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Chilling with ChatGPT: Can Future Fighter Aircraft Environmental Control Systems be Crafted with AI Assistance?

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Abstract: The usefulness of ChatGPT has been investigated in several scientific studies. In this study its usefulness in manned fighter aircraft environmental control system (ECS) design was evaluated and analyzed. A Turing test was conducted at Saab AB. It was noted that ChatGPT could aid an ECS design team. Also, deep knowledge of very experienced engineers at Saab could be combined with the generic knowledge of ChatGPT to effectively train less experienced engineers. The method in this study could be applied to evaluate the usefulness of ChatGPT or other AI tools for various aircraft subsystems.

Keywords: Artificial Intelligence (AI), Engineering Design, Design Methods

1 Introduction

OpenAI released its chatbot called Chat Generative Pre-Trained Transformer (ChatGPT) in November 2022 and since then its usefulness in various fields of science and engineering has been investigated. Some studies include investigating its usefulness as a tool for specialized education (e.g., Seth et al., 2024) and information providing (e.g., Choi et al., 2024). Some include support in scientific writing (e.g., Salvango et al., 2023) and support in object detection (e.g., Chen et al., 2024). In this paper, its usefulness in aircraft subsystem design is investigated.

Aircraft subsystem designers face challenges at the concept stage. This is due to the number of interdependencies and connections between subsystems and components that are not clearly defined at the concept stage. There is also a lack of definite requirements at this stage (Drego, 2022). The subsystems that provide basic aircraft functions are collectively called aircraft vehicle systems. The environmental control system (ECS) is a vehicle system, and it is typically designed to provide multiple functions such as air pressurization, temperature maintenance, and climate control for various systems, components, and sections of the aircraft. Further, a manned fighter aircraft ECS must be able to perform its functions in challenging and dynamic external environmental conditions. In a single mission, it could fly fast (Mach number ≥ 1) at low altitudes (below 1000m) and then climb to a high altitude (above 5000m) and fly fast within a few minutes. Also, depending on nations operating the aircraft, the ECS must perform in cold and dry climate and hot and humid climate, the latter proving particularly challenging for some ECS components (Drego and Steinkellner, 2022). Therefore, with the design challenges they face, ECS designers require suitable support at the aircraft concept stage. Could ChatGPT or other artificial intelligence (AI) tools be part of that design support at an aircraft developer like Saab?

1.1 The Purpose of the Paper

The purpose of this paper is to demonstrate how to evaluate and analyze the usefulness of ChatGPT in manned fighter aircraft ECS design at Saab. To meet this goal a method was designed for this study that included a Turing test that was conducted at the Aircraft Vehicle Systems department at Saab. Thereby this paper possibly provides Saab and other aircraft developers with a method to evaluate the usefulness of AI tools in subsystem design.

1.2 Outline of the Paper

First, the method developed for this study is described in detail in §2. Then, the results from this study are presented in §3. Reflections on the results are provided in the discussion section in §4. Finally, the conclusions of this study are noted in §5.

2 Method

The method designed for this study consists of four sub-sections. A description of the participants of the study involved in data collection is provided in §2.1. A detailed description of how the Turing test was conducted is provided in §2.2. The last two sub-sections, §2.3 and §2.4 describe how the authors tried to minimize bias in data collection and data analysis, respectively.

2.1 Participants of the Test

Four entities (three humans and one AI-tool) were part of the data collection in this study. They included three engineers and ChatGPT NEO. ChatGPT NEO is a variant of the GPT model developed by OpenAI where NEO stands for nearly efficient optimization. It is specifically designed to be more resource-efficient and environmentally friendly compared to larger models like GPT-3, while still offering strong performance in natural language understanding and generation tasks. The specific tasks conducted by ChatGPT in this study are described in §2.2.

The three engineers chosen for this study work with early design of fighter aircraft ECS at Saab. While Saab also develops other types of aircraft, the functional requirements and design constraints differ to those of fighter aircraft. Therefore, the engineers partaking in this study were limited. The three engineers in this study may also be the primary users of an AI support tool for fighter aircraft ECS design in the future. Engineer 1 was employed at Saab for 29 years of which 25 years were spent working with concept design, detailed development, and operational support for aircraft vehicle systems. Engineer 2 and Engineer 3 were employed for 28 years and 7 years, respectively doing similar tasks to Engineer 1 in their roles at Saab. All three engineers worked on the same project at Saab at the time the data was collected. The first author of this paper conducted all data collection. All participants provided their responses in English. The role of each engineer in the study is described in §2.2.

2.2 The Turing Test

A Turing test was conducted on the four participants of the study to collect data. First, ChatGPT and engineer 1 were each separately tasked with generating an ECS architecture using some steps from the framework in Drego (2022). They were also tasked with listing evaluation criteria and design variables for the architecture they each generated. Then engineers 2 and 3 conducted a blind evaluation of the responses from ChatGPT and engineer 1 for some tasks. All three engineers were familiar with the framework in Drego (2022). However, ChatGPT was not explicitly informed about Drego (2022). The paper was not uploaded to ChatGPT during its official task session with the first author.

There were ten tasks performed by ChatGPT and engineer 1. Framework steps 1, 3, 4, 5, 6, 7, and 8 in Drego (2022) are similar to tasks 1 through 8 in this study described in Figure 1 and Table 1. The first six tasks focus on architecture generation. Note that the definition of an architecture and concept in this paper are adopted from Drego (2022) where a concept is a mapping between function and form and an architecture is a graphical representation of the relationships between form and operand (the entity that function changes). The last four tasks of the study focus on architecture analysis and evaluation.

