for the DA over time are calculated. The importance of certain parameters and threat types can be customized. Visualizing object kinematics over time and calculating a threat value based on underlying parameters is more similar to the task of this thesis than the previous work of Grandt et al. (2004). There is still, however, no available option to visualize kinematics over time with respect to each other and ideal parameter values.

3. THEORETICAL BACKGROUND

Aircraft flight parameters and maneuvering make up a substantial part of the prerequisites for successfully intercepting a target with a beyond visual range (BVR) air-to-air missile (AAM). Mapping the aerodynamics and techniques behind effective maneuvers is an exceedingly complex and lengthy task (Smith et al., 2001). Aside from the complex aerodynamics revolving air-to-air combat, there are some fundamental flight and maneuver parameters that generally apply to BVR air-to-air combat.

Panarisi (2001) and Smith et al. (2001) describe the target aspect angle as a critical parameter and tactical measure that must be determined during debriefings of air-combat scenarios. Panarisi considers aspect angle to be the primary parameter pilots must control for successful weapons employment. He explains that if an aircraft has locked-on to a target, the radar can accurately display the aspect angle in the shooting pilot’s Heads-Up Display (HUD) within the cockpit. Without such radar lock-on information, pilots rely on visual cues to manually estimate the aspect angle. Misperceiving factors such as aspect angle can result in poor maneuver and weapons employment decisions by the pilots. Manual estimation methods do not provide sufficient means of debriefing crucial aspect angle measurements. Atesoğlu (2007) describes the angle-off, also called heading-crossing angle (HCA), as a critical parameter.

Other important kinematical factors include speed, altitude and heading of the aircraft, which in turn affect a fired missile’s kinetic energy. According to Broadston (2000), firing a missile at lower altitudes affects the range and speed of the missile negatively since lower altitude contains higher air density and provides more air resistance (drag). In long-range duel situations, altitude relative to the opponent is a particularly important factor (Jarmark, 1985).

Another factor that can cause increased drag is the angle the missile is fired at (Broadston, 2000). A higher angle between the aircraft’s heading and the missile’s PIP forces the missile to a steeper initial turn rate, which results in energy loss and thereby a decreased missile speed and range. The PIP is actively determined in the targeting computer of the aircraft. This is projected as a PIP marker onto a HUD in the cockpit. Visualizing this allows the pilot to see how his maneuvers force a missile to recalculate its PIP, thus draining the missile of its kinetic energy (Borgvall et al., 2011).

Birkmire (2011) describes the definition of a Weapon Engagement Zone (WEZ), also known as a Launch Acceptability Region (LAR) or a Dynamic Launch Zone (DLZ), as a means to predict and present air-to-air missile maximum and minimum engagement ranges. This region is calculated and dynamically defined depending mainly on the airspeed, positional geometry, heading, altitude as well as the selected weapon-type of both the shooter and the target aircraft. Panarisi (2001) mentions aspect angle as a primary factor in determining the weapons employment envelopes. Birkmire (2011) further specifies WEZ viewed as DLZ within the pilot’s HUD as a critical measure when aiming for successful target interception.

4. CONTEXTUAL BACKGROUND

4.1 Overview

The floor plan of the simulator hall as illustrated in figure 1:

1. Four JAS 39 Gripen aircraft cockpits with half-domed displays.
2. Two Ground-control intercept (GCI) stations.
3. Multi-view area for simulation playback and debriefings (AAR).
4. Four JAS 39 Gripen aircraft cockpits with large screen displays.
5. Two briefing rooms for planning and tactical briefings.

The AAR is centralized in the multi-view area. This section contains a seating area for the air force units, as well as system operator desks used for managing simulation playback during debriefings. Figure 2 illustrates the multi-view screen layout, consisting of 10 4K large screen TVs and one central projection display. By utilizing FLSC’s in-house developed scenario visualization tool HawkEye, 8 cockpit views and a large central projection named the God’s eye view are displayed.

The God’s eye view is a three-dimensional overview of the theatre of battle and the main screen of the AAR, in which the entire performed simulation is visualized. Although the playback is typically viewed from a bird’s eye perspective, multiple viewing angles are available. Little visualization apart from the simulation playback itself is used in the God’s eye view currently. Out of the few visualizations used, most are surrounding the event of a missile launch; for instance: the flight path of missiles and aircraft, missile lock information, and changes in color of the flight path depending on the status of missile lock after launch. In the top left corner of the God’s eye view display, all aircraft’s
altitude, fuel, speed and weapon storage are displayed. For more details, instructors turn to the cockpit views.

Currently, AAR instructors use the cockpit views to estimate flight parameters during missile launch evaluation. Figure 3 shows what displays are available inside the ownership cockpit. Altitude and speed are numerically visible in section 1. More complex measures such as aspect angle or angle-off require cross-referencing between sections 2, 3 and God’s eye view. Distance-to-target is shown in section 4 (if target is locked-on), but to fully understand targets’ positional relation to WEZ or maximum range, sections 2 and 3 are necessary.

While in simulation, pilots interact with the central display inside the cockpit by adding radar or map information. If the central display gets cluttered, pilots can clear the screen to remove non-current information. Currently, during AAR, instructors view the same central displays when interpreting information such as flight parameters surrounding a missile launch. Since the cockpit views are direct representations of pilots’ flight instruments from the simulation runs, it is not possible to display external visualizations within these views. However, the 4K screens vacate large spaces above, under and beside the cockpit views, providing room for new visualizations to be displayed.

4.2 Simulation training
The combat simulation session begins with the presentation of a training scenario and its mission-critical objectives. The participating air force unit is typically divided into two teams. One is assigned to fly the blue forces, representing the aircraft, weapons and capabilities of the own air force, while the other represents the red adversary forces, adopting foreign air forces’ tactics and behavior. Both teams gather in separate briefing rooms to formulate plans and tactics for the upcoming simulation. One group of four pilots (a four-ship) from each team then takes seat in their respective cockpits to join the simulation. The combat simulation is concluded when all objectives are met or when either of the two four-ships are defeated through termination. Then the entire air force unit and involved staff members from FLSC gather in the dim-lit multi-view area to participate in the subsequent after action review.

