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LLM ASSISTED NO-CODE HMI DEVELOPMENT FOR SAFETY-CRITICAL SYSTEMS

Insights of a Short Impirical Study

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A (VERY) SHORT RÉSUMÉ

Contact information at the end of this presentation...

SHORT RÉSUMÉ

Some call it CV...

Name	Prof. Dr. Matthias Harter Fields of interest / profession • Patents and IP • AI, AGI and humanity • ASICs, Circuits and Systems • Aviation, Simulators
since 07/11	Professor for Embedded Systems and Microcomputers Hochschule RheinMain University of Applied Sciences
10/12 – 09/18	Head of the Department of Electrical Engineering and Information Technology
10/17 – 10/23	Head (founder) of new study program „Electrical and Aviation Engineering“

STATE OF THE ART: EMBEDDED SOFTWARE FOR SAFETY-CRITICAL APPLICATIONS

Examples from Aviation Engineering

A320 COCKPIT

Safety-Critical Embedded SW development today

CESSNA 172 (4 SEATS)

Replacement of analog instruments

DEVELOPMENT OF COCKPIT INSTRUMENTS

How is it done today?

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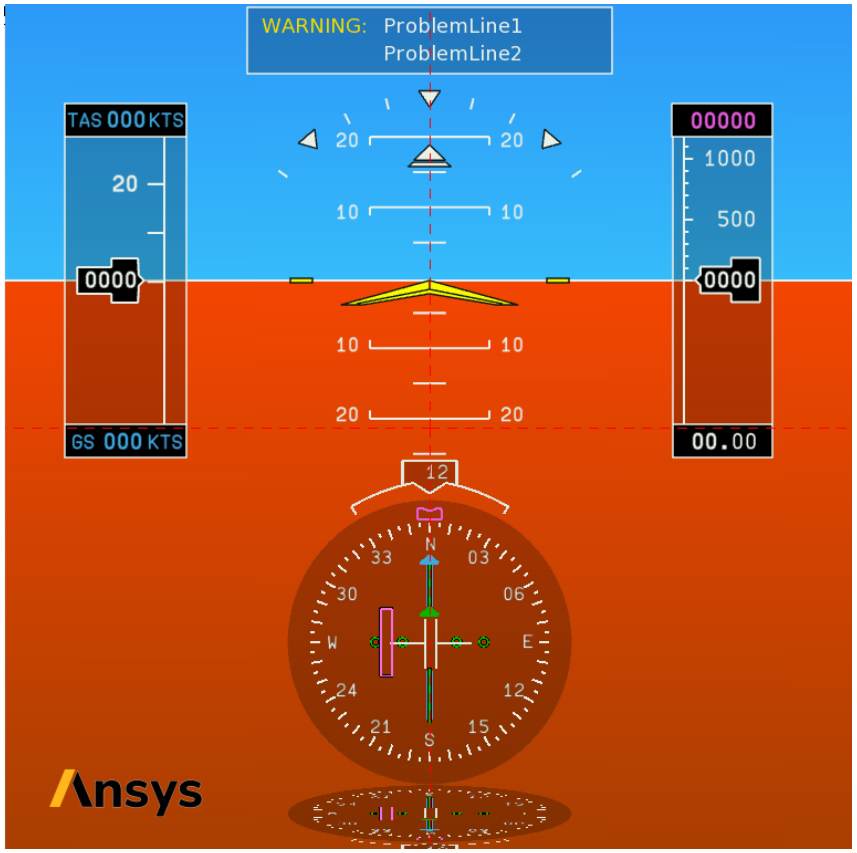
Scenario (example):

Artificial horizon used as Primary Flight Display (PFD) in an aircraft‘s cockpit.



State of the art:

