Zurich University
of Applied Sciences

School of Engineering

ZAV Centre for Aviation

<u>Bachelor thesis</u>
<u>(Aviation, Technical Engineering)</u>

Implementation of Flexible Displays in the Research and Development Simulator

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Abstract

The "ReDSim", short for research and development simulator, is a simulator with a fully equipped cockpit. It is used by the ZHAW as well as external researchers. The system consists of a cockpit side and a simulation side. The simulation side defines the model and sends the data via user datagram protocol. This data will be processed by the cockpit side. The Cockpit Instrument Framework on the cockpit side will set up the displays in the cockpit and constantly deliver data to the instruments. There is one aircraft multifunctional display to choose from. To increase flexibility, the Cockpit Instrument Framework was updated during project work and requirements for the new instruments have been determined. Those instruments were implemented and tested in the bachelor thesis. The newly designed instruments focused on providing an accurate visualization of the systems that the pilots are used to operate with as well as experimental implementations. A human-centred evaluation has shown that pilots tend to like new designs combined with some traditional instruments. They quickly got accustomed to it and went on flying circuits with the new instruments. The evaluation was done on a modified PA28 because no other flight model was provided. Based on these findings a manual was written which provides information and instructions about the cockpit side of the research and development simulator.

Management Summary

The project work updated the system on the cockpit side of the ReDSim. This provided the benefits of using GLStudio 7.0. As a result, new instruments were designed for the system and a manual was written with all the details. If an instrument requires adjustment, the manual acts as a guideline. Furthermore, it would be beneficial to consult with the person in charge of the ReDSim beforehand to avoid any disruptions in the functioning of the system. If any changes have been made, it is necessary to write them down in the manual to ensure traceability. Another consideration is to have a valid runtime license. A license is required for GLStudio and the RSO loader (in the cockpit instrument framework), which is responsible for loading the instruments. A dongle with a valid license can be used for this purpose. It is recommended that future licenses be obtained that do not require the use of a dongle. One final step would be to upgrade to GLStudio 8.0 to receive the latest features and updates. Finally, it is important to keep the manual up to date and check if the cockpit side has the latest updates at least once a year.

Preface

Having the opportunity to get into an airplane and fly by the side of my own father has given me an enthusiasm about aviation from an early age. Therefore, it was clear to me that I wanted to continue my education in this field. I chose this bachelor thesis because the challenge was to renew the system and at the same time to establish and carry out new ideas and implementations. Personally, I would like to thank my two supervisors, Mr. Capone and Mr. Monstein, who actively supported and motivated me throughout the process of planning and carrying out my project as well as writing my bachelor thesis.

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List of Abbreviations

Abbreviation	Meaning
.exe	Executable
CHT	Cylinder Head Temperature
CIF	Cockpit Instrument Framework
DLL	Dynamic Link Library
EGT	Exhaust Gas Temperature
FS	Full Stop
G/A	Go Around
gls	GLStudio Design File
GUI	Graphical User Interface
H/C	Helicopter
ITT	Interstage Turbine Temperature
M.P.	Manifold Pressure
MFD	Multifunction-Display
N1/N2	Rotational Speed of Turbine Engines
NG	Gas Generator Speed
NP	Propeller RPM
PFD	Primary Flight Display
Qt	"Cute", Application framework and GUI toolkit
ReDSim	Research and Development Simulator
SEP	Single Engine Piston
SFML	Simple Fast Multimedia Library
UDP	User Datagram Protocol
VSI	Vertical Speed Indicator
VTOL	Vertical Take-Off and Landing
XML	Extensible Markup Language

Table 1: List of Abbreviations

Glossary

System	Explanation
C++	C++ is a programming language that is an extension of C. It is considered to be very efficient because the language is object-oriented. This is why it is often used for applications.
CRT	A cathode-ray tube is a type of vacuum tube in which an electron beam hits a phosphorescent surface and makes images. Most computer displays are equipped with a CRT. The CRT in a computer screen is like the picture tube in a TV.
DLL	A dynamic programme library is called a dll. The common data format for executable .exe files is also used.
GLStudio	Design tool for creating a interface for a system.
Properties	Contain the functions and attributes of an object in C++.
UDP	User Datagram Protocol is a simple way to send and receive information over the internet. It does not require any connections. UDP allows programs to transmit messages over IP-based computer networks.
Variables	Variables are values that can be accessed via a function in a property.
Visual Studio	Visual Studio is a software development platform for numerous high-level programming languages.

Table 2: Glossary

Table of Contents

1. Introduction

1.1. Initial Situation

Flight simulation has become more significant with the advancement of technology and digitalisation. It allows companies to test experimental aircrafts and systems in a flexible way so that some research can be done before going over to the actual flight testing. Furthermore, crews have now the possibility to train flight operations in a safe environment.

For this reason, the ZHAW has also a simulator, called ReDSim. The ReDSim provides an environment for research and flight-testing purposes, which is widely used by students and researchers. However, it provides only one flight model for use, the Piper PA28. In addition to this, there is one set of given cockpit instruments, which consists of an PFD and MFD. This caused problems, as one had to adapt the task to the flight model with its instrumentation. There is a need for flexibility. New instruments for different aircraft types are needed to perform certain tasks in aviation.

Since the system is going to be updated with new designed instruments, a manual regarding the adjustments and implementation of instruments will be written.

1.2. Objective

The research objective of the bachelor thesis is the following:
- Implementation of newly designed engine instruments for the research and development simulator.

New engine instruments will be designed for SEP, turboprop, turbofan, helicopter and tiltrotor. The PFD (airspeed, attitude, VSI, heading, Mach number) will not be adjusted because it can be applied to all aircrafts.

To achieve this goal, the following research question is addressed:
- How should the engine instruments be designed to comply for experimental purposes as well as flight training?

This question then has been divided into four tasks. The first two tasks were part of the project work, and the remaining two are part of the bachelor thesis.

1.3. Task

The bachelor thesis consists of the following two tasks:

1. Define a solution (Task 3)
2. Update ReDSim and testing. Writing of a user manual to be used to modify / develop instrumentation in the ReDSim (Task 4)

Task 1 (Collection of Requirements) and Task 2 (Familiarization of ReDSim and Systems) were completed during the project work.

1.4. Requirements

A collection for the requirements is listed in the project work under section 1 page 8. Some adjustments were done during the bachelor thesis, so the final list is as follows:

SEP

Indicator	Units
Prop	RPM
PWR	%
Fuel	lt
Flaps	° and Text
Trim Elevator/Aileron/Rudder	[]
COMM	Message as a string
Solar and Sim time	Solar [hh:mm:ss] / sim [s]

Table 3: Requirements for single engine piston. [1]

Turboprop

Indicator	Units
NG	%
ITT	°C
NP	RPM
Torq	PSI
Fuel	gal
Flaps	° and Text
Trim Elevator/Aileron/Rudder	[]
COMM	Message as a string
Solar and Sim time	Solar [hh:mm:ss] / sim [s]

Table 4: Requirements for turboprop. [1]

Turbofan

Indicator	Units
EGT l/r	°C
N1 l/r	%
N2 l/r	%
System Page	Flaps, Spoilers and Trim Aileron/Rudder
Fuel Flow l/r	Kg/h
Horizontal Stabilizer	[]
COMM	Message as a string
Solar and Sim time	Solar [hh:mm:ss] / sim [s]

Table 5: Requirements for turbofan. [1]

Helicopter

Indicator	Units
Engine	RPM
Rotor	RPM
EGT	°C
PWR	%
Fuel	lt
System Page	Trim Rudder/Roll/Nick
Dead-Men curve	Diagram with X- and Y-Coordinates
COMM	Message as a string
Solar and Sim time	Solar [hh:mm:ss] / sim [s]

Table 6: Requirements for helicopter. Can be applied for turbine and piston. [1]

Tiltrotor

Indicator	Units
Rotor	RPM
PWR	HG
EGT	°C
Nacelle Angle	°
Fuel	lbs
Flaps	° and Text
Corridor	Diagram with X- and Y-Coordinates
System Page	Trim Rudder/Roll/Aileron
COMM	Message as a string
Solar and Sim time	Solar [hh:mm:ss] / sim [s]

Table 7: Requirements for tiltrotor. Specifically for the XV-15. [1]

1.5.   Overview of the Bachelor Thesis

This bachelor thesis is structured as follows:

Section 1:   Introduction
Section 2:   Theoretical Background
Section 3:   Methods
Section 4:   Results
Section 5:   Discussion and Outlook
Section 6:   Conclusion
Section 7:   Bibliography
Section 8:   List of Figures
Section 9:   List of Tables
Section 10:   Appendix (Project Management, Meeting Protocols, etc.)

The bachelor thesis is aimed at all those who work with the ReDSim or are active in the aviation industry as well as the scientific researchers. Knowledge in flight simulation, basic aviation and programming skills in general are advantageous.

2. Theoretical Background

From a general perspective of aircraft instrument design there are two forms of data display:

- Quantitative displays
- Qualitative displays

Quantitative displays being the most used ones where the measured variable is displayed by a numerical value as well as by a relative position between a pointer and a graduated scale as seen in Figure 1. Qualitative displays represent the data in a symbolic form. [2]

It is possible to create a variety of indicators such as single- and dual-indicators, straight scale displays and digital counter displays.

However, to highlight specific limits markings are used in form of coloured arcs, radial lines and sectors applied to the scale of instruments. This allows the pilot to read instruments more efficiently as it helps to make decisions in certain flight phases. [2]

Figure 1: There are many possibilities to design a quantitative display. This is determined by the requirements that have to be met. [2]

The definition marks are as follows:
- Red: Maximum and minimum limit.
- Yellow: Take-off and precautionary range
- Green: Normal operating range

In general, instruments can be defined as a measuring device that ...
- shows two forms of data: quantitative or qualitative.
- has a wide variety of indicators dependent on the use.
- highlights specific limits with colours.