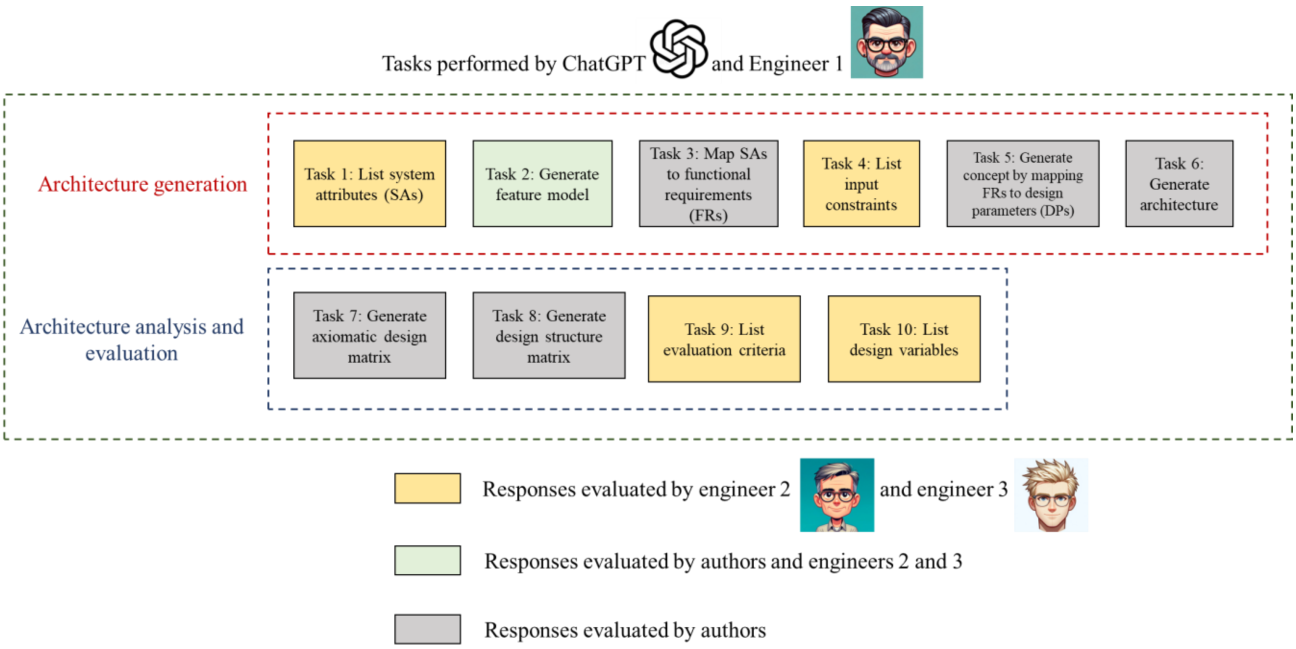

Figure 1: The tasks performed by ChatGPT and engineer 1 in this study. The responses to these tasks were evaluated by engineers 2 and 3, and the authors of this paper.

Concise instructions were provided to ChatGPT and engineer 1 for each task. The first author went through each task in the order provided in Figure 1 and Table 1 with engineer 1 and ChatGPT. The instructions for each task are outlined in

Table 1. Note that beyond the instructions no further prompting was provided to ChatGPT or engineer 1. This is so their responses could be fair.

The tasks to generate the ECS architecture commenced with system attribute (SA) listing. Drego (2022) regards system attributes akin to customer attributes defined in the customer domain when using axiomatic design theory by Suh (2007). This is because system attributes are internal to the organization with internal stakeholders and not external to the customer. As shown in Figure 1, feature listing (using the feature modelling method) was the next task. This was followed by translating the SAs to functional requirements (FRs) and then followed by listing input constraints. An ECS concept was generated by mapping functional requirements to design parameters (DPs), followed by architecture generation. Hence the first six tasks resulted in architecture generation as highlighted in Figure 1. The final four tasks focused on evaluation and analysis commencing with generating an axiomatic design matrix using the concept generated. This was followed by design structure matrix (DSM) generation for dependency analysis. Finally followed by evaluation criteria and design variables listing.

Table 1: Task list and specific instruction for each task to engineer 1 and ChatGPT.

Task	Instruction to Engineer 1	Instruction to ChatGPT
Task 1: System attributes	Please list five main system attributes of an environmental control system (ECS) for a manned fighter aircraft.	Using axiomatic design theory by Nam Suh replace the definition of ‘customer attributes’ with ‘system attributes’. Now list five main system attributes of an environmental control system (ECS) for a manned fighter aircraft.
Task 2: Feature model	Using Eclipse FeatureIDE, create a feature model of an environmental control system (ECS) for a manned fighter aircraft with four abstract features.	Using Eclipse FeatureIDE, create a feature model of an environmental control system (ECS) for a manned fighter aircraft with four abstract features.
Task 3: Functional requirements	Using axiomatic design theory by Nam Suh, please map the system attributes listed above to functional requirements (FRs) for an ECS.	Using axiomatic design theory by Nam Suh, please map the system attributes listed above to functional requirements (FRs) for an environmental control system (ECS) for a manned fighter aircraft.
Task 4: Input constraints	Using the definition of input constraints from axiomatic design theory, list three primary input constraints on an ECS.	Using the definition of input constraints from axiomatic design theory, list three primary input constraints on an ECS for a manned fighter aircraft.
Task 5: Design parameters (concept)	Map the FRs listed above to design parameters (DPs) using the feature model created previously and the input constraints listed above.	Using the definition of design parameters from axiomatic design theory, map the FRs listed above to DPs using the feature model created previously and the input constraints listed above.
Task 6: Architecture	Create a system architecture for the ECS concept generated above.	If the definition of an architecture is a pictorial layout showing the connections between DPs could you please create an architecture of the ECS using the DPs listed above.
Task 7: Axiomatic design matrix	Using the FRs and DPs please create an axiomatic design matrix linking the relationships between the FRs and DPs.	Using the FRs and DPs please create an axiomatic design matrix linking the relationships between the FRs and DPs.
Task 8: Design structure matrix	Generate a design structure matrix for the ECS concept generated	Please list the inputs, DPs, and outputs of the ECS.