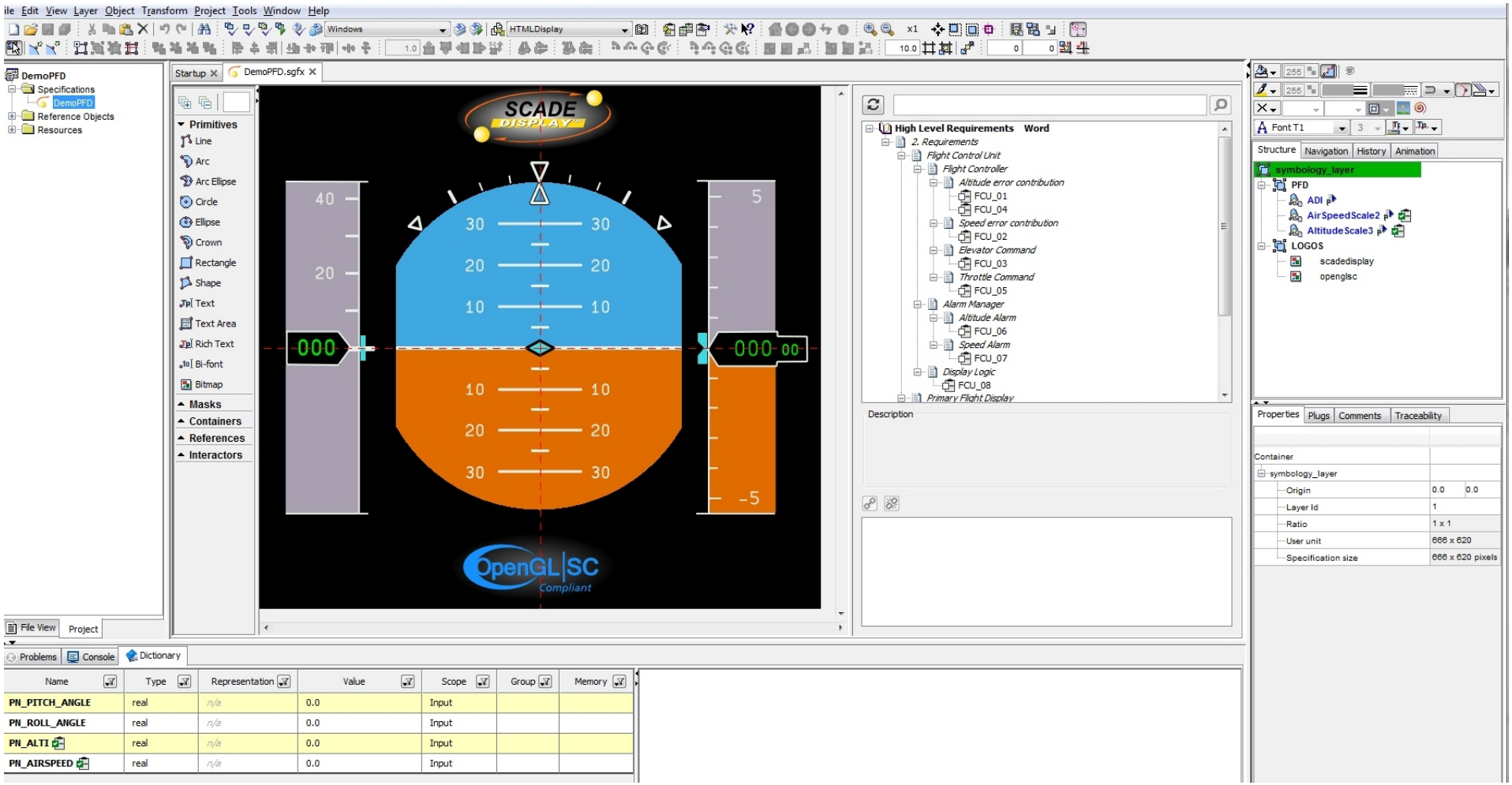
Automation of the development process with certified tools, e.g., Ansys SCADE

- Visual part specified as graphical models based on OpenGL primitives
- Usage of pre-defined widgets (fast!)
- Functionality as SysML models
- SW code is *generated* from models, (almost) no hand-written source code

=> Safety-critical! Can AI assist? How?