4.3 AAR
The duration of the AAR session usually is 10-20 minutes depending on how eventful the simulation was. One of the team leaders, or an assisting FLSC staff member, gets appointed to lead the debriefing as facilitating training instructor. The AAR commences with the four-ship leads explaining their tactics and how the simulation played out in relation to them. All participants then watch the playback in God’s eye view. When an interesting event, such as a missile launch or threatening situation, occurs in the playback, the instructor, other experienced pilots or the simulation system operator can initiate a discussion. The pilots who were involved in the event then reflect on the experiences before and during the event. Questions like why or how the incident occurred are answered. After verifying whether these conclusions were correct or not, the team leader or instructor then describes how the incident could have been handled in a better way. These steps are then repeated for each significant incident that occurred in the simulation. Depending on the result of the AAR, it is decided whether the next session should continue with the same scenario and teams or not.

4.4 Missile launch events
During a missile launch event in the AAR, viewers trace the missile trajectory before the playback is manually reversed. The event is then replayed and reviewed at a slower pace before it is paused, turned around or zoomed in/out in order to find out the shooter’s flight parameters and to get a general sense of the situation. Each involved aircraft’s speed and altitude is looked up, while questions such as “could the missile be launched at a different moment?” and “why did the missile miss?” are often brought up. Underlying flight parameters are interpreted or estimated by the instructor live and then conveyed to pilots using general expressions such as a good or bad “position to shoot” (not strictly geographical) or a “shot opportunity”. One of the instructors at FLSC clarified: “The pilots have a uniform understanding of what is considered a “good shot opportunity”, and they constantly do geometrical estimations in real-time to find good shooting angles”.

4.5 Clarifications
The missiles addressed in this study are limited to fire-and-forget-types (F&F); meaning that a required lingering lock-on after missile launch is not taken into consideration. This assumes that the focus should be on the time period before and leading up to the event of missile launch. Some specific training settings, like air-to-sea, may require lower altitudes, but for this research, a higher speed and altitude is pursued, as BVR air-to-air is the implied combat scenario.

4.6 Missile launch procedure
The four typical events related to F&F missile launch are presented as follows:

1. Pilot commits radar lock-on to one or more targets.
2. Pilot manually selects one prioritized target (visualizations like the PIP and distance-to-target are now calculated and displayed in the cockpit view).
3. Pilot fires a missile against the prioritized target.
4. The missile hits the target, misses it or runs out of fuel.

The visualizations presented in this design process mainly addressed the time frame from 2-3 and slightly thereafter. The reason was that the missile launch event was deemed as particularly relevant to visualize. Another factor was that it is only during the mentioned time frame that missile lock-on data can be fully accessible and utilized in order to determine the missile launch parameters without manual estimation methods.

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1 In training and simulation technology, ownership is the vehicle or platform being simulated.
4.7 Missile launch definitions

Before conceptualizing design suggestions of flight parameters some formal definitions established in the theoretical background had to be harmonized with notions used by staff, pilots and instructors in the AAR context.

The instructors’ and pilots’ definition of the air-to-air missile maximum and minimum engagement ranges utilized during the simulation training is similar to the shooter centered LAR described by Birkmire (2011) in figure 4. Instructors often refer to this region as the missile envelope or shooting area.

Whenever envelopes, LAR or shooter-centered values are mentioned, this is what is being referenced.

During the AARS, angle-off is often mixed up with aspect angle. The words aspect, aspect angle and “angular difference” are often used interchangeably for both angle-off and aspect angle, depending on the geographical relationship between the shooter and target. As presented in figure 5 (Ateşoğlu, 2007), the purpose of aspect angle is to inform about the position and heading of the target relative to the ownership, regardless of owndship heading. This conjoins with Panarisi’s (2001) discourse of the aspect angle as the number of degrees measured from the tail of the target aircraft to the position of the maneuvering aircraft. The angle-off, on the other hand is the angle between the two aircraft’ heading and is often what is implied when the word aspect angle is used during AAR. It can be seen as the angular difference between the line of flight of an attacking aircraft and that of an aerial target (Ateşoğlu, 2007).

Error angle (Swe: styrfel) was proposed as a definition of the parameter involving the angular difference in degrees (0-180) between the ownership heading and a line drawn from the ownership directly toward the PIP.

5. METHOD

5.1 Constraints

Conducting a publishable academic design study within a high security national defense research agency (FLSC) will naturally have implications on research methodology. The Swedish law concerning publicity and secrecy (2009:400) strictly prohibits accessing or spreading any information that is considered secret. In order to be determined eligible for access to the facilities and research personnel at FLSC, it was required to be approved by several steps of security clearances. A security clearance alone does not grant an individual access to classified material. It was therefore decided that the first level of access would be sufficient for this research work. This security level granted access to some of the facilities and all of the personnel at FLSC, but did not include access to multiple pilots for meetings or free passage to the simulator hall and actual training. Information regarding the context of air force training therefore had to be acquired without witnessing an actual AAR or meeting an air force unit in person.

When designing concepts for applications within the military research and defense sector it is vital that the design choices do not negatively affect the current practices or systems used at FLSC. In this case, security precautions prohibited the access to any simulator related hardware, software or data from previous training sessions.

This setting presented the following initial constraints:

- No room for misunderstandings (aim for self-evident design)
- No extensive/thorough user testing/study other than quick evaluations.
- No access to existing visualizations, display information, HUD, screen measurements, real parameter sample data or limit values.
- No possibility to test concepts in simulator, to determine how it would look in the intended environment.
- Designs should fit in the context of AAR, meaning they should be kept simple, clean and be compatible and relatable to the current system and display.
- Color tones should be adapted to a dark or low-light viewing setting.
- Visualizations should serve as a support system that does not distract or take too much attention from the actual simulation process.

5.2 Methodology

The complex and secretive nature of the research area meant that instead of planning the entire research methodology beforehand, an iterative and partly ad hoc planning process was implemented. Through this process, several methods were formulated. Because this is considered a new and undocumented research field, an exploratory design approach was used, as it is a suitable way to tackle design tasks in new fields (Martin and Hanington, 2012). This method combines and utilizes a broad variety of complementary methods in order to gain a comprehensive understanding of both the target users and existing systems.

5.3 Interviews

The research involved introductory meetings and unstructured interviews with staff members and senior researchers employed at FLSC as well as a guided tour around the simulator hall. The purpose of these interviews was to map out the current practices and clarify the needs of the stakeholder (FLSC). After the initial meetings, a semi-structured interview with a fighter pilot and a technical engineer followed. With the purpose of determining the scope of the research, this interview involved investigating which flight parameters are significant in the context of evaluating missile launches, understanding the dynamics behind the simulator system and training process, as well as finding out details regarding what data and visualizations are currently used and readily available in the system.
5.4 Context observation
In order to obtain information about the communication between pilots and instructors during AARs, three senior researchers at FLSC video-recorded and observed live training sessions on the author’s behalf, before compiling the observatory data. By gaining access to the compilation and later conducting a semi-structured interview with the involved senior researchers, it was possible to procure declassified observatory data from live AAR sessions.

