Requirements Document

Future Aircraft Energy Management Systems

Version Final

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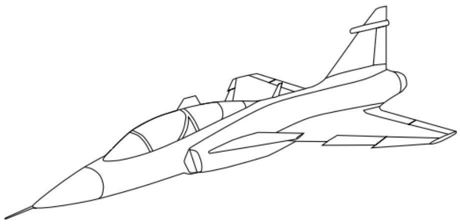

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Document History

Version	Date	Changes made	Sign	Reviewer
0.1	16/9-21	First draft.	Emil Boström	Kristoffer Ekberg
0.2	21/9-21	Version 2	Emil Boström	Kristoffer Ekberg
0.2	30/9-21	Version 3	Emil Boström	Alessandro Dell'Amico

Contents

1 Introduction

This document is the requirement specification for the project *Future Aircraft Energy Management Systems* in the Automatic Control - Project Course (TSRT10) at Linköping University autumn term of 2021. The purpose of this documentation is to set the requirements for the project.

1.1 Background

The aircraft industry is the trending towards electrification, also known as More Electric Aircraft, MEA. Electrification is expected to help the industry reach future objectives such as reduced aircraft weight, increased efficiency, lower maintenance and higher safety. In practice this means the development and implementation of a more efficient electric power distribution, more efficient and electric driven components and intelligent control of available power. Energy management will be important when more high power electric consumers, such as actuation system and sensors, are integrated in the aircraft.

1.2 Project basis

Figure 1 depicts a test rig, an Iron Bird, which is a research platform under development. The test rig is a colloboration between Saab AB and Linköpings university and its purpose is to evaluate future electric flight control system, electric power architectures and control strategies, including energy management.

The project is supported by Saab Aeronautics who is the main stakehold and customer. The complete project is a bilateral collaboration between the departments IEI/Flumes and ISY/Vehicular Systems at Linköpings university. Two projects, one from each department, will work together to deliver the final demonstration. The IEI-project will focus on the development and implementation of the aircrafts electric consumers while this project (ISY-project) will focus on the electric supply system and energy management.

Figure 1: The Iron Bird test rig.

1.3 Parties

- The group consisting of six students studying electrical engineering.
- The customer and orderer Alessandro Dell'Amico, Saab Aeronautics/IEI.
- The advisor Kristoffer Ekberg, post doc ISY.

1.4 Purpose and goal

The scope of this project is to develop a Digital Twin of the power generation system and to create a Vehicle Management System that can supply power to tactical systems, while ensuring that the flight control system gets the desired power.

To reach the objective, the Iron Bird needs to be prepared with the development and implementation of the electric power distribution system, power consumers and control strategies.

1.5 Definitions

- **AC** - Alternating current.
- **BAT** - Battery.
- **DC** - Direct current.
- **Digital Twin** - Virtual representation of a physical object or system.
- **EHA** - Electro Hydraulic Actuator
- **EMA** - Electro Mechanical Actuator
- **FAEM** - Future Aircraft Energy Management Systems.
- **ICD** - Interface Control.
- **Iron Bird** - The test rig used in the project.
- **ME** - Main Engine.
- **MEA** - More Electric Aircraft.
- **MGEN** - Main Generator.
- **SHA** - Servo Hydraulic Actuator
- **SSPC** - Solid-State Power Controllers.
- **VDC** - Voltage of direct current.

1.6 Requirement description

The requirements for the project will have the format shown in Table 1. If a requirement has been negotiated and revised, it will be shown as v2, v3 etc. Each requirement will have a description and a priority; 1,2 or 3 where 1 is the highest priority. Requirements with priority 1 shall be achieved before the final deadline. Priority 2 and 3 will be fulfilled if all priority 1 are fulfilled and there is time left.

