Human-Machine Systems Exam August 2005 – Problems

1 Crossover model theorem

Consider a general closed loop manual control task. The system to be controlled is described by $H_c(j\omega)$ and the pilot dynamic control behavior is given by $H_p(j\omega)$. The reference signal is i, the output is y, the error is $e = i - y$ and the system input is u.

1. The human controller adapts his/her control behavior to the dynamics of the system to be controlled. McRuer and his colleagues have captured this adaptation in a theorem, the Crossover Model Theorem.

   Describe this theorem in the frequency domain, i.e. in terms of $H_c(j\omega)$ and $H_p(j\omega)$.

2. Consider the single-axis manual control task, a following task with a compensatory display. The dynamics of the system $H_c(j\omega)$ to be controlled are:

   $$H_c(j\omega) = \frac{1.0}{j\omega(j\omega + 0.2)}. \tag{1.1}$$

   The bandwidth of the input forcing function ω_i is 2.0 rad/s.

   Draw a Bode plot of the system to be controlled.

3. Assume that the human controller will adjust his/her control behavior $H_p(j\omega)$ to the system to be controlled $H_c(j\omega)$. What model *structure* would you choose, in terms of the Simplified Precision Model. Explain your answer.

4. Determine the model parameters τ_L, τ_I and τ_e according to McRuer's Verbal Adjustment Rules. Compute the crossover frequency ω_c, the phase margin ϕ_m and the value of the model parameter K_p.

5. A graduation student has implemented a single-axis manual control task, a following task with a *pursuit display.* The dynamics of the system $H_c(j\omega)$ to be controlled are:

   $$H_c(j\omega) = \frac{1.0}{j\omega(j\omega(j\omega + 2.0))}. \tag{1.2}$$

   The bandwidth of the input forcing function ω_i is 1.0 rad/s.

   Explain using a sketch what the main differences are of this particular tracking task with respect to the task conducted in the previous question.

6. Can the system be controlled? Explain your answer. Is this something that can be predicted using the Crossover Model?

7. In order to improve performance, the student includes a *prediction symbol* on the display. The prediction symbol shows what the output of the system will be after T_p seconds, using a first order prediction algorithm. That is:

   $$y_p = y + \dot{y}T_p, \tag{1.3}$$

   with y the output of the system, y_p the position of the predictor symbol on the screen, and T_p the prediction time.

   Does the addition of the prediction symbol help the operator in controlling the system H_c? Explain your answer.

8. Does the operator change his/her control strategy when the prediction symbol is included?
9. How would you choose the value of the prediction time T_p.

2 Visual perception and visual displays

Consider an airplane flying over a flat surface at a height h above the ground. The world consists of lines perpendicular to the line of motion. The distance between the lines no the flat surface plane is 200 meters. This is called situation I.

1. Which two effects play a major role in the perception of the velocity of self-motion? Explain their origin and, if possible, provide a mathematical background.
2. Assume that the distance between the lines is reduced to 100 meters (situation II). The velocity V and height h of the observer remain the same. How does this affect the perception of the velocity of self-motion?
3. Now, we decrease the height above the plan with 50% (situation III). How does this affect the perception of the velocity of self-motion?
4. Do you think that the perceived velocity of self-motion is the same in situations I and III? Explain your answer.

3 Abstraction hierarcy

The Abstraction Hierarchy (AH) as introduced by Jens Rasmussen can be used to map knowledge about a system at different levels of abstraction.

1. Name the different levels of the Abstraction Hierarchy as described by Rasmussen. Give a description of the kind of representations at the different levels.
2. Consider a 'holiday project' in which you want to roam around in a relatively uninhabited region, and you can take either a tent or a caravan to get shelter during the night. The goal of taking a tent or caravan is to have a mobile resting place. The following descriptions of a device for camping are from different levels in the abstraction hierarchy; mobile resting place, isolation, shelter, tent, caravan, mobility, light brown cloth and aluminum support, light weight, wheels.

