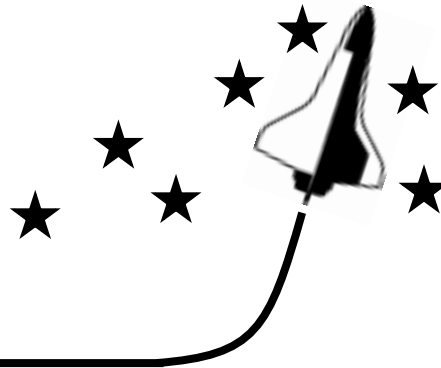


FACULTY NOTES

The LTAs and Spinoffs are designed so that each professor can implement them in a way that is consistent with his/her teaching style and course objectives. This may range from using the materials as out-of-class projects with minimal in-class guidance to doing most of the work in class. The LTAs and Spinoffs are amenable to small group cooperative work and typically benefit from the use of some learning technology. Since the objective of the LTAs and Spinoffs is to support the specific academic goals you have set for your students, the Faculty Notes are not intended to be prescriptive. The purpose of the Faculty Notes is to provide information that assists you to take full advantage of the LTAs and Spinoffs. This includes suggestions for instruction as well as answers for the exercises.



FACULTY NOTES

LTA 14

Space Vehicle Hold Down and Release Mechanism Design

General Remarks:

Typical story problems in mathematics require students to formulate an equation to model a situation. This LTA requires students to develop a qualitative graph to model the physical situation and to interpret graphs representing a physical event.

Section I

Restraining Force vs. Displacement Graphs

Hand out the first few pages of LTA 14 (Space Vehicle Hold Down and Release Mechanism Design) through Section I. This will provide the students with a general description of what a soft-release hold down system should do.

Students should work in groups of 2 - 4 for approximately 20 minutes to determine from the information handed out what the graph of Force vs. Displacement should look like. Then, have the groups critique each other's graph to see if the graphs satisfy the description of a soft release mechanism. Results should be a decreasing function in the first quadrant which ends on or near the x-axis, where x is displacement. As an example, see the restraining force graph in Figure 3, Section II.

It is sufficient to accept oral discussion for the explanations of Section I - a written explanation is not required. If a written report is desired, students tend to need a good deal of direction as to the structure of the report. Since Section I is to be used to elicit student ideas and stimulate discussion, a written report is not recommended.

Section II

Characteristics of a Restraining Force vs. Displacement Graphs

Hand out the rest of the LTA. The graph of the CRM restraining force in Figure 3 has several important features. a) The force starts out high and decreases to either a zero or to a small positive value. When the launch vehicle is released, any net upward force imparts a "kick" to the launch vehicle. Such an impulse or kick must be kept small. b) A near zero slope at beginning and end makes the change in the restraining force in those regions very small and leads to a smoother liftoff. However, not all soft release mechanisms have small initial and ending slopes. The graph of the CRM restraining force shown in Figure 3 is based on the release mechanism for the Saturn V used during the Apollo program.

Solutions

- 1) The graph should show that as the displacement increases the restraining force decreases. The graph should be smooth and it should decrease to zero.
- 2) **Mechanism A:**
 - a) Characteristics exhibited:
 - Energy absorbed by the CRM is within the acceptable range: 125,000 - 250,000 in-lb.
 - No sharp corners on graphCharacteristics lacking:
 - Flat or nearly flat graph at initial and final displacements
 - Decreasing graph throughout displacement interval
 - Low restraining force at release
 - b) Energy Absorbed is approximately 175,000 in-lb. (The result is based on one triangle with height = 50,000 lbs and base = 7 inches.)

General comments: Mechanism A is a bad design since the Force vs. Displacement curve increases throughout the displacement interval. We want a high restraining force initially and a low one at release.

- 3) **Mechanism B:**
 - a) Characteristics exhibited:
 - Flat or nearly flat graph at initial and final displacements
 - Decreasing graph throughout displacement interval
 - Low restraining force at release
 - No sharp corners on graphCharacteristics lacking:
 - Energy absorbed by the CRM is within the acceptable range: 125,000 - 250,000 in-lb.
 - b) Energy Absorbed is approximately 25,000 in-lb. (The result is based on 3 trapezoids and one triangle.)

General comments: Except for the small amount of energy that Mechanism B absorbs, it is a good design. The Force vs. Displacement curve is decreasing, smooth, and relatively flat at both ends. The restraining force is initially high, and near zero at release. This curve has the best overall shape, but the mechanism does not absorb enough energy.

4) **Mechanism C:**

a) Characteristics exhibited:

- Low restraining force at release
- No sharp corners on graph
- Energy absorbed by the CRM is within the acceptable range: 125,000 - 250,000 in-lb.

