DELFT UNIVERSITY OF TECHNOLOGY
FACULTY OF AEROSPACE ENGINEERING

Course : Aerospace Human-Machine Systems (resit) (AE4316)
Date : April 7, 2016 from 13:30 until 16:30 hr
Lecturer : dr.ir. M.M. van Paassen et al.
Remarks : Write your name, initials and student number on your work.
Answer all questions in English and mark all pages with your name.

Instructions

This exam consists of 6 questions.

Allowed Items

Formula sheet ae4316
Calculator (programmable calculators are not allowed)
scrap paper, ruler, protractor

Grading information

The exam consists of 6 questions, each correctly answered question is awarded 15 points. The final mark is then:

$$1 \leq 1 + 6/10 * (0 \ldots 15) \leq 10$$

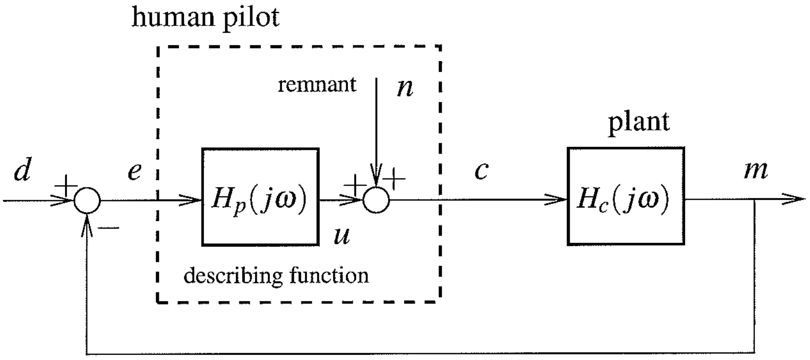

Figure 1: Closed loop manual control task: a following task with a compensatory display.

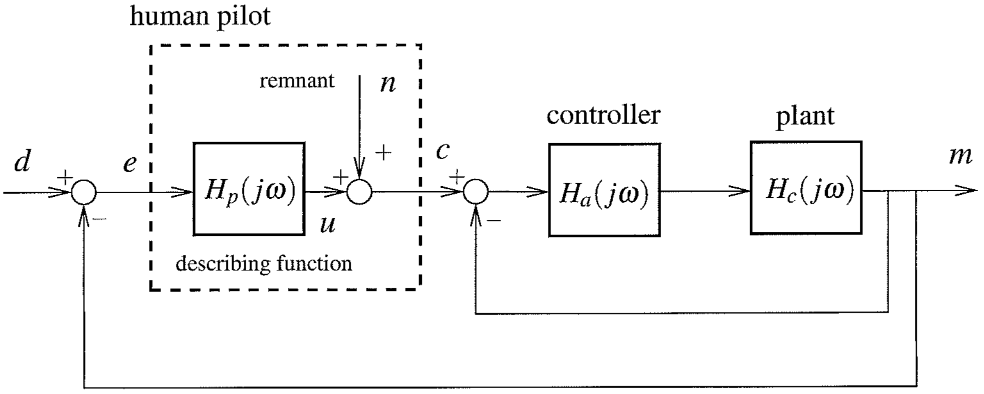

Figure 2: Closed loop manual control task: a following task with a compensatory display, with a control system added.

1. PILOT MODELS

Figure 1 shows a closed loop manual control task. In this figure, $H_c(j\omega)$ depicts the system to be controlled and $H_p(j\omega)$ the pilot frequency response function. The system to be controlled has the following dynamics:

$$H_c(j\omega) = \frac{K_c}{j\omega(1 + j\omega)},$$

with $K_c = 4$. Also in this figure, n represents the pilot remnant signal, and d represents the signal to be followed, which has a bandwidth of 1.1 rad/s.

[a] Draw a Bode plot of the system dynamics $H_c(j\omega)$.

[b] Derive a relationship between the inputs to the closed loop (n and d) and the output m.

[c] Based on McRuer's crossover model, what do you suggest to be the structure of the pilot model $H_p(j\omega)$? Explain your answer.

[d] Using the Verbal Adjustment Rules, compute the parameters of the pilot model, the crossover frequency, and the phase margin.

Now, a bright student decides that in order to help the human pilot, a fly-by-wire system needs to be installed, see Figure 2. Here, $H_a(j\omega)$ represents an automatic controller with *dynamics of your choice.*

[e] What are the 'equivalent dynamics' to be controlled by the human pilot?

[f] What would the dynamics of the automatic controller *ideally* be, from the perspective of the pilot? Derive the controller's frequency response and explain your answer.