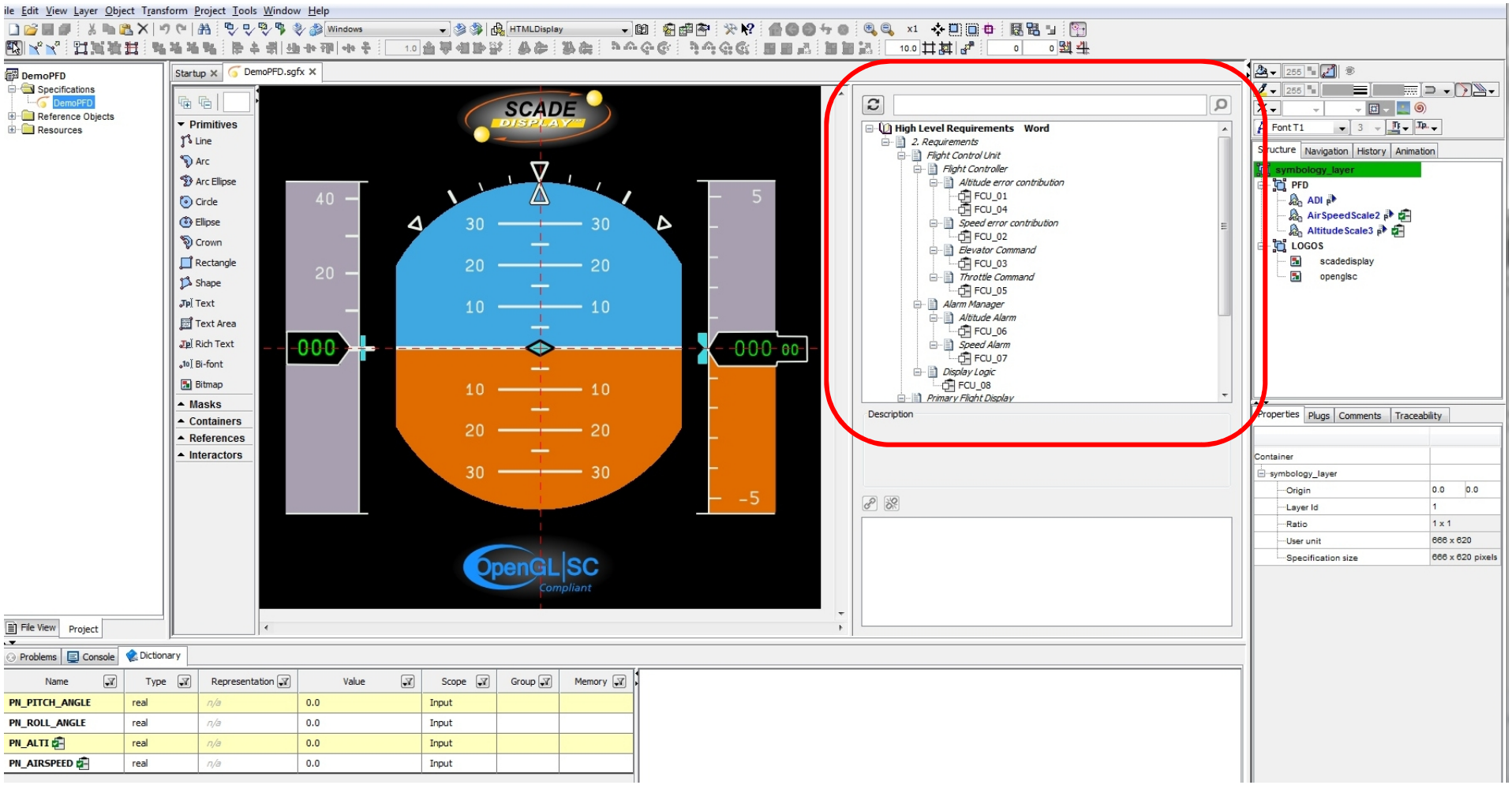
ANSYS SCADE

Certified tool, used by Airbus, Boeing, etc.
for Model Based Systems Engineering (MBSE)



„IN THE BEGINNING WAS THE WORD“

Requirements written in natural language are perfect for LLMs (e.g., GPT-4)



SCENARIO FOR THE FUTURE

How realistic (how wise) is it to use AI in safety-critical applications?

FUTURE:

Graphical and functional model, with interface to Model Based Systems Engineering (MBSE) tool

