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Prelim Summative Activity: Process Model

A340 Flight Control System

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Introduction

The aviation industry's innovation yielded the invention of a revolutionary system called **"fly-by-wire" (FBW)**. The Airbus A340 is an illustration of this very system. The A340 flight control system houses one of the most complex and safety-dependent systems ever created, essential to security. The advancement of the fly-by-wire technology first noticed on the Airbus A320, released in 1988 (Briere & Traverse, 1993). The crux of fly-by-wire systems lies in their innate ability to convert flight control movements into electrical signals, which are subsequently transmitted to the flight control computer via electrical wires. This allows the pilot to seamlessly communicate their desired movements to the plane (Nicolin & Adrian, 2019). It mediates between the pilot and the airplane.

Our case study will examine the selection process and justify the software processing model we chose. Our goal is to find the software processing model best suited for the Airbus **A340 flight control system.** The weight of this research rests on the fact that we are dealing with a system of paramount importance to safety. The chosen process model can affect various aspects of the project, including error rates, cost, development speed, and the probability of success. The incorrect choice of model can lead to dire outcomes, including worst-case scenario disasters.

Selecting the Software Process Model

Nowadays, aircraft rely heavily on sophisticated machinery that needs to operate reliably and safely. Safety and security should be the top priority for every aircraft development team. The team looked at three different process models: **Incremental, Spiral,** and **V**. Fully account for software type and size, predecessor experience, user demand difficulty, development techniques/tools, team composition, development risks, and development methods when creating a software development plan to determine the best software process model (Gao & Feng 2012). To determine which process model is the most appropriate, a thorough understanding and consideration of the following model's strengths and weaknesses are crucial.

Incremental Model

The Incremental model is a useful variation of the waterfall method for system updates or additions (Reytérou, 2023). A "multi-waterfall" model life cycle refers to multiple development cycles. Smaller iterations make larger cycles more manageable. To create this model, they divide the development process into smaller steps called "builds." This lets them build and test different parts of the project individually. Due to the continuous input from users and early code testing, developers can catch mistakes in user requirements early (Singh, Thakur, & Chaudhary, 2015).

The fact that this model allowed each component to grow separately helped reduce risks. Problems with particular components do not hinder the progress of others. The "divide and conquer" approach is used by this model to minimize complexity by focusing on individual component parts. When solving problems, separating the components proves especially difficult thanks to their natural interconnection schema. To overcome this barrier, an understanding of challenges, potential solutions, and the broader context is crucial. Another challenge is present when steps are occurring simultaneously, causing some parts to need support from others (Tsui & Bernal, 2023).

Spiral Model

Adapting to different software development scenarios, the Spiral model is a versatile process model. Based on experience with large government software projects at TRW, the Spiral model is a cycle of steps for every part of a product, from the overall concept to individual program coding. First comes defining objectives, then considering different implementations and assessing constraints. Risk assessment is vital, influencing the chosen direction based on technical or control risk dominance. Technical risks lead to prototypes and evolutionary development steps; control risks use a classical life cycle approach with validation and incremental development (McDermid, 2013).

The Spiral model stands out due to its flexibility in accommodating different project scenarios, strong emphasis on risk assessment and management, and capacity to adapt development directions according to dominant risks. While additional risk analysis and a more complex model can result in an increased project overhead. Although it offers various advantages, the Spiral model requires a careful appraisal of potential risks and a deep understanding of the project context in order to identify an appropriate development trajectory (McDermid, 2013).

V-Model

The V-Model, as used in the avionics industry, like Airbus processes, is used as the system development model. It begins by establishing requirements at the aircraft level and then systematically derives systems and equipment requirements in a top-down manner. The high-level aircraft specification is progressively broken down into more detailed system specifications, further leading to the definition of lower-level specifications for equipment and components (Schallert, 2016).

These processes occur concurrently for all aircraft systems, often involving multiple iterations for each system. Equipment specifications, especially for electronic components, are typically divided into hardware and software, forming the lower portion of the model. The right branch of this model illustrates how components and equipment are integrated into systems, with testing at each level to ensure integrity. This comprehensive approach involves simulator, ground, and flight testing to validate performance at the aircraft level (Schallert, 2016).