In summation, instruments have a purpose to fulfil. In order to test instruments a physical model or experimental aircraft is required since a part of a test flight is to test the avionics system as well as to make certifications for those systems. However, it requires a lot of time and effort to perform such a test. [3]
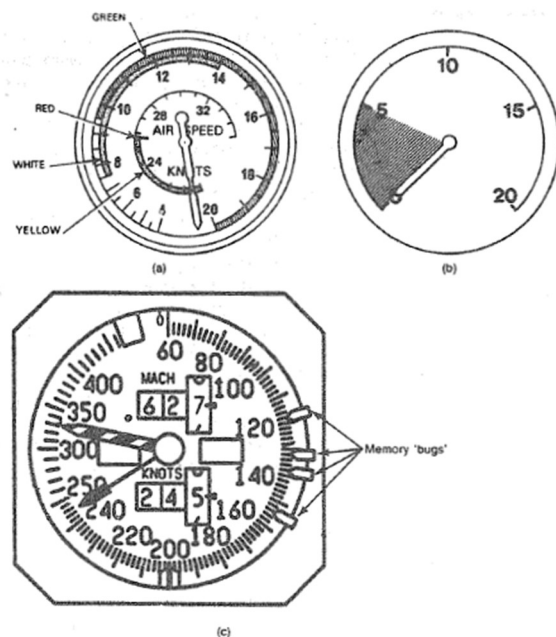
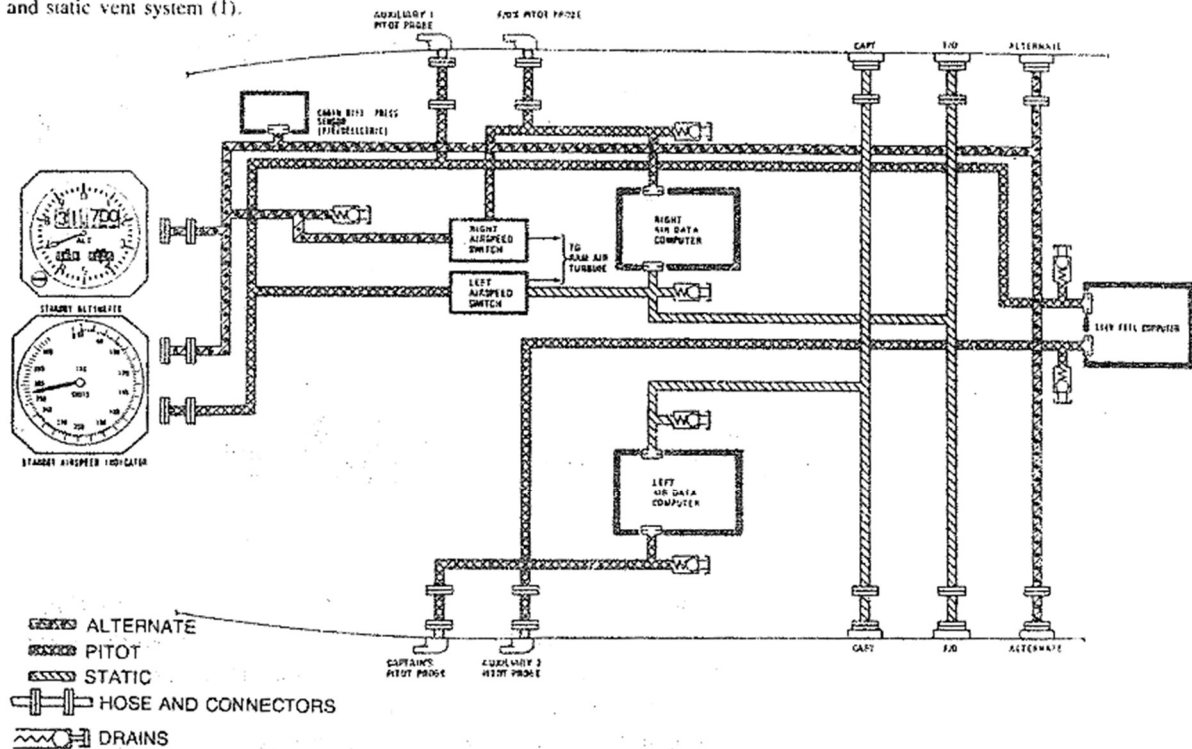*Figure 2.3 Typical pitot probe and static vent system (1).*

Figure 2: Typical pitot prob and static vent system for an altimeter and airspeed indicator. Already two instruments can produce a high degree of complexity. [2]

Figure 2 shows how complex such a system can get. It would be convenient to replace all the mechanical connections to a more simplified system to be able to test such a system more efficiently.

With the rise of digital signal-processing technology colloquially known as "avionics", many things that were solved mechanically became more and more digitalised (a famous example would be the electrical car). This made it possible to make drastic changes to quantitative and qualitative display methods. The point has already been reached whereby numerous conventional clock-type devices, which for so long have served as the primary source of information display, can be completely replaced by a microprocessing technique. This microprocessing technique paints identical information displays onto the screens of cathode ray tube display devices. [4]
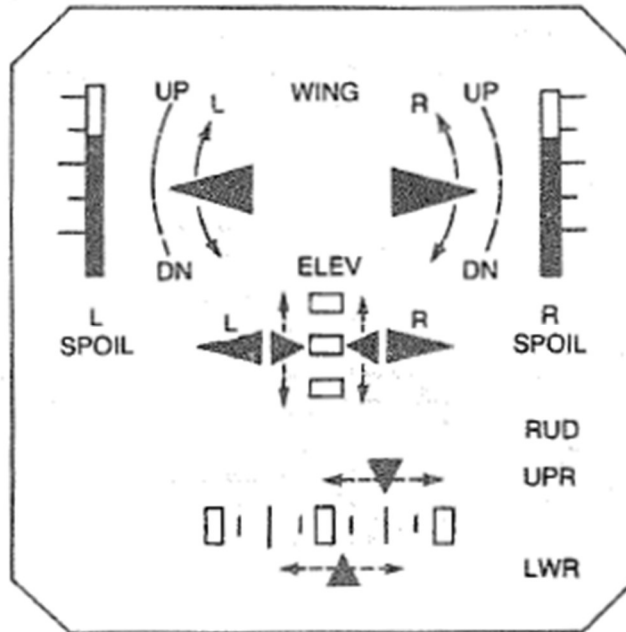
Figure 3: A typical example for a qualitative display. Note how quickly the trim setting can be read without having to concentrate on some values. [2]

Classical cockpit instruments such as attitude or airspeed indicator became part of the glass cockpit. In Figure 3 is an example of qualitative data form of the trim surfaces and spoilers.

A glass cockpit is a cockpit where flight data is shown on Electronic Flight Displays rather than separate gauges for each instrument. [4]

This has various benefits:
- Lack of parallax errors (reading does not depend on the angle a person is looking at).
- It needs less space and therefore shows more information.
- Warnings can be more noticeable as they are linked to a computer which processes various signals.
- Different layers of information can be presented.

Regarding the ReDSim it has a glass cockpit as shown in Figure 7. Consequently, there is a shift from mechanical engineering to programming. Programming is a major part of the bachelor thesis as it consists of designing and programming the functional capabilities of an instrument. The programming language used in this research is C++, which is an object-oriented language.

The concept of object-oriented programming emphasizes the concept of a data type that possesses both information and functional properties. Before the object-oriented programming was established, programmers usually thought of a codebase as a collection of individual command line instructions. The identification of built in objects with data and functions led to a novel approach to encapsulating and automating codes. [5]
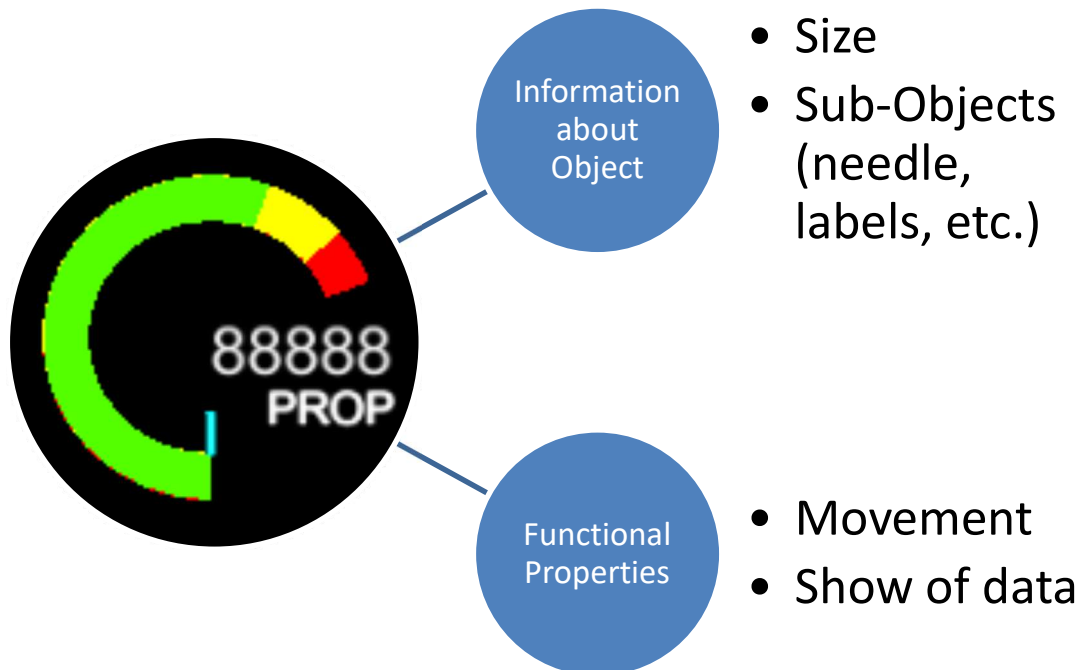

Figure 4: Example of a radial gauge object with properties and functions.

All the engine instruments in the ReDSim are indicators on a single page (MFD) which contain their own properties and functions. Those objects are fed with data from the simulation via UDP to give the pilot some information. Figure 4 shows an example of a radial gauge indicator. All indicators are being designed and programmed after this principle of objects with their properties and functions. The advantage of this process is that they can be universally applied to different aircraft instrument pages as the objects already contain their properties and functions.

To meet the given requirements a human-centred process must be followed since the aircraft instruments and systems are all about human-machine interaction. This means that during the design process aspects like layout, interaction and so on have to be iterated where appropriate.

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Design cycle for interactive systems
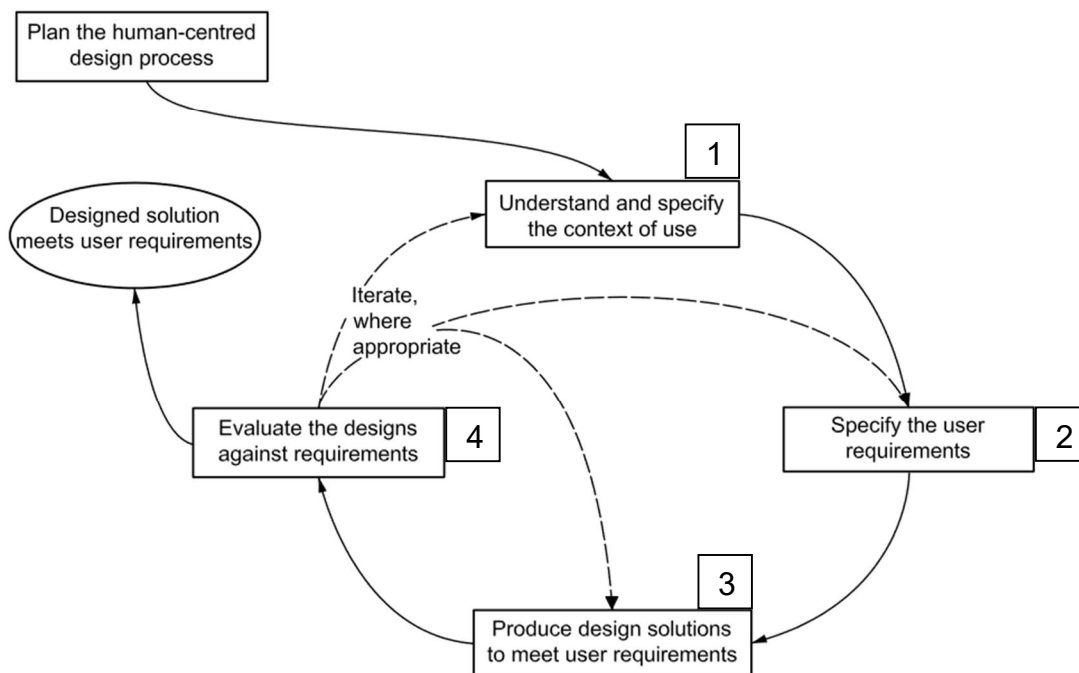### according to ISO 9241-210

Figure 5: Design cycle for interactive system provides information about which steps are needed to meet the user requirements.

The ISO 9241 "Ergonomics of human-system interaction" part 210 focuses on human-centred designs for interactive systems. Figure 5 represents the design cycle for these interactive systems which is as followed: [6]

1. To understand and specify the context of use that focuses on who the users are (ZHAW), the characteristics (Pilots), goals and tasks (Flight labs and research work) and the environment (ReDSim).
2. To specify the user requirements: It defines what values should be implemented as instruments for certain aircraft types.
3. To produce design solutions to meet user requirements makes the design solutions more concrete.
4. Presenting the solutions to the supervisors. Additionally, conducting a user-centred evaluation to obtain feedback from pilots for improvement.