Req. no.	Version	Description	Priority
X	Original	Description of requirement X	1,2,3
Xa	V2	Revised description of requirement X	1,2,3

Table 1: Example of requirement specification

2 Overview of the system

This projects main focus is the development of a Digital Twin of an aircrafts electric supply system that will be integrated with another Digital Twin of the aircrafts system consumers. These Digital Twins shall then work together with a flight simulator and the Iron Bird test rig according to Figure 2.

The aircrafts electric power generation consists of a generator (driven by an engine) and battery emulation units for 270 VDC and 28 VDC. The high voltage system of 270 VDC supplies power to the actuators and the radar while the low voltage system of 28 VDC will supply power to the computers. The power generation system is arranged to assimilate an aircraft system with dual redundant configuration.

The aircrafts consumers consists of an electrical flight control system and a generic DC-load which allows it to emulate any other consumer in the platform, i.e. other vehicle systems or tactical systems such as a radar. The electric power delivery is monitored and controlled by Solid-State Power Controllers (SSPC). The intended layout of the system is presented in Figure 3.

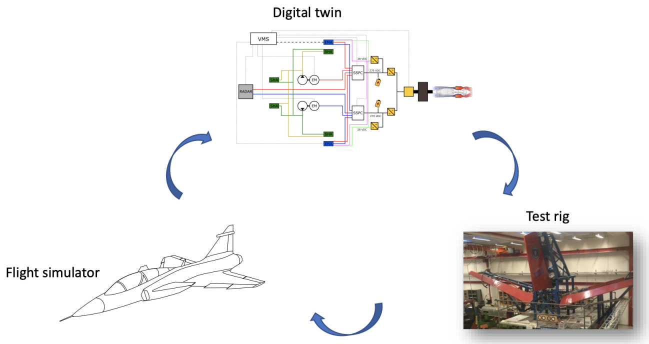

Figure 2: An overview of the project, simulation will work with the digital twin, that in turn shall resemble the test rig

2.1 Rough description of the system

The product that this project will produce will primarily consist of a Digital Twin of an aircraft power generation system. The Digital Twin will be developed in Simulink and shall include models for the engine, generators, inverters, batteries and control logics. Failure conditions shall be included in all of the models.

The Digital Twin shall be adapted to real-time requirements (from e.g. a flight simulator) and therefore development and implementation of strategies for controlling the systems static and dynamic characteristics, in real-time, will be required. Interfaces for communication and data-logging will be developed.

Development and implementation of strategies for energy-management will also be included in the project. Based on an actual flight-mission, these strategies will determine how the system distributes power and handles electric outbursts.

The Digital Twin for the aircraft power generation system shall be able to be connected to the models for the aircraft system consumers created by the IEI group.

2.2 System components

The aircrafts energy management system includes several components, some that supply power and some that consume, as well as a control system between these two groups.

The models for the power generation system includes the following:

- Main engine
- Generators
- Inverters
- Battery system
- Control logic

These components will only exist digitally, but the electricity generated by these will be generated by the 80kW power supply system.

The models for the power consuming products will be the following:

- Tactical systems
- Hydraulic pump
- Electro Mechanical Actuators (EMA)

The tactical system could for example be a radar system.

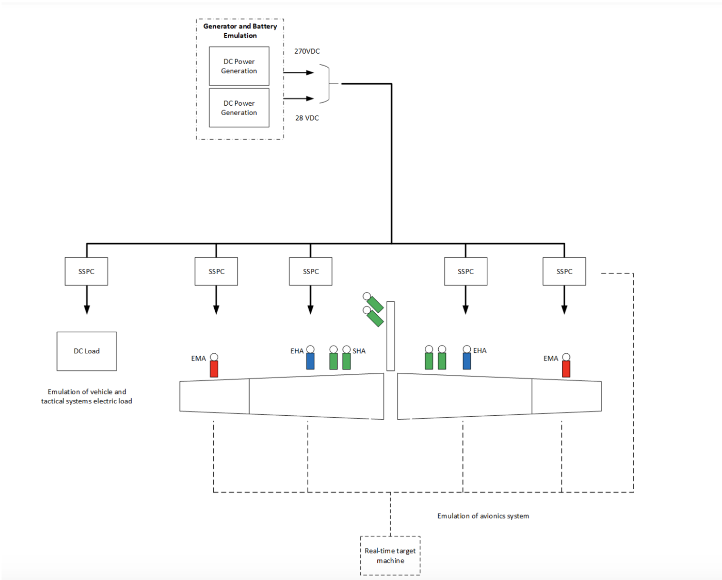

Figure 3: Layout of the electrical system. The system has a high and a low voltage system, that supplies actuators, sensors and computers.