	above using the inputs, DPs, and outputs of the ECS.	Now take the complete list of inputs, DPs, and outputs of the ECS and create a design structure matrix (DSM).
Task 9: Evaluation criteria	Consider the three most important ‘ilities’ to evaluate the ECS generated above. What would the impact of each of these three ‘ilities’ be on the operational and overall design aspects of a fighter aircraft?	Can you please list the three most important criteria to evaluate the ECS generated above.
Task 10: Design variables	List three design variables for an ECS and populate each variable with a data range using educated guess estimates for the application at hand.	List three design variables for an ECS and populate each variable with a data range using educated guess estimates

The tasks session was conducted with engineer 1 first and he received the tasks 24 hours before his session. Engineer 1 was asked not to discuss the tasks with ChatGPT but to prepare his responses based on his work experiences at Saab. Engineer 1 wrote or drew his responses on a white board for each task. The first author noted each response. He also provided reasoning for his responses where possible.

This was followed by the task session with ChatGPT. The task session with ChatGPT was not run on a local network at Saab. It was run on the distributed network of OpenAI. The authors did not train any GPT model or create an application specific interface to communicate with it. However, following this study if an AI tool is used for ECS design support at Saab, then the model will be trained and run locally on the Saab network to protect sensitive data.

The raw responses from ChatGPT and engineer 1 were discussed and analyzed by all three authors. The first author then formatted the language of the raw responses to make them as indistinguishable as possible from each other. This was done because Swedish is the mother tongue of engineer 1 and English is his second language. Therefore, in terms of English language correctness, his responses were not on par to those provided by ChatGPT. The formatted responses for five tasks of the study were jumbled. Two weeks after the task session with ChatGPT and engineer 1, the first author conducted the evaluation session with engineers 2 and 3. Engineer 1 was asked not to discuss his session proceedings with engineers 2 and 3 during the two-week gap before their evaluation session.

The task responses evaluated by engineers 2 and 3, those analyzed by the authors, and those evaluated by both parties are marked using a color scheme in Figure 1. Engineers 2 and 3 did not evaluate the FRs produced in Task 3, concepts in Task 5 and system architectures in Task 6 created by ChatGPT and engineer 1. The authors thought that it would be evident to engineers 2 and 3 to distinguish between the solution produced by ChatGPT and the one produced by engineer 1 for those tasks. The close working relationship between the engineers could have influenced the evaluation by engineers 2 and 3 which would have then rendered the Turing test invalid. Therefore, these responses were evaluated by the authors. The axiomatic design matrices (Task 7) and design structure matrices (Task 8) produced by ChatGPT and engineer 1 were also only evaluated by the authors. This is because to evaluate them, the concept and architecture are needed.

The jumbled responses for tasks 1, 2, 4, 9, and 10 were evaluated by engineers 2 and 3 for their relevance in generating an ECS concept. The first author provided them with the description of the relevance ranking scale at the start of their session. They ranked the responses in what they deemed most relevant to least relevant from 1 to n, respectively where n is an integer value greater than 1. In some instances, for a single step, multiple responses received the same ranking because they were deemed to have equal relevance. Engineer 2 and engineer 3 conducted the response evaluation test in the same room at the same time with the first author present. They were not provided with the responses in advance but at the time the test was conducted. They each conducted their evaluations on separate computers, and they were asked not to converse with each other. They were also asked to provide reasons for their ranking choices for each of the five tasks. They filled in the evaluations forms and when they had completed the task, they emailed it to the first author and then left the room. The evaluation of responses by engineers 2 and 3 were analyzed by the authors. Then the first author structured the evaluations in Microsoft Excel. The results of the study are presented in §3.

2.3 Minimizing Bias in Data Collection

Bias can arise when collecting data in qualitative research. Frankfort-Nachmias and Nachmias (1996) discussed three types of bias that can arise during observation. They include ‘demand characteristic’, ‘experimenter bias’, and ‘measurement artefact bias’. Demand characteristic bias happens when the participants are conscious of being studied and attempt to act in a manner that is expected of them. To reduce this type of bias, the first author informed all three engineers prior to the start of the task and evaluation sessions to provide responses that reflect their opinions based on their individual experiences at Saab. Experimenter bias happens when researcher expectations are inadvertently communicated to participants. To reduce this type of bias, the instructions for each task for ChatGPT and engineer 1 as shown in Table 1 were carefully pre-structed prior to the task sessions. Similarly, prior to the start of the evaluation session, engineers 2 and 3 were informed about the evaluation process and relevance ranking scale.

2.4 Minimizing Bias in Data Analysis

Bias can also arise when analyzing data in qualitative research. Miles et al. (2020) identified four archetypical types of analytical bias, namely, ‘holistic fallacy’, ‘elite bias’, ‘personal bias’, and ‘going native’. Elite bias occurs when there is a discrepancy in data representation with an overrepresentation of data from well-informed, high-status participants and an underrepresentation from lower-status ones. Engineers 1 and 2 can be considered well-informed, high-status employees at Saab due to their length of work experience. Therefore, if only engineer 2 evaluated the responses, then it could have introduced elite bias. To reduce elite bias when designing the test, engineer 3 was added because he had a shorter length of work experience than engineers 1 and 2 at Saab. Therefore, engineer 3 was less-informed and represented the data from lower-status participants.