After the initial context observation had taken place, a second, more intricate, visit to the simulator hall was scheduled. A “dummy AAR”-session was performed with the purpose of getting a deeper insight of the pilots’ point of view and the simulator system. Throughout the session, two instructors played out a debriefing that replicated a plausible AAR scenario, allowing questions to be asked in real-time. This method was chosen to get a realistic impression of the instructors’ dialog and technology utilized in a real AAR. Since the security classification prohibits any recordings to be brought from the simulator hall, observatory notes and sketches were taken by hand.

5.5 Design workshop
The main goal of the workshop was to let participants sketch and discuss their own ideas of visualizations related to missile launch events and aircraft flight parameters during AAR. This was then compared to conceptual design suggestions developed prior to the workshop.

5.5.1 Participants
During previous methods, additional feedback and ideas related to the design research were received. A fighter pilot and a military ground controller currently employed as instructors at FLSC displayed particular interest to contribute in improving visualizations to be used during AARs. With over 20 years of experience in their respective fields, these subject matter experts are both well aware of the current practices and expressed this with their own solutions and design suggestions. In order to conceptualize and present their ideas related to the research question, they were invited to participate in a design workshop, as this is a method that allows for efficient and constructive ways to gain creative input and valuable insight from participants (Martin and Hanington, 2012).

5.5.2 Preparations and setup
Prior to conducting the design workshop, low-fidelity sketches and conceptual design suggestions based on the results from the other research methods were created using Adobe Photoshop CS. In order to facilitate the participatory design elements, A3-sized paper printouts depicting the multi-view area screen layout, as well as larger A2-sized map printouts of the God’s eye view display were prepared. Small red and blue colored paper models of aircraft, strikers and missiles were constructed as board game style pieces, with less saturated colored models giving the appearance of preceding frames in flight paths.

According to Rogers et al. (2007), providing a familiar space by simulating the regular work situation could help participants to draw on their experience and tacit knowledge. This may also help designers gain a better understanding of participants’ mental models. The purpose of the constructed artifacts was to aid in presenting different AAR scenarios while providing such a space, with the aim to encourage discussion, move around objects, sketch visualizations and conceptualize ideas in.

The workshop was documented using an omnidirectional microphone and wide-angle lens camera mounted above the design work space. For ethical and confidentiality reasons, the camera was positioned so that it captured the entire desk without revealing the identities of the participants.

5.5.3 Tasks
The workshop was divided into three parts, lasting ca. 5, 45 and 15 minutes. The first part addressed the overall layout of the AAR and visualizations. Questions here regarded display, screen layout and placement options. In the second part, the workshop leader used available material to map out a missile launch scenario and proceeded to ask questions about when, how and if visualizations should be shown. Three basic visualization concepts related to the research question and previously acquired results were presented: an alert or indication of an upcoming missile launch during playback, a gathered view of flight parameters, as well as flight parameters viewed over time.

Since the second part involved exploratory as well as participatory design methods, it was essential that the workshop leader did not influence the design results of the participants. It was made sure that the discussion about possible design alternatives was kept open. The participants were frequently requested to contribute with their own illustrations in order to explain or clarify their ideas.

During the final part, low-fidelity sketches of the three visualizations and example graphs from D3JS 2 were presented for feedback.

5.6 Designing/Prototyping
After the design workshop had been conducted, the development of a final interactive prototype commenced. The prototype was developed iteratively, alongside feedback meetings with staff at FLSC, using the Java based prototyping tool Processing 3. In order to circumvent the lack of sample and limit data, these had to be estimated and generated by the author. A sample-creation tool was created in Processing and 160 parameter samples of aircraft, missile and PIP positions were generated into a CSV file. All simulation, flight paths and visual data were therefore limited to geometrical relations and calculations based on this sample data. Other design constraints presented by Processing as a prototyping tool were the inaptitude to handle more advanced 3D visualizations, utilize multiple screens or dynamic screen resolution support. In order to compensate for these limitations, a 2D setting was selected and fitted into a single big window.

6. RESULTS
6.1 Established needs
Three main needs or features for improving the evaluation of missile launch scenarios were identified:

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2 https://d3js.org/
3 https://processing.org/
1. Improved detection of where and when in the simulation playback a missile launch occurred.
2. Collected view of flight parameters to prevent confusion and cross-referencing between various displays.
3. A temporal view of composed aircraft flight parameters.

Further design constraints and requirements

- Avoid cluttering the God’s eye view, as it is considered cognitively strenuous.
- Visualizations near aircraft in God’s eye should be limited in size to avoid taking focus from the aircraft model itself (position, maneuver and heading).
- Represent information in a way that is relatable and in line with visualizations used by pilots inside the cockpit during flight, to increase recognition and avoid confusion.
- Linked visualizations are desirable; they should be connected functionally, even if separated on screen, and link God’s eye view with cockpit views.
- Minimize manual input and pause/play moments resulting from flicking on/off visualizations by having them automatically display/fade away at the right moments.
- Visualizations and limits should be manually customizable and adjustable, but only in preparation for debriefings. It should not interfere with the training itself.
- Keep visualizations simple enough so they become self-evident to pilots who experience them for the first time, e.g. visiting squadrons.
- Avoid using multiple flashing symbols as this indicates that something is wrong, and can cause an anxious impression that will lead to pilots having difficulties assimilating what is actually important in the visualization.

6.2 Missile launch alert

During the context observation, one of the senior researchers noticed that locating and navigating to the moment of missile launch during AAR is consistently delaying and elongating the debriefing process. The researcher suggested an indicator or alert signaling that a missile launch event is about to occur. It was confirmed that this would work for the playback part of the AAR but not predictively during active real-time simulation.

During the workshop, the pilot confirmed what the senior researcher had suggested: “A visualization that alerts of an impending missile launch would be very good as we then would have time to slow down the playback before the event occurs”. The ground controller added: “The downside is that we usually replay the simulation at 3–4x normal speed during uneventful sequences. It is therefore important that the time frame for the launch alert is very long, or that the system links the time frame to the current playback speed, so it is consistent”.

