Team AI - 26

AVIONICS INTEGRATION TEST BENCH

REQUIREMENTS

ELEC 491 Capstone Project

University of British Columbia

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Glossary

Term	Definition
ADF	Automatic Direction Finder
ARINC	Aeronautical Radio Inc.
AHRS	Attitude and Heading Reference System
COTS	Commercial Off-the-Shelf
DADC	Digital Air Data Computer
DME	Distance Measuring Equipment
ESD	Electrostatic Discharge
GUI	Graphical User Interface
I/O	Input/Output
LRU	Line Replaceable Unit
OTS	Off-the-shelf
RX	Receive
TX	Transmit
USB	Universal Serial Bus
VHF	Very High Frequency
VOR	VHF Omnidirectional Range

1. Background

1.1 Client and Industry

This capstone project's development of an *Avionics Integration Test Bench* is conducted on behalf of KF Aerospace, the largest commercial aviation maintenance, repair and overhaul (MRO) organisation in Canada. KF Aerospace services and modifies a diverse array of components in commercial and military aircraft, including the suite of installed avionics equipment [1]. The company often undertakes projects to replace, reconfigure and add pieces of avionics equipment in ageing aircraft. These pieces of equipment are referred to as "line replaceable units" (LRUs) in the industry. A few examples of such equipment are presented in Figures 1.1 through 1.3.

Figure 1.1 - A LITEF LCR-100 Attitude and Heading Reference System (AHRS).

Figure 1.2 - A Thommen AC32 Digital Air Data Computer (DADC).

Figure 1.3 - Back panel of a SkyTrac ISAT-200A-08 data acquisition and satellite communications terminal.

1.2 The Problem: Avionics Integration On-Board Aircraft

KF Aerospace has experienced a notable challenge in carrying out the process of installing supplementary or replacement avionics equipment on in-service aircraft: verifying the correct operation of new avionics being introduced to an aircraft has historically required installing the equipment in the aircraft before doing the verification. Evaluating the selection and configuration of the new equipment for compatibility with existing avionics on the aircraft, and validating the technical assumptions used to perform these selections/configuration, has been problematic. Specifically, installing the new avionics on an aircraft before assessing whether or not the systems will function together as intended often results in rework of the installation to correct unforeseen compatibility problems. This delays projects and increases the cost due to the extra work required. Furthermore, this results in a loss of income for the aircraft owner due to the lengthened downtime until the retrofit is complete.

1.3 The Solution: An Avionics Integration Test Bench

The digital communication between avionics devices is the determining factor for their compatibility and co-operation on an aircraft. As such, averting the challenge of testing interoperability of a new piece of avionics equipment is possible, given the ability of an avionics engineer to emulate the communication to and from existing equipment while situated off the aircraft with the new equipment.

KF Aerospace wishes to create an *Avionics Integration Test Bench* system that will allow them to emulate the digital communications of existing avionics on aircraft for preparatory testing and evaluation of new equipment before installation.

A common digital communication standard used in commercial aircraft is Aeronautical Radio Incorporated Specification 429, colloquially called “ARINC 429.” Waldmann [2] provides a concise overview of ARINC 429. A significant portion of the data transferred between avionics using ARINC 429 data buses are aircraft flight data parameters (altitude, airspeed, attitude, etc.). It is possible to transfer other types of data according to ARINC 429, such as equipment configuration (“maintenance” data) and aircraft control data [2], but flight data parameters are of immediate interest to KF Aerospace for support by the test bench system.

With this in mind, KF Aerospace's avionics integration test bench should emulate avionics communication by generating flight data parameters according to user (engineer) input, and transmitting these parameters to avionics equipment under test via ARINC 429 data buses. In order for the engineer to assess the behaviour of the equipment under test, the test bench should also be capable of receiving ARINC 429 data from the equipment.

The system is controlled from a computer using a software program with a graphical user interface (GUI), and connected to the hardware via USB. The expected setup is presented in Figure 1.4.