A human-centred process should also include a long-term monitoring (after the bachelor thesis). Collection of user inputs over a period of time is often a formal part of the system evaluation and is being carried out after a certain period of time. This should help to evaluate the performance and to check if any changes in the requirements are needed. [6]

3. Methods

To meet the requirements of the research objective the following two methods were used:

- Individual case study
- Structured interview

An individual case study is conducted to focus on the research question. A structured interview may reveal insights that were not considered during the design process. Task one, two and three were an individual case study whereas task 4 was a validation and therefore a structured interview. Again, task one and two were part of the PA but the method used was the same.

3.1. Individual Case Study

The first step is to recognize the unit of analysis. Since the bachelor thesis depends on the cockpit instrumentation and the simulation the ReDSim was used. Therefore, there are two main parts to consider:

- The cockpit side with all the systems
- The simulation side with the flight models

To break down the cockpit side it is easier to have a look at the whole ReDSim first:
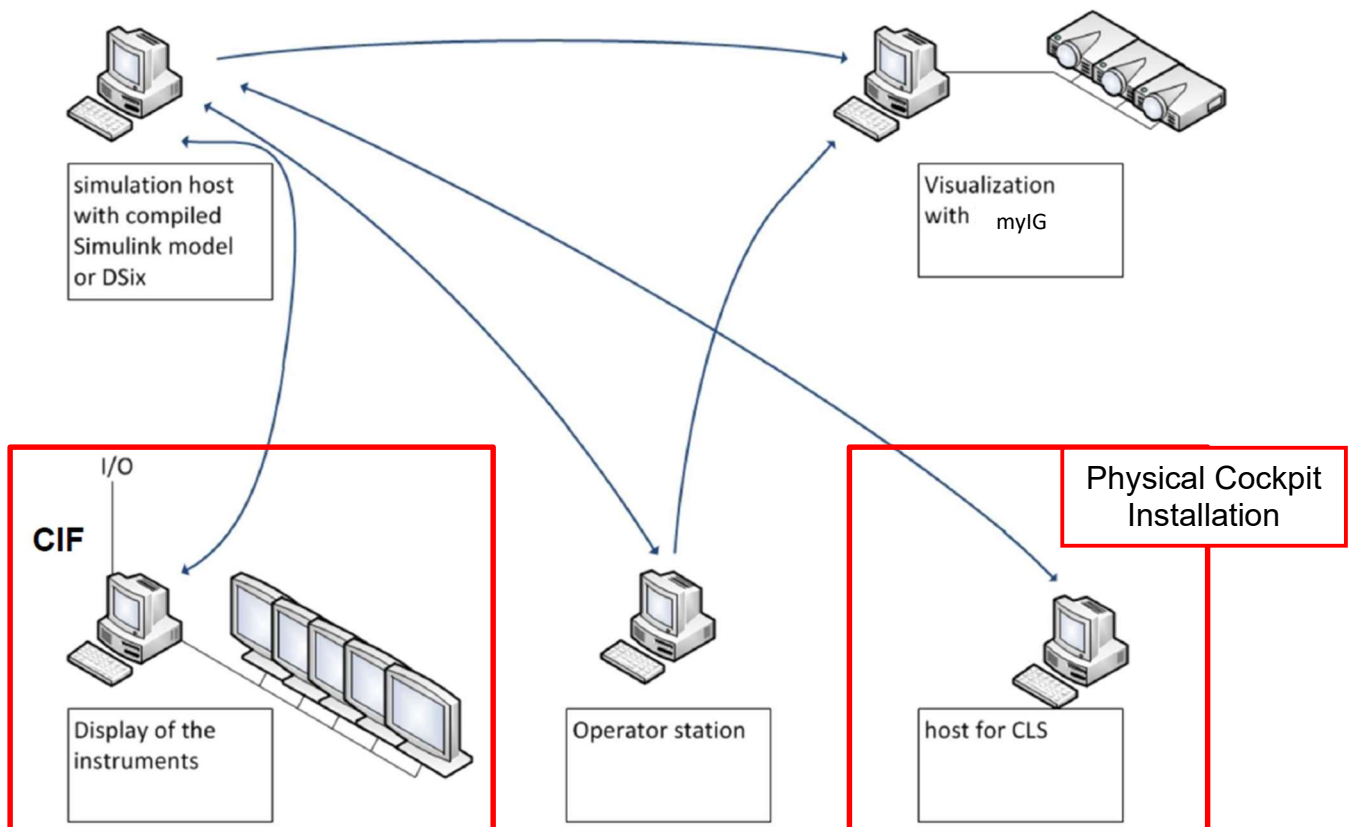

Figure 6: The ReDSim setup. Note that all the instrument settings are done in the CIF on the cockpit side. [7]

The cockpit side communicates via UDP, a data communication protocol with the simulation side. Both sides must have the same order in the protocol.

Since new instruments will be developed a closer look must also be given to the old setup. It includes the following features which are also shown in Figure 7:

Figure 7: The original instruments from 2010 have remained unchanged. [1]

1   Primary Flight Display – Has indicators for speed, altitude, attitude, vertical speed indicator, heading and Mach number. Will not be changed.
2   Multi-Functional Display – Displays engine parameters as well as qualitative information such as trim and flaps position.
3   Parameter Window – A list of data that can be displayed for research purposes such as C_L, C_D, or angle of attack.
4   Same as number one.
5   Autopilot – This display is a touchscreen. The pilot can set speed, heading and altitude.

Of course, there are the flight controls as well. On the left side is a yoke and on the right side a stick. There is a throttle, flaps, spoiler, and landing gear lever. The trim for elevator is on the yoke.

Since the research question focuses on engine instruments only the MFD will change. New indicators have been designed for 5 different aircraft types.

- SEP
- Turboprop
- Turbofan
- H/C
- Tiltrotor

To implement new instruments into the system some things need to be considered first:

- New data variables must be defined because new instruments generate new variables.
- Old instrument settings must be contained within the new system (backward compatibility)

For this reason, a new data list was written, which expands upon the original list for maintaining compatibility. To test this the old instruments were compiled and tested in a flight in the ReDSim.

New instruments were designed according to the requirements, compiled, and stored on the cockpit computer. To have a better idea of the new system here's an overview:

5 Aircraft Pages for Engine Instruments	New Data list	New Flight Model
• SEP • Turboprop • Turbofan • H/C • Tilt-Rotor	• All original data from previous implementation • New data added to the list	• PA28 • New flight model with additional data (engine parameters)
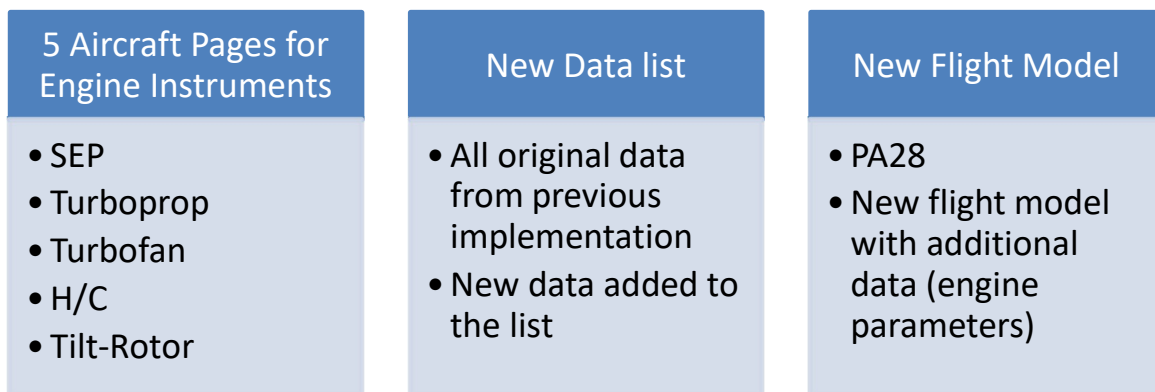
Figure 8: The implemented design solution. Left block are the instruments stored on the cockpit side. Block in the middle is the share of the same data list for communication. Right block is the experimental flight model on the simulation side.

Since the new setup was created in the same environment the usage of the new instruments is the same as the old procedure with one exception: A license dongle must be used to load the instruments because they were created with a newer version of GLStudio.

There are four dependencies. The following overview will help to understand how the system works with the new instruments.

Figure 9: The four important components of the ReDSim.

CIF

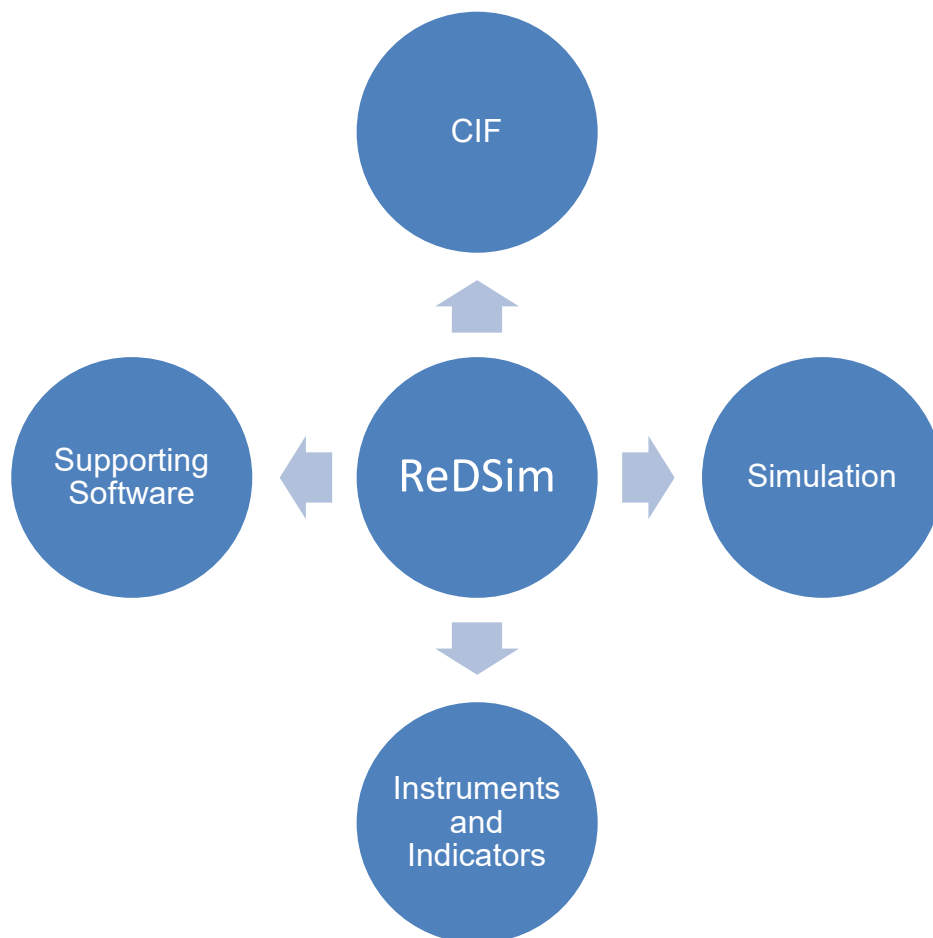The cockpit instrument framework gets the data via UDP from the simulation and assigns the values to the different instruments. For this it has a "Configurator Mode" and a "Cockpit Mode". The first one is for putting the instruments onto the monitors and making connections to the inputs / outputs. The second one is for loading the created layout and deploying it.

Simulation

The simulation is the selected flight model which sends the data via UDP to the CIF. The flight model is provided by the supervisor and is not part of the BA.

Instruments and Indicators

The instruments and indicators are stored as DLL within the CIF. They are imported through the "Configurator Mode". It is important to have a valid license as the instruments require a new license. The same goes for the "Cockpit Mode" because the RSO Loader, which loads the instruments, requires the same license.

Supporting Software

The cockpit side has two main programs with two sub-programs that need to be supported regularly. The two main programs are Visual Studio (CIF and project folder

for instruments / indicators) and GLStudio (Design Tool). The two sub-programs are Qt (Framework for functions of CIF) and SFML (Windowing Tool).