2. AUTOMATION

[a] In the early days of automation, human-machine interaction was approached by so-called function allocation models. What is the most famous function allocation model called and briefly describe how this model allocates functions between humans and machine. In your answer, include at least two examples of functions allocated to humans and to machines. (4 points)

[b] Describe two issues associated with function allocation models. (2 points)

[c] Another way to look at human-machine interaction is captured by so-called "Level of Automation" (LOA) taxonomies. Explain what LOA taxonomies are about and explain which two things they consider in terms of human and machine roles. (2 points)

[d] A typical LOA taxonomy is depicted in Figure 3, which shows a discretized human-machine 'control' continuum. When applied to advisory systems, this LOA taxonomy typically contains 5 levels which are named as follows:

1. None
2. Information Integration
3. Management by Consent
4. Management by Exception
5. Full Automation

What are 'Management by Consent' and 'Management by Exception' and what is the difference between them? (2 points)

[e] At which level can one typically find the Traffic Collision Avoidance System (TCAS), the Flight Management System (FMS), and an ATC radar display? Briefly motivate your answers. (3 points)

[f] Briefly describe two issues related to the usability of LOA taxonomies in the design of human-machine systems. (2 points)

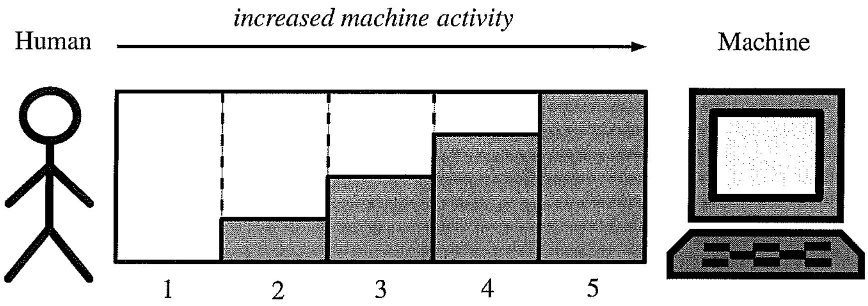

Figure 3: A discretized human-machine control continuum.

3. WORKLOAD

[a] Explain the difference between Task Demand Load and Mental Load. (2 points)

[b] When designing a *control* support system, is the designer trying to influence the Task Demand Load or the Mental Load? Explain your answer. (2 points)

[c] When designing a *display* support system, is the designer trying to influence the Task Demand Load or the Mental Load? Explain your answer. (2 points)

[d] One of the measurement techniques used in workload assessment uses a secondary task. While maintaining performance on the subject's primary task (the one that has to be measured), a subject also performs a secondary task.
What is measured with the secondary task technique, Mental Load or Task Demand Load? (1 points)

[e] What is the rationale of the secondary task technique? (2 points)

[f] Any workload measurement technique needs to fulfill at least the requirements concerning *obtrusiveness*, *sensitivity*, *reliability*, and *consistency*. Briefly describe what these requirements mean. (4 points)

[g] Can the secondary task technique be combined with subjective indicators for workload measurement, such as the NASA TLX or the Modified Cooper-Harper rating? Explain your answer. (2 points)

4. HUMAN ERROR

The following description is about an incident with an Airbus A330-200

Description

On 8 March 2013, the crew of an Airbus A330-200 (VH-EBV) being operated by Qantas on a scheduled passenger flight from Sydney to Melbourne unintentionally descended prematurely during an attempt by the crew to fly an approved visual approach in day VMC and activation of an EGPWS 'PULL UP' Warning was followed by a full recovery climbing to 4000 feet. None of the 222 occupants were injured during that manoeuvre.

Investigation

An Investigation was carried out by the ATSB. It was noted that the Captain had accumulated over 20,000 flying hours including approximately 2270 on the A330. The First Officer had accumulated just over 10,000 including approximately 1000 on the A330.

It was established that, shortly before the crew had been about to begin descent with the Captain as PF and the AP engaged, ATC had "cancelled all speed restrictions, requested a high-speed descent and advised the crew to expect track shortening" and the high speed descent was accepted. Approaching approximately 20 nm from destination and in descent just above 4000 feet ATC asked the crew to report when visual which, already having the runway in sight, they then did - although the Captain later told the Investigation that "visibility was affected by sun glare and terrain shadowing due to mid-level scattered cloud". At this stage, the aircraft "was about 2,000 ft below a nominal 3° descent profile and 1,500 ft above the lower limit of controlled airspace". After further descent clearance, 3000 feet altitude was reached when 14 nm from touchdown and "on a bearing displaced 45° from the extended landing runway 16 centreline". This position was 800 feet above the lower limit of controlled airspace and about 1,800 feet below the operator-recommended nominal 3° descent profile. Then, leaving 3000 feet, the Captain selected a 1000 feet altitude target (equivalent to 550 feet agl) and began to descend in 'Open Descent' mode. ue The First Officer subsequently stated that he had not heard the Captain verbalising these actions and had been unaware that the altitude selector had been changed. The resultant rate of descent remained high (about 2000 fpm) although the aircraft was already well below a 3° descent profile.