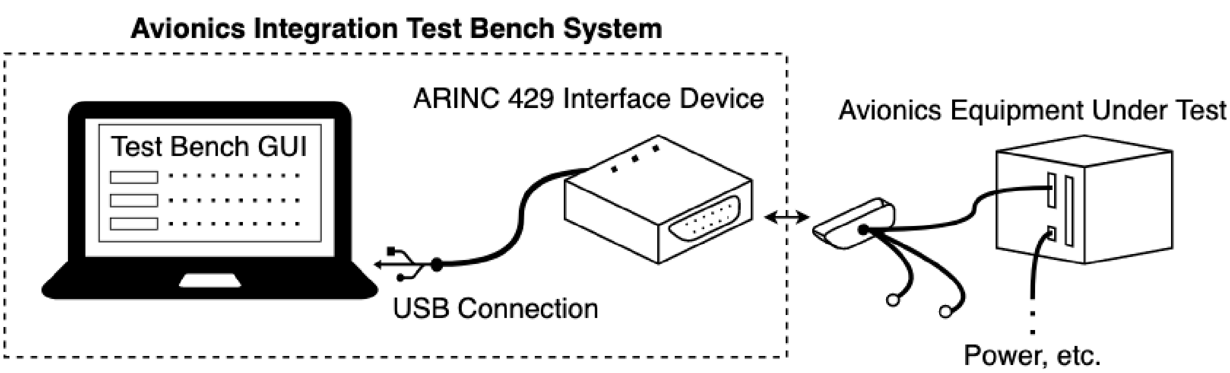

Figure 1.4 - Expected setup of the avionics integration test bench system.

1.4 Commercial Off-the-Shelf (COTS) Avionics Testing Solutions

The need to interface with avionics equipment for testing purposes is not a new one. Indeed, there are several off-the shelf solutions produced by test equipment vendors for interfacing a computer to avionics equipment via ARINC 429 data buses for equipment maintenance as well as equipment testing in the field and in development. Therefore, it seems at first glance that KF Aerospace should invest in one of these products as a complete solution or as a base system on which the project team could add custom functionality to. A survey of commercial COTS products was completed by the project team and is included in the project files. A few such COTS interface devices are presented as examples in Figures 1.5 and 1.6, with snapshots of their associated software programs presented in Figures 1.7 and 1.8.

Figure 1.5 - Astronics (Ballard) UA-2000 USB Avionics Interface.

Figure 1.6 - TechSAT A429-USB-NT ARINC 429 USB device.

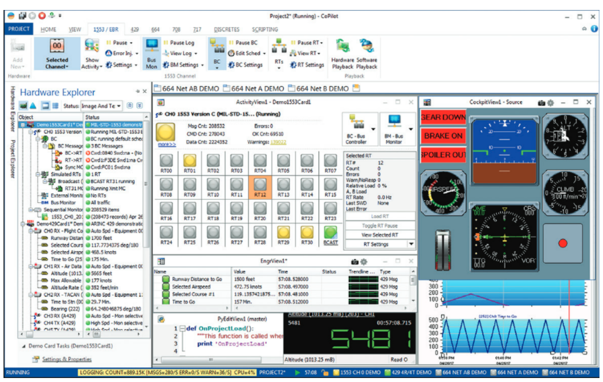

Figure 1.7 - Astronics CoPilot Databus Simulation and Analysis Software.

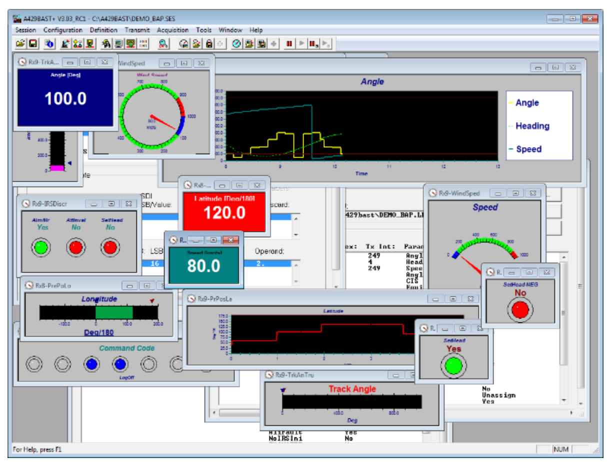

Figure 1.8 - TechSAT A429-BAST ARINC 429 Bus Analyzer and Simulation tool.