The next step is, as already mentioned in section 2, to conduct a user-centred evaluation is to get feedback from the pilots. This will be carried out only for SEP.

3.2. Structured Interview

To answer the research question written in section 1, data is still needed that can support what has been researched so far. Since the ReDSim has been adjusted to the new instruments and the flight model, some testing with actual pilots will take place.

The goal of the structured interview is to get feedback for the instruments. To gather useful data from such a test three phases will be carried out: Briefing, flight mission, and debriefing. This was done on purpose to create an authentic experience as well as explaining all the details to the pilot.

Briefing:
In this phase the flight mission as well as the controls and instruments will be explained to the pilot. Additionally, a task will be given to the pilot. This task consists of reading engine instruments when asked at any point of the circuit. With this method the pilot must read some values while flying the aircraft in a short time.

Flight Mission:
The pilot will fly one circuit in Buochs as training to get used to the environment and instruments. After the circuit the pilot can ask some questions if needed. If everything is clear, then the pilot is going to fly circuits with:
- 2 G/A
- 1 FS
- Performing the task while flying

G/A because the rudder that controls the yaw axis on ground do not work properly in the flight model.

Debriefing:
At the end the pilot will fill out a questionnaire with various question types. The pilot should explain how the instruments felt during the flight, what is important and which changes should be made. The original questionnaire and the results will be listed in the appendix.

The questionnaire includes three blocks. Block A has questions with a rating scale to get an initial score of the pilots. Block B is a multiple choice part, where pilots can choose from several answers regarding priorities and distractions. And Block C has open questions so that if the pilot feels like something is missing it is possible to write it in the end.

4. Results

4.1. SEP
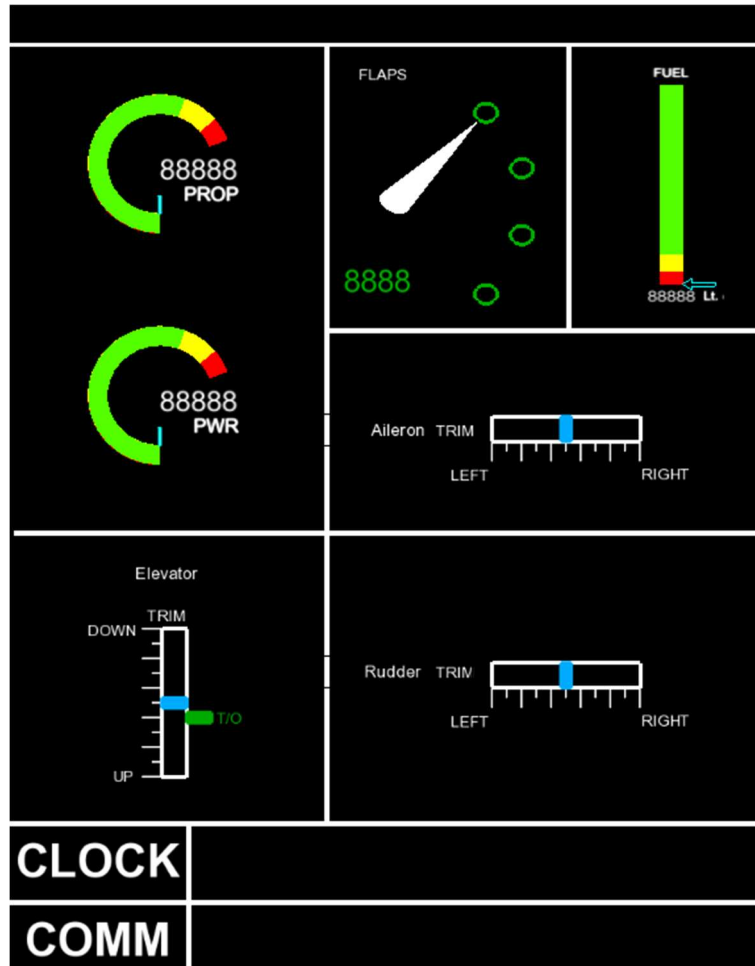
Figure 10: SEP profile. Used for the user-centred evaluation.

There is a total of 7 indicators:
- 2 Radial Gauge
- 1 Flap Indicator
- 1 Fuel Indicator
- 3 Trims
- Clock and Message Box

The colour arc is fixed for PWR but adjustable for PROP. Flaps have 3 positions but the last dot is not used. Fuel bar is realised but not implemented in the final flight model and is therefore static. It has 3 trims with the difference that the elevator has a marking for take-off. Since there are no controls for aileron and rudder trim yet they remain static. CLOCK shows the sim time in seconds and the solar time. COMM is for messages that are being sent from the simulation.

4.2. Turboprop
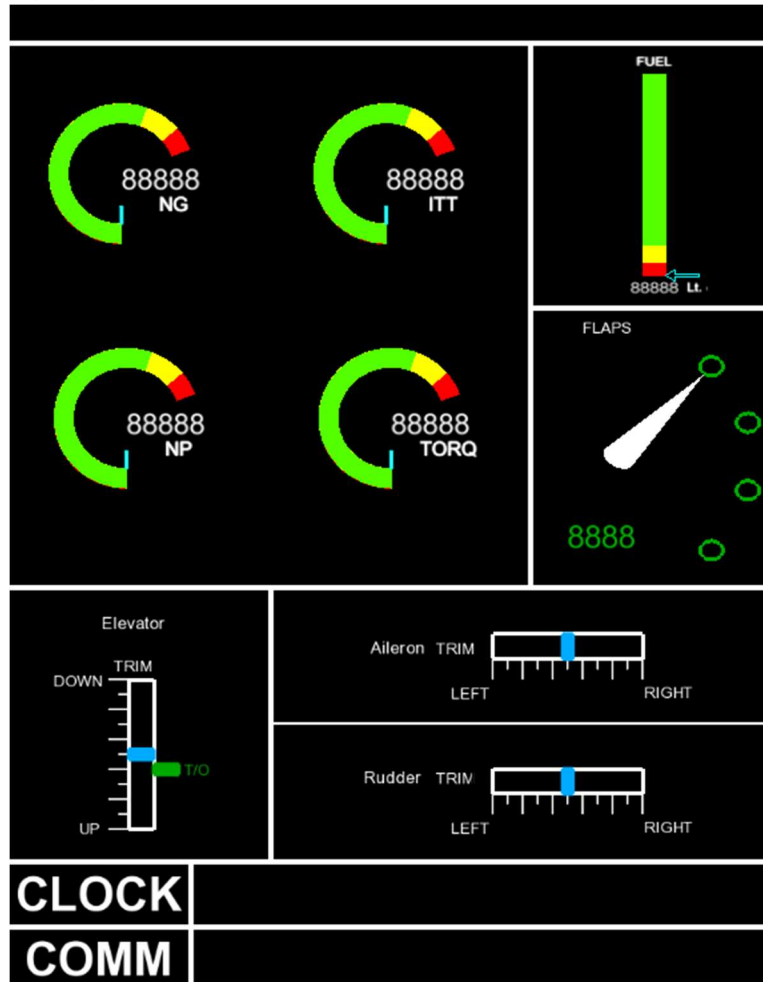
Figure 11:Turboprop profile. Similar to SEP with the exception of having more radial gauges.

There is a total of 7 indicators:
- 4 Radial Gauge
- 1 Flap Indicator
- 1 Fuel Indicator
- 3 Trims
- Clock and Message Box

Turboprop is similar to SEP with the exception that it has 4 instead of two radial gauges. The radial gauge is assigned to their corresponding values. Flaps have now 4 positions instead of 3. The remaining indicators work the same way as in SEP.

4.3. Turbofan
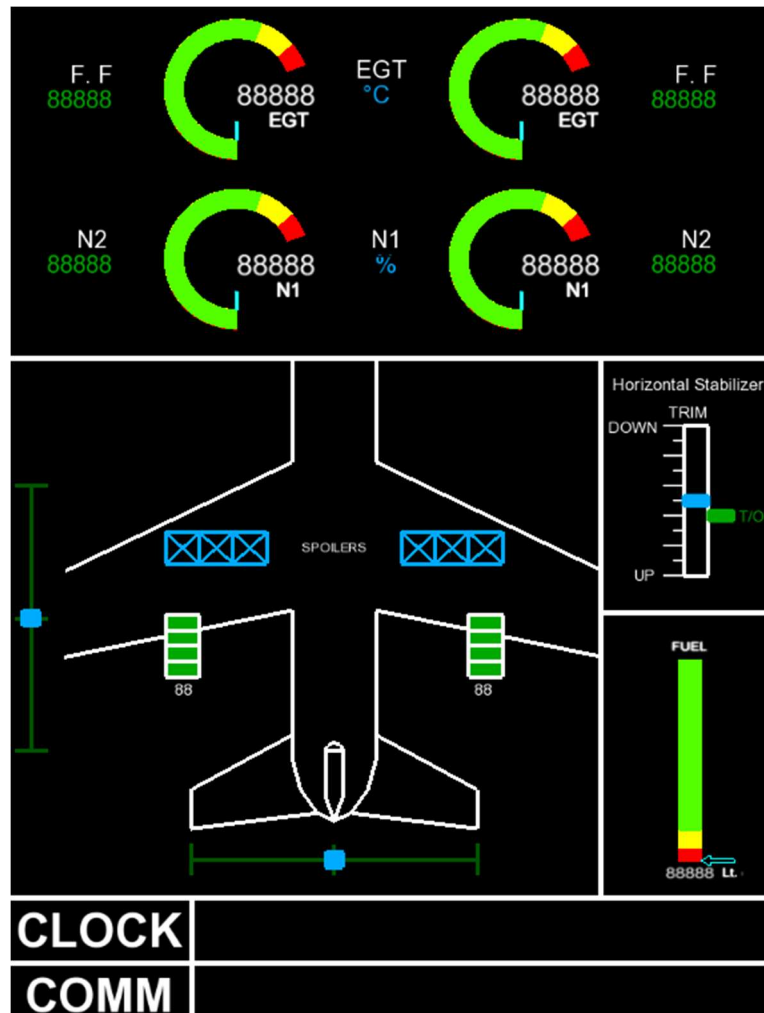
Figure 12: Turbofan profile. A more creative approach to use quantitative indicators.

There is a total of 11 indicators:
- 4 Radial Gauge
- 4 Digital Counter
- 2 Flap Indicator (working as one)
- 1 Fuel Indicator
- 3 Trims (Horizontal Stabilizer separately)
- 1 System Page for Control Surfaces
- Clock and Message Box

The turbofan has now a left and right side for the radial gauge. Although the same value for left and right is used. In addition to this, there are digital numbers for fuel flow and N2 for left and right. Flaps has a different appearance but with the same number of steps as turboprop. Rudder and aileron trim have been simplified to fit in the system page. Since this is a turbofan and should resemble a large aircraft there is an indication for spoilers as well with three stages (X = deployed, empty = retracted).