Pros and Cons of Chosen Models

The table below shows the pros and cons of our selected process models for the Airbus A340.

Process Model	Pros	Cons
V Model	- Defects of the product are found at the early stages of the development stage; this will reduce costs in fixing	- Very Rigid and is the least flexible. For every change of the development mid-way, both tests and requirements

	defects since the problem has not grown and ensures safe and reliable considerations. (Regulwar et.al., 2021) - Aligns with the regulations, safety, and reliability requirements of the aviation industry. (Schallert, 2016)	documentation must be updated (Regulwar et.al., 2021) - This process model is very expensive and uses up a lot of resources which makes small companies unable to use this model. (Regulwar et.al., 2021)
Iterative Model	-Faster/Quicker development of an aircraft system. (Tsui and Bernal, 2023) - Easier to manage risks, test, and debug due to its small iterations. This may help in solving different problems in the aviation industry. (Tsui and Bernal, 2023) - Faster and quicker to find errors (Tsui and Bernal, 2023) Tsui and Bernal, 2023	- Not good for dynamic structures (fly-by-wire system) (Tsui and Bernal, 2023; Nicolin and Adrian, 2019) - Problems may pop up randomly due to lack of information (Tsui and Bernal, 2023) - Must finish first iteration in order to go to the next iteration (Tsui and Bernal, 2023) Komal - Scope Creep, temptation to add more features, leading to more costs and delay (Komal et.al., 2019)

Spiral Model	-A high volume of risk analysis is done (Boeham, 2019). - Focuses on removing errors and ugly alternatives in a faster way (Boeham, 2019). - Like the iterative model, it also derives data from the phase before the current phase (Boeham, 2019). - The crucial question of "how much is enough" is addressed. (Boeham, 2019).	- The process may not end if the client is not satisfied with the development (Boeham, 2019). - Like the iterative model, it must first finish the current phase in order to proceed to the next one (Boeham, 2019). - A set of experienced developers is needed to use this model and it can be costly (Boeham, 2019). - This model solely relies on its risk analysis (Boeham, 2019).

Phases of the Selected Software Process Model

The well-known verification and validation model goes by the name "V Model" (Regulwar et.al., 2021). Verification involves evaluating the outcome of a process to ensure accuracy and coherence according to the input and established criteria. But at its core, validation entails verifying that the requirements are correct requirements and fully covered (Pratt, 2017). The V model may be seen as an enhancement or addition to the Waterfall framework thanks to its correlation with the testing segment and production phases. This indicates that all stages of C models are related to the testing phase, which is an intensely managed phase (Khan, 2023).

Within the Verification Phases

Validation is transferred from the code to the design level (Virelizier 2022), Airbus employs abstract interpretation tools to verify non-functional properties of programs and proof-based tools to verify functional properties within manually coded components.

Models are tested during the system design level verification process in a simulated environment. Virelizier (2022) describes these tests as taking place on desktop simulators with a panel of commands representing pilot actions. Test scenarios are defined based on detailed requirements and executed on the simulator to evaluate their success.

Requirement Analysis

The V-model's verification is the first step for the Requirement Analysis stage. In the phase of analyzing needs, the requirements of the proposed system are gathered by examining the needs of the user(s) (Regulwar et.al., 2021). It is centered on identifying what the perfect system should be capable of doing.

For seat availability, the Airbus A340 features a customizable alternative, accommodating between approximately 240 and 440 travelers. Grouped according to type, these seating arrangements supply Airlines with multiple opportunities for selection. For its capabilities, it was built for long journeys, able to fly far distances; the plane can cover between 7400 to 9000 nautical miles without refueling. Four gas turbines are what propel the A340; they come from Rolls-Royce. The engine is what allows the plane to fly dependably and effectively (Airbus A340 Specifications, Cabin Dimensions, Performance, n.d.).

Equipping the cockpit with innovative digitized flying controls and exceptional navigation gear allows safe operations of the A340 thanks to these advanced features in the cockpit. While for cabin configuration, the aircraft's interior layout comprises three classes: The economy, trade, and ultimately, accommodating the different preferences and necessities of travelers were our top priority. Its safety is governed by elementary safety protocols, enveloping vital operations, handling potentially deadly situations, and adhering to regulatory mandates.