1.5 The Case for a Custom Test Bench System

Despite the initially apparent suitability of COTS ARINC 429 avionics test solutions, the client and the project team decided to develop a custom test bench system including the necessary hardware instead. This was decided based on the following 5 considerations:

First, COTS testing solutions for specialised applications such as avionics digital communication have few customers to spread the development and support cost amongst, and are therefore extremely expensive. Furthermore, aviation is a highly regulated industry, so many products intended for validation and verification of aviation equipment also carry certifications/endorsements and a very high level of reliability that is beyond the needs of KF Aerospace's informal testing use case.

Second, the breadth of functionality offered by most COTS ARINC 429 interface devices is beyond KF Aerospace's needs. The intended usage environments of COTS adapters span a much wider scope than KF Aerospace's expected usage for the test bench system.

Third, dependence on a test equipment vendor for continued support of a proprietary test system is undesirable for KF Aerospace. Also undesirable is the potential for licensing restrictions imposed on the system. Time with technical support staff can also incur additional costs.

Fourth, KF Aerospace expects the test bench system to be extended over time by future capstone teams as their testing needs evolve. A custom test bench system is more appropriate for this development endeavour.

Finally, from the project team's perspective, utilising a COTS solution as a starting point for the project does not offer as worthwhile or interesting a learning and growth opportunity. Taking this path would likely result in a purely software-focused project, rather than a multidisciplinary project.

2. Project Outcome

- Develop and construct a custom test bench for KF Aerospace that can emulate commercial avionics digital communication of flight data parameters according to ARINC 429.
- Enable KF Aerospace to de-risk avionics integrations by testing integration behaviour of new avionics equipment, and validating technical assumptions made with respect to this behaviour, prior to undertaking the expensive process of modifying an in-service aircraft.
- Reduce KF Aerospace’s time, money, and effort on avionics integration projects.
- Facilitate experimentation with novel integration techniques by KF Aerospace’s avionics engineering team.
- Maintain KF Aerospace’s independence from test equipment vendors offering expensive and proprietary commercial solutions. These solutions are over-featured relative to KF Aerospace’s needs and may carry restrictive licensing.

3. Specification Conventions

Specifications for the *Avionics Integration Test Bench* system are presented in the 3 proceeding sections corresponding to 3 categories: functional requirements, non-functional requirements, and constraints.

These specifications are described and used according to the following conventions:

- For a specification to be considered satisfied, all of its sub-specifications must be satisfied.
- Specifications are referenced by their index with a prefix determined by their category as defined by Table 3.1.
- Several specifications may be referenced at once by use of an “x” in part of the specification index. For example, FR1.x refers to FR1.1, FR1.2, and so on.
- The notation “**(S)**” at the beginning of a requirement indicates that it is optional - a stretch goal.
- Notes in the requirements are prefaced by “**NOTE**” and set in italic. These give justification or background for specific requirements, or draw attention to related requirements.

Table 3.1 - Specification prefixes for each specification category, to be used for referencing specifications throughout project documents.

Category	Prefix
Functional Requirement	FR
Non-functional Requirement	NFR
Constraint	C

The functional requirements are also indexed and split into 3 areas: Requirements for the system as a whole are listed under FR1. Requirements for the hardware component of the system are listed under FR2. Requirements for the software component of the system are listed under FR3. There are no specific groupings for non-functional requirements and constraints.

4. Functional Requirements

4.1 Top-Level Requirements (FR1)

1. The system must facilitate communication between a computer and commercial avionics equipment ("connected equipment").

   NOTE*: There are two main interface types to support for interfacing to connected equipment, specified by sub-specifications FR1.x.*

   1.1. The system must perform ARINC 429 digital communication bidirectionally with connected equipment.

   1.1.1. The system must generate simulated aircraft flight data to transmit to connected equipment as ARINC 429 words.

   1.1.1.1. The system must be able to transmit up to at least 10 different flight data parameters (ie. ARINC words with differing labels) on any single transmitting ARINC 429 bus.

   NOTE*: 10 labels transmitted on one bus is a sufficient quantity to cover all of the data parameters that the system is required to be capable of generating according to FR1.1.3, considering that typically only data parameters corresponding to one equipment identifier are transmitted on a single bus. To do otherwise would introduce the potential to overload the meaning of a given label on a single bus since a given label value can correspond to different data under a different equipment ID.*

   1.1.1.2. The time interval between transmission of ARINC 429 words with the same label on the same bus ("transmit interval") must be independently configurable in the system for each label within a range of 1 second to the minimum interval between words permitted by the ARINC 429 standard.