Characteristics lacking:

- Flat or nearly flat graph at initial and final displacements
- Decreasing graph throughout displacement interval

- b) Energy Absorbed is approximately 227,000 in-lb. (The result is obtained by doubling the area for the left half of the region. The area for the left half is based on 7 trapezoids and one triangle.)

General comments: Mechanism C is a bad design since the Force vs. Displacement curve is increasing during a part of the displacement. The curve is smooth but is not flat at both ends. One good feature is that the force at release is near zero. The initial restraining force is zero leading to a big jerk at the beginning. The CRM represented by this curve would be good if it were preloaded to about 3.5 in of displacement.

5) **Mechanism D:**

a) Characteristics exhibited:

- Decreasing graph throughout displacement interval
- Low restraining force at release
- No sharp corners on graph
- Energy absorbed by the CRM is within the acceptable range: 125,000 - 250,000 in-lb.

Characteristics lacking:

- Flat or nearly flat graph at initial and final displacements

- b) Energy Absorbed by the CRM is approximately 248,000 in-lb. (The result is based on 7 trapezoids.)

General comments: Mechanism D is a good design. The Force vs. Displacement curve is decreasing, smooth, and flat at the beginning. The curve is not flat at release, but the force at release is near zero. It would be better if the curve flattened a bit more at the end.

6) **Mechanism E:**

a) Characteristics exhibited:

- Decreasing graph throughout displacement interval
- Low restraining force at release
- No sharp corners on graph
- Energy absorbed by the CRM is within the acceptable range: 125,000 - 250,000 in-lb.

Characteristics lacking:

- Flat or nearly flat graph at initial and final displacements.

b) Energy Absorbed by the CRM is approximately 175,000 in-lb. (The result is based on one triangle with height = 50,000 lbs and base = 7 inches.)

General comments: If the curve for Mechanism E were flattened at the ends, it would be a good force vs. displacement profile for a CRM.

The following table summarizes the answers for Exercises 2 - 6.

Summary table for Exercises 2 - 6

Characteristics	Ex 2 Mech A	Ex 3 Mech B	Ex 4 Mech C	Ex 5 Mech D	Ex 6 Mech E
Flat or nearly flat at both ends	L	E	L	L	L
Decreasing on entire interval	L	E	L	E	E
Low force at release	L	E	E	E	E
No sharp corners	E	E	E	E	E
Energy absorption within range	E	L	E	E	E
Energy absorbed (in-lbs.)	175,000	25,000	227,000	248,000	175,000

E = Exhibits characteristic, L = Lacks characteristic

- 7) The only candidates for good CRM Mechanisms are B, D, and E because they are the only ones with a decreasing restraining force throughout the entire displacement. However, each of these could be improved. Mechanism B would be better if it absorbed more energy to bring it within the acceptable range, 125,000-250,000 in-lb. Mechanism E would be better if its graph were flattened at the beginning and end of the displacement. Mechanism D would be better if its graph were flattened at the end of the displacement.
- 8) In order from least to most energy absorbed, we have Mechanisms B, A or E, C, D.
- 9) Mechanism B would be the best one if it absorbed enough more energy to bring it within the Acceptable range, 125,000 - 250,000 in-lb, while its graph retained the same general shape. On the other hand, Mechanisms D and E would be very good if their graphs were flattened at both ends.

Section III

Controlled Release Mechanism for the Evolved Expendable launch Vehicle

10. a) Graph 1: Tensile Bar Mechanism
 - b) The description of the Tensile Bar Mechanism indicates that pre-loading is required. Because Graph 1 increases for the first part of its displacement, it represents a CRM that must be pre-loaded to the length at which the restraining force is largest. That is, the graph represents a restraining force that must be pre-loaded to the top of the curve where it is relatively flat. A second reason for making this selection is that the description of the Tensile Bar Mechanism

states that the material's properties may not allow for a flat or nearly flat curve just before release. Certainly, Graph 1 is not flat just before release.

- c) The force versus displacement graph after preloading is obtained by shifting the original graph to the left so that its maximum value intersects the vertical axis. Only the first quadrant part of the shifted graph is retained.

11. a) Graph 2: Friction Rod and Washers Mechanism

- b) The description of the Friction Rod and Washers Mechanism as well as its sketch indicates that as the central rod clears each level of washers the restraining force decreases in steps. This is because fewer washers remain to exert a force on the central rod. Another reason for selecting the Friction Rod and Washers Mechanism is that it exerts a maximum force at zero displacement. Graph 2 shows a maximum force at zero displacement.
- c) No preloading is required.