The A340 was created with an eye toward meeting strict fuel consumption targets, propelling eco-friendly aircraft innovation. Moreover, its certification aligns with airworthiness safety standards dictated by regulators, giving peace of mind knowing it exceeds the highest safety benchmarks (Airbus | Pioneering Sustainable Aerospace, 2021).

The effectiveness of this system is directly tied to comprehensive guidelines outlining takeoff measurements, touchdown sites, climbing speeds, constant flight processes, and a variety of other key factors, intricately planned to achieve maximum productivity. In order to facilitate the carry of passenger belongings as well as supplies, the designates separate compartments for these purposes, following established industry benchmarks. Abiding by rigorous aerodynamic protocols, the plane's structure emphasizes steadiness and productivity, necessitating minute mechanical deliberation. In terms of weight and balance, we give meticulous consideration to make sure it won't interfere with how well the plane flies. Meeting global criteria and best practices established for commercial planes, it functions within an internationally accepted framework of aviation standardization (Images and Opinions, n.d.).

The safety-critical functions of the Airbus A340

The Airbus A340, similar to its family, functions focused on its fly-by-wire systems (EFCS) failure detection and redundancy along with the functional specifications written through the use of computer-assisted methodologies (Briere & Traverse, 1993).

Risk analysis of Airbus A340

In reality, there is no perfectly developed system. A route from Japan to London Heathrow involved an incident regarding Airbus A340. It was recorded as the first accident report together with Airbus A320/ A330 Series where software and hardware were the main underlying problem in terms of their reliability. The issues we're looking at involve problems with radio communication talk, the directions given by air traffic control, how well the instrument landing system works, the accuracy of fuel amount indicators, when both Flight Management Guidance Systems fail at once, and the certification of the aircraft type (Neumann, 1995).

System Design

System design helps to define the hardware and system requirements and also helps to define the overall system architecture (Singh et al., 2022).

The software part is critical for the Airbus A340 because it is an integral part of the aircraft system. It oversees a number of functions, from aircraft maintenance and navigation to in-flight entertainment and communication systems. Unfortunately, the Airbus Code of Conduct prohibits anything, such as giving away software components to individuals or employees, and states, *"We must protect any Airbus property, including physical property, confidentiality and intellectual property.This includes theft, vandalism, misuse, and inappropriate disposal. while doing business with us. We must also protect property entrusted to us by others."* Since Airbus employees have access to confidential government information, they must abide by the company's rules (Airbus, n.d., p. 50).

Communication with air traffic control, ground personnel, and other aircraft is part of a communication protocol that the Airbus A340 uses in any given situation, which is essential for the safety and efficiency of the plane and its passengers.

Some of the key communication protocols used by the Airbus A340 include:

- Since its introduction in 1978, the **ACARS (Aircraft Communications Addressing and Reporting technology)** digital data connection technology has been used to transmit communications between aircraft and ground stations**.**At first, it relied exclusively on VHF channels but more recently, alternative means of data transmission have been added which have greatly enhanced its geographical coverage (*Aircraft Communications, Addressing and Reporting System*, n.d.).

- **VHF (very high frequency).** VHF communications radios are the primary communications radios used in aircraft. Seven hundred and twenty separate channels are specified in this section with a difference of 25 kHz between each channel (Aviation Radio Communication, n.d.).

- **HF (High Frequency).** HF radio is used for long-range voice and data communication between aircraft and ground stations. The ionosphere layer of the atmosphere serves as a reflector for these radio waves. As a result, transoceanic aircraft often use HF radios for voice communication (*Aviation Radio Communication*, n.d.).

- **SATCOM (Satellite Communication).** Aircraft onboard equipment for SATCOM includes a satellite data unit, a high power amplifier and an antenna with a steerable beam (*SATCOM*, n.d.). It is often used for communication over oceanic and remote areas where VHF and HF communication are not available.

In addition to these key communication protocols, the Airbus A340 also uses a number of other communication protocols for specific purposes, such as:

- **ADS-B (Automatic Dependent Surveillance-Broadcast).** Every second, this system transmits an aircraft's GPS coordinates, elevation, surface velocity, and additional data to both ground stations and other aircraft (Automatic Dependent Surveillance - Broadcast (ADS-B), 2023).