2.3 Dependecies towards other systems

The IEI group will create models of aircraft system consumers, that this group will have to supply power to. This group will therefore rely on the IEI group to model these and generate power demand data to the logic system.

2.4 Limitations

- The main limitations set on the project is the number of components for the system. No other components exist but those stated.

2.5 Subsystems

- Models for energy supply system
- Vehicle management system (VMS)
- Physical components
- Models for energy consuming components

2.6 General requirements for the complete system

Req. no.	Version	Description	Priority
1a	V3	System will run in real time on keysight, but not with Iron Bird	1
2	Original	Simulink models shall be validated against existing hardware in the test rig, where applicable.	1
3	Original	An offline flight simulation shall be performed successfully.	1
4	V2	Real-time simulation including Keysight with pre-defined flight simulator results from JSBsim will be performed.	1
5	Original	The project shall consider safety aspects in terms of protecting both the test objects and the users. Both hardware and software safety functions shall be considered upon test at the rig.	1
6	Original	Failure conditions shall be included in all of the models.	1
7	Original	Models and control algorithms shall be well documented and commented.	1
8	Original	The simulation shall be user friendly to run.	2
9	Original	A document of how to use simulation and code shall be written for future users of the system.	1

Table 2: Requirements for the whole system

3 Subsystem 1 - Models for energy supply system

3.1 Introduction to subsystem 1

Subsystem 1 will consist of a number of models that will provide real time information to a number of Keysight regenerative power supplies to simulate the power producing components. The output will be used to power the Iron Bird. The power suppliers will run simulated models of the following components:

3.2 Modelling in- and outputs for Energy producing components

3.2.1 Main engine (ME)

The source of power to the aircraft is the jet engine used for propulsion, that will also power the generator via a gearbox for electricity production. This model will have the following in- and output.

Model input

- Air data
- Required power (thrust)

Model output

- Power
- Engine RPM
- A/C gearbox RPM and gearbox shaft power

3.2.2 Main generator (MGEN)

Converting rotational energy from the ME to AC-current.

Model input

- Required system voltage level
- Shaft power
- Shaft rpm

Model output

- Power
- Frequency

3.2.3 Battery (BAT)

Provide power for systems and engine startup and limited emergency power if main engine fails.

Model input

- Required system power level

Model output

- Current
- Remaining capacity

3.2.4 Inverter

Converts AC voltage from the generator to DC voltage that the SSPC can supply.
Model input

- AC voltage

Model output

- DC voltage

3.2.5 SSPC

Distributes power and secures. The SSPC is used to monitor the power used by every component in the system. The VMS can prioritize certain components and the SSPC makes sure that the prioritized components receive their demanded power. This prioritization can be re-configured based on available power supply.

3.3 Models Design requirements

Req. no.	**Version**	**Description**	**Priority**
10	Original	A interface which shows real time data for energy production.	1
11	Original	Monitor real time energy consumption from producing components of the system.	1
12	Original	Models shall be implemented in Simulink.	1
13	Original	The total generated power shall be a variable in the interface	1