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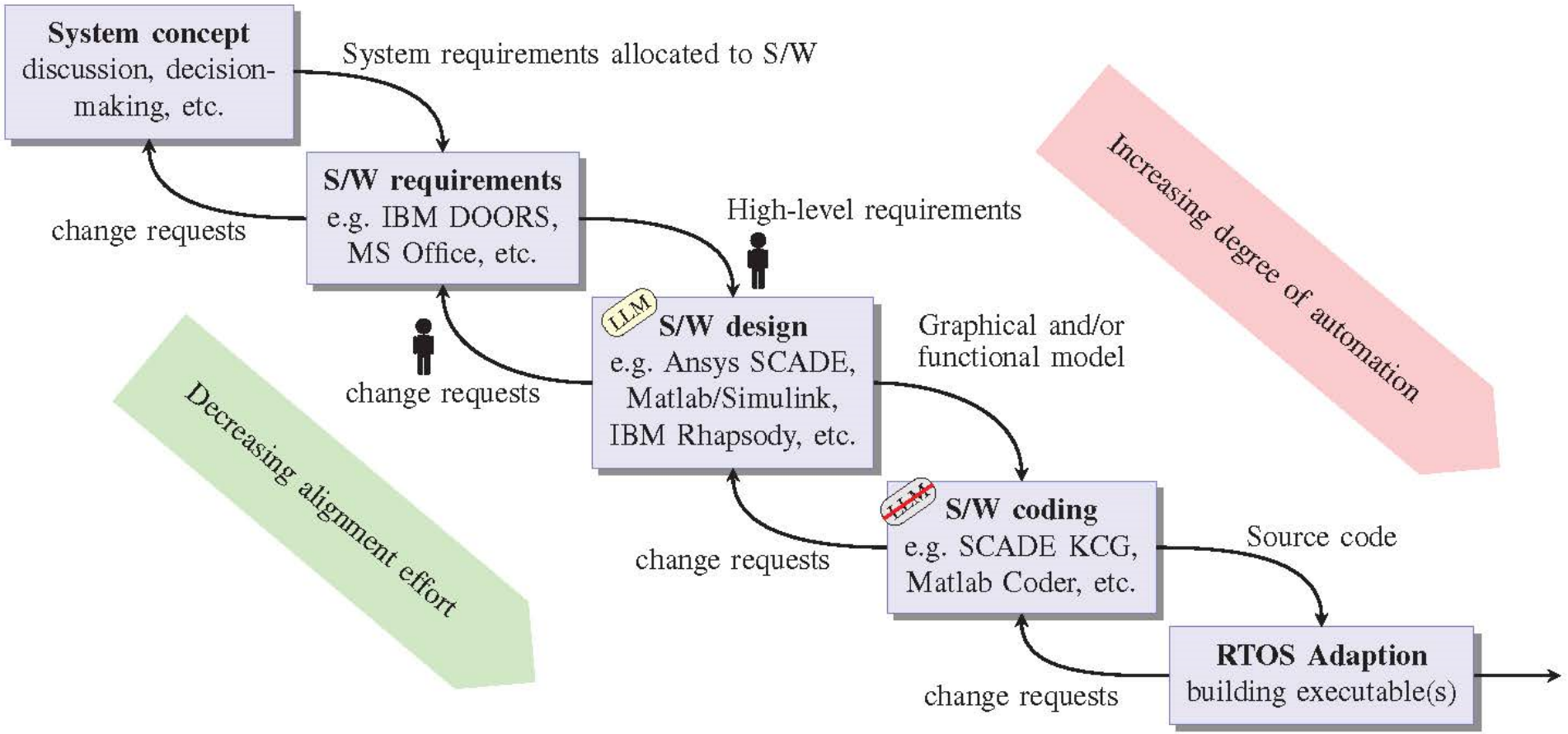
Step 1	Step 2	Step 3
Requirements written in natural language are fed into LLM (e.g., GPT-4).	Models are transferred into internal representation by development tool.	C/Ada source code is generated automatically by code generator (e.g., KCG).
LLM generates API calls for the development tool to create and connect the instances of the **graphical and functional model** of the embedded SW.	Models are analyzed and edited **by human engineer** in the development tool, only **when necessary** (human-in-the-loop policy).	Source code is compiled into binary (executable) for adaption by Real-Time-OS (RTOS)
Alternative: LLM generates models directly in native file format (e.g., XML) of MBSE tool		

V-MODEL OF DEVELOPMENT PROCESS

Crucial: Usage of LLM (AI) in which step?



METHODOLOGY FOR EVALUATION

Evaluation of the capabilities of current LLMs for a limited test case

TODAY: LIMITATIONS

Limited to graphical model, without direct (automatic) interface to development tool editor

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Step 1	Step 2	Step 3
Requirements written in natural language are fed into LLM (e.g., GPT-4).	Code is executed by interpreter and graphical models displayed.	C/Ada source code is generated automatically by code generator (e.g., KCG).
LLM generates code (e.g., Python, TikZ/LaTeX) for the **graphical models** of the embedded SW only.	Graphical models are analyzed and transferred into development tool editor **manually by human engineer**.	Source code is compiled into binary (executable) for adaption by Real-Time-OS (RTOS)