- **FIS-B (Flight Information Service-Broadcast).** The cockpit receives the meteorological and aviation data via FIS-B. It is, in essence, a system that disseminates news, weather, and other data (Ins and Outs, 2023).

- **Datalink usage**. Datalink refers to digital air/ground communication between aircraft and ground systems (Datalink | EUROCONTROL, 2012). It is a system that allows aircraft power to communicate with ground stations using data link protocols such as ACARS and VDL (Aircraft Communications, Addressing and Reporting System, n.d.) Datalink is often used to send and receive flight plans, weather reports , and others.

System design is tackled by Airbus using officially published SCADE materials as guides. Symbols are employed in optimization of execution speed. As per Virelizier (2022), these signals are utilized in aircraft control applications owing to their explicit specification in lower-level programming tongues like C coding or Assembly.

Airbus leverages the SCADE environment, an acronym for "Safety Critical Application Development Environment," to aid in the creation of crucial embedded systems. This environment houses a variety of tools: a graphical editor, simulator, code generator that translates graphical specifications into C code, and a model checker. The design is expressed in SCADE formal language, and investigating the potential for using formal analysis for part of the verification at this level has been explored. The SCADE model serves as a thorough design plan from which embedded code is automatically generated (Virelizier, 2022).

Architectural Design

In the context of architecture design, the verification strategy centers around synchronous observers, which play a critical role in ensuring system correctness and safety. According to Virelizier (2022), these observers monitor the system's behavior without providing feedback. The verification architecture encompasses two categories of observers: one for the property to be verified and one for hypotheses about the system environment. A SCADE sheet contains information on these observers and how they relate to the target design.

The primary objective is to utilize the SCADE model-checker to determine whether the design complies with the defined safety property under the given assumptions. The property observer computes a true Boolean flow (P) as long as the design satisfies the property, while the other observer computes a Boolean (H), and the model-checker maintains H as true throughout the P analysis. The lack of error is guaranteed for all executions of the design under the provided assumptions if the model-checker finds that P always holds. However, if at least one error exists, the model checker provides a counterexample, which is a sequence of inputs that, when applied to the design, leads to a state violating the property. The SCADE simulation facilities may then be used to replay the counterexample and investigate the reason for the violation (Virelizier, 2022).

Module Design

Low-level design is the term we use to describe the intricate internal layout of every system module at this stage. The design must be compatible with other system architecture module designs as well as external system designs (Khan, 2023).

The Airbus A340 is constructed from a collection of modular components, granting versatility in both its design and assembly process. For the assembly process of the engine the modules are preassembled and then assembled to the complete engine (Springer et al., 2008). This design makes the aircraft easier to maintain and fix. Each module requires separate assembly and testing before it can be part of the complete aircraft. This design is modular, giving us tight control over quality, simplifying problem identification and resolution.

The main modules of the Airbus A340 include:

- **Engine**

  The primary modules of the Airbus A340's engine comprise several key components, including the fan and booster, high-pressure compressor, combustion chamber, High-Pressure Turbine (HPT), Low-Pressure Turbine (LPT), and accessory drive gearbox (AIRBUS, n.d.).

- **Nacelle**

  Regarding the nacelle, it serves as a protective enclosure for the engine and its associated accessories. It also facilitates the aerodynamic flow around the engine during operation. Each engine is encased within a nacelle suspended from a pylon, which is attached below the wing of the aircraft (AIRBUS, n.d.).

- **Fuselage**

  In Toulouse, the A340 is usually assembled, and the fuselage is developed in Germany; the fuselage is the fundamental structure of an airplane, a tube-like part that keeps all the pieces of the aircraft together (*Development of Airbus A340 and Its Uniqueness*, 2019).

- **Wing Section**

  The Airbus A340 Flight Lab's first takeoff equipped with outer wings sections designed for highly smooth airflow over their surfaces, a technology that won the prestigious 2018 Aviation Week Laureates Award for Commercial Technology. Known as natural laminar flow, such smoothed passages of air creates less drag than the airflow on traditional wings, **potentially reducing fuel burn** (*A340-300*, n.d.).