   NOTE*: The transmit interval is prescribed by the standard for* *each flight data parameter. This requirement specifies the range of transmit intervals that should be supported for compatibility with diverse avionics equipment using diverse flight data parameters (for system flexibility).*

1.1.2. The system must be capable of receiving flight data from connected equipment as ARINC 429 words, then displaying and logging these data.

1.1.3. The exact flight data parameters to be generated and interpreted by the system according to FR1.1.1 and FR1.1.2 at a minimum are specified in Table 1.1. Each flight data parameter has a label and equipment ID assigned in reference to the ARINC 429 standard, which dictates the exact format and transmission characteristics of each flight data parameter on an ARINC 429 bus.

1.2. The system must provide avionics-style discrete electrical signal outputs to connected equipment. These signals operate independently of one another and implement simple “asserted” and “deasserted” states.
***NOTE**: It is typical for avionics equipment to have electrical signal inputs like these as toggles for device configuration or other functions [5], [6].*

Table 1.1 - Flight data parameters to be generated and interpreted by the system. See FR1.1.3. Each row of this table may be referenced as a sub-specification of FR1.1.3.

FR1.1.3.__	Flight Data Parameter Name	ARINC 429 Label (Octal)	Associated Equipment ID
1	Pressure Altitude (1013.25 mbar)	203	0x006
2	Computed Airspeed	206	0x006
3	True Airspeed	210	0x006
4	Altitude Rate	212	0x004
5	Total Air Temperature	211	0x002

FR1.1.3.__	Flight Data Parameter Name	ARINC 429 Label (Octal)	Associated Equipment ID
6	True Heading	044	0x004
7	Magnetic Heading	014	0x004
8	Pitch Angle	324	0x004
9	Roll Angle	325	0x004
10	Selected Altitude	102	0x002
11	Selected Airspeed	026	0x003
12	Barometer-corrected Altitude	204	0x006
13	Barometer correction (millibar)	234	0x006
14	Barometer correction (inches of mercury)	235	0x006
15	Selected Heading	023	0x020
16	Pitch Rate	326	0x004
17	Roll Rate	327	0x004
(S) 18	Mach Number	205	0x10A
(S) 19	Body Normal Acceleration	333	0x004
(S) 20	Vertical Acceleration	364	0x005
(S) 21	Automatic Direction finder (ADF) Bearing	162	0x012
(S) 22	Distance Measuring Equipment (DME) Ground Speed	312	0x060
(S) 23	DME Time-to-Station	002	0x115
(S) 24	TACAN Selected Course	027	0x002
(S) 25	Very High Frequency [VHF] Omni-Directional Range (VOR) Omnibearing	222	0x011

FR1.1.3.__	Flight Data Parameter Name	ARINC 429 Label (Octal)	Associated Equipment ID
(S) 26	Radio Height	164	0x007
(S) 27	Localizer Deviation	173	0x010
(S) 28	Glideslope Deviation	174	0x010

4.2 Hardware Requirements (FR2)

2. The system must include an interface hardware device (“hardware”) to physically connect the computer to connected equipment.
   NOTE*: This hardware device facilitates the interfaces specified by FR1.x.*

   2.1. The hardware must be able to connect to avionics equipment with multiple ARINC 429 buses, and multiple pieces of avionics equipment, simultaneously.
   NOTE*: It is typical of ARINC 429-supporting avionics units to have multiple ARINC 429 transmitting and receiving buses in order to connect to several other pieces of equipment, or introduce redundancy for the electrical interfaces. For example, a Northrop-Grumman LCR-100 Attitude and Heading Reference System has 6 input buses and 6 output buses. 2 input buses are allocated for each of a digital air data system, a global navigation satellite receiver, and a control display unit [5]. Each ARINC 429 bus may host only one transmitting device, but up to 20 receiving devices [3]. As such, multiple ARINC 429 bus connections are necessary to fully exercise the functionality of many avionics devices.*

   2.1.1. The system must have, at minimum, 2 transmitting ARINC 429 bus interfaces to the connected equipment.

   2.1.1.1. **(S)** The quantity of transmitting buses desired by the client is 6, with a stretch goal of 12 transmitting buses.

2.1.2. The system must have, at minimum, 2 receiving ARINC 429 bus interfaces to the connected equipment.

2.1.2.1. **(S)** The quantity of receiving buses desired by the client is 8, with a stretch goal of 12 receiving buses.