When asked how such a launch indicator should look in order to be intuitively understood by the pilots without causing confusion, the ground controller picked up one of the missile models from the desk and placed it in a vertical position with the tip facing upwards underneath a blue aircraft: “Mark it by placing an arrow or a missile nearby the aircraft”, “Since it is a missile launch, why not use a missile-like symbol rather than an exclamation mark or something that could mean pretty much anything to pilots who are new to debriefings”. The fighter pilot filled in: “Yeah, you could make the alert symbol appear 30 seconds before launch and then grow in size, like ‘woo-oo, poo’” [the fighter pilot illustrated this twice by vocalizing a sound that increased in intensity until it popped]. The ground controller agreed that this would be a good way to get a heads up that something is about to happen. Regarding the color of the visualization, the participants emphasized that the symbol should be of a color that does not currently exist within the simulation: “You really want it to be noticeable; white or orange perhaps? As long as it is not the ‘team colors’ red and blue”. The ground controller points out that the AAR displays mainly contain gray nuances in order for all other colors to be clear and to stand out.

6.3 Aircraft flight parameters

When first assigned with the research task, three main flight parameters were mentioned as important when determining hit prerequisites for missiles. These were speed, altitude and error angle towards the predicted point of impact. During the theoretical studies, Panarisi (2001) mentioned aspect angle as another important parameter to consider. This was later confirmed during the introductory interviews, along with the distance-to-target parameter being another important parameter. While only speed and altitude are explicitly visible as numerical parameters inside the cockpit view, distance-to-target, error and aspect angles are displayed graphically before being interpreted and taken into consideration by pilots during flight. There are several more intricate underlying factors surrounding missile launch, but from the pilots’ point of view, the five parameters mentioned above were considered the most relatable and important maneuvering parameters.

During the design workshop, the participants were asked what they feel is missing when it comes to visualizing composed measures of flight parameters. The ground controller answered: “Well, today in the current display, we [instructors] are left guessing about these parameters. We try to interpret them by reversing the playback to the exact moment of missile launch and then cross-referencing between different cockpit views showing at which direction the aircraft was pointing in relation to the PIP, what the heading was, where the PIP was located inside the central display within the cockpit view etc. After all that, you do the math and try to estimate the parameters”. The pilot added that there currently is no visualization at all regarding things such as error angle: “There are no numbers, so we’re kept guessing”. When asked if it would be desirable to gather and visualize these parameters as numerical values, the pilot said that it is a good option, but might need to be complemented by some other visualization.

The ground controller suggests that a collected view of pilots’ individual flight parameters should be presented underneath the respective cockpit view at the event of a missile launch during AAR: “The information should be displayed with large text while the missile launch situation is active and current within the playback, but then afterwards get faded out or into some other area beside the
cockpit view”. When asked whether there is some interest in using the God’s eye view to display parameter data, the pilot stated: “I think we can discard that idea immediately, because having this information in the God’s eye view will be too disturbing, too distracting.” “The added value of displaying it underneath the corresponding cockpit view is that it becomes self-evident which pilot’s individual information it is and who the fired missile belongs to”.

![Figure 6: Bar-style sketch of individual parameter data.](image)

The fighter pilot then proceeded to draw a model (figure 6) representing individual parameter data displayed using bars, with their value numbers located underneath each bar. The bar height should depend on how close the parameter value is to a normal value. The normal value could be represented by a green colored bar at 50% height (in the middle of the graph). Since a 0.7 value of speed is below the normal, and considered bad, it is drawn as a shorter bar with red color fill. The next green bar at 75% height represents an altitude of 34000 feet. The pilot described: “You’ll want to have all bars visible, even the ones with good values”. The ground controller then suggested that it would be desirable to enable customization and adjustment of the flight parameter limit values in preparation for future feedback from statistical analysis of probability of kill linked to aircraft flight parameters, “If such feedback proves that having more red values than green generally results in more missile misses, it would be easier to point towards the collected aircraft flight parameters and relate them to cause and effect”.

![Figure 7: Alternative angle and distance displays.](image)

During the final part of the workshop, several different ways of portraying flight parameters were presented. The option visible in figure 7 suggested alternative ways of displaying angles and distance parameters. The distance parameter was designed to look similar to the DLZ visible in the pilots’ HUDs as seen in Birkmire (2011). Another suggestion was the radar chart view that Grandt et al. (2004) utilized. The participants thought both suggestions were too complicated and unclear.

![Figure 8: Numerical values with color.](image)

A second, simpler design was then suggested (figure 8). In this model, strictly numerical values would be used to display launch parameter information. Similar to what was previously suggested in figure 6, color ranges from green to red was used to clarify if a value is good or bad. Later feedback showed that the color scale preferably should range from green to white and white to red with the white colored range in the middle representing “normal” or “acceptable” values. This design was well-received with the participants.

During the dummy-AAR, an instructor exemplified issues that appear due to lack of parameter visualizations: “Sometimes we can’t tell foreign air force units that they should have shot earlier or later because of the different tactics and practices implemented by different squadrons. Maybe they maneuvered correctly according to their own practices. It is therefore important that visualizations do not strongly point out erroneous flight behavior or the exact correct shot opportunity, but instead present clear trends that the training instructor can note or interpret”.

### 6.3.1 Altitude and speed

In order to display numerical values without causing unnecessary cognitive strain for pilots, they should be rounded off to 3 value digits. For instance: 18700 ft. instead of 18690 ft. or 1.15Ma instead of 1.153Ma. The reasoning behind this was that pilots are used to viewing and communicating parameter data as rounded values.

![Figure 9: Target percentage within weapons envelope.](image)

### 6.3.2 Distance-to-target

In the design workshop, the ground controller commented on the current way of viewing distance-to-target on the cockpit view: “This is a cumbersome way of doing it, because it demands a lot of cross referencing between different cockpit views in order to form an understanding”.

Then pilot then drew a sketch, as can be seen in figure 9, to explain how he perceives distance based on a percentage of how deep within the weapons envelope the target enemy aircraft is located: “Fighter pilots use phrases like ‘I shot at 75%’ to depict that the target was at 25% within the weapons envelope”. During the tactics briefing, before a training session, team leaders often mention goals for the upcoming simulator run with regards to distance-to-target: “A typical statement could be: ‘ok, today we’re going to shoot at 75%’. Then it is important to be able to determine if the pilots actually did shoot at that range”, “What’s interesting about visualizing the percentage is that it doesn’t exist in the current display”. In the current displays, instructors must interpret these values live graphically during the AAR, which leaves room for errors and inconsistency.