12. a) Graph 3: Mandrel Mechanism

- b) The description of the Mandrel Mechanism states that pre-loading is required. Since Graph 3 increases during the first part of its displacement, it represents a mechanism that requires pre-loading to the top of the curve where it is relatively flat. Also the Mandrel Mechanism indicates that its restraining force can be made relatively flat just before release, and we see that Graph 3 is nearly flat just before release.
- c) The force versus displacement graph after preloading is obtained by shifting the original graph to the left so that its maximum value intersects the vertical axis. Only the first quadrant part of the shifted graph is retained.

Section IV

Data Analysis and Curve Fitting

Mathematica™, Excel™, or a TI-83/85/86™ will fit a polynomial to data.

The TI-83/85/86™ only go up to degree 4. For Mathematica™ or Excel™ you can set the order you wish.

13) TI-83/85/86™ gives $F(x) = 87.523 x^4 + 1498.2 x^3 - 7387.9 x^2 + 1216.2 x + 49964$.

Excel™ for order 6 gives $F(x) = 2.542 x^6 - 51.104 x^5 + 293.19 x^4 + 214.24 x^3 - 5492.7 x^2 + 278.48 x + 49989$. Observe that the coefficients in these polynomials have been rounded to five significant digits. Note: When calculating the answers for the following exercises, all digits of the coefficients produced by the calculators or spreadsheets were used. If you use the polynomials from this exercise, whose coefficients have been rounded to five significant digits, your answers will be somewhat different.

14) 531 lbs is from the TI-83/85/86™; Excel™ order 6 gives 443 lbs.

15) 6.412 inches is from the TI-83/85/86™; Excel™ order 6 gives 6.221 inches.

16) 50% is 7 inches. 47% elongation is 6.58 inches, and the corresponding restraining force is 863 lbs from the TI-83/85/86™ and 619 lbs from Excel™ order 6.

17) 53% elongation is 7.42 inches, and the corresponding restraining force is - 1003 lbs on the TI-83/85/86™ and 723 lbs for the Excel™ degree 6. Each of these don't make much sense. The result from TI-83/85/86™ implies that the restraining force is pushing the rocket off the pad instead of restraining it. The result from Excel™ implies that the restraining force for a displacement of 7.42 inches is larger than the restraining force for a displacement of 6.58 inches. That is, according to the Excel™ polynomial, the restraining force would increase as the displacement increased beyond 7 inches. This situation points out the problem with polynomial extrapolations. The graphs of the polynomials of order 4 and order 6 are shown below in Figures 1 and 2 respectively.



Figure 1: graph of polynomial of order 4

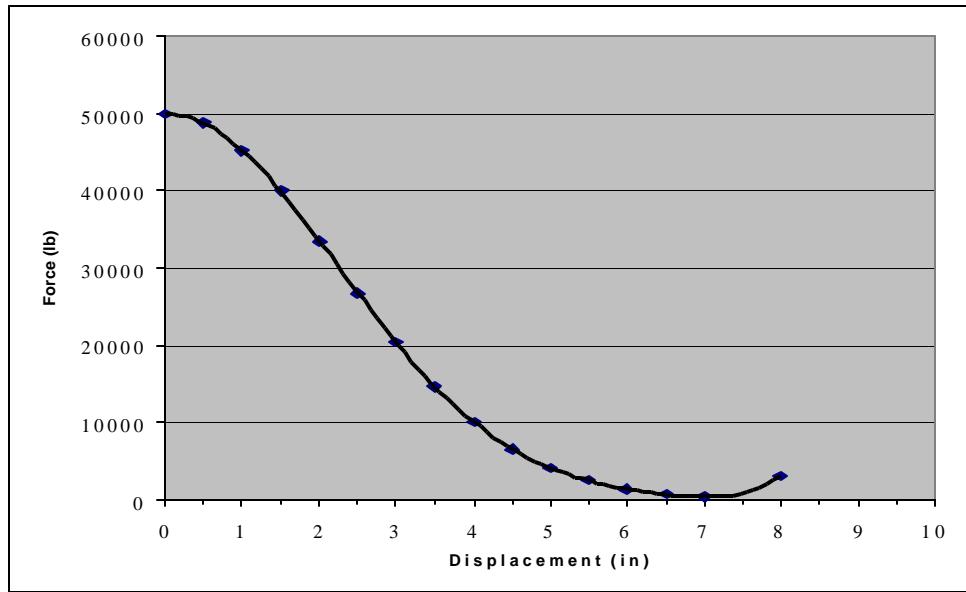


Figure 2: graph of polynomial of order 6