Table 3: Design requirements for the energy producing components

3.4 Performance requirements

Req. no.	Version	Description	Priority
14	V2	The steady state 270 DC voltage level shall be regulated in a interval of 250 V to 280 V for components which are in need of such voltage level.	1
15	V2	The steady state 28 DC voltage level shall be regulated in a interval of 22 V to 29 V for components which are in need of such voltage level.	1
16	V2	The voltage level in the 270 DC system shall be able to be regulated from 200 V to 250 V within 30 ms also from 330 V to 280 V within 20 ms.	1
17	V2	The voltage level in the 28 DC system shall be able to be regulated from 18 V to 22 V within 85 ms also from 50 V to 29 V within 70 ms.	1
18	Original	Being able to regulate power distribution between radar and system components which are critical. This shall be done by varying the power to the radar.	2

Table 4: Performance requirements for the control system

3.5 Functional requirements

Req. no.	Version	Description	Priority
19	Original	Having a model for energy produced by ME.	1
20	Original	Modelling the conversion losses in gear-boxes before generator.	1
21	Original	Having a model for energy conversion in the generator.	1
22	Original	Having a model for the battery.	1
23	Original	Having a model for the inverter.	1
24	Original	The SSPC shall be able to cut off power to certain components when needed.	1
25	Original	The SSPC shall be reprogrammable.	1
26	Original	React to ME, MGEN failures by having battery as fail safe.	2

Table 5: Functional requirements for the energy producing components

3.6 Limitations

- Max total capacity of the system is 80kW.

4 Subsystem 2 - Vehicle management system

4.1 Introduction to Vehicle management system

Vehicle management system (VMS) is the brain behind the system. The VMS control and monitor all components in the system. The VMS includes an energy management part which purpose is to manage the distribution of power for an actual flight mission. The control strategy shall be able to distribute the power and handle electric power bursts. Some of the requirements for the VMS will be based on the MIL-STD-704F standard for aircraft electric power characterstics.

4.2 Design Requirements for VMS

Req. no.	**Version**	**Description**	**Priority**
27	V2	No control of the Iron bird required.	1

Table 6: Design requirements for the control strategies

4.3 Reliability Requirements for VMS

Req. no.	**Version**	**Description**	**Priority**
28	Original	The components required for safe flying shall always receive their desired energy demand.	1
29	Original	The control system shall be able to handle one component failing.	1
30	Original	The control system shall be able to handle two or more component failing.	3

Table 7: Reliability requirements for the control system

4.4 Performance Requirement for VMS

Req. no.	Version	Description	Priority
31	Original	Being able to gather information from every component in the energy supply system.	1
32	Original	Being able to communicate to every component in the energy supply system	1
33	Original	Shall be able to control the maximum allowed current via controlling the SSPC	1

Table 8: Performance requirements for the control system

5 Subsystem 3 - Physical components

5.1 Introduction to subsystem 3

Subsystem 3, Physical components, consists of hardware in the system related to the power supply and communication between components. This includes, a switch, Ethernet connections, windows computer running the simulation and a real time computer.

5.2 Limitations

For windows computer running the simulation and the real time computer no requirements are set. This due to the fact that these are already existing components which we are not able to change.

5.3 Design Requirements for subsystem 3

Req. no.	**Version**	**Description**	**Priority**
34	V2	The switch shall be have at least 7 Ethernet ports.	1
35	V2	A switch must be used.	1

Table 9: Design requirements for physical components

5.4 Functional Requirements for subsystem 3

Req. no.	**Version**	**Description**	**Priority**
36	V2	No significant data transfer on the switch is required.	1
37	Original	The power source shall be able to distribute power to the power receiving source.	1
38	V2	It is no need for the power source to be able to power components on the Iron Bird	1
39	Original	The power source shall be able to send back information about a power distribution to the real time computer.	1

Table 10: Functional requirements for physical components

6 Subsystem 4 - Energy consuming components

6.1 Introduction to subsystem 4

Subsystem 4 consists of models for the energy consuming components. The purpose is to supply these components with the sufficient power to operate. These components are listed below.

6.2 Limitations

While there are requirements for models for each energy consuming part they will not be developed by the authors of this report, but rather in close contact with the IEI group.