Considering the established importance of the percentage value display, the participants were asked if it would be desirable to display the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway”. The pilot then suggested a visualization using text that displays the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway”. The pilot then suggested a visualization using text that displays the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway”. The pilot then suggested a visualization using text that displays the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway”. The pilot then suggested a visualization using text that displays the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway”. The pilot then suggested a visualization using text that displays the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway”. The pilot then suggested a visualization using text that displays the distance parameter at all, to which the pilot answered: “No, well, you might as well include it, too, because you display the other parameters anyway". During the tactics briefing, before a training session, team leaders often mention goals for the upcoming simulator run with regards to distance-to-target: “A typical statement could be: ‘ok, today we’re going to shoot at 75%’. Then it is important to be able to determine if the pilots actually did shoot at that range”, “What’s interesting about visualizing the percentage is that it doesn’t exist in the current display”. In the current displays, instructors must interpret these values live graphically during the AAR, which leaves room for errors and inconsistency.

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at what percentage the target lies on a straight line drawn between the ownership (0%) and the outer limit (100%) of the missile envelope. Both the pilot and engineer pointed out the importance of the target’s heading; The difference between if a target is heading toward or away from the center of the shooter-centered LAR matters a lot, especially if the target is close to the outer edge of the LAR.

The ground controller argued that since the correlation between different envelope-zones vary, it is more relevant to display additional detailed information of at which G-limit4 within the envelope the target is positioned (5G and 1G are the currently existing limits). The pilot disagreed and claimed that the percentage view would be more relevant, since the G-limit view focuses on the defensive aspects of the target, rather than the offensive range of the fired missile. One of the technical engineers at FLSC later added that the G-limits are non-linear and that pilots would have difficulties relating detailed values to what is visible in their central display during flight.

Both workshop participants wanted the visualizations of parameters and weapon envelopes to be displayed and adjusted automatically when selecting new weapon types and firing scenarios.

6.3.3 Error and aspect angle
During the final part of the workshop, the participants were asked if they preferred graphical or numerical representations of error and aspect angles. The fighter pilot explained: “Graphical is not necessary, as it is visible within the cockpit view. Rather a numerical value: For instance, error angle should be displayed numerically with a plus or minus sign”. The ground controller added: “Sometimes, graphical imagery is very good, but you have to have time to process the information as well”.

6.4 Temporal view of composed parameters
The ground controller brought up the task of evaluating aircraft flight parameters over time by adding derivative trend arrows to the launch parameter display (figure 6). When asked how this could be visualized further, it was suggested that each aircraft’s temporal parameters should be visualized individually beneath the corresponding cockpit view: “A graph can show the correlation between for instance altitude and speed. Altitude could be the height of the bars and speed could be represented by a gradient scale of color; green for good speed and red for bad”.

Regarding the time frame of the graph visualization, the ground controller recommended a fixed time interval sampling before the missile launch, since the lock-on can occur several minutes before the missile launch actually takes place. As end-time it was recommended that the graph would be continuously sampling values until the missile hits, misses or times out. The pilot mainly considered the graph to be relevant leading up to and surrounding the missile launch: “That’s why it isn’t so interesting after the missile got fired, because then pilots will make maneuvers that change the entire situation. You can rarely say that ‘you should have waited until this particular moment before firing the missile’. because the pilots have always done some defensive maneuver that in turn decreased their potential to fire another missile”.

The ground controller brought up a possible issue that a lot of pilots might “mask” their shots by keeping the parameter values low on purpose to not reveal that they are about to fire and then at the moment of launch, they turn to the correct position so all parameter values go up. The pilot points out: “But that is a purpose of the graph, to monitor pilots’ flight parameters and determine if the flight pattern matches that tactic. If they consistently commit errors when launching missile, the values will get worse and it should show up in the visualization. That is the most relevant aspect; how it looked like when they fired the missile”.

![Figure 10: Missile launch scenario presented during workshop. Image detailed in appendix.](image10)

During the workshop, participants were presented with the scenario depicted in figure 10. In the scenario, aircraft were placed in a duel situation; the blue aircraft having five aircraft models depicting the flight path history. At the third faded aircraft model, a missile was fired. In this situation, it appears that the blue aircraft shoots too early; since it later does the same turn that the missile is forced to do. The pilot and ground controller both agreed that a parameter graph in this case cannot provide the instructors with enough reliable feedback for them to determine that a pilot should have fired the missile later.

“What the instructor could have said is that ‘if you wanted to fire here; turn up towards the target, so you get a smaller error angle’”. The fighter pilot adds that an exception could be if the pilot fired the missile from a distance close to the maximum weapons envelope percentage: “That would’ve been an unnecessary waste, since the target could have just turned slightly to be out of harm’s way”.

When asked about whether the temporal graph should be displayed at all times during AAR, the ground controller said: “If the graph is placed underneath the cockpit view, it could be displayed at all times, because then the pilots can view their own progress. But in some training sessions, this might not be interesting”. The pilot then clarified that “it is a thousand times more important that the launch parameter information shows up clearly when the missile is fired. So if you sacrifice that clarity in order to always view it over time, it is not worth it!”. The ground controller then suggested that both the launch alert and the launch graph could be functions that are visible strictly during playback and not in real-time, while the simulation is still running.
During the final part of the workshop, design suggestions and example graphs from D3JS were presented to the participants. The suggested graphs included steam graphs, continuous graphs and bar graphs. All examples were stacked, since they represented the total sums of parameters. Both workshop participants strongly preferred the stacked bar graph: “Well, stacked bars are much better! This is very good and you can clearly see what is going on.” “It is absolutely a good way of visualizing it”. Regarding graph colors, the ground controller thought that the colors of the smaller bar-blocks should be consistent depending on which parameters they represent. “Meddling with other colors, or having them vary according to the parameter values might confuse the users”. The pilot agreed and pointed out that it is obvious that the height of the bars is what is important and that the parameters should be clearly distinguishable as separate blocks within the bars. They both agreed that the bar height in the graph should be evenly distributed among the parameters so that one deviant parameter is not enough to radically change the height of the entire stacked bar.