3 Results

3.1 Evaluation by Engineer 2 and Engineer 3

Engineers 2 and 3 evaluated the responses from ChatGPT and engineer 1 for tasks 1, 2, 4, 9, and 10 as listed above in Figure 1 and Table 1. The responses by ChatGPT and engineer 1 and the evaluation of these responses by engineers 2 and 3 for these five tasks are shown in Figure 2 and Figure 3 below.

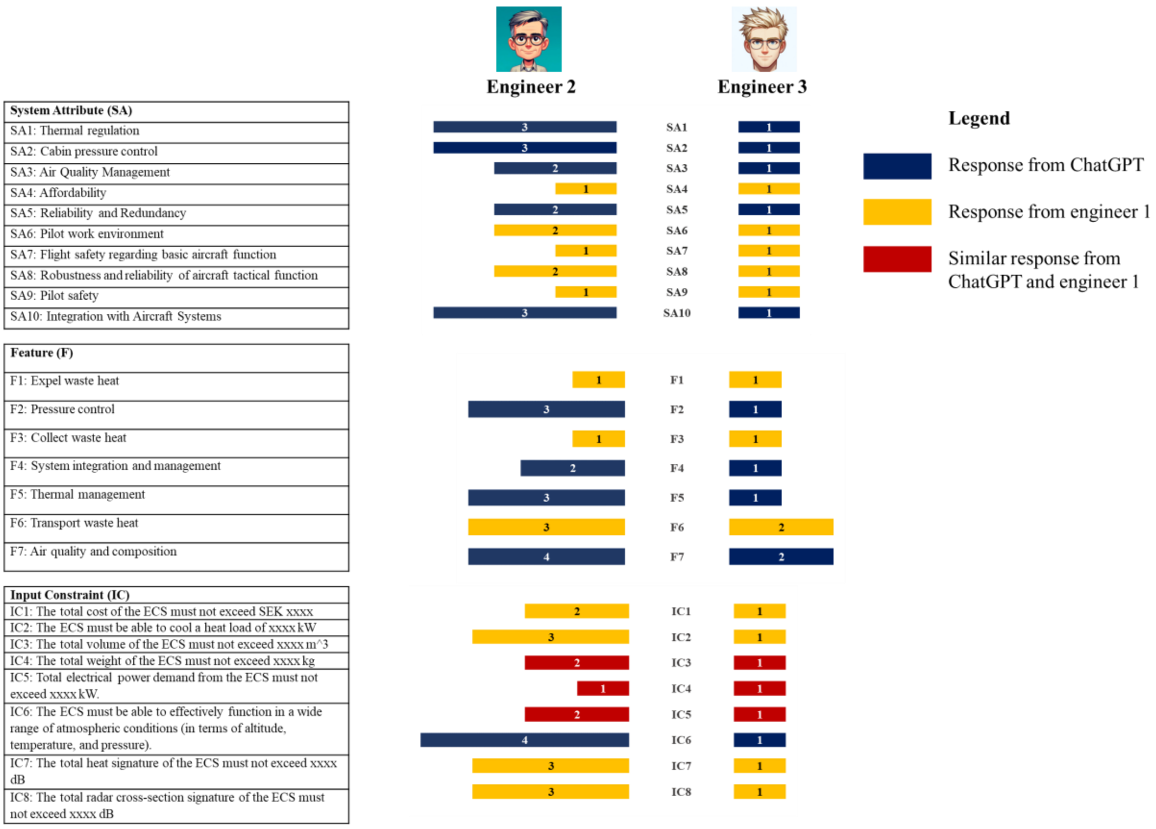

Figure 2: Relevance ranking by engineers 2 and 3 of the responses from ChatGPT and engineer 1 for system attribute-, feature-, and input constraint- listing for generating a manned fighter aircraft environmental control system. A ranking of 1 is deemed most relevant and a ranking of n is deemed least relevant where n is an integer value greater than 1.

Evaluation Criterion (EC)
EC1: Cost efficiency: Evaluate the ECS for its ability to use the available cost efficiently (kW/SEK)
EC2: Performance efficiency: Evaluate the ECS's ability to maintain optimal cockpit temperature, air quality, and cabin pressure, especially under all operating conditions
EC3: Volume efficiency: Evaluate the ECS for its ability to the use the available volume efficiently (kW/m^3)
EC4: System safety and reliability: Evaluate the ECS's robustness, fail-safe features, and overall dependability to ensure a safe and viable environment for the pilot.
EC5: Integration with aircraft systems: Evaluate how well the ECS will integrate with other systems on the aircraft
EC6: Weight efficiency: Evaluate the ECS for its ability to use the weight allocation efficiently (kW/kg)

Design Variable (DV)
DV1: Cabin Pressure Altitude (kPa): The range of pressure altitudes that the ECS can maintain for pilot survivability.
DV2: Fuel flow rate (kg/s): The range of fuel flow rates to the ECS heat exchanger.
DV3: Temperature regulation range (°C): The range of temperatures that the ECS can maintain within the cockpit.
DV4: Bleed air outtake (kg/s): The range of mass flow rates of bleed air from the engine for the ECS to use.
DV5: Air filtration efficiency (%): The range of efficiency that aligns with HEPA filter standards capable of filtering out dust, pollen, mold, bacteria
DV6: Tactical heat load (kW): The range of heat flow rates produced by the tactical systems.