   Put the above descriptions at the proper levels in the abstraction hierarchy.
3. Rasmussen distinguishes two concepts in relation to the abstraction hierarchy, reasons and causes. These concepts are used in reasoning upwards (to a higher level of abstraction) and downwards (to a lower level of abstraction).

   Explain the concepts of reasons and causes as Rasmussen defines them.
4. If you consider the abstraction hierarchy for design, i.e. reasoning from the goals you want to achieve, you can choose different solutions for achieving these goals, and end up with different systems, such as the tent and the caravan. Discuss where the tent and caravan have common representations in the AH and where they differ.

4 Human error

Background: The following is an excerpt from an accident report. The approach was flown with a DC-9. This type of DC-9 was equipped with a High/Low/Off hydraulics system. In the Low position, the hydraulics system provides enough power for use in-flight. The hydraulics must be set to the High position to provide enough power for the landing gear and the flaps. Checking that the hydraulics are set correctly is part of the in-route checklist.

The First Officer is the pilot flying, the Captain is the pilot not-flying, this means that he must make the configuration changes and supervise the aircraft systems. Any diagnostic tasks are primarily to be carried out by the PNF.

In this company, the rule called the 'sterile cockpit rule' must be adhered to. This means that any irrelevant conversation or activity may not take place during critical phases of the flight.

At 0840:42, air traffic control (ATC) at Houston Center issued a clearance to flight 1943 to descend from the en route altitude of 35,000 feet to 13,000 feet mean sea level. The first officer began the descent, and the captain performed the descent checklist.

At 0845:31, the first officer called for the in-range checklist. Between 0845:37 and 0846:10, the captain referred to each of the seven items on the in-range checklist, in the correct order, except for the fourth item, 'Hydraulics,' to which the captain did not refer. The first officer responded 'checked set' to the third item, 'Flight Instruments, Altimeters,' and 'on' to the fifth item, 'Shoulder Harness.'

Flight 1943 received clearance to descend to 10,000 feet at 0847:12. At 0848:39, the captain made initial contact with the Houston Terminal Radar Approach Control Arrical East controller and requested runway 27. At 0849:33, the controller cleared flight 1943 to descend to 7,000 feet. At 0853:23, the controller instructed flight 1943 to 'join the two seven localizer' and descend to 4,000 feet.

At 0854:49, the first officer called for the approach checklist. Between 0854:49 and 0855:18, the captain referred to the first four of the nine items on the checklist. At 0855:27, the checklist was interrupted by the first officer informing the captain that he intended to use manual spoilers and 40° of flaps for landing. The captain resumed completing the checklist at 0855:56, and accomplished the next three items before he was interrupted again at 0856:06, when the controller transmitted 'Continental nineteen forty three, thirteen miles from the marker, maintain two thousand till established on the localizer, clear ILS two seven approach.' At 0857:02, the controller instructed flight 1943 to maintain a speed of 190 knots or faster to the outer marker and to contact the tower. According to the captain, the ATC request to maintain 190 knots or faster to the marker was not unusual at IAH on a visual flight rules (VFR) day. In his post-accident statement, the captain reported that at the time ATC made the request, the airplane's indicated airspeed was approximately 210 knots, so no speed adjustment was necessary.

After making the landing public address (PA) announcement, the captain contacted the Houston Intercontinental Air Traffic Control Tower Local East controller, and at 0857:58, the flight was cleared to land. At 0858:08, the captain said 'now, where was I,' referred to the last two items on the approach checklist, and stated 'approach check complete.'

At 0858:48, the captain commented 'aw shoot. I can't play tennis when it's like this... well maybe this afternoon it'll clear up. Actually I've still got a lot of time.' At 0859:00, the first officer said 'go slats and five.' After the CVR recorded the sound of a click at 0859:03, the captain stated 'slats are going to five.' The captain later recalled that he felt the slats extend, and the first officer recalled that the blue 'SLATS EXTENDED' light illuminated. Between 0859:14 and 0859:37, the captain engaged the first officer in nonessential conversation about the weather. At 0859:50, the first officier initiated dialogue with the captain to clarify whether the controller had asked them to maintain 190 knots to the outer or middle marker. The discussion ended at 0900:00, when the first officer commented 'heh' and then made two remarks, of which only a few words were intelligible on the CVR recording. In a written statement submitted to the Safty Board on January 27, 1997, the first officer reported that he had noticed the flap gauge indicating 0° at 0900:00 and that his subsequent remarks had been in reference to the flap gauge. At 0900:11, the captain reported the airport in sight.