2.1.3. Each transmitting ARINC 429 bus of the system must support both “high speed” (100kbit/s) and “low speed” (12.5kbit/s) bitrates specified by the ARINC 429 standard.

2.1.3.1. The bitrate of each transmitting bus must be independently configurable.

2.1.4. Each receiving ARINC 429 bus of the system must support both “high speed” (100kbit/s) and “low speed” (12.5kbit/s) bitrates specified by the ARINC 429 standard.

2.1.4.1. The bitrate of each receiving bus must be independent of other buses’ bitrates.

2.1.4.2. **(S)** The hardware should be capable of receiving data at either bitrate without any configuration by the user.

2.1.5. The hardware must be able to operate with all the ARINC 429 buses in use at full load (as dictated by the ARINC 429 standard) simultaneously.

2.2. At minimum 4 avionics-style discrete electrical signals specified in FR1.2 must be present on the hardware that are toggle-able between open circuit when de-asserted and shorted to ground when asserted.

2.3. **(S)** At minimum 2 avionics-style discrete electrical signals may be present on the hardware that are also toggle-able between open circuit when de-asserted and +28V when asserted.

2.4. The hardware must visually indicate power status and the presence of any detectable faults in the hardware.

2.4.1. The power status indication indicates whether or not the device is connected to DC power.

2.4.2. One indicator is used to indicate any system fault.

***NOTE**: The exact nature of detectable faults depends on the hardware design.*

2.5. The hardware must have a rigid enclosure for protection of the hardware electronics from shorts and mechanical damage.

2.5.1. Connectors for programming the hardware must be concealed when the enclosure is in place.

2.6. All ARINC bus terminals, discrete outputs, and electrical ground shall be broken out to one or more connectors on the hardware whose mating connector(s) are removable.

2.6.1. The mating connector of each connector specified by FR2.6 must be incompatible with all other connectors on the hardware and have a poka-yoke connection orientation to prevent incorrect connections.

2.7. The hardware must possess ESD protection on USB data lines.

2.8. The hardware must possess overvoltage and reverse-polarity protection.

4.3 Software Requirements (FR3)

3. The system must include a software program with a graphical user interface (GUI) that runs on the computer.

3.1. All control of the system by the user shall be done via the GUI.

***NOTE**: This precludes the need for any human interface hardware (buttons, switches, etc.) on the interface device specified by FR2. This is for convenience of the user, simplification of the hardware construction, and flexibility for future expansion of system functionality.*

3.2. All feedback to the user from the system shall be delivered via the GUI, with the exception of the hardware indicators specified by FR2.4.

3.3. The GUI must have user controls for managing all of the system functionality specified by FR1. The specific user controls present in the GUI, and their associated functionality, are specified by sub-requirements collected in Table 3.1.

3.4. The GUI must group user controls and feedback interfaces into separate and distinct sections for
a) generating and transmitting flight data parameters according to FR1.1.1,
b) managing the system's data receiving functionality specified by FR1.1.2, and
c) controlling the discrete electrical outputs of the system specified by FR1.2.
***NOTE**: These three sections may each be partitioned further as needed.*

3.4.1. If these sections are not arranged so as to be visible concurrently, the GUI must have a means of switching between visible and hidden sections.

3.5. Data received from connected equipment must be displayed by the GUI.

3.5.1. At a minimum, the received data should be displayed in a numerical readout format.

3.5.1.1. Each data parameter must be displayed in physical units (eg. metres, degrees, etc.).

3.5.2. An indication of which bus interface each data parameter was received on, as well as the time interval since the last preceding reception of the data parameter, should accompany each readout.

3.6. The GUI should be capable of recording the received ARINC 429 messages into a comma-separated values (CSV) log file to save locally onto the computer.

3.6.1. The log file must include each received ARINC 429 word on a separate line of the log file in chronological order of reception.

3.6.2. Each line of the log file must include all of the information in the ARINC 429 word, separated by bit field (label, SDI, data field, SSM and parity), the textual name of the parameter contained in the word (ie. name corresponding to the ARINC 429 label), the data parameter value, and unit text, as displayed in the GUI according to FR3.5.1.1, and a time stamp of reception.

3.7. The GUI must return to its initial, unmodified state upon restart, and/or closing/opening of the software. Closing of the application must ensure the ending of all transmission and reception via serial, as well as ensure that all discrete outputs are set to open.