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The Captain reported that despite not being on or near the extended runway centreline, he had been monitoring the ILS GS deviation indication and that it had been continuing to indicate that the aircraft was above the glide slope. Despite the fact that other valid flight path information was available he continued to use this indication as his "primary vertical flight path guidance". Meanwhile, the First Officer stated that he had been monitoring the aircraft flight path by visual reference to the ground and he had considered the approach to be "proceeding normally" until he realised from looking out that the aircraft was too low. He reported having then cross-checked the ILS GS deviation on his PFD and finding that it showed the aircraft to be below-profile. This had prompted him to warn the Captain that the aircraft was too low and in response, the Captain had selected V/S mode at 500 fpm on the FCU. However, eight seconds later and 9nm from touchdown, two EGPWS 'TERRAIN' alerts occurred with the aircraft at about 600 feet agl. Activation of an EGPWS 'PULL UP' followed almost immediately and the Captain responded by initiating a full recovery climbing to 4000 feet. At the point this action was taken, the aircraft was 1900 feet below a nominal 3° approach vertical profile and had also just left controlled airspace. On completion of the recovery and reaching 4000 feet, radar vectors were provided for an ILS approach to runway 16 and this and the subsequent landing were normal.

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After the occurrence, ANSP Airservices Australia advised that the MSAW system "had been inhibited in certain areas to the north-east of Melbourne to reduce the number of false alarms in those areas" and that "when a flight is cleared for a visual approach, its corresponding cleared flight level is set to zero feet on the controller's air situation display which automatically inhibits the MSAW aural alarm and display for that flight.

In respect of pilot SOPs applicable to visual approaches, it was noted that Qantas had a prohibition on the use of Open Descent Mode for 'final approach' and also required that the rate of descent when between 5000 feet and 1000 feet agl should not be greater than the aircraft height agl. Any excessive rates of descent required the PM to call 'Rate of Descent' and the PF "to acknowledge and adjust accordingly". In the investigated approach, once the aircraft was descending below 2000 feet agl, this maximum rate was mainly exceeded and, as the aircraft descended through 1000 feet agl, the achieved rate of descent was almost double the maximum permitted. It was also noted that an EGPWS PULL UP Warning occurring in "daylight visual conditions, with terrain and obstacles clearly in sight" could be considered cautionary subject to "positive action was to be taken until the alert stopped or a safe flight path was assured". Use of ILS GS indications when an aircraft was not on the ILS LOC was not specifically addressed in Qantas SOPs, but the ILS signal protection requirements in ICAO Annex 10 only cover the integrity of the GS within 10 nm of the runway and up to 8° either side of the ILS LOC.

Abbreviations

EGPWS	Enhanced Ground Proximity Warning System
ATC	Air Traffic Control
AP	Autopilot
PF	Pilot Flying
ILS	Instrument Landing System
GS	Glide Slope
MSAW	Minimum Safe Altitude Warning (an ATC system)

[a] From the abstract above, identify four errors. Indicate whether the error was skill-based, rule-based or knowledge-based, and motivate that. For two of these, indicate the possible error shaping factor. (4*2.5 points)

[b] The high-speed visual approach with path shortening can be seen as an attempt by ATC to increase the throughput of the system in favourable metereological conditions. In the conclusion by the investigating authorities, it was stated that "the absence of a shared mental model increased the risk that the First Officer would not identify and respond appropriately to the Captain's actions". However, also, the automation aids (EGPWS on board of the aircraft and the MSAW system) did not provide timely help in monitoring the approach.

Using this incident as an example, shortly discuss (a) why the monitoring task for co-pilot and for the automation support was more difficult than for a conventional approach and (b) what would happen to the air transportation system if more automation is to be introduced, e.g. in the form of single-pilot flight decks and UAV flights. (max 60 words, (5 points)).

5. EXPERIMENTAL DESIGN

In his landmark experiments, McRuer found that compensatory tracking behavior is strongly influenced by the dynamics of the controlled element, $Y_c(j\omega)$. McRuer, however, never investigated tracking tasks in which the operator received vestibular motion feedback. Now suppose that you are interested in extending his results, by looking at differences in compensatory tracking behavior in conditions with and without vestibular motion feedback, and how these differences are affected by the dynamics of the controlled system. To verify this using an experiment, you formulated the following hypotheses:

- Tracking performance gets better with vestibular motion feedback.
- When vestibular motion feedback is available, higher crossover frequencies will be adopted.
- The effects of vestibular motion feedback are equivalent for a wide variation in controlled element dynamics.