4.4. Helicopter
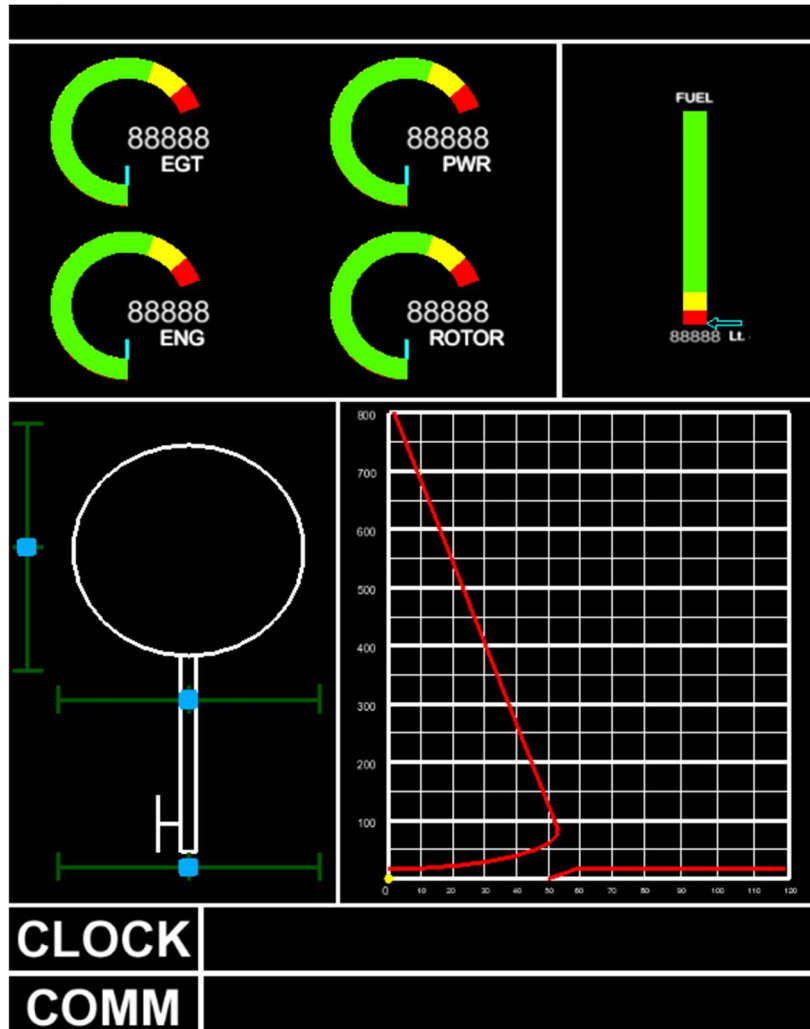
Figure 13: Helicopter profile. The dead-men curve is exclusively for this profile.

There is a total of 7 indicators:

- 4 Radial Gauge
- 1 Fuel Indicator
- 3 Trims
- Dead-Men Curve
- Clock and Message Box

This page can be applied to helicopters with piston and turbine. That is why it has four radial gauges. The more specialized indicator is the dead-men curve. This curve is basically an x-y system which shows the position of the helicopter with a yellow dot.

4.5. Tiltrotor
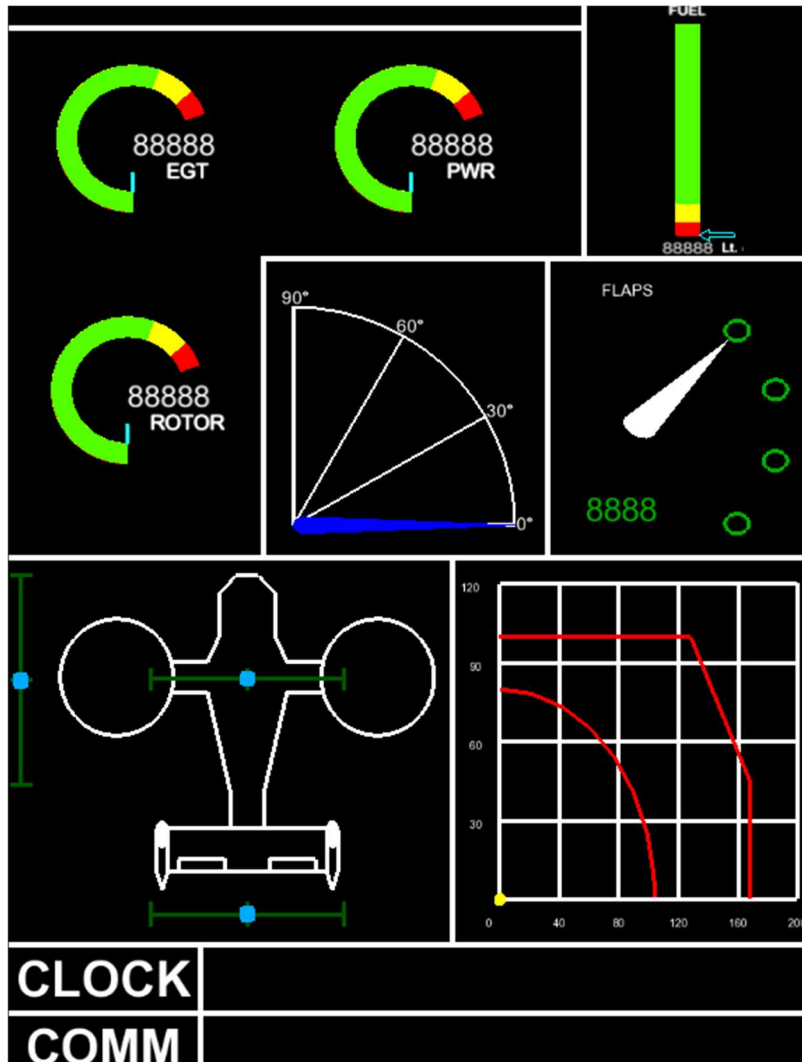
Figure 14: Tiltrotor profile. The corridor is exclusively for this profile.

There is a total of 7 indicators:
- 3 Radial Gauge
- 1 Flap Indicator
- 1 Nacelle Angle
- 1 Fuel Indicator
- 3 Trims
- Corridor
- Clock and Message Box

This system page can be described as a combination of a helicopter and turbofan. Tiltrotor has a system page with the trims, flaps, and fuel indicator. Nacelle Angle and corridor are aircraft type specific.

4.6. User-Centred Evaluation

Block A – Rating Scale

On a scale 1-5 answer the following questions:	1 Not at all	2 Not very much	3 Neutral	4 Rather	5 Very much
Were the instruments easy to read?				✗	
Are the instruments big enough?					✗
Is the position of the instruments justified?				✗	
Are the used colour schemes meeting the expectations?				✗	
Would you feel comfortable flying with those instruments in a real aircraft?			✗		

Table 8: Results of Block A – Rating Scale. Generally the participants had a positive impression of the instruments. [8]

The initial result shows that the participants were rather satisfied with the instruments except with the last question which resulted in a neutral position.

Block B – Multiple Choice

Was something on the MFD page distracting?

☐ Too many indicators.

☐ Not a clear distinction between the instruments.

☒ No.

☒ Other: *Flickering power value at full throttle (99 ⇔ 100)*

What do you prioritise in general for engine instruments?

☒ To meet a general standard (like the Garmin G1000 -> familiarity).

☒ Reliable flow of information's structured in a logical way.

☒ The use of colours to attract attention.

☐ Other: _____

The majority did not find anything disturbing except that the full throttle at the PWR indicator resulted in flickering between 99 and 100. Furthermore, the strongest priority was on "Reliable flow of information's structured in a logical way". [8]

Block C – Open Questions

If you could change something, what would it be?
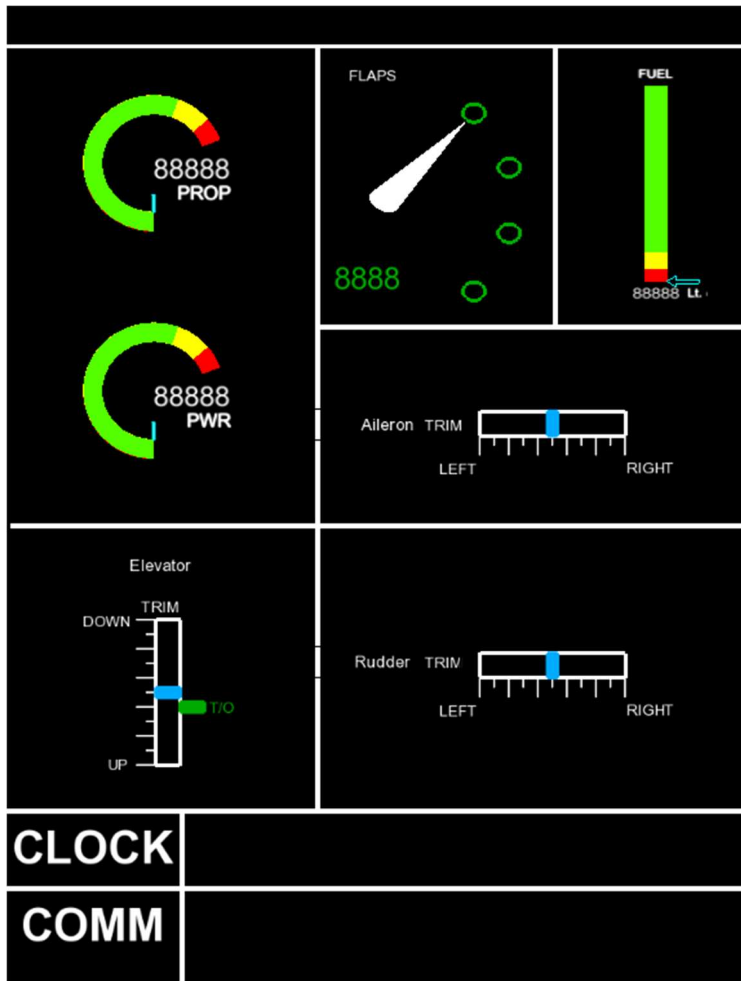
Elevator Trim too tail-heavy.

Flaps display easy to read, but movement should be fluently.

PWR indicator should not show lever position but engine power. In addition to this, in a SEP usually only one of the two is necessary.

Make needle larger and white, overlapping the arc.

Round RPM to 10

Change colour arc values, red seemed too high.

Add tickets to the arc so that reading does not depend on looking at the digital number.

Figure 15: SEP profile for Block C – Open Questions. [8]

Is there anything else you want to add?

- *After setting the correct trim the feeling of the aircraft with the instruments is very good.*

There were some general comments about the power indicator. Some suggested that it would be more convenient to display the available engine power instead of the position of the throttle lever. There were some comments about the appearance of the radial gauge. [8]

5. Discussion and Outlook

To discuss whether the results were satisfying or not a closer look must be given to the two tasks again:

1. Define a solution (Task 3).
2. Update ReDSim and testing. Writing of a user manual to be used to modify / develop instrumentation in the ReDSim (Task 4).

A solution has been defined during the design-cycle process. It was created with the collected requirements in section 1. Consequently, aircraft engine instruments were designed for SEP, Turboprop, Turbofan, Helicopter and Tiltrotor. From a design point of view the indicators fulfil their purpose according to the collection of requirements. But there are indicators that are not used which is for example the fuel gauge. The reason for this is that the flight model does not support all of the new collected requirements yet, which is out of scope for this bachelor thesis.

The last task was the human-centred evaluation and writing the manual for the ReDSim. This evaluation has shown that the participants tend to like new ideas of indicators for the aircraft. However, there were some comments about what should be displayed in the cockpit. That is an important discussion because in the end ZHAW mostly uses the ReDSim. Every person that works with the ReDSim also has different priorities. However, with the redesign of the system it is possible to adjust the instruments to the new manual.

For the future it is still necessary to evaluate what people think of the new designs and implementations of the requirements. The ongoing and regular reflection reinforces the actual task of the ReDSim which is to be used for research purposes.

6. Conclusion

To determine if the research goal is reached the research question is conducted again:

- How should the engine instruments be designed to comply for experimental purposes as well as flight training?

Here are two parts to consider. The first one is concerning the experimental purposes. Experimental purposes can be some system prototype testing or some form of evaluation. The ReDSim can provide for both purposes now solutions. With the manual it is possible to adjust the instruments according to the task. No longer has the task to be adjusted to the instruments.

The second part is about flight training. In order to be able to do a flight training a cockpit with controls and standard instruments are needed. The old PFD instruments in the ReDSim have been compiled again to be used in combination with the new engine instruments. Now it is possible for pilots to train certain flight manoeuvres with instruments that are reliable.