RESULTS: REQUIREMENTS 1...9 AND GPT-4

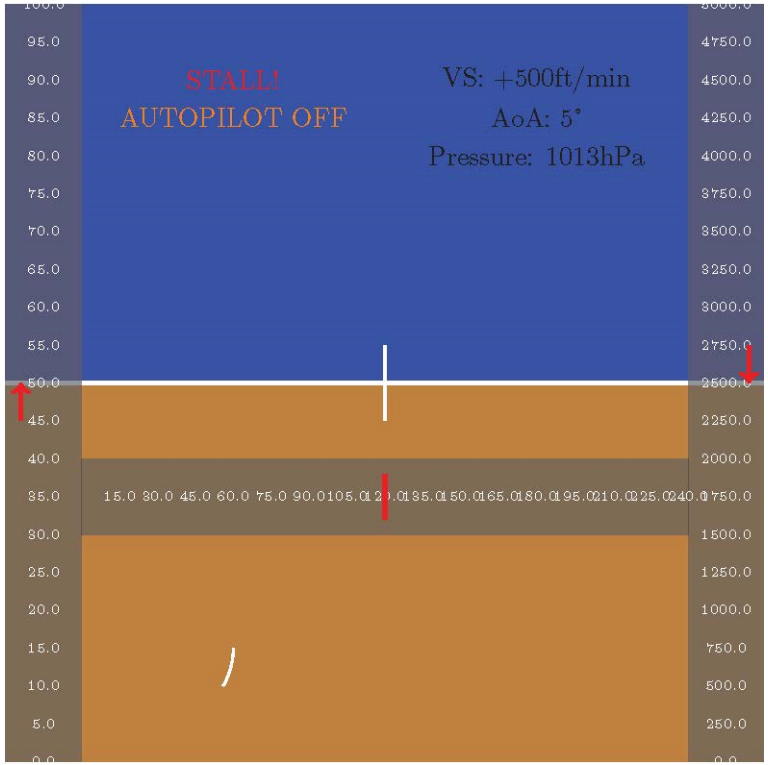
Variant (1 of 14) of the visual model, generated using TikZ / LaTeX code from GPT-4

1. General Layout & Dimensions:

- The PFD shall have a rectangular aspect
- ratio suitable for installation in standard cockpit instrument panels.
- The sky and earth shall be perfectly aligned at the horizon line.
- The horizon line shall be centered horizontally on the PFD, and its vertical placement shall adjust based on the aircraft's pitch angle.

2. Color and Appearance:

- The PFD shall represent the sky in blue.
- The PFD shall represent the earth in brown.
- The horizon line shall be a distinct, bold white line for easy visibility against both the sky and earth backdrops.



RESULTS: REQUIREMENTS 1...9 AND GPT-4

100% fulfillment achieved

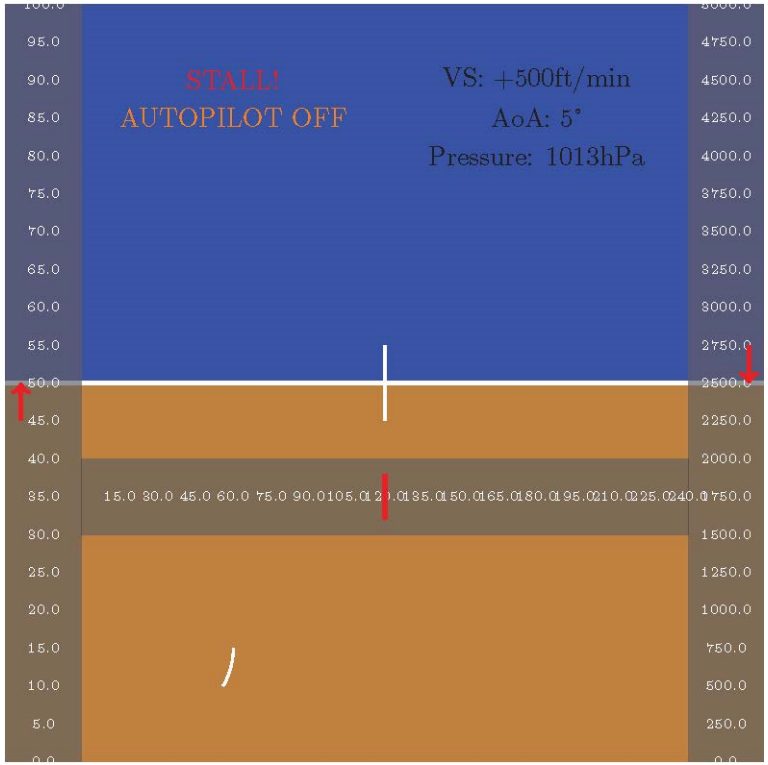
3. ... 7. *omitted for clarity*

8. Additional Flight Information:

- The PFD shall display other pertinent flight data such as vertical speed, angle of attack, and barometric pressure.
- This information should be arranged in a manner that does not clutter the primary attitude information.