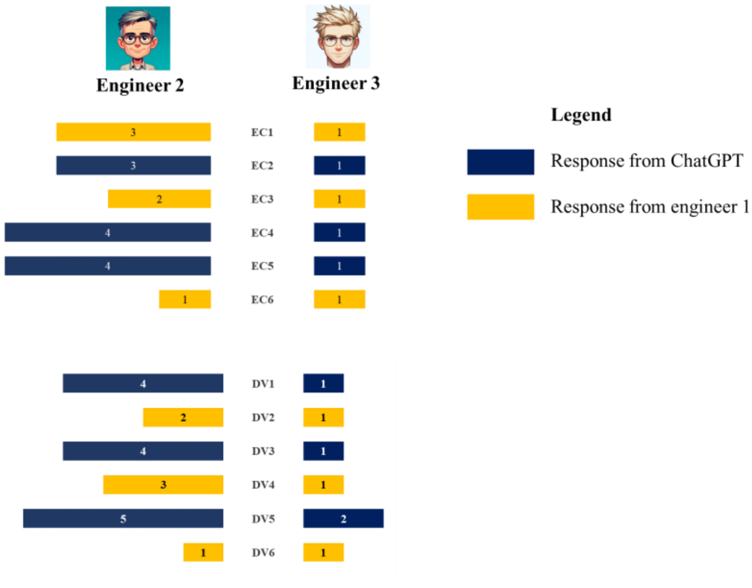

Figure 3: Relevance ranking by engineers 2 and 3 of the responses from ChatGPT and engineer 1 for evaluation criterion-, and design variable- listing for generating a manned fighter aircraft environmental control system. A ranking of 1 is deemed most relevant and a ranking of n is deemed least relevant where n is an integer value greater than 1.

Engineer 1 considered affordability, pilot work environment, flight safety regarding basic aircraft function, robustness and reliability of aircraft tactical function, and pilot safety as the attributes of a manned fighter ECS. He reasoned that affordability is important because the national defense budget of Sweden is smaller compared to larger nations and therefore Saab must focus on building affordable aircraft with affordable subsystems for the Swedish Armed Forces. He reasoned that pilot safety is important for pilot survivability in terms of oxygen supply and air pressurization. While pilot work environment is important to ensure their comfort so they can perform their tasks efficiently during a mission. Finally, he reasoned those systems providing basic aircraft function and those providing tactical function should always be maintained within their operating temperature levels. On the other hand, ChatGPT considered thermal regulation, cabin pressure control, air quality management, reliability and redundancy, and integration with aircraft systems as attributes. It stated that they reflected the requirements and capabilities of the system focusing on its operational efficiency, safety, and reliability within the demanding environment of a fighter aircraft. It can be noted from Figure 2 that engineer 2 ranked three attributes from engineer 1 as most relevant with a ranking of 1 while giving all attributes from ChatGPT a lower ranking (2 or 3). His ranking choice was based on prioritizing cost and safety first followed by reliability and pilot workload and finally design attributes such as thermal regulation, cabin pressure control, and integration with aircraft systems. Engineer 3 on the other hand gave all attributes the same ranking noting that all are equally important. He noted that it was difficult to balance the attribute ranking when designing the ECS and that all attributes are needed to comply with stakeholder needs.

The feature models created by ChatGPT and engineer 1 were evaluated by engineers 2 and 3 and analyzed by the authors. Engineers 2 and 3 only evaluated the first level of features and these are listed in Figure 2. Engineer 1 regarded the first levels of features of a manned fighter aircraft ECS to be expel waste heat, collect waste heat, and transport waste heat. While ChatGPT regarded its first level of features to be pressure control, system integration and management, and air quality and composition. As noted from Figure 2, engineer 2 ranked two aspects from engineer 1 as most relevant while giving a lower ranking to those of ChatGPT. He noted that his ranking was based on the impact the features would have on the aircraft. While engineer 3 ranked most features as most relevant with a ranking of 1 noting that you cannot have one without the other. He ranked transport waste heat and air quality composition with a ranking of 2 noting that they have a lower relevance because he thought they have a lower impact on aircraft design. It can be noted that engineer 2 also gave transport waste heat a lower ranking of 3.

Although instructed to list only three input constraints, engineer 1 provided seven stating that all seven were important for designing a manned fighter aircraft ECS. They include constraints on cost, heat load to be cooled (in kW), weight, volume, power demand from ECS (in kW), and heat signature and radar cross-section signature (dB). On the other hand, ChatGPT provided three input constraints. The unformatted response from ChatGPT included constraints on ECS performance with respect to the aircraft operational environment, ECS space and weight, and ECS power and energy consumption. For the formatted response for engineers 2 and 3 to evaluate, space (volume) and weight were split into Input Constraint 3 (IC3) and IC4 as shown in Figure 2. IC3, IC4, and IC5 are common constraints provided by both ChatGPT and engineer 1. Engineer 2 ranked IC4 to be most relevant since he judged it to have the greatest impact on aircraft capability. He ranked

IC1, IC3, and IC5 as second most relevant but judged them to equally impact the aircraft and the aircraft development project as IC4. Engineer 3 ranked all constraints as most relevant, noting that it is not possible to judge the relevance of constraints on a sub-system (i.e., ECS) that are already budgeted on an aircraft level.

Engineer 1 listed cost, volume, and weight as the most important criteria to evaluate a manned fighter aircraft ECS as shown in Figure 3. He noted that the system should fit within the volume, weight, and cost budgets allocated for it. On the other hand, ChatGPT listed system performance, system safety and reliability, and integration with aircraft systems as the most important criteria. It stated that each criterion is crucial for the ECS to satisfy its purpose effectively in the demanding environment of a manned fighter aircraft. Engineer 2 ranked weight as the most relevant, volume as the second most relevant, and cost and performance as the third most relevant evaluation criteria. He noted that his judgement was based on the impact the criterion has on the aircraft. Again engineer 3 ranked all criteria as most relevant noting that evaluation criteria are dependent on the specific aircraft being built and cannot be judged generically.