Of course, there are some important points to consider. The complexity has increased with the number of new instruments. Sometimes it can be a bit confusing because the data list has become much longer and there are more variables. Therefore, it is crucial to consult the manual, as it provides a guideline for what to look when handling the latest instruments.

The research question answer is: The instrument design should be valid in standard flight procedures and adaptable on demand to achieve the given research objective. A manual explains the details and illustrates the possibilities of each case. Furthermore, it is important to have some kind of validation to make sure the requirements are met.

Looking back at the research objective:

- Implementation of new designed engine instruments for the research and development simulator.

Even though there are not any corresponding flight models for all aircraft engine instruments, all instruments could be designed and tested with an experimental flight model. In this respect, the goal was partially achieved, as the final tests with the corresponding flight models are still pending. Nevertheless, the functionality as well as the attractiveness of the ReDSim were significantly increased with these innovations from the project work and bachelor thesis, as was shown by the user-centred evaluation.

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7. Bibliography

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[6] ISO International Standard, "Ergonomics of human–system interaction - Part 210: Human centered design for interactive systems," International Organization for Standardization, 2010.

[7] R. Monstein, "ReDSim - Software Interfaces," 2010.

[8] P. Spatharis, "Human-Centred Evaluation SEP Profile," ZHAW ReDSim, 2023.

8. List of Figures

9. List of Tables

10. Appendix
10.1. Project Management
10.1.1. Original Task given by Supervisor

Implementation of Flexible Displays in the Research and Development ...   ✕

Typ der Arbeit
- Bachelorarbeit
- Projektarbeit

Titel
Implementation of Flexible Displays in the Research and Development Simulator

Beschreibung
The ReDSim (Research and Development Simulator) of the Center for Aviation (ZAV) is currently used for several internal and external projects. Some of these projects require the implementation in the simulator of dedicated display layouts.
The displays shall contain a certain number of basic instruments such as: altimeter, airspeed indicator, turn and bank indicator, vertical speed indicator, artificial horizon (attitude indication), directional gyro / heading indicator.
Additionally, several other instruments shall be developed to support the current simulation models of airplanes, helicopters and convertiplanes. The implementation of such items may require the programming / modification of the existing display panels in the simulator that have been designed in GL Studio.
The work consists of the following 5 phases:
1. Familiarization with current simulator panels setup
2. Definition or required instruments
3. Development and testing of the instruments
4. Writing of a user manual to be used to modify / develop instrumentation in the ReDSim
It is understood that the required tasks may exceed the amount of work intended for a single PA/BA. In this case, the work will be started in the PA and completed in the BA. The goals of the PA and BA will be agreed with the supervisor.

Voraussetzungen
Interesgin in flight simulation and in programming.

Figure 16: Original task written by the supervisor.

10.1.2. Project Plan
The tasks of the bachelor thesis were discussed during a kick-off meeting. A timetable according to these tasks was created and milestones have been set.

10.1.3. Milestones
Milestone 1
The first milestone was to have all engine instruments for each aircraft type designed. There was a small delay because of problems with some functions within the instruments and adapting the requirements.

Milestone 2
Next was to implement a first solution into the system with the updated framework and test one aircraft type. Due to some problems with setting up the new CIF this milestone had some delay.

Milestone 3
Last milestone was about to have all aircraft types tested within the implemented solution. Because a new flight model had to be made (which also caused some problems) with all the new data connections there was a major delay.

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10.1.4. Timetable

	Aufwand	Termine Meilensteine
Creation and implementation	**50**	
Create Indicators	5	
SEP Profile	7	
H/C Piston Profile	7	
Turboprop Profile	6	
Turbofan Profile	8	
H/C Turbine Profile	7	
XV-15 Profile	10	11.04.2023
Testing	**56**	
Prepare ReDSim and CIF for implementation	4	
Update ReDSim with new Framework	6	
Test 1 aircraft type	5	14.04.2023
Test all aircraft types	29	13.05.2023
Field testing with a few pilots	12	
Troubleshooting	**0**	
	0	
Meetings and Documentation	**40**	
Meetings	13	
Documentation	27	
Projektende		

Arbeitsaufwand geplant	**365**

	Aufwand	Termine Meilensteine
Creation and implementation	**50**	
Create Indicators	5	
SEP Profile	7	
H/C Piston Profile	7	
Turboprop Profile	6	
Turbofan Profile	8	
H/C Turbine Profile	7	
XV-15 Profile	10	11.04.2023
Testing	**56**	
Prepare ReDSim and CIF for implementation	4	
Update ReDSim with new Framework	6	
Test 1 aircraft type	5	14.04.2023
Test all aircraft types	29	13.05.2023
Field testing with a few plots	12	
Troubleshooting	**0**	
	0	
Meetings and Documentation	**40**	
Meetings	13	
Documentation	27	
Projektende		

Arbeitsaufwand geplant	**365**

	Aufwand	Termine Meilensteine
Creation and implementation	**50**	
Create Indicators	5	
SEP Profile	7	
H/C Piston Profile	7	
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Prepare ReDSim and CIF for implementation	4	
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Troubleshooting	**0**	
	0	
Meetings and Documentation	**40**	
Meetings	13	
Documentation	27	
Projektende		

Arbeitsaufwand geplant	**365**

10.2. Meeting Protocols

Implementation of flexible displays in ReDSim

Kick-off meeting

16.02.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 22.02.2023, 17:00 o'clock, ZAV America

1. **Topics**

    - Recap the aim of the BA

    - Get an overview of the BA

    - Meeting date

    - Dependencies

2. **Goals**

    Agreement for further procedure of the BA.

3. **Findings**

    - 2 phases within the BA

        o   Define a solution

        o   Implementation and testing

    - BA and the manual will be written in English.

    - New meeting date: Wednesday, 1700 – 1730, ZAV America

    - Do not put too much effort into testing with pilots

4. **What to do next**

    - Creation of timetable

Create BA thesis document according feedback (structure)

5. → Appendix¶

Preparation
- Kick-Off Meeting
- Discussion of topics
- Timing

Define a Solution
- Create new instruments (Creation and impementation)
- Accoridng requirements
- Consideration of HMI
- New communication protocol

(Implementation and) testing
- Update ReDSim
- (Implement new instruments)
- Maybe test it with actual pilots for feedback (a couple of pilot for each type, collueges etc.)

Closing
- Allow time for troubleshooting
- Documentation
- Thesis and manual

1st meeting

22.02.2023

Present:	Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting:	01.03.2023, 17:00 o 'clock, ZAV America

1. Topics

- Overview of the BA

- Plan B (worst case scenario)

    o Without field testing

    o ~~Leave out a few aircraft~~

- Support from the the course "Schlüsselkompetenz Wissenschaftliches Arbeiten" about the structure of the BA.

2. Goals

Inform about the start and continuation of the BA.

3. Findings

- Before implementing an instrument, a sketch should be made first. => common ground on what to implement.

- 2 Versions will be run in the ReDSim because it is still used by other courses.

- It ***should be possible*** to implement the CIF in the new environment with the required dependencies (wink, wink).

4. What to do next

- Creation of SEP Profile (sketch)

- Prepare CIF for implementation

5. Questions

- Do I need to prepare something specifically for the ReDSim?
    - RSOLoader Installer, Compiled CIF, Instruments, all dependencies
- Should we do keep both versions until the end of BA?
    - Yes, one solution would be to have two folders with the different versions in it.

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2nd meeting

01.03.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 08.03.2023, 17:00 o 'clock, ZAV America

1. Topics

- Mistake in PA: It's not VTOL, it's tiltrotor.

- Idea of enlarging xml data file step by step.

- Correction of SEP profile.

2. Goals

SEP profile must satisfy collection of requirements.

3. Findings

- Nice to have: automatic adjustability of the colour bars

- The aim of the BA is to create a new set of instruments.

4. What to do next

- Design SEP profile

- Make a sketch of turbofan

5. Appendix
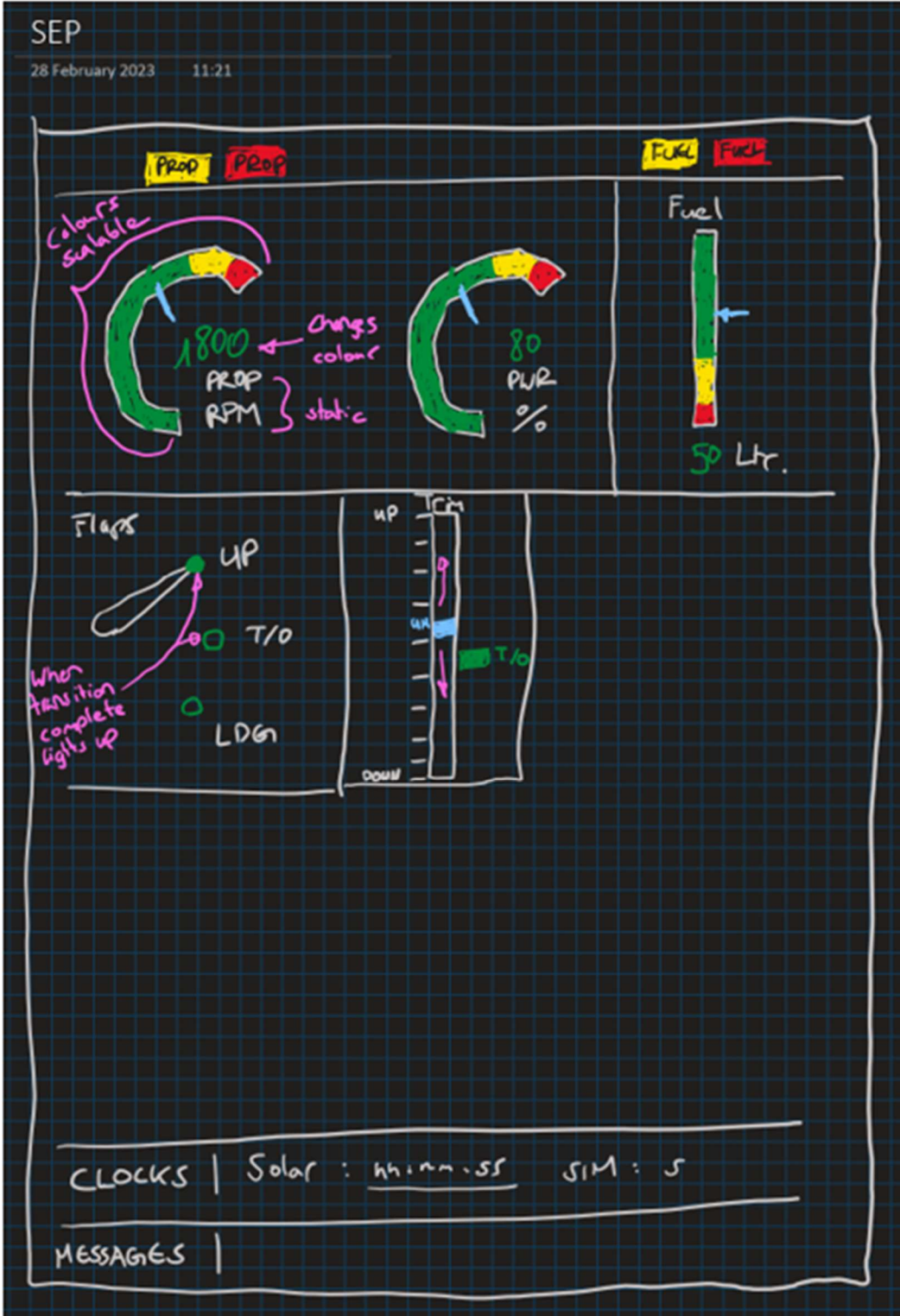
3rd meeting

15.03.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 22.03.2023, 17:00 o 'clock, ZAV America

1. Topics

- Research objective and questions

- How to exactly design the instruments and data definitions

- Show sketches

2. Goals

Define data definitions. Determine a date for testing. Discuss sketches of turbofan, turboprop and h/c.