9. Warning and Caution Indicators:

- The PFD shall have provisions for displaying warning (red) and caution (amber) indications for critical flight parameters, such as stall warnings or autopilot disengagement.



RESULTS: REQUIREMENTS 1...9 AND GPT-4

Same requirements: Variant with 84% fulfillment

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Requirements **not** met:

6. Heading Indicator:

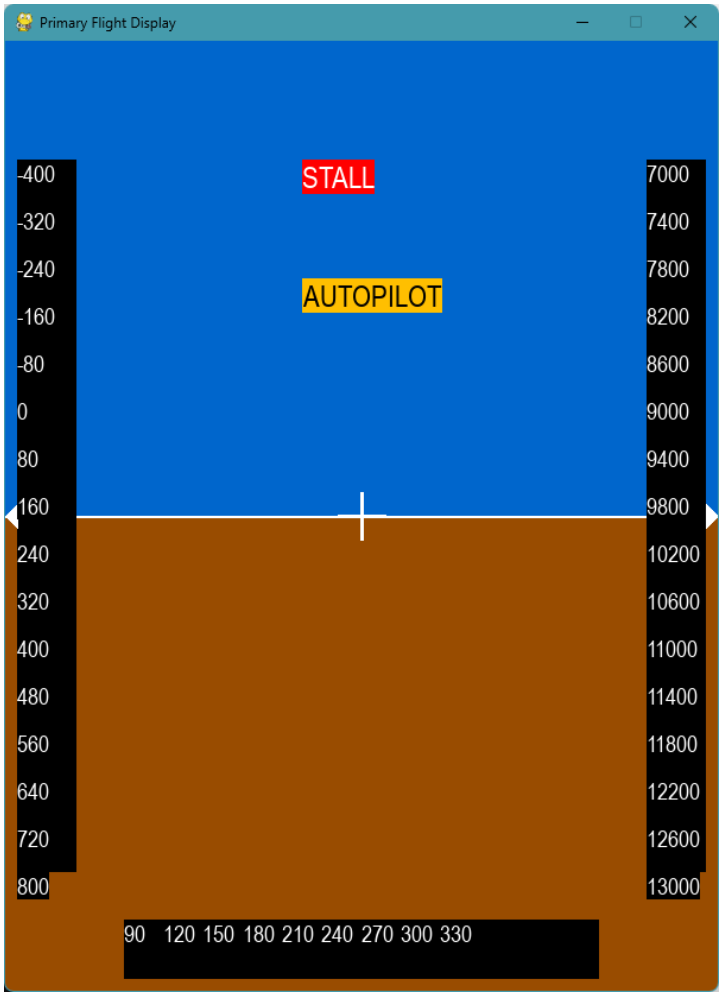
- ...
- The current heading shall be indicated by a fixed pointer or triangle, with the tape/rose rotating behind it.

7. Turn Coordinator:

- The PFD shall incorporate a turn coordinator, represented by a curved line or other suitable graphical representation, to show the rate and direction of turn.

8. Additional Flight Information:

- The PFD shall display other pertinent flight data such as vertical speed, angle of attack, and barometric pressure.



RESULTS FOR ALL 9 REQUIREMENTS

Only GPT-4 and GPT-3.5 succeeded

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- GPT-4 always generated error-free code
- GPT-3.5 generated correctable code
- Other LLMs tested not ready for integration

Not to be confused:
Code generated by LLM
vs.
Code generated by KCG

LLM	Degree of fulfillment	# of error-free code variantes	# of correctable code variants
GPT-4	Min. 37% Median 74% Max. 100%	14 of 14	N/A
GPT-3.5	Min. 16% Median 39% Max. 68%	7 of 8	1 of 8[a]
CodeLlama	0%	0 of 2[b]	0 of 2[b]
StarChat	0%	0 of 2[c]	0 of 2[c]
CodeGen2.5	0%	0 of 2[c]	0 of 2[c]

Footnote:
[a] contained errors that GPT-3.5 corrected after being instructed
[b] code output ended after approx. 5000 characters
[c] timeout after several minutes without any output