Table 3.1 - User controls that must be present in the GUI. Each row is a sub-requirement of FR3.3. Note that some rows have sub-sub-requirements that may be referenced as FR3.3.x.y.

FR3.3._	User Input	Description
1	COM Port Selection	Selection of the virtual COM (serial) port corresponding to the test bench system's hardware connected via USB.
2	COM Port Connect / Disconnect	Open and close the virtual COM port connection to the system hardware. 1. The user shall be warned about the action affecting the current communication with the system hardware when they attempt to switch COM ports
3	Discrete Output Toggles	Control of each avionics-style discrete electrical output between asserted and deasserted states.
4	TX Bus Bitrate Selection	Each ARINC 429 transmitting bus of the system must be independently configurable between high speed and low speed operation.

5	RX Bus Bitrate Selection	If optional requirement FR2.1.4.1 is not satisfied, the bitrate to be expected by each ARINC 429 receiving bus must be independently configurable between high speed and low speed operation.
6	TX Enable	Globally start or pause all configured data transmission on the ARINC 429 transmitting buses. 1. This functionality shall be disabled if any of the following cases is true: a. A COM port has not been configured
7	RX Enable	Start or pause reception of data on all ARINC 429 receiving buses. 1. This functionality shall be disabled if any of the following cases is true: a. A COM port has not been configured
8	Log Enable	Enable or disable the logging of received data as specified by FR3.6.
9	Log File Location Selection	Selection of the absolute file path and file name to which received data should be logged per FR3.6. 1. The selection interface must include a graphical file explorer and text entry.

10	Flight Data Parameter Values	Control of the value of each flight data parameter generated and transmitted by the system. 1. The GUI must offer numeric data entry for this user input, and may offer other types of user controls in addition to this. 2. The set value for each parameter should be entered and displayed in physical units (e.g. metres, degrees). 3. Values outside the possible range of the data parameter entered by the user will be rejected and the rejection must be indicated to the user. 4. The parameter must have a default value. 5. Empty value selection must be inhibited. 6. If the user changes the value while the parameter is enabled for transmission, the value of the parameter being transmitted will be updated on the fly. 7. Flight data parameters' interface elements should be grouped together according to the equipment each parameter is associated with.

11	TX Bus Selection	Selection of the ARINC 429 bus(es) on which to transmit flight data parameters. 1. This must be configurable for each flight data parameter independently, or alternatively, for each group of flight data parameters having the same associated equipment ID. 2. Any combination of the system's buses may be selected. 3. The bus selection toggles must prevent more than a certain maximum number of data parameters from being selected for transmission on any one bus, with the maximum number determined by the interface device implementation.
12	Flight Data Parameter TX Enable	Start or pause transmission of an individual flight data parameter. 1. For a flight data parameter to be transmitted, the following conditions must be satisfied: a. The toggle to control transmission of this individual parameter must be ON b. The global TX Enable toggle of FR3.3.6 must be in the ON state c. A COM port connection must have been established to the system hardware as defined by FR3.3.2. d. Any bus the parameter is to be output on MUST have its bus bitrate configured

13	Flight Data Parameter Filtering	Ability to filter flight data parameters shown on the TX Menu screen. 1. Parameters selected to be filtered out by the filtering method must not be displayed to the user and the user shall not have any control over them 2. Parameters not selected for filtering must be displayed to the user and the user shall have normal control over them

5. Non-Functional Requirements

1. **Flexibility for Future Extensions to the System** - The test bench system should be designed in such a way as to provide room for enhancements and extensions to be added to the system's functionality and capabilities.

    1.1. **Software Scalability and Modularity** - The software application must be scalable and designed in a modular way to allow, for example, additional parameters or automation to be added without having to re-work other unrelated parts of the software.

    1.2. **Hardware Capability Headroom** - The system's hardware should use components with ample processing power, capabilities, speed, available system resources, etc. to avoid imposing limitations on new feature development, but without infringing upon NFR2.

2. **Cost Effectiveness** - Product hardware must be more cost-effective compared to off-the-shelf devices.