Prototype feedback received later on in the design process indicated that it is has to be clear in the missile launch graph (MLG) at which moment the missile launch occurred, especially when overviewing or moving the graph to compare different moments in time. The sample and limit values of the MLG should be manually customizable and it should be easy to set the limits according to weapon types or as new statistical information is revealed.

7. DESIGN SUGGESTIONS

7.1 Overview

The proposed design suggestions link back to the three established needs visualized below in figure 11:

1. Simulation of a missile launch scenario in God’s eye view, using launch alert to improve detection of missile launches.
2. Collected aircraft flight parameters (launch data) from the shooter.
3. Missile launch graph, illustrating composed measures of the shooter’s launch data over time.

The prototype is centralized around a simulated missile launch scenario, similar to that of God’s eye view.

By displaying a playback scenario, it becomes evident where in space and time the visualizations are visible. Changes to parameter limit values or settings are therefore instantly reflected in the visualization. Navigational controls such as pause/play and speed-settings are added for presentation purposes. All settings, sliders and navigational controls visible in figure 11 (further detailed in figure A.5 in appendix) will be exclusively available to the simulator system operator, and would therefore not be visible to the air force unit during AAR. The color tones of the visualizations were selected to suit the dim-lit setting of the AARs, while keeping in mind neither to interfere with colors already in use nor cause distractions.

7.2 Launch alert

![Image](image1.png)

Figure 12: Launch alert procedure. Image detailed in appendix.

The launch alert is represented by a white hollow missile symbol located next to the aircraft model in God’s eye view. The symbol appears and starts filling up (counting down) as the moment of missile launch approaches. In figure 12, the launch alert procedure is described: As the launch alert appears beside the shooting aircraft at a fixed time interval before launch, a MLG starts displaying temporal composed launch data underneath the shooter’s corresponding cockpit view. This provides a cognitive link between the aircraft models in god’s eye view and the corresponding cockpit view area. In order to display these automatically, and ahead of time, it is required that the simulation is in playback mode and not real-time. The same applies to the sequence of the MLG that appears before the launch moment. When the missile is launched, the launch alert automatically disappears and the collected launch data (figure 13) from the moment of launch is displayed nearby the MLG underneath the cockpit view.

7.3 Launch data

In real-time and playback, the five underlying flight parameters (figure 13) deemed relevant are collected and displayed underneath the cockpit view linked to the attacking aircraft. This launch data display lingers in view until another missile is fired by the same shooter, or until the missile misses or intercepts its target.

Numerical values are rounded off to three-value digits in order to be recognizable by the pilots. They utilize the green-white-red color scale gradient to display if the value was good or bad, with white color representing values within the “normal” or “acceptable” range. Since the color levels vary depending on the launch data values’ relation to the parameter limits, an option to easily customize, save and load limit value settings was requested and later implemented in the prototype. Error angle is displayed as degrees, with a plus or minus sign before it.

![Image](image2.png)

Figure 11: Overview of the prototype. Image detailed in appendix.
The distance parameter is based on percentage within the shooter-centered LAR rather than the actual distance-to-target. In the prototype, aspect angle is actually calculated using the definition of angle-off, while still referring to it as aspect angle. The reason for that design decision was that “aspect” is the common and relatable terminology used in this case among pilots and instructors during AAR at FLSC.

Later on in the design process, an alternative design suggestion of the launch data view was discussed with the participants of the workshop. This idea was then conceptualized in Adobe Photoshop CS, but not implemented or tested thoroughly in a prototype due to time constraints. As visible in figure 14, numerical values of launch data are complemented with bars, whose height and color fill are linked to parameter limit values. This view provides a quicker and perhaps less cognitively strenuous overview of the launch data. Next to the collected launch data, a snapshot of the shooter-centered missile envelope, at the launch moment, is visualized. This view shows the positional relationship between shooter and target in a simple and uncluttered manner. By incorporating the target’s position and heading alongside the percentage value, it becomes easier to evaluate the shot opportunity. During a feedback meeting, the pilot who participated in the workshop was presented with this alternative concept: “The missile envelope view is a good idea!” “Of the two launch data visualizations, I think this one is the best [referring to opt 2]”.

**7.4 Missile launch graph**

As seen in figure 15, the temporal view of composed flight parameters is displayed as a stacked bar graph. Every bar consists of a composed measure of five launch parameter blocks that are summed together and stacked to form a total bar height. The height of these individual blocks are based on the same parameter limit values that determine which color level a launch data parameter belongs to; a green (good) value equals a tall block. The maximum height of a block has a fixed pixel value, allowing all values to be represented equally, thus preventing deviating values from radically changing the stacked bar height. All parameters use their numerical launch data values when determining the block height, except the distance parameter, which uses its percentage value.

In order to facilitate the detection of the launch moment within the MLG, this is marked with a bright white missile symbol on top of the corresponding stacked bar. A transparent line was added to the symbol to ease the comparison between tracked parameters. Visible at the bottom of figure 15, a launch index meter was later implemented so that a possibility to view different potential launch moments is enabled. This is similarly marked with a gray missile symbol and line. The amplitude setting sliders above the launch index meter allows for separate values to be filtered out or enhanced if the specific mission scenario requires a detailed look on separate parameters over time.

**8. DISCUSSION**

The goal of this thesis was to improve AARs by exploring and conceptualizing design suggestions that could serve as aids to instructors and facilitate in evaluating missile launch scenarios. It was discovered that the current practices rely on the expertise of the instructors, in order to get an added value from the training and debriefing. Currently, this evaluation process is in some aspects strewn with manual estimations, requiring and causing a lot of cross-referencing between different display views. Some existing visualizations have poor usability and are too cluttering to keep switched on at all times. These are then manually switched on/off frequently, something deemed by the participants and systems operator as cumbersome and annoying. A main part of the focus was therefore the creation of visualizations that were quickly recognizable and relatable to the users, compatible with the current context and systems, while limiting cross-referencing and manual interaction and estimation. These visualizations could lead to more effective debriefs, which according to Artman et al. (2013) could substantially enhance the effect of simulator-based team training. An added bonus is that by visualizing measures that currently are only estimated manually would increase the uniformity in how the AARs...
are conducted, which, by extension, could facilitate in the comparison of performance between different individual pilots and air force units.