- **Undercarriage**

  The undercarriage is the aircraft's landing gear. In comparison to the series 200 and 300, the second generation A340 can be identified by two key characteristics. They have different engines with separated fan exhausts. The middle main landing gear leg has four wheels instead of two. It is rotated forward, while the other two bogeys are tilted backward. The A340-500 is the shortest of the second series, about four metres longer than the A340-300 (Airbus A340, n.d.).

The modular design of the Airbus A340 offers several advantages, including:

- **Easier maintenance and repair**. The modular design makes accessing and repairing aircraft components easier.

  Maintenance activities are essential to uphold the inherent safety and reliability ingrained in an aircraft's design. In cases where the inherent reliability of the design falls short, maintenance endeavors aim to gather pertinent information for necessary design modifications. These modifications are approached with the objective of achieving the highest level of safety and reliability while keeping costs minimized (Aircraft Maintenance and Repair | New Materials for Next-Generation Commercial Transports, n.d.).

- **Reduced Costs**. The modular design can help reduce maintenance and repair costs.

  The costs for modifications increase tremendously the further downstream that changes become necessary. Costs are to be taken into account, not only for the repetition of work in the flight controls department but also in neighboring disciplines such as, for example, in the loads, flutter, systems, and test departments. This leads to the requirement to reduce the number of change cycles. especially if they are late in the development process; the emphasis must be on getting it right for the first time (Pratt, 2017).

- **Increased flexibility**. The modular design allows for greater flexibility in terms of aircraft configuration.

  The A340s avionics are highly integrated to provide efficient crew use and optimal maintenance (de Montalk, n.d.). A340's ability to carry more fuel has enhanced efficiency in long and ultra-long distances; especially the A340-500 which has a long-range capability than most planes. The wide variety has enhanced operational flexibility in both short and long flights (Development of Airbus A340 and Its Uniqueness, 2019).

Coding Phase

The coding phase comprises the actual coding and implementation of designs from the design phase. This phase determines the best and appropriate programming language based on the identified requirements and architectural design (Pandey, 2021; Khan, 2023). Since this phase is where the production of the code happens, this is the primary focus of developers. Developers also follow a coding standard or code guidelines in writing the code (Khan, 2023). After the developers write the code, multiple code optimizations and reviews must be done to create the most satisfactory functionality and to check code performance (Pandey, 2021 and Khan, 2023). These procedures are needed to verify the code in preparation for the external delivery and final build (Khan, 2023).

The programming language used in most critical systems, like the flight control systems of Airbus, is the formal language SCADE (Bochot et al., 2009). The SCADE (Safety-Critical Application Development Environment) language is a high-level programming language and environment that is built for developing safety-critical systems with control software. It has been used in various applications like automotive, transportation, nuclear plants, and avionics (Colaço et al., 2017a). A capable code generator automatically generates the majority of the embedded code. Airbus also developed a library of operators to design flight control systems. Moreover, to optimize the execution time, a low-level programming language like C or Assembly was used to describe the domain-specific operators used in flight control functions (Bochot et al., 2009).

Airbus has its formal verification of codes to verify the codes written. In order to verify non-functional properties of programs like the absence of runtime errors, abstract-interpretation-based tools are used by Airbus. On the other hand, to verify the manually coded parts of the code and its functional properties, Airbus uses proof-based tools (Bochot et al., 2009). The expected deliverables or outputs in this phase are the build configurations of the code, documentation, reports, and the verified code. In addition, the programming language used is also identified, which are SCADE and low-level languages like C or Assembly.

Validation Phase

As the V-model is a linear model and does not support iterations (IAEME Publication, 2021), the validation phase will help evaluate the Airbus' Flight Control System (FCS), particularly its SCADE sheets, to ensure that it meets the specified requirements and complies with the regulatory standards of the avionics industry. These SCADE sheets will be tested to ensure that there are no errors in the definition of the FCS to ensure its reliability and safety. Additionally, each module of the Airbus will be tested. Essentially, each phase is connected to one verification phase

Unit testing

This is connected to module design. The first is unit testing, where the SCADE sheets' correctness will be verified; this includes the functionalities of each module and components developed during the module design phase. The functionalities will be tested using the unit test plans created from the module design phase. The tool used in this phase is the SCADE test capabilities, where the simulation of the Airbus' engine and its control panel will be created to test the capability of the built design in the module phase. With the simulated control panel for the Airbus, the tracking of fuel consumption can be seen, and this can provide data such as total fuel and total time, which can be used to calculate the total fuel consumption.