At 0900:13, after crossing the outer marker, the first officer called for the flaps to be extended to 15°. During an interview on February 20, 1996, and in his written statement dated February 27, 1996, the first officer indicated that at this point he realized that the flaps had not extended and touched the flap gauge to show the captain that it indicated zero. According to the captain, he responded by confirming that the flap handle was positioned to 15°. At 0900:33, the captain said 'I think the flaps <<unintelligible>>.' At 0900:35, three intermittent sounds from the landing gear warning horn were produced, according to the first officer, by the captain rapidly moving the throttles back and forth. At 0900:37, the captain said 'well we know that, you want the gear.' At 0900:38, the first officer called 'gear down,' and 2 seconds later, the CVR recorded the sound of [the gear handle]. At 0900:41, the first officer called for the landing checklist and the flaps to be extended to 25°. At 0900:46, the gear warning horn began to sound. During the next 12 seconds, the first officer called for the flaps to be extended to 40° and then to 50°. At 0901:00, the first officer stated 'I don't have any flaps.' In his postaccident statement, the captain reported that 'the aircraft did not feel as though we had 50 flaps (didn't balloon and aircraft didn't slow).' The CVR does not indicate that the landing checklist was ever started.

The aircraft made a crash landing with the gear up and the flaps at 0 degrees.

Explain the difference between latent and active errors.

Identify the slips/lapses and mistakes made by the captain and the first officer, and classify them according to the Rasmussen levels of behaviour (if possible). Try to find at least four errors!

5 Vestibular system

Prolonged exposure to a zero-gravity environment, such as during interplanetary flight, can lead to reduction of bone and muscle strength. To prevent these conditions, people have proposed the use of rotating spacecraft ('wheels etc.') where the centripetal acceleration provides an artificial gravity.

1. If the threshold for perception of angular velocity is 0.1 deg/s, how large should the spacewheel have to be to generate a 5 m/s^2 artificial gravity with a rotational rate that is below the threshold for perception of angular velocity?
2. If a smaller wheel is used, with a rotational velocity above the threshold for perception, e.g. 10 deg/s, describe the sensations that a person in the wheel would feel who, after standing with his face in the direction of wheel velocity, would turn 90 degrees to the left, now facing the direction of the rotation vector. Assuming an axis system fixed to the head with x pointing forward, y pointing to the right and z pointing down, sketch the rotational sensations around the x and y axes.
3. What would be the best orientation for a bed if we want to minimize the effects on a person sitting up from a position lying on his/her back?
4. Assume a sleeping orientation with your feet in the direction of the rotation vector. Should you have the wall of the cabin on the left or right side of the bed (assuming a position lying on your back in the bed), to minimize the risk of falling out of bed if you sit up from a lying position? Explain your answer.

6 Visual perception and visual displays

1. What are the two phases in visual processing?
2. Consider figure 1, illustrating an important visual effect. Describe the visual effect that you experience.
3. What is causing this effect to happen?
4. How can we use this effect in designing interfaces?

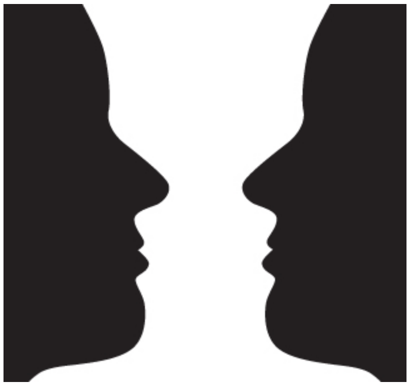

Figure 1: One vase or two faces?