Finally, engineer 1 listed fuel flow rate (kg/s), bleed air outtake (kg/s), and tactical heat load (kW) as design variables as shown in Figure 3. While ChatGPT listed cabin pressure altitude (kPa), temperature regulation range (°C), and air filtration efficiency (%) as design variables. Engineer 2 selected tactical heat load as the most relevant variable, fuel flow rate as the second, and bleed air outtake as the third. It can be noted that engineer 2 selected all three variables from engineer 1 in his top three ranking. On the other hand, engineer 3 ranked all but one variable as most relevant. He noted that all variables are equally important, however filtration efficiency can have a ranking of 2 because he did not consider it an important design variable in his work. Note that despite ChatGPT and engineer 1 providing design ranges for each design variable they listed, the authors deemed an evaluation of these ranges would not add any value to the results of the study. Therefore, they were excluded from the evaluation conducted by engineers 2 and 3.

3.2 Analysis by Authors

The authors analyzed the responses from ChatGPT and engineer 1 for tasks 2, 3, 5, 6, 7, and 8. The responses by ChatGPT and engineer 1 for these six tasks are shown in Figure 4, Figure 5, Figure 6, and Figure 7 below.

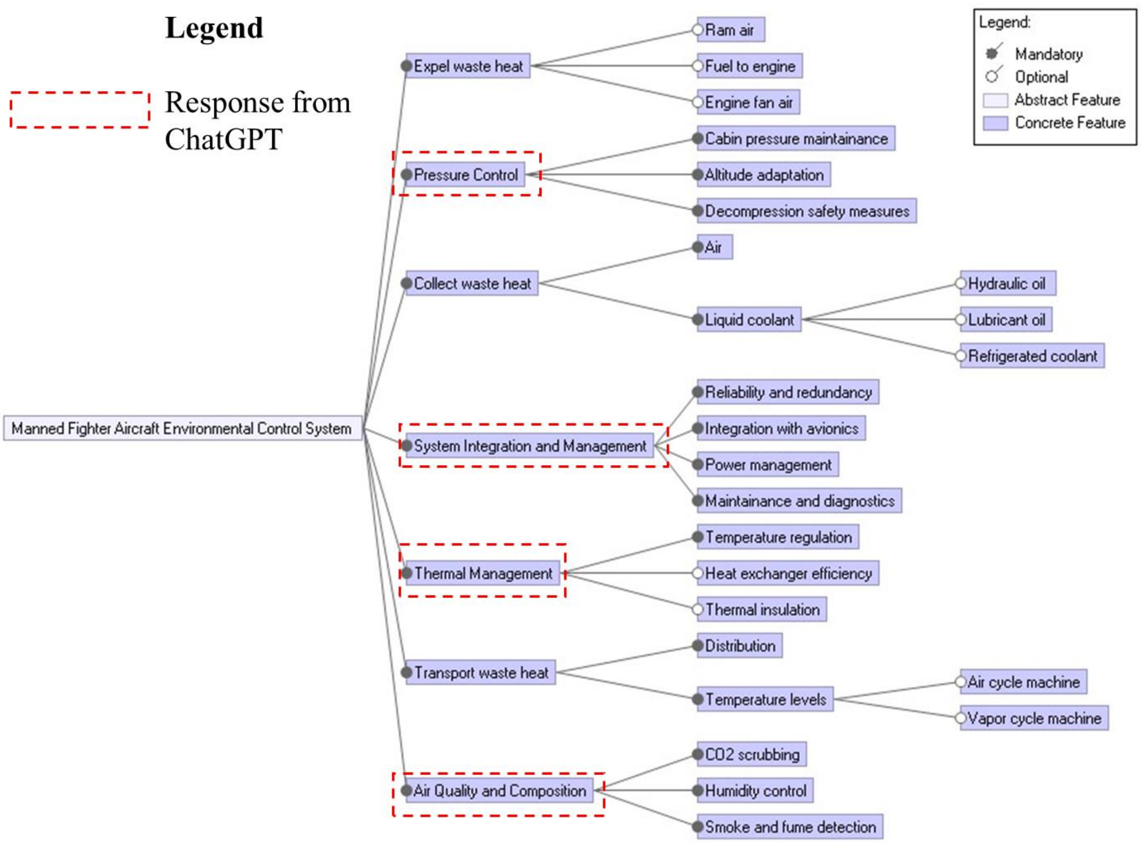

Figure 4: Feature model created using FeatureIDE (METOP GmbH, (2020)) for a manned fighter aircraft environmental control system. The features were provided by ChatGPT and engineer 1.

The feature models created by engineer 1 and ChatGPT for a manned fighter aircraft ECS were collated and are presented in a single feature model shown in Figure 4. The first level of features is followed by a second and, in some cases, a third level as well. The second and third level are a mix of mandatory and optional features based on the opinions of engineer 1 and ChatGPT. For example, engineer 1 has three alternatives for the ECS to expel waste heat, namely, ram air, fuel to engine, and engine fan air. On the other hand, ChatGPT has three mandatory features for ECS pressure control, namely, cabin pressure maintenance, altitude adaptation, and decompression safety measures. It can be noted that the second and third level of features from engineer 1 are solutions while those from ChatGPT are functions.

Figure 5 displays the mapping of the SAs to FRs to DPs and the axiomatic design matrices linking FRs and DPs, for both ChatGPT and engineer 1. It can be noted that FR1 and FR2 from ChatGPT are like FR3 and FR5 from engineer 1. FR2, FR4, and FR9 from engineer 1 are very typical for an ECS for a manned fighter aircraft. On the other hand, FR4, FR5, and FR6 from ChatGPT are generic FRs that are applicable to other aircraft vehicle systems. Similarly, it can be noted that the DPs from engineer 1 are specific components or solutions as opposed to the general solutions provided by ChatGPT. On comparing the design matrices, ChatGPT generated an uncoupled or diagonal matrix and thus the concept from ChatGPT does not violate the independence axiom of axiomatic design theory. Conversely, multiple FRs are mapped to the same DPs in the concept by engineer 1 leading to a coupled matrix. Integrated functionality from a single DP is expected in fighter aircraft subsystems as noted in Ganev and Koerner (2013) and Wiegand et al. (2018).

