

# Lecture S1 Muddiest Points

## General Comments

It's great to be back lecturing! Now the mud:

## Responses to Muddiest-Part-of-the-Lecture Cards

(29 cards)

1. *Are we going to review what we did last term? (1)*

No, but I'd be happy to answer any questions you have about last term in office hours.

2. *Would you say that Unified Signals and Systems (both terms) is more 6.002 or 6.003 stuff? (1)*

The fall term was a small slice of 6.002; the spring term is much of 6.003, except that we do not do discrete-time signals.

3. *Has the problem with Airbuses you discussed in class ever caused the loss of an aircraft? (1)*

No, thankfully.

4. *Are all physical systems linear or nonlinear? Time-invariant or time-varying? Please give an example of a nonlinear equation. (1)*

Yes, all physical systems can be characterized as linear or nonlinear, and time-invariant or time-varying. In fact, all physical systems are nonlinear for large enough input signals, but many can be modeled as linear for reasonable inputs.

The differential equations for the dynamics of an aircraft are nonlinear, because the lift is a nonlinear function of the velocity — dynamic pressure is proportional to the square of the velocity.

5. *I liked your example of the actuator problem in the Airbus aircraft. (1)*

Great!

6. *Is there a limit to the number of inputs and outputs to and from a system? (1)*

No, although we will deal almost exclusively with single-input, single-output systems. I had a grad student who designed a control system for a system with 55 inputs and 55 outputs.

7. *The analogies between systems in general and aircraft systems was helpful. (1)*

Good! I think it's clear, but aircraft are examples of systems, not analogies.

8. *Is modeling a system response as a sum of step responses more or less accurate, or more or less useful than Fourier analysis? (1)*

Good question! In fact, they are closely related, as we will see. Both are completely accurate, and both are useful.

9. *How does a plane take off if it is time-invariant? Won't it just remain at the gate? (1)*

“Time-invariant” doesn’t mean that the plane isn’t moving (or that the state of the system isn’t varying). It means that the dynamics of the system don’t change over time. That is, the differential equations that describe the system don’t vary over time.

10. *To approximate a system with step responses, how exactly can you write it out without writing the exact equation of the function? (1)*

We’ll see the answer to this in the next lecture.

11. *How much are we going to use the book? (1)*

We won’t follow the book closely, but there will be a reading assignment for each lecture that you will be responsible for. It’s a nice text to have as a reference, too.

12. *Can you explain more carefully how*

$$\dot{m} = -V_e |f|$$

*makes*

$$\ddot{x} = \frac{1}{m(t)} f$$

*nonlinear? (1)*

The states of the system are  $x$ ,  $\dot{x}$ , and  $m$ . The differential for  $x$  (the second equation above) is nonlinear in  $m$ , because  $m$  enters the equation in a nonlinear way — it doesn’t appear as a linear term in the differential equation.

13. *If you were modeling an aircraft in industry, would you model it as a linear system and then compare your results to its true nonlinearity, or would you just accept your linear model as is? (1)*

Most likely, you would use the linear model for analysis and design, and then use a nonlinear simulation to ensure that the nonlinear effects do not produce unexpected results.

14. *What was the intention of asking the ambiguous PRS question about linearity and time-invariance? (1)*

To get you to think carefully about the definitions of linearity and time-invariance.

15. *If we know the system, why bother with steps? Wouldn't we know a [unreadable] function? (1)*

(a) Sometimes, we don’t “know” the system. That is, we might not know the differential equation, but we might be able to measure the step response. (b) As we’ll see, the step response is a good way to characterize a system.

16. *Didn't follow what you wanted to understand about the step response. (1)*

OK. We’ll talk more about this in the next lecture.

17. *Confused about what nonlinear is. (1)*

One way a system might be nonlinear is that the response to a given input doesn’t scale directly with the size of an input. A good example is the lift on an airfoil. If you increase

the angle of attack a little, the lift increases a little. If you increase the angle of attack a lot, the lift doesn't increase a lot, because the airfoil stalls.

Ultimately, a system is linear if and only if the superposition principle holds, that is, if the response to a sum of inputs is the sum of the response to individual inputs. That's important, because all the tools we'll work with this term on built on the superposition principle.

18. *If most systems are nonlinear, to what extent can we model those systems [as linear] without a loss of accuracy. (1)*

It turns out that many systems can be modeled quite well as linear. In fact, this is the norm — linear analysis is almost always a useful way to start.

19. *For the Airbus landing scenario: To keep the system linear, couldn't we just limit the input of the pilot? (1)*

Perhaps, but the fundamental problem is that if the pilot hits the limit, she will still have a problem controlling the aircraft. From her point of view, the plant dynamics have changed, and she will not be able to adapt fast enough to prevent the oscillations. However, you are right that a careful change in the aircraft dynamics can prevent the oscillations.

Pilot-induced oscillations are always the result of interactions between a pilot and a system with poor dynamics.

20. *Is this a good way to think about a linear model: If you look at any system in a short enough time interval, it appears linear. (1)*

No, not really. It is true that a system can be continuously re-linearized about its current operating point. However, this would then make the system time-varying, which isn't much better. If all this is confusing, don't worry about it too much. The point is that the definition of linearity looks at whole time histories, and looking over short time intervals is inconsistent with this view.

21. *No mud. (10)*

Good! There were some comments: *"I believe that requiring a muddy card from a student is completely absurd."* I'm not requiring that you have mud, I'm requiring that you reflect on the lecture, and then tell me if you do have mud. If you don't, you can just tell me the most important part of the lecture. *"Excellent lecture."* Thanks!