8.1 Evaluation of missile launch scenarios
In order to thoroughly evaluate a missile launch event, it is necessary to discuss what the non-physical parameter “good shot opportunity” really implies. Even though this general concept was central throughout the entire design process, it was difficult to find a simple definition. It was more based on a mixture of underlying flight parameters, experience, geometrical observations and the pilots’ “hunches”. While it became apparent in the context study that detailed parameters such as error or aspect angle are not frequently specifically mentioned during AAR in favor for this general expression, it could be argued that the expression is used partly because there are currently no clear visualizations or numerical representations available of mentioned parameters. Since every fighter pilot has a unique background, skill and experience level, it feels improbable that the expression is guaranteed to be consistent or uniform in nature. Less experienced pilots may not have the same mental model of ideal parameters or the impact these could have on launched missiles. Similarly, Borgvall et al. (2011) mean that such non-physical parameters represent knowledge that typically differentiates a more experienced individual from a less experienced. I agree with the authors that enhancing the scenario visualization with non-physical parameters and composed measures can make knowledge that is usually limited to more experienced pilots available.

It becomes essential to show and visualize the actual underlying parameters, to make pilots aware of their maneuvers and flight behavior, before finally harmonizing the expression “good shot opportunity” between the different experience levels.

8.2 Flight parameters
The G-limit idea suggested by the ground controller was discarded because its non-linear values felt redundant when compared to the percentage view. Another factor was that these values were not deemed recognizable or relatable enough to pilots during flight. The reason why the workshop participants had different preferences on how to view distance parameters may relate to their respective tasks during simulation training. The fighter pilot (acting instructor during AARs) views distance and percentage values similar to the pilots in training. The Ground-control intercept (GCI) on the other hand has a task of measuring and communicating exact distances between aircraft manually during flight, while determining both defensive and offensive risk. In that separate usage-scenario, a G-limit value display could prove useful as well, for the GCI.

From the missile-perspective, an optimal distance would be as close as possible to the target. However, in reality, a closer distance also means a higher threat level. The ground controller expressed it as “What you can do to the enemy, he can do to you”, meaning that improving certain flight parameters may also increase the risk towards the ownership. Logically, a risk factor should affect the parameter limit values of what is considered a good or bad value. It is therefore proposed that the distance-to-target parameter has two red-zones, utilizing a red-white-green-white-red color scale gradient, in order to account for values either too close (high risk) or too far away (low probability of kill).

An observation during the context study revealed a frequent mix up in the use of aspect angle and angle-off parameters. Even though these phrases were mixed up, pilots and instructors still seemed to have a uniform understanding of the underlying concept. I suspect that what they really mean with respect angle is angle-off combined with the positions and headings of the shooter and target visualized in the cockpits and God’s eye view. I believe this mix up has emerged from instructors and pilots relying too much on visual cues and manual estimation to determine the aspect angle. Like Panarisi (2001) suggested, I think that this is a scenario where a more automatized estimation process could prove beneficial. Furthermore, it could prevent poor maneuver and weapons employment decisions by the pilots.

8.3 Design suggestions
Similar to how Grandt et al. (2004) categorized information into groups of “need-to-know” or “nice-to-know” or how Shneiderman (1996) formulated the Visual Information-Seeking Mantra, the context and results from this study slightly limited the suggested visualizations to a “need-to-know”-category, showing an initial overview of the most critical aspects for evaluating a missile launch. The “nice-to-know” on-demand information can be obtained when using the settings to change the playback speed, filter the MLG into separate parameters or review different launch opportunities. Separating the collected parameters into numerical values complemented by easier perceptible visualizations in the launch data view aligns with the consideration of Grandt et al. (2004) that composed values might encounter difficulties if the evaluation requires knowledge of specific parameters.

The importance of linking the visualizations of aircraft models in God’s eye view with their corresponding cockpit view was requested several times during the research process. While taking extra precaution not to make the launch alert stand out too much in God’s eye view, and limit its size related to the aircraft model, I think the design suggestion could help create such a link. The question remains if this could be considered enough to form a self-evident cognitive connection between the two view areas, or if additional visualizations are needed. I think that by shifting the focus to individual pilots and creating a link between aircraft models and cockpit views, this might facilitate in improving pilots understanding of their maneuvering behavior and create a more clear connection between the different displays in the AAR.

The reason for not delving into specific details about the definition of the percentage value within the LAR or the snapshot suggested in opt 2 is that these are either currently not clearly defined, are classified or require further user and system tests. The same reason applies to why HUD DLZ as mentioned by Birkmire (2011) and Panarisi (2001) was not further investigated or incorporated in the design.

It is not clear why the participants preferred the opt 2 view of launch data over opt 1. Perhaps by adhering to the innate human ability for pattern recognition, as mentioned by Grandt et al. (2004), this design option might be beneficial
when the instructor just wants to glance quickly over at the display, without really looking at exact numerical values, in order to get a brief sense of the situation surrounding a missile launch.

Initially, the MLG was meant to provide pilots with alternative, definite and optimal points in time at which they should have fired the missile. Results and feedback from the study later revealed that this was not possible for time frames subsequent to missile launch. It was stressed by the workshop participants and a technical engineer at FLSC that no assumptions could be made because of the “what if”-factor surrounding predicted scenarios. However, they did think that the MLG could be useful as an indicator when evaluating if the missile could have been fired earlier. MLG might also prove valuable when analyzing trends in individual flight behavior, to check if the pilot followed an appropriate offensive or defensive maneuvering pattern, before and after firing a missile. The wish to use discrete stacked bars rather than non-discrete, even though the latter would show more detail, might be because the subject matter experts use the discrete values as a reminder of their pre-existing mental models. As was the case with rounded value digits, this may also be a situation where “less is more” is applied. Although workshop participants did not strictly request the aspect of filtering separate parameters by changing their amplitude, this function was implemented as it coincides with the inclinations of Rivero et al. (2014), Grandt et al. (2004) and Shneiderman (1996) for details-on-demand and multiple visualization layers.

### 8.4 Research methodology

Since aerial combat simulation and the evaluation thereof is an extremely complex area to conduct research and design studies within, the context study itself allocated large portions of the total research time. Because the staff members at FLSC already possess profound knowledge and predefined mental models of all aspects of simulation training, the purpose of extensive context studies was to get a deep enough understanding of the current practices to be able to present design suggestions relevant to subject matter experts. As the availability of actual users was close to nonexistent, a user centric design study was not possible. A more encompassed understanding of relevant design patterns for pilots with varying skill level could have been attained if the study was conducted over a longer period of time and featured statistical analysis and limitless access to personnel, data and equipment from simulator sessions.