6.3 Energy consuming components

- Tactical systems
- Hydraulic pump
- Electro Mechanical Actuators (MEA)

6.4 Design Requirements for subsystem 4

Req. no.	**Version**	**Description**	**Priority**
40	Original	An interface which shows real time data for energy consumption.	1
41	Original	Models shall be implemented in MATLAB/Simulink.	1
42	V2	There is no need for the models to be able to work with the Iron bird	1

Table 11: Design requirements for the energy consuming components

6.5 Functional Requirements for subsystem 4

Req. no.	**Version**	**Description**	**Priority**
44	Original	Integrate model for tactical system (radar) in the complete system.	1
44	Original	Integrate models for hydraulic pump systems in the complete system.	1
45	Original	Integrate models for electro mechanical actuators (EMA) in the complete system.	1
46	Original	Implement failure conditions for each energy consumption model.	1

Table 12: Functional requirements for the energy consuming components

7 Simulation Requirements

Req. no.	Version	Description	Priority
47	Original	The models in Simulink shall be a first order system that describes both the static and dynamic characteristics of the components	1
48	Original	The models in Simulink shall be of higher complexity than a first order system	2
49	Original	An offline simulation shall be performed successfully. A simulation is deemed unsuccessful if one of the requirements in table 4 fails.	1
50	Original	A real time simulation shall be performed successfully. A simulation is deemed unsuccessful if one of the requirements in table 9 fail.	1
51	Original	After the simulation the user shall be told if it was successful or not.	2
52	Original	The simulation shall save variables and produce plots for all the outputs from the models during the whole simulation.	1
53	Original	During the real time simulation the user shall be able to monitor the states in real time.	1
54	Original	The simulation can be controlled via a GUI.	1
55	Original	Simulink files of version 2020b shall be used to guarantee compatibility.	1
56	Original	Simulink must be able to compile the information to Ethernet protocol.	1
57	V2	The system shall be able to send a signal of power distribution to a component, and receive confirmation that the power was distributed 100x faster than the voltage need to be regulated. This corresponds to 0.2 ms	1
58	Original	A feature of the simulation shall be the possibility to simulate failures in specific components	1

Table 13: Simulation requirements

8 Economic

There is also some economical requirements that needs to be fulfilled, those can be found in the table below.

Req. no.	**Version**	**Description**	**Priority**
59	Original	Group member shall contribute with 240 h each, on the project.	1
60	Original	Fundamental hardware for the project shall be granted by the customer.	1
61	Original	The group shall be granted access to the fumes lab, where the Iron Bird is located.	1

Table 14: Economic requirements.

9 Documentation

The full documentation of the project can be found in in table 15, which also describes the aim of respective document and which format it shall be in.

Document	**Language**	**Aim**	**Format**
Requirement specification	English	Document with the project's specified requirements.	PDF
Project plan	English	Describes how the construction of the project, with milestones and deliveries.	PDF
Time plan	English	Points out how the time is to be distributed over the various parts of the project.	PDF
ICD	English	Provides all interface information (such as tables, quantities and textual information).	PDF
Design specification	English	An overview of the system and the three subsystems.	PDF
Test plan	English	Documentation containing tests that are to be execute and their requirements from this document, that they shall fulfill.	PDF
Test protocol	English	Documentation of the tests made and whether they were satisfied.	PDF
After study	English	Reflection of the project in large, what went well and what could have be done better?	PDF
Status report	English	Coverage of what team members have done.	PDF
Meeting minutes	English	The agenda and notes of all meetings.	PDF
Technical documentation	English	A documentation with the technical results.	PDF
User Manual	English	Documentation of how the product is to be used.	PDF
Poster	English	A poster that briefly explains the project, primarily results and conclusions.	PDF
Web page	English	A web page presenting the project with all its important documents.	HTML
Movie	English	A movie that summarizes the finished project and how it functions.	Video
Time report	English	A report of how much time each member spent on the activities.	PDF

Table 15: Documentation that is to be delivered during the project.