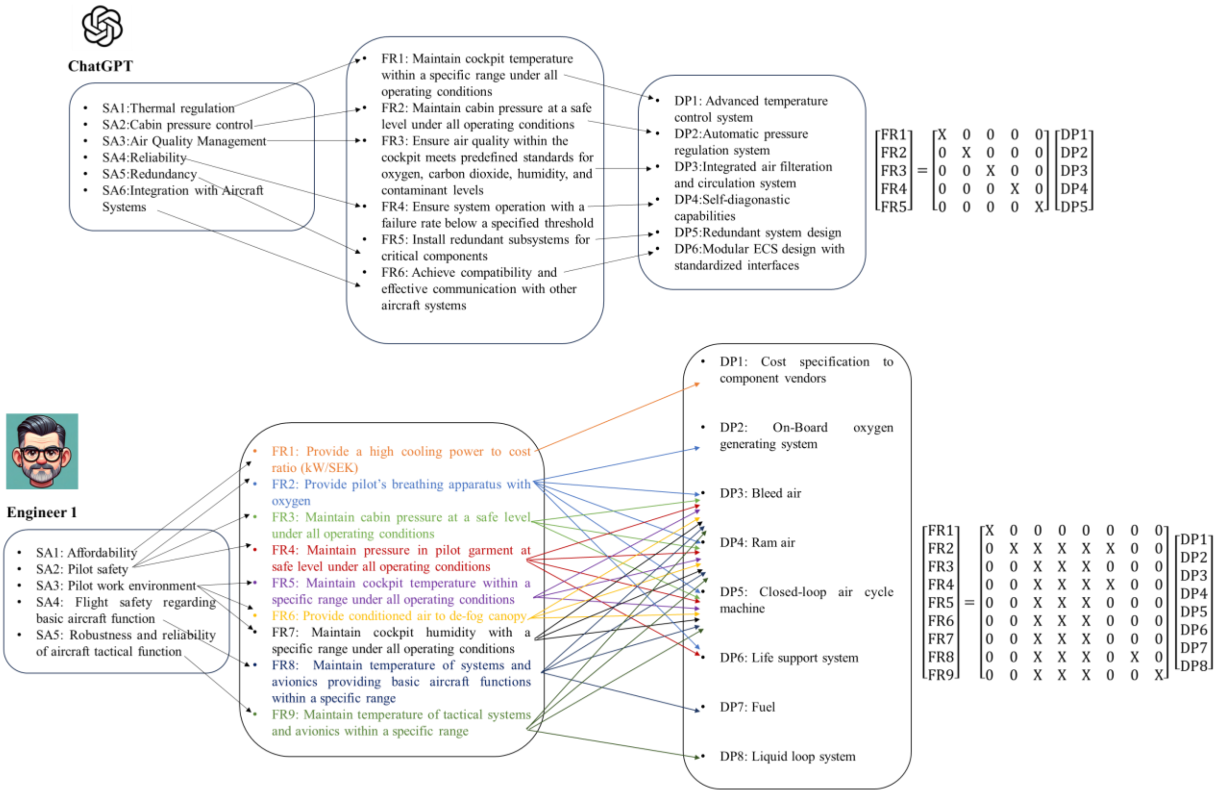

Figure 5: Mapping of system attributes (SAs) to functional requirements (FRs) to design parameters (DPs) and the axiomatic design matrix linking FRs to DPs for a manned fighter aircraft environmental control system. The top concept was generated by ChatGPT, and the bottom concept was generated by engineer 1.

The architectures generated from the concepts by ChatGPT and engineer 1 are shown in Figure 6. It can be noted that architecture by ChatGPT is limited to the DPs of the ECS. On the other hand, that by engineer 1 includes the systems and components that provide energy to the ECS and those that consume energy from the ECS. For example, the engine provides bleed air to the ECS to run and the auxiliary power unit provides electric power. While the ECS provides pressurized air to the on-board oxygen generating system and life support system for the pilot, the cockpit, and other systems. Compared to the generic architecture by ChatGPT, that by engineer 1 seems to be influenced by his experiences working in other military aircraft projects at Saab as it contains specific components with specific connections. While the architecture by ChatGPT can be used as a generic template to test combinations of different components.