[a] An experimental design is commonly characterized by three different types of variables. What are the names of these variables and what is their definition? (3 points)

[b] For the experiment (based on the description above), give two examples for *each* of these three types of variables. Explain your answers. (4 points)

As time in the simulator is very expensive, you decide that you want to limit your experiment to four experimental conditions, which you plan to evaluate in an experiment with a "within-subjects design" with four participants (subjects).

[c] Explain what the main benefit of an experiment with a "within-subjects design" is, compared to the alternative of a "between-subjects design". (2 points)

[d] Define four experimental conditions that would allow you to test your three hypotheses. (1 points)

[e] Propose a suitable experiment matrix (order of condition testing) for your experiment. (2 points)

Now suppose that you performed your planned experiment and analyzed the data. You found nice results that seem to confirm your hypotheses, but unfortunately the statistical analysis you performed showed that *none* of your results were statistically significant. To improve the significance of your results, you would now like to collect data from more participants than initially planned.

[f] Given your experiment design, how many additional participants would you invite? Explain your answer. (1 points)

[g] Could you re-use your experimental design (from subquestion [e]) for collecting this extra data, or not? Explain your answer. (2 points)

6. MOTION PERCEPTION

The Subjective Vertical (SV) is the direction perpendicular to the earth's surface, as perceived by a human observer. Thereby, the SV tells you how you think you are *oriented* with respect to the direction of gravity. Due to imperfections in human motion perception, your SV may sometimes tell you that you are in a different orientation than really is the case.

It is well-known that the perception of the SV is based on signals from the vestibular organ, *but it is also strongly influenced by visual inputs* perceived with the eyes. The *visual attractor* model proposed by Van der Steen can help us understand this visual influence on the SV.

[a] What are the inputs and outputs of Van der Steen's *visual attractor* model? (2 points)

[b] What is the working principle of the visual attractor model? (4 points)

The working principle of the visual attractor is exploited in a theme park ride known as the "madhouse", see Fig. 4. An example of this type of ride is "Villa Volta" in the *Efteling*, a well-known amusement park in the Netherlands. This type of ride is designed to induce huge changes in people's subjective vertical, using strong visual stimuli (pitch-axis rotation of house interior) in combination with limited vestibular inputs (pitching of seating platform).

[c] Assume that the madhouse starts from a normal upright orientation at $t = 0$ seconds with a constant (pitch-axis) rotational velocity of 10 deg/s as the visual stimulus. Further assume that the vestibular stimulus provided at the same time is only 5 deg/s in magnitude. Does the visual attractor model predict that the 10 deg/s rotation is perceived perfectly if the madhouse is set up like this? To support your answer, provide sketches (*plots with time on the x-axis!*) of the rotational velocity perceived with the visual system only (Sketch 1) and the vestibular systems only (Sketch 2), as well as a sketch of the resulting output of the visual attractor model (Sketch 3). (7 points)

[d] To ensure that the mismatch in visual and vestibular inputs is not noticeable, the visual

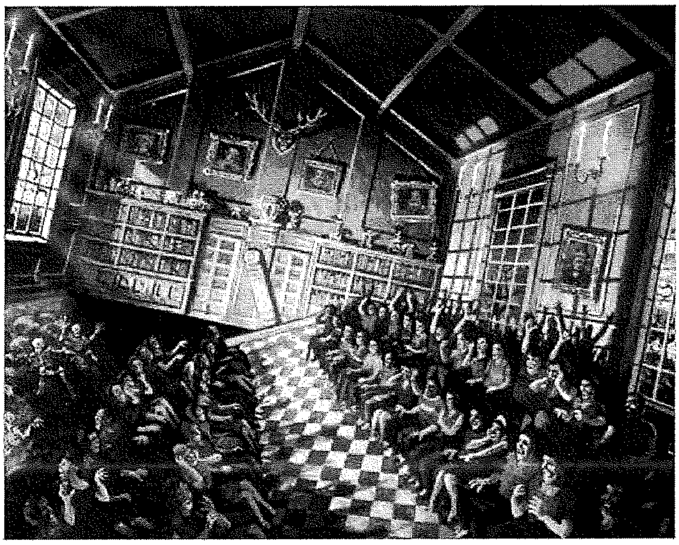

Figure 4: The "*madhouse*" theme park ride.

stimulus is made especially strong and convincing. This is done by maximizing *optical flow*, using extensive wall decorations, etc. This ensures a stronger "pull" by the visual attractor. Which parameter of Van der Steen's visual attractor model can be adapted to model this effect? And should it be increased or decreased for a stronger visual attractor? (2 points)