RESULTS FOR REQUIREMENTS 1 TO 5

CodeLlama now produced code

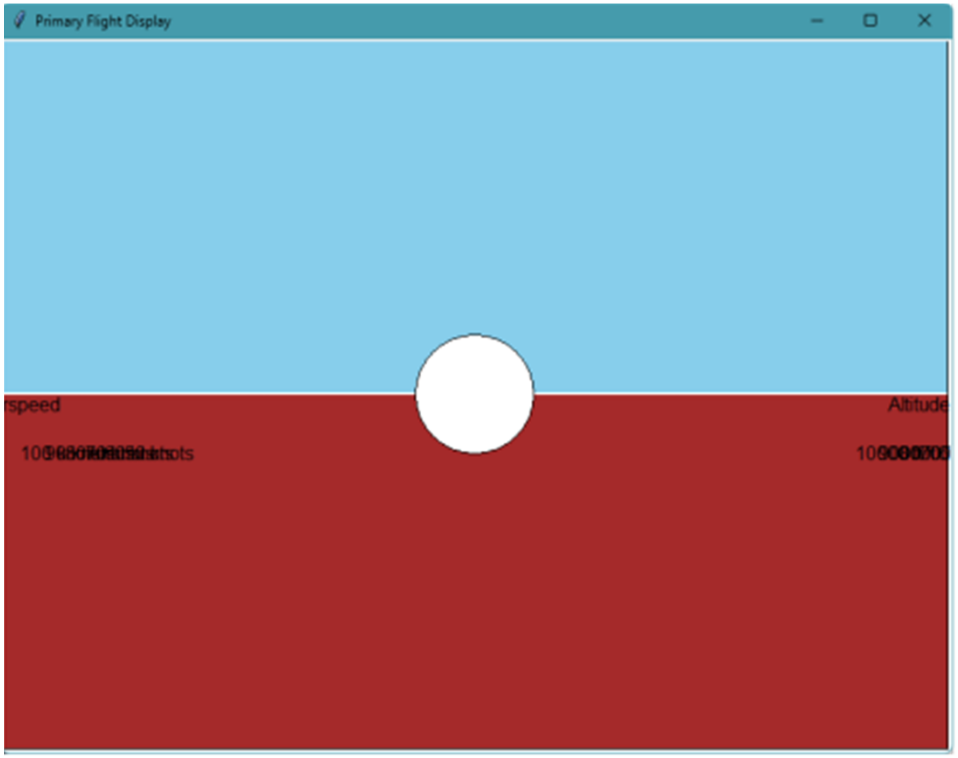
- CodeLlma generated model for shorted list of requirements due to restricted context window
- Other LLMs tested still not usable

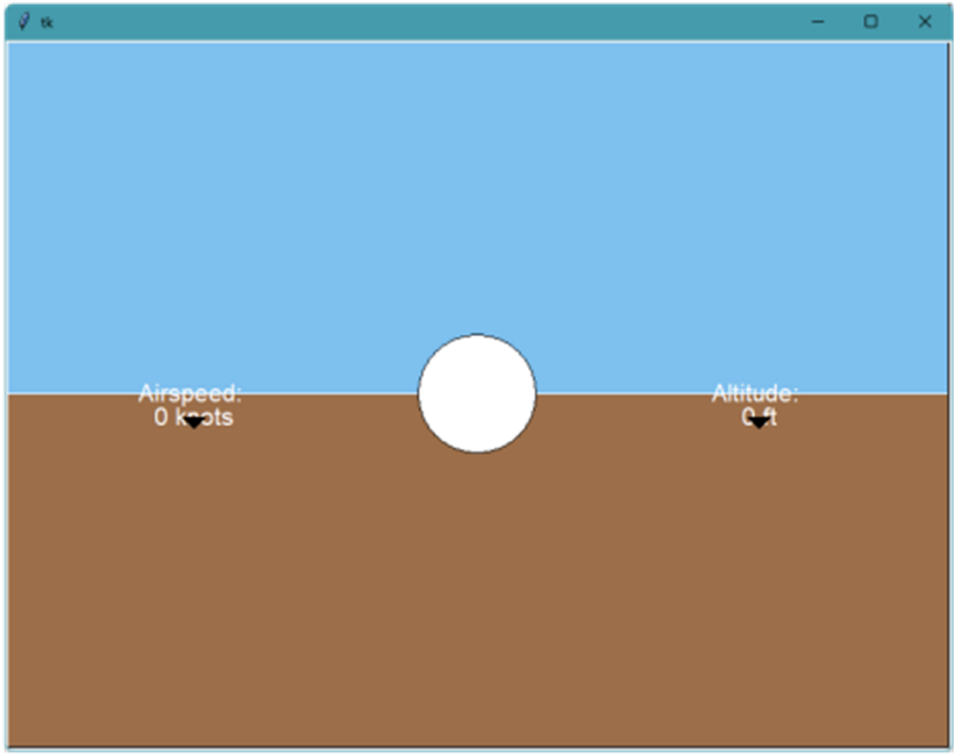
LLM	Degree of fulfillment	# of error-free code variantes	# of correctable code variants
GPT-4	100%	8 of 8	N/A
GPT-3.5	Min. 64% Median 85% Max. 96%	4 of 4	N/A
CodeLlama	Min. 14% Median 29% Max. 86%	0 of 6	6 of 6[a]
StarChat	0%	0 of 2[b]	0 of 2[b]
CodeGen2.5	0%	0 of 2[b]	0 of 2[b]