3. Findings

- Data definitions like ranges, areas will be sent via udp to the cockpit side.

- A first new data definitions will be made for testing and then later expanded.

- Research questions should be defined more specific so that it is possible in the end to quantify the results.

4. What to do next

- Draw all a/c instruments

- Design Turbofan and Turboprop

- SEP testing

5. Questions / Remarks

- First version of research topic and questions:
  - Implementation of new designed engine instruments for the Research and Development Simulator (continuation of PA)
    - How should the instrument be designed in order to comply for experimental purposes as well as flight training (human factors)?
    - What are the requirements of the aviation industry that the ReDSim should fulfil?
- Sketches of the turbofan, turboprop and h/c are in the appendix.
- The new data definition will include data like ranges and labels. With this method it is possible to have a flexibility on side of the simulation to auto-adjust the instruments.

6. Appendix
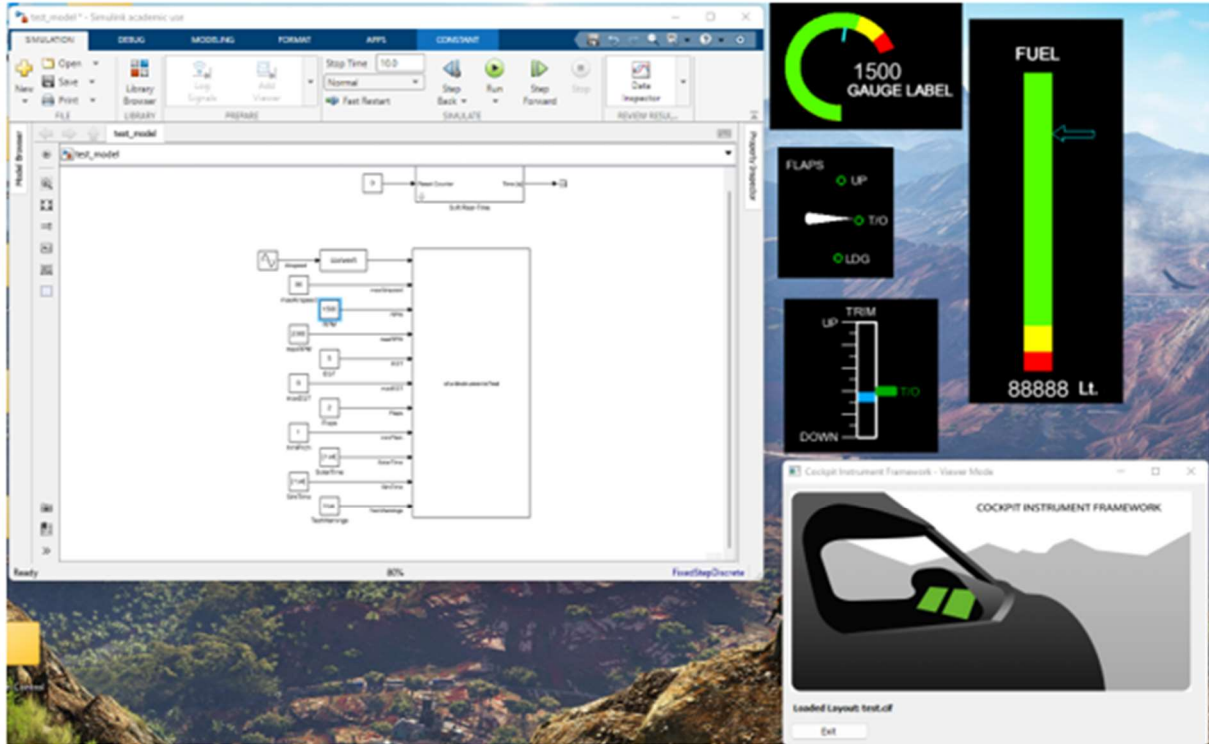
Designed indicators work with the test simulation as intended.
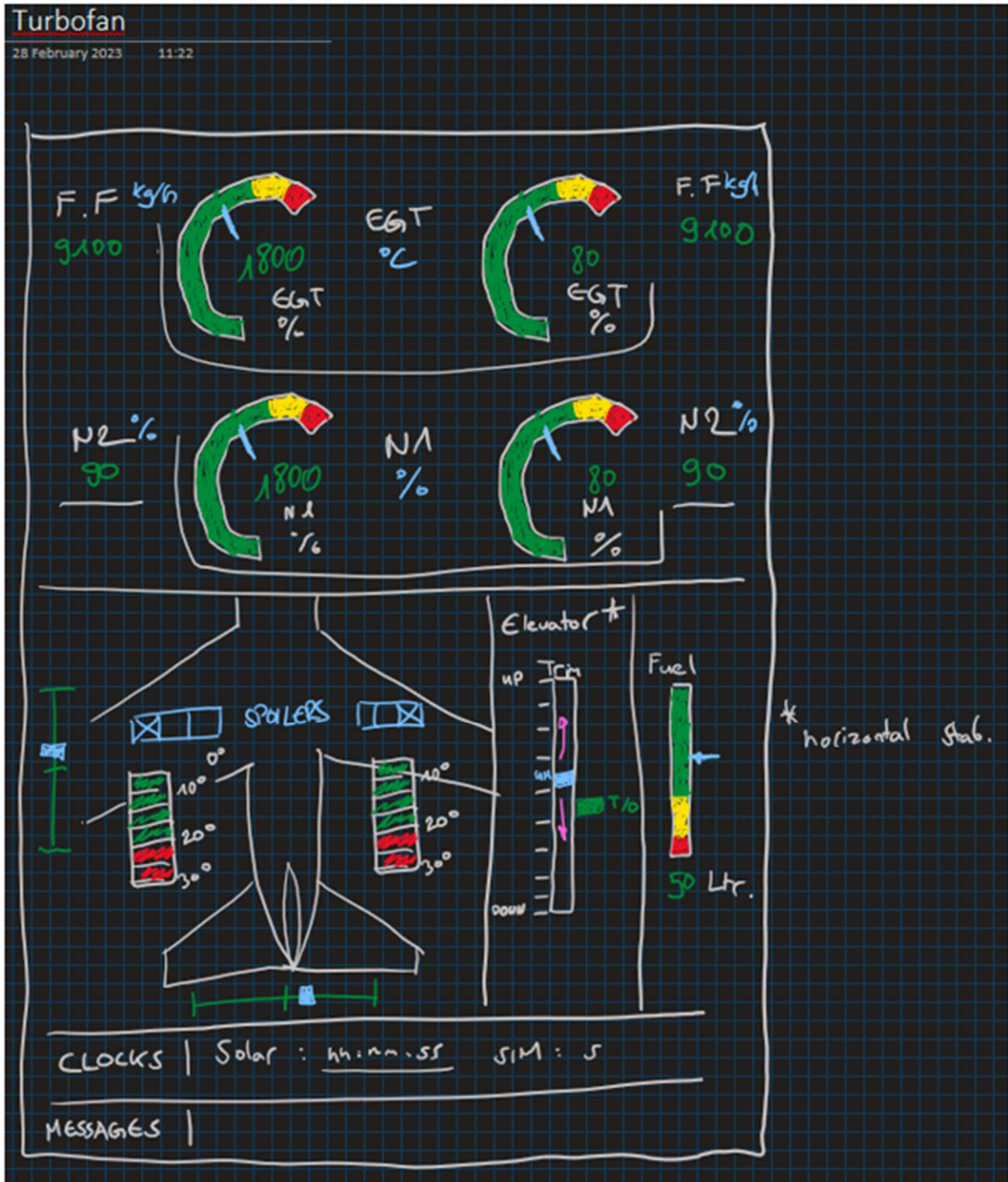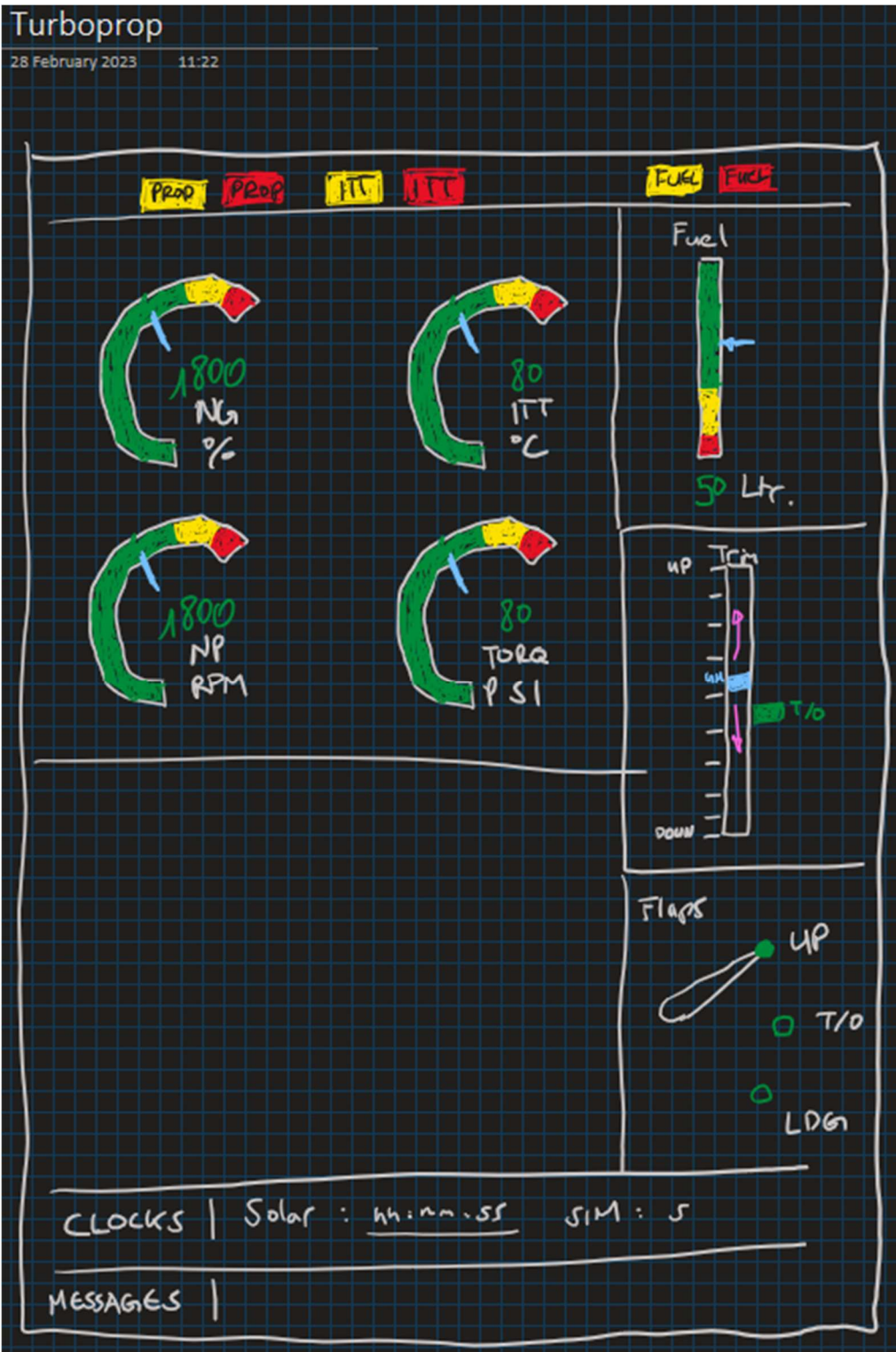
4th meeting

05.04.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 12.04.2023, 17:00 o 'clock, ZAV America

1. Topics

- A/C pages
- GLStudio 8.0
- Documentation

2. Goals

Get into the testing phase of the BA.