3. **Commonality of Components** - Both hardware components and software components (e.g. code libraries and development toolchains) selected for construction of the system should be well-established, well-supported with documentation and active user bases, and widely available wherever possible. ***NOTE**: This requirement exists to promote ease of development by students, especially considering that the project is expected to be built upon by future capstone teams.*

4. **User Friendliness** - GUI must be clear, readable, and comprehensible by the intended audience: avionics team engineers at a commercial aircraft maintenance, repair and overhaul business. This audience is familiar with the function, operation and maintenance of avionics equipment at the device level, but not necessarily familiar with component-level electronics hardware design and device programming.

5. **Physical Robustness** - The test bench system must be designed such that it can withstand everyday usage and mild abuse including light shaking, dropping and tampering.

6. Constraints

1. The system shall adhere to the ARINC 429 Digital Information Transfer System Standard (“the standard”), references [3] and [4]. The sub-specifications below summarise the areas of constraints imposed by compliance with this standard. However, the standard documentation must be referred to for all details.

    1.1. The electrical characteristics and behaviour of the transmitter/receiver on each bus interface of the hardware, for example the output/input impedance, digital data encoding format, and voltage levels, must align with the standard.

    1.2. The timing specifications of the standard, including bitrates, word-to-word minimum separation, and time interval between transmission of a given piece of data depending on its identity must be followed.

    1.3. The structure of data words (ie. label, source/destination ID, data field, sign/status matrix, and parity), assignment of label numbers to aircraft data parameters, and digital format of any given data parameter depending on the label and associated equipment all specified by the standard must be implemented by the system.

2. USB 2.0 must be used to connect the hardware of the system to the connected computer.
   NOTE*: The client requires that USB is used for the computer-side connection of the interface hardware device. USB 2.0 is specified in favour of other variants of USB (for example, the more capable and newer USB 3.0 and USB type C) for widest compatibility with different computer systems.*

3. **(S)** The hardware should be powered solely from the USB connection.

    3.1. **(S)** The hardware may not draw more than 0.5A of DC current at 5V per the USB 2.0 power output standard [7].

4. The system hardware must be suitable for desktop or benchtop use (as opposed to, for example, installation in a rack-mounted equipment setup).

    4.1. The size of the system's hardware component, including enclosure but excluding connecting cables, must not exceed a length, width and height of 20cm by 20cm by 10cm.

5. The mechanical enclosure for the hardware must be removable from the device electronic assembly, not permanently installed, in order to allow for probing and programming hardware during development.
6. The computer software for the system shall run on Microsoft Windows 10 and higher.
7. The GUI window area must be at minimum 960 x 540 pixels.
8. The entire GUI window should fit on a typical 13-inch laptop screen without losing access to any interface elements or functionality.

Appendix A: Team Information

Name	Initials	Tech Lead	Management Lead
Anthony Wang	AW	GUI software (front end)	Deliverable Organiser
Nursultan Tugolbaev	NT	Hardware	Internal Discussions / Meetings
Patric McDonald	PM	GUI software (back end)	Treasurer Minute taker
Andrew Hanlon	AH	Firmware	Client Communication
Isabelle André	IA	Digital logic design	Internal/External Communications

Appendix B: Project Report Contributions

Section	**Major Content**	**Minor Content**	**Author**	**Reviewer**
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5. Non-Functional Requirements	AH	PM AW	PM AW	IA NT
6. Constraints	PM AW	AH	PM AW	IA NT
All sections formatting	AW IA	AW AH NT	AW IA	IA NT

Appendix C: References

[1] Kelowna Flightcraft Ltd, "About KF Aerospace," KF Aero. https://www.kfaero.ca/who-we-are/about-kf-aerospace/ (accessed Nov. 2, 2022).

[2] B. Waldmann, *ARINC 429 Tutorial Manual*, version 2.2. AIM, Freiburg, Germany, Jul. 2019. Accessed: Nov 2, 2022. [Online]. Available: https://www.aim-online.com/wp-content/uploads/2019/07/aim-tutorial-oview429-190712-u.pdf

[3] *Digital Information Transfer System (DITS) Part 1 Functional Description, Electrical Interfaces, Label Assignments And Word Formats*, ARINC Specification 429P1-18, AEEC, Maryland, USA, Nov. 29, 2012.

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[5] *Attitude and Heading Reference System (AHRS) LCR-100 Part No. 145130 Installation/Maintenance Instruction,* rev. F, Northrop Grumman LITEF, Freiburg, Germany, Jul. 2009.

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