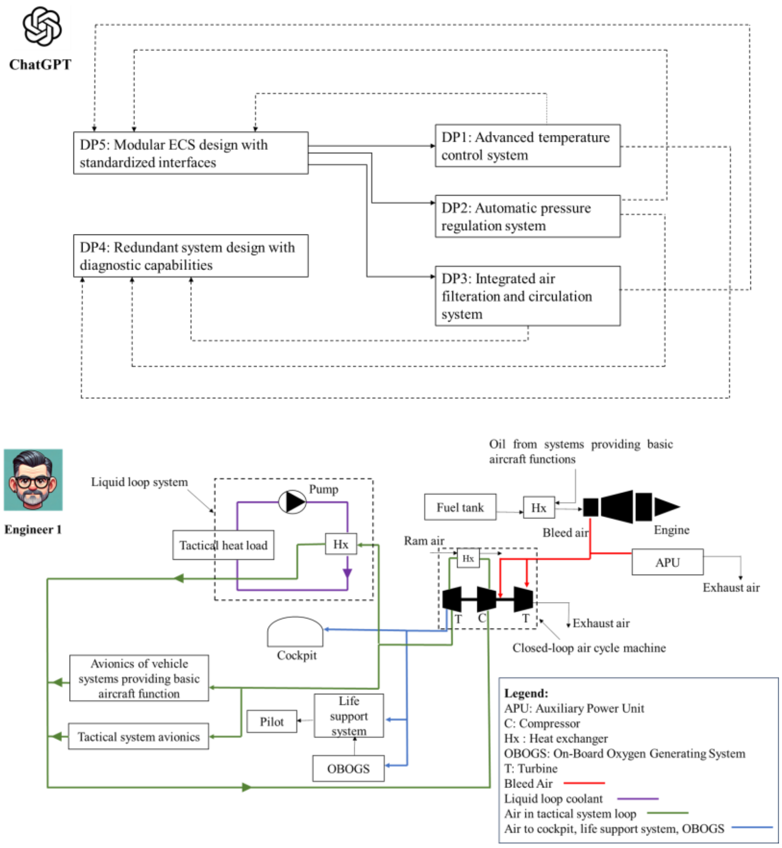

Figure 6: Architectures of a manned fighter aircraft environmental control system generated by ChatGPT (top) and engineer 1 (bottom).

ChatGPT

- 1. External environmental conditions
- 2. Aircraft operational data
- 3. Pilot/crew input
- 4. Aircraft system feedback
- 5. Advanced temperature control
- 6. Auto pressure regulation
- 7. Integrated air filtration
- 8. Redundant system design
- 9. Modular ECS design
- 10. Cabin temperature
- 11. Cabin pressure
- 12. Air quality
- 13. System status

PROVIDES TO →

DEPENDS ON ↓

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1				x	x	x			x	x	x	
2		2			x	x				x	x		
3			3		x	x	x			x	x	x	
4				4	x	x	x	x	x				x
5					5				x	x			
6						6			x		x		
7							7		x			x	
8								8	x				x
9					x	x	x	x	9	x	x	x	x
10										10			
11											11		
12												12	
13													13

Engineer 1

- 1. Engine
- 2. Ram air
- 3. Fuel
- 4. APU
- 5. OBOGS
- 6. Closed-loop air cycle machine
- 7. Life support system
- 8. Liquid loop system
- 9. Cockpit
- 10. Pilot
- 11. Basic aircraft function systems (vehicle systems)
- 12. Tactical systems
- 13. Vehicle systems avionics
- 14. Tactical systems avionics

PROVIDES TO →

DEPENDS ON ↓

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1				x	x	x	x	x	x	x	x	x	x
2		2			x	x	x	x	x	x	x	x	x	x
3	x	x	3	x	x	x	x	x	x	x	x	x	x	x
4				4	x	x	x		x	x	x		x	
5					5		x			x				
6					x	6	x	x	x	x		x	x	x
7							7			x				
8								8				x		
9									9	x				
10										10				
11											11			
12												12		
13													13	
14														14

Figure 7: Component/subsystem design structure matrices for the ECS concepts generated by ChatGPT (top) and engineer 1 (bottom)

ChatGPT and engineer 1 were tasked with first listing the inputs, DPs, and outputs of the ECS in that order and then using that list to create a DSM. The list and DSM for each of them are shown in Figure 7. It can be noted from the DSM by ChatGPT that external environmental conditions impact multiple DPs, and ECS outputs. Also, the DP ‘Modular ECS design' influences all other DPs and ECS outputs. With the DSM by engineer 1, all entities depend on fuel. He reasoned that without fuel the engine cannot run and hence the aircraft cannot fly. Similarly, many entities depend on the engine and ram air to function. The next step would be quantifying the dependency effect using an integer scale.

4 Discussion

General trends can be observed in the evaluations by engineers 2 and 3. Engineer 2 tended to rank the responses from engineer 1 with greater relevance than those from ChatGPT. On the other hand, engineer 3 mostly gave all responses the same ranking noting that they all had equal relevance. It could be deduced that ChatGPT was able to deceive engineer 3 but not engineer 2. Therefore, ChatGPT passed the Turing test with engineer 3 but not quite with engineer 2. This could be due to the large discrepancy in work experience at Saab between engineers 2 and 3 with the former having almost four times more experience than the latter. Therefore, specific system attributes, constraints, evaluation criteria, and design variables inherent to aircraft vehicle systems at Saab have not been instilled in engineer 3 yet. Therefore, engineers 1 and 2 have gained a lot more tacit design knowledge at Saab than engineer 3. To train engineer 3 in general vehicle system design and in design aspects unique to Saab, an AI tool like ChatGPT could prove useful. It can be trained with company-specific design aspects. Therefore, engineer 3 could catch up to the Saab-level of knowledge of engineers 1 and 2 faster. Further, ChatGPT or another AI tool could assist engineers 1, 2, and 3 in designing a manned fighter aircraft ECS.

The concept and architecture created by engineer 1 could be fed to an AI tool as part of tool training. Therefore, the design knowledge inherent to Saab from engineers 1 and 2 could be efficiently and effectively passed on to the next generation. On the other hand, the more-generic concept and architecture generated by ChatGPT could be used at Saab as a template to evaluate and analyse various combinations of different state-of-the-art vehicle system components.

5 Concluding Remarks

This study demonstrated the usefulness of ChatGPT using the framework from Drego (2022) and the Turing test for the case study of a manned fighter aircraft ECS. It was noted that ChatGPT could aid an ECS design team. It was also noted that the deep knowledge of very experienced engineers at Saab could be combined with the generic knowledge of ChatGPT to effectively train less experienced engineers in ECS design. The method designed for this study could be applied to evaluate the usefulness of ChatGPT or other AI tools for other aircraft subsystems. The results of this study and future studies like it could be used by companies like Saab to determine what knowledge AI tools need to be trained on to pass on company-specific expertise to future generations.

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