3. Findings

- Dead-men curve will be tested in two variants
- Until testing in the ReDSim is possible the instrument pages will be adjusted

4. What to do next

- Redraw tiltrotor system page
- Finalize a/c pages
- Continue writing the documentation

5. Questions

- Should we try GLStudio 8.0?
    - Not now. First GLStudio 7.0 must work.
- Adjustments?
    - SEP and turboprop: 4 trims
    - Turbofan: no red colour for flaps
    - Helicopter: no pitch trim
    - Tiltrotor: No dead-men curve
    - Dead-men curve with 2 variants:
        - One with an import of a texture file
        - One with redraw of the limits and fixed grid
    - Indicator for nacelle position
    - Redraw the xv-15 (like system page for turbofan)
    - Flaps Position with actual value
- What to cover in the manual?
    - How to create and import in GLStudio
    - How to use in CIF
    - What adjustments need to be made.
- What to cover in BA Documentation? Split between manual and documentation?
    - BA documentation focus on creation of new instruments according to the requirements.
    - ReDSim manual covers everything that has to do with adjustments of the instruments.

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5th meeting

19.04.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 26.04.2023, 17:00 o 'clock, ZAV America

1. Topics

- Show adjustments that were made

- Discuss field testing

- Data list

2. Goals

Determine the test details.

3. Findings

- Test dates were defined

- It will be tested with the model by Raphael

- For field testing: Max. 5 persons

- SEP model generates all the data as being presented in the original data file

4. What to do next

- Define the goal for the field testing

- Prepare a feedback formular

- List with data will be created in excel

5. Questions

- SEP- Model: Which data is generated?
  - All the data that is in the original data file.
- Still any other adjustments?
  - No, now it is important to test the adjustments made to the different a/c pages.

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6th meeting

26.04.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 03.05.2023, 17:00 o 'clock, ZAV America

1. Topics

- Questionary for field testing

- How to test with the sim model

- How to use the spoilers

- GLStudio 8.0

2. Goals

Prepare for the field testing with an actual model.

3. Findings

- GLStudio 8.0 will not be implemented (for now)

- Make a group of spoilers with 3 different steps

- Compile the old instruments with the new system

- Instruments will be tested with SEP model

4. What to do next

- Complete data list

- Write the questionary

- Once all instruments are tested make a short presentation

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5. Questions

- Is it ok to refer to my own work?
  - Yes, but citation is a must. The BA should be a self contained document so that the expert does not need to read the PA
- Use every single spoiler or per group?
  - Per group, with 3 steps.
- What do I need to prepare for the testing with the SEP model in MATLAB?
  - The data list only for SEP.
- What needs to be down in order to get GLStudio 8.0 running?
  - GLStudio 8.0 will not be used.

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7th meeting

10.05.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 17.05.2023, 17:00 o 'clock, ZAV America

1. Topics

- Questionary

- Old instruments work with new environment

- Data List

- Presentation on 15.05.23

2. Goals

Enter testing phase.

3. Findings

- Flaps need to be adjusted

- Prepare first presentation

4. What to do next

- Do a first flight test with SEP instruments

5. Questions

- Which sections are essential for the presentation?
  - Same as documentation
- How do the flaps work (lever)?
  - Numerical value as feedback
- Flaps position for all a/c the same?
  - No, some have more positions, but this is part of the flight model
- Is it necessary to explain how to use the CIF in the manual?
  - No, but you can refer to the PA
- N1, N2, fuel flow max values? In %?
  - Same as original data list
- SEP: Trim Aileron and Rudder no controls.
  - Yes, but keep the indicators for future use.

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8th meeting

31.05.2023

Present: Mr. Capone, Mr. Monstein, Mr. Spatharis
Next meeting: 07.06.2023, 17:00 o 'clock, ZAV America

1. Topics

- BA Presentation

- Results of Flight Testing

- Documentations

2. Goals

Enter the end phase of the BA

3. Findings

- Methods should build upon theoretical background

- No changes in instruments and indicators after results

- Time limit in the presentation

4. What to do next

- Finish documentation

5. Questions

- 2 Documents to submit
    - Bachelor Thesis and Manual
- Should something be changed according to the results?
    - No, everything stays the same
- Any special wishes for the presentation?
    - Time limit: Presentation max 20min

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10.3. Further

10.3.1. Data List

Original Data:

Type	Length	Offset	Name	Description	Unit	sub total
				Header		
unsigned short	2	0	msg_type			
unsigned short	2	2	msg_length			
				PFD data		4
float	4	4	pitch	[-90, 90]		
float	4	8	roll	[-180, 180]		
float	4	12	airspeed			
float	4	16	mach			
float	4	20	altitude			
float	4	24	radioAlt			
float	4	28	verticalSpeed			
float	4	32	flightDirectorX	[-1, 1]		
float	4	36	flightDirectorY	[-1, 1]		
char	1	40	flightDirectorVisible	0 or 1		
float	4	41	nz			
float	4	45	ny	[-1, 1]		
float	4	49	heading	(to draw the heading on the compass)		
float	4	53	course	(to draw the arrow)		
char	1	57	courseVisible	0 or 1		
float	4	58	headingBug			
char	1	62	headingBugVisible	0 or 1		

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Systems Diyplay data						59
float	4	63	alieronL	[-1, 1]		
float	4	67	alieronR	[-1, 1]		
float	4	71	elevatorL	[-1, 1]		
float	4	75	elevatorR	[-1, 1]		
float	4	79	rudder	[-1, 1]		
float	4	83	trimPitch	[-1, 1]		
float	4	87	trimRoll	[-1, 1]		
float	4	91	trimYaw	[-1, 1]		
char	1	95	uwp1LFailed			
char	1	96	uwp2LFailed			
char	1	97	uwp3LFailed			
char	1	98	uwp4LFailed			
char	1	99	uwp1RFailed			
char	1	100	uwp2RFailed			
char	1	101	uwp3RFailed			
char	1	102	uwp4RFailed			
float	4	103	uwp1LDefl			
float	4	107	uwp2LDefl			
float	4	111	uwp3LDefl			
float	4	115	uwp4LDefl			
float	4	119	uwp1RDefl			
float	4	123	uwp2RDefl			
float	4	127	uwp3RDefl			
float	4	131	uwp4RDefl			
char	4	135	uwp1LLabel			
char	4	139	uwp2LLabel			
char	4	143	uwp3LLabel			
char	4	147	uwp4LLabel			
char	4	151	uwp1RLabel			
char	4	155	uwp2RLabel			
char	4	159	uwp3RLabel			
char	4	163	uwp4RLabel			
float	4	167	n1L	[0, 120]		
float	4	171	n1R	[0, 120]		
float	4	175	n2L	[0, 120]		
float	4	179	n2R	[0, 120]		
float	4	183	egtL	[0, 120]		
float	4	187	egtR	[0, 120]		
char	1	191	ffSi			
float	4	192	ffL			
float	4	196	ffR			
float	4	200	flaps	[0, 3]		
float	4	204	cgPos	[-1, 1]		
float	4	208	cgMax			
float	4	212	cgMin			
float	4	216	oat			
float	4	220	alpha			
float	4	224	beta			
char	1	228	fpmVisible			
float	4	229	acceleration			
char	1	233	speedBugVisible			
float	4	234	speedBugValue			
float	4	238	dStabilizer			
char	150	242	textMessages			

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New Data:

New Systems Diyplay data						329
float	4	392	np	Value of NP	RPM	
float	4	396	npYellow	End of green arc	RPM	
float	4	400	npRed	End of Yellow arc	RPM	
float	4	404	npMax	Maximum Value for NP	RPM	
float		408	propRpm	Value of the Propeller	RPM	
float		408	propRpmYellow	End of green arc	RPM	
float		408	propRpmRed	End of Yellow arc	RPM	
float		408	propRpmMax	Maximum Value for Prop	RPM	
float	4	408	throttle	Value for the Power (position of the lever)	%	
float		412	Flaps	Flaps position 0-4 (displayed in degrees in the framework)	[]	
float	4	412	ng	Value of NG	%	
float	4	416	ngYellow	End of green arc	%	
float	4	420	ngRed	End of Yellow arc	%	
float	4	424	ngMax	Maximum Value for NG	%	
float	4	428	itt	Value of ITT	°C	
float	4	432	ittYellow	End of green arc	°C	
float	4	436	ittRed	End of Yellow arc	°C	
float	4	440	ittMax	Maximum Value for ITT	°C	
float	4	444	torq	Value of Torq	PSI	
float	4	448	torqYellow	End of green arc	PSI	
float	4	452	torqRed	End of Yellow arc	PSI	
float	4	456	torqMax	Maximum Value for TORQ	PSI	
float		460	EGTL	Value of EGTL	PSI	
float		460	egtYellow	End of green arc	°C	
float		460	egtRed	End of Yellow arc	°C	
float		460	egtMax	Maximum Value for EGTL	°C	
float		460	EGTLYellow	End of green arc	°C	
float		460	EGTLRed	End of Yellow arc	°C	
float		460	EGTLMax	Maximum Value for EGTL	°C	
float		460	EGTR	Value of EGTR	°C	
float		460	EGTRYellow	End of green arc	°C	
float		460	EGTRRed	End of Yellow arc	°C	
float		460	EGTRMax	Maximum Value for EGTR	°C	

Type		Offset	Name	Description	Unit
float		460	N1L	Value of N1L	%
float	4	460	n1Yellow	End of green arc	%
float	4	464	n1Red	End of Yellow arc	%
float	4	468	n1Max	Maximum Value for N1L	%
float		472	n1LYellow	End of green arc	%
float		472	n1LRed	End of Yellow arc	%
float		472	n1LMax	Maximum Value for N1L	%
float		472	N1R	Value of N1R	%
float		472	n1RYellow	End of green arc	%
float		472	n1RRed	End of Yellow arc	%
float		472	n1RMax	Maximum Value for N1R	%
float		472	FFL	Value of Fuel-flow left	gal/h
float	4	472	ffMax	Maximum Value for FFL	gal/h
float		476	ffLMax	Maximum Value for FFL	gal/h
float		476	FFR	Value of Fuel-flow right	gal/h
float		476	ffRMax	Maximum Value for FFR	gal/h
float		476	N2R	Value of N2R	%
float	4	476	n2Max	Maximum Value for N2	%
float		480	n2RMax	Maximum Value for N2R	%
float		480	N2L	Value of N2L	%
float		480	n2LMax	Maximum Value for N2L	%
float	4	480	spoilersL	Value for spoiler group left (3 positions, 0-4)	[]
float	4	484	spoilerR	Value for spoiler group right (3 positions, 0-4)	[]
float	4	488	egt	Value of EGT	°C
float	4	492	egtYellow	End of green arc	°C
float	4	496	egtRed	End of Yellow arc	°C
float	4	500	egtMax	Maximum Value for EGT	°C
float		504	eng	Value of Eng	RPM
float		504	engYellow	End of green arc	RPM
float		504	engRed	End of Yellow arc	RPM
float		504	engMax	Maximum Value for Eng	RPM
float	4	504	nr	Value of Rotor	RPM
float	4	508	nrYellow	End of green arc	RPM
float	4	512	nrRed	End of Yellow arc	RPM
float	4	516	nrMax	Maximum Value for Rotor	RPM
float		520	Dead-Men-X	X-value for dead men curve	[]
float		520	Dead-Men-Y	Y-value for dead men curve	[]
float	4	520	nacelleAngle	Angle of the nacelle (0-90)	°
float		524	Corridor-X	X-value for corridor	[]
float		524	Corridor-Y	Y-value for corridor	[]
char	8	524	wallClockTime	[hh:mm:ss]	[]
float	4	532	simTime	[s]	[]
String		536	COMM	Just for writing messages	[]
float	4	536	fuel	fuel in [lt] (does not need to be implemented, I have included it for later use)	gal
					148
Total	**540**				**540**