Footnote:
[a] repeatedly the same error using Qt (code could be corrected manually)
[b] timeout after several minutes without any output

CODELLAMA VARIANTS

Best results (57% and 86% fulfillment) for shorted list of requirements (requirements 1...5)





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CONCLUSION

LLMs / AI can *assist* human engineers, but should never replace them completely

SCENARIO

AI acting as assistant to engineering teams

Challenge / Risk:

What if the assistant (AI) becomes more experienced, efficient and reliable than the human team?

⇒ get rid of human-in-the-loop policy?

⇒ humans only for high-level requirements?

REFERENCES AND CONTACT INFORMATION

Comments and discussion always welcome!

SELECTED REFERENCES

Full list: see paper

1. OpenAI, “Gpt-4 technical report,” ArXiv, vol. abs/2303.08774, 2023. [Online]. Available from: https://arxiv.org/abs/2303.08774
2. H. Touvron et al., “Llama 2: Open foundation and fine-tuned chat models,” 7 2023. [Online]. Available from: https://www.semanticscholar.org/paper/104b0bb1da562d53cbda87aec79ef6a2827d191a
3. R. Li et al., “Starcoder: may the source be with you!” 2023. [Online]. Available from: http://arxiv.org/abs/2305.06161
4. E. Nijkamp, H. Hayashi, C. Xiong, S. Savarese, and Y. Zhou, “Codegen2: Lessons for training llms on programming and natural languages,” arXiv preprint, 2023.
5. R. Bagnara, A. Bagnara, and P. M. Hill, “The misra c coding standard and its role in the development and analysis of safetyand security-critical embedded software.” CoRR, vol. abs/1809.00821, 2018. [Online]. Available from: http://dblp.uni-trier.de/db/journals/corr/corr1809.html#abs-1809-00821
6. R. Bagnara, M. Barr, and P. M. Hill, “Barr-c: 2018 and misra c: 2012: Synergy between the two most widely used c coding standards.” CoRR, vol. abs/2003.06893, 2020. [Online]. Available from: http://dblp.uni-trier.de/db/journals/corr/corr2003.html#abs-2003-06893
7. J. Holt, SysML for Systems Engineering: A Model-Based Approach, ser. Computing. Institution of Engineering and Technology, 2018. [Online]. Available from: https://digital-library.theiet.org/content/books/pc/pbpc020e

SELECTED REFERENCES

Full list: see paper

8. D. Iqbal, A. Abbas, M. Ali, M. U. S. Khan, and R. Nawaz, “Requirement validation for embedded systems in automotive industry through modeling,” IEEE Access, vol. PP, pp. 1–1, 01 2020.
9. H. Touvron et al., “Llama: Open and efficient foundation language models,” 2023. [Online]. Available from: http://arxiv.org/abs/2302.13971
10. P. Liang et al., “Holistic evaluation of language models,” 2022. [Online]. Available from: https://arxiv.org/abs/2211.09110
11. F. Chollet, “On the measure of intelligence,” 2019. [Online]. Available from: http://arxiv.org/abs/1911.01547
12. A. Srivastava et al., “Beyond the imitation game: Quantifying and extrapolating the capabilities of language models,” 2023. [Online]. Available from: http://arxiv.org/abs/2206.04615
13. E. Davis, “Benchmarks for automated commonsense reasoning: A survey,” 2023. [Online]. Available from: https://arxiv.org/abs/2302.04752
14. T. B. Brown et al., “Language models are few-shot learners,” 2020. [Online]. Available from: https://arxiv.org/abs/2005.14165
15. H. W. Chung et al., “Scaling instruction-finetuned language models,” 2022. [Online]. Available from: https://arxiv.org/abs/2210.11416

THANK YOU FOR LISTENING

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