Additionally, the creation of the test cases for the SCADE sheets is going to be on the SCADE test target execution paired with the Vectorcast. As stated by Balashov et al. (2012), Vectorcast enables test generation. This process of creation is based on the inputted source code of the SCADE sheets. As for the SCADE test target execution, it will be used to build communication to the Vectorcast system, which creates the communication of the target system in the Vectorcast. The expected outcome is the early detection of issues in the SCADE sheet this can be shown through the use of SCADE test model coverage, where it gives a coverage report for the model and code. This can potentially reduce overall costs by up to a hundred times more than if detected during the stage for deployment (Regulwar et al., 2021).

Integration testing

This is connected to architecture design. Integration testing aims to check and ensure that the various components and equipment of the SCADE sheets can smoothly interact with each other when they are combined. The goal is to reveal the faults in the interfaces and reactions between the integrated module and components (Regulwar et al., 2021). As the Vectorcast supports integration testing (Balashov et al., 2012), it will be used alongside SCADE test target execution. The same concept applies when creating the test cases where the integrated code of the module or component will be inputted into the Vectorcast to validate their compatibility. The integration testing process comprises of two categories, which are the property and hypothesis observers.

The expected deliverable is improved synchronization of the modules and components to reduce their needed time to communicate with one another, resulting in an efficient exchange of information. This can done by the use of SCADE test model coverage, which can show the compatibility of the integrated modules and components.

System testing

After the integration testing, comes the system testing, which measures the similarity and dissimilarity of the system specification with the built system (IAEME Publication, 2021). In this case, the refined SCADE sheets from the previous validation phases are again inputted to the SCADE test target execution via the Vectorcast to create new test cases. This creates a comparison between the first SCADE sheets and the refined SCADE sheets. With this, the FCS's performance will be identified if it has a similar performance from its first written SCADE sheet or a much higher or lower performance. This testing will also show how ready the developed SCADE system is if used in the real-world scenario.

User Acceptance testing

This is connected to reqs analysis. The objective is as follows: This type of testing serves as a way between the requirements analysis and the system itself. This testing is to confirm that the system aligns with defined requirements, this includes seating capacity, travel range, engines, cockpit and more. The main objective is to verify or introduce changes according to the original needs (Regulwar et al., 2021). Additionally, configuration management and aircraft documentation is created through the use of airnavX, which is a configuration checker tool. This enables the maintenance technician and flight crew to have the right information and approach to thoroughly maintain the A340. This ensures the safety and reliability of A340 after the its development.

Essentially, the validation phase is a crucial point for the Airbus 340 as it checks if the developed SCADE sheets, modules, and components meet the objective requirement. It serves as the final quality assurance before the Airbus is deployed, contributing to the FCS's and its modules' overall safety and efficiency.

Conclusion

We looked into the most useful software development processes for our case study - the incremental mode, the spiral model, and the V-Model. We learned about their distinctive abilities and challenges. The Incremental model takes an approach that reduces risks & finds errors quickly; meanwhile, the Spiral model is flexible & good at handling different types of projects. With a comprehensive understanding of aviation, we recognize the effectiveness of the V Model as it adopts an organized, top-down structure. Yet, difficulties may surface towards completion.

Moreover, as part of our deliberations, we explored the use of the W model, yet, regrettably, we did not possess sufficient resources, thus deciding in favor of the V model. Go ahead and choose the W-model for your study, but only if you can access the required resources which were formerly made public. We explored potential sources of supply by interviewing those familiar with aeronautical engineering along with an officer from the United States Air Force. They advised looking into different aircraft makers due to their lack of involvement in building Airbuses from beginning to end directly.

To sum up, choosing the V-model for the Airbus A340 flight control system was a wise move since prioritizing security and efficiency aligns perfectly with our core values in air travel. Yet, there are certain obstacles involved, such as inflexibility and high resource needs. Even despite this, Airbus might still make an effort to implement & manage different phases of the V-model accurately enough so as to achieve peak safety standards & efficiency while designing the flight control systems of their A340 planes. As things stand now, all these efforts should allow them to protect both passengers' & personnel safety within those very aircraft.

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