Since the simulation facility at FLSC is a highly active work place, addressing multiple different research topics simultaneously, it was proven valuable to commit to an iterative design process with ad hoc elements. This made it easier to adjust the design direction and concept ideas as the context knowledge and understanding increased with time.

A big takeaway from the methodology was the workshop documentation process. The high fidelity setup greatly facilitated the subsequent analysis of the workshop recordings by providing the possibility to scrub through audiovisual data and keeping track of participants’ hand movements, motioning, pointing and sketching in real time.

### 8.4.1 Security constraints

The first encounter with the complexity of the research area was when searching for related work. Except for research published by or in connection with FLSC, no published literature regarding the use of visualizations to enhance the evaluation of missile launch events in air-to-air combat simulation training was found. In order to obtain some information about visualizations used, the situation had to be looked at from a reversed perspective, defensively rather than offensively: e.g. “What flight parameter values did the shooter have when attacking me, and what was his threat level?” rather than “What flight parameters should the shooter have when posing a threat against a target?” I think the reason for the scarcity of relevant literature is that nearly all related research is conducted by other foreign nations’ defense research institutions, and is therefore not approved for public release. Another reason could be that it is still a fairly novel research area.

During the context observation, when access to observe a live AAR was denied, it became particularly apparent what effects the surrounding security and confidentiality constraints had on methodology. Although access to a compilation of observational data was granted, it is hardly the same thing as conducting the observation yourself. It is interesting nonetheless that this process made it possible to procure declassified data from a classified setting.

Throughout the prototyping process, security constraints were a big factor that had to be taken into account frequently. The sampling and limit estimation work process was lengthy and exhausting. In hindsight, I think that a lot of work hours could have been spared if less intricate prototyping tools were utilized. There is a clear value connected to having produced a high fidelity object-oriented java-based prototype, but I think some of the points could have gotten across to viewers using more basal design and presentation techniques as well.

### 8.5 Ethics

When conducting research and design studies within security classed agencies, and especially defense research, ethical aspects and considerations are always highly prevalent. One ethical aspect was the secrecy entrusted in the author by the agency, where it has to be made sure that information that can pose a security risk toward the agency or the general public is not spread or published. The main ethical consideration that the author had to come to terms with during this design study was the fact that by designing simulation aids for the training of fighter pilots, this could essentially be contributing to improving the pilots’ efficiency to conduct live military force and harm onto others. Since the focus of the SwAF is mainly to defend Sweden and the country’s interests, its people’s freedom and their right to live the way of their choice, it was concluded that well educated SwAF pilots are a valuable resource for the future defense of the country.

### 8.6 Future work

First and foremost, the recommendations for this research are to implement, test and evaluate the usability of the design suggestions with a larger selection of users, in order to obtain quantitative results. Current HUD DLZ should
also be taken into consideration for future development of visualizations.

Data-mining and statistical analysis would be required to determine optimal parameter limits and then establish the connection between the collected launch data parameters and probability of kill. This could verify the correctness and relevance of the launch data view and perhaps to some extent harmonize it with the non-physical expression “good shot opportunity”. The performance measurement tool PETS, mentioned by Artman et al. (2013), could provide a good basis in such analysis of parameter data and statistics. Statistical analysis could also assist in establishing a definition of the percentage value within the shooter-centered LAR. Further studies are needed in order to concretize pilots’ mental model of the percentage value, and determine a relevant visual representation of the missile envelope.

If individual pilot launch data (speed, altitude, distance-to-target, angle-off and error angle) would be logged and saved for statistical purposes, it should then be analyzed and compared to the pilot’s previous training sessions. This could provide an overview of how a specific pilot’s launch data changes over time, from session to session. By also logging the corresponding missile launch graph (MLG) data, pilots could use tablets to monitor their own maneuvering habits, launch data build-up trends and parameter statistics surrounding missile launches. Together, by obtaining data compilation after a series of simulation training sessions, the logged data could provide a new way to measure and represent individual pilots’ performance in terms of offensive and defensive maneuvering.

9. CONCLUSION
What are the limitations of the current evaluation procedure?
The current practices rely on the expertise of instructors in order to get an added value from the training and debriefing. Locating and navigating to the moment of missile launch is a lengthy process of fast forwarding, reversing and pausing the playback. Since there are not any existing visualizations strictly focusing on facilitating the evaluation of missile launches, the evaluation process becomes permeated with manual estimations, requiring and causing cross-referencing between different display views. There is also a lack of visualizations that show composed measures of parameters over time.

What individual flight parameters are deemed relevant to visualize?
The five parameters deemed relevant to visualize were: speed, altitude, error angle, aspect angle and distance-to-target. Speed and altitude were displayed as numerals with three value digits. Error angle was defined as the angular difference in degrees between the ownship heading and a line drawn from the ownship directly toward the missile’s predicted intercept point. The error angle range between 0-180 degrees and is displayed with a + or - sign. Angle-off, referred to as aspect angle, is displayed in degrees. Distance-to-target includes both the actual distance between the shooter and the target aircraft, but mainly a percentage-value describing how deep within the ownship shooter-centered launch acceptability region the target is positioned.

What are the needs for improving the evaluation?
Three main needs were established.

1. Improved detection of where and when in the simulation playback a missile launch occurred.
2. Collected view of flight parameters to prevent confusion and cross-referencing between various displays.
3. A temporal view of composed aircraft flight parameters.

Recalling the research question:
“When compared with current practices, during After-Action Reviews of aerial combat simulation, what are the most relevant visual mappings and structures of aircraft flight parameters that support instructors and pilots evaluating missile launch scenarios?”

1. A Launch alert symbol next to the aircraft counts down as the moment of missile launch approaches. Links the God’s eye view aircraft model of the shooter with its corresponding cockpit view and may prevent lengthy navigation in playback.
2. A Launch data view displays the shooter’s five aforementioned flight parameters gathered in one place. Bars of varying height and color grading (red-white-green) help determining if an individual parameter value is considered good or bad.
3. A Missile launch graph displays a composed measure of launch data over time. The graph uses stacked bars, which heights are based on parameter values. Shows trends in pilot maneuvering and enables comparative analysis between shot opportunities.

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The views presented in this paper reflect those of the author and not necessarily the Swedish Armed Forces, the Swedish Defence Research Agency or the Swedish Air Force Combat Simulation Centre.

REFERENCES


APPENDIX - IMAGES

Figure A.1

Figure A.2

Figure A.3