ROYAL CANADIAN AIR CADETS

PROFICIENCY LEVEL FOUR

INSTRUCTIONAL GUIDE

SECTION 6

EO C440.04 – APPLY THE MATERIAL SCIENCE OF TRUSSES

Total Time: 90 min

PREPARATION

PRE-LESSON INSTRUCTIONS

Resources needed for the delivery of this lesson are listed in the lesson specification located in A-CR-CCP-804/PG-001, *Proficiency Level Four Qualification Standard and Plan*, Chapter 4. Specific uses for said resources are identified throughout the instructional guide within the TP for which they are required.

Review the lesson content and become familiar with the material prior to delivering the lesson.

Create slides of Attachments A and B.

For each pair of cadets, construct one suspended container mount (SCM), described at Attachment C, for use in TP 3.

Photocopy the handouts at Attachment C for each pair of cadets.

Obtain one lightweight container for suspension from the SCM, such as a sandwich bag and wire, for incrementally adding marbles when testing the strength of trusses.

PRE-LESSON ASSIGNMENT

Nil.

APPROACH

An interactive lecture was chosen for TP 1 to generate interest in the material science of trusses and summarize the teaching point.

A practical activity was chosen for TPs 2 and 3 as it is an interactive way to allow the cadets to design and test a truss in a safe and controlled environment.

INTRODUCTION

REVIEW

Nil.

OBJECTIVES

By the end of this lesson the cadet shall have applied the material science of trusses by constructing and testing a truss.

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IMPORTANCE

It is important for cadets to apply the material science of trusses as they are a common aerospace structural component due to their light weight and strength.

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Teaching point 1 **Explain the material science of trusses.**

Time: 15 min Method: Interactive Lecture

Successful structures must withstand the loads and forces that act upon them. When a load (external force), such as gravity or a person's weight, is applied to a structure, forces are produced within the structure (internal forces) to resist the load. Provided the internal forces equal the external forces, the structure will retain its integrity. When imbalances of internal and external forces occur, a structure may suffer a catastrophic failure.

TYPES OF LOADS

The two most significant forces on structures are compression and tension. In order for a structure to resist static and dynamic loads, it must be engineered appropriately.

Static loads. Loads that remain constant. The weight of the materials from which a structure is made exerts an internal static force on the structure. Gravity is a static load.

Dynamic loads. Loads that exert constantly changing forces upon a structure. A car crossing a bridge exerts external dynamic forces on the bridge that must be counteracted by internal forces within the bridge. The structure of the International Space Station (ISS) must resist bending and twisting when it is moved by docking spacecraft or the Canadarm 2.

PROPERTIES OF MATERIALS

Elastic. Material is considered elastic when it is capable of sustaining deformation without permanent loss of size or shape. Almost all materials have some elastic properties. Glasses and crystals tend to be the least elastic solids whereas organic substances such as rubber and wood tend to show considerable elasticity. Some metals, especially some alloys of iron, can be very elastic.



Show the cadets Figure A-1 located at Attachment A.

Plastic. If a substance is compressed or stretched beyond a certain limit (called its elastic limit) it begins to exhibit plastic-like properties and it will become permanently deformed. Once a material is stretched or compressed beyond its elastic limit it is said to enter a plastic phase.



Show the cadets Figure A-2 located at Attachment A.



The word "plastic" in this case refers to the physical properties of the material, NOT the substance(s) we call "plastic"—which is the common term for a wide range of synthetic or semisynthetic organic solid materials used in the manufacture of products.

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Materials that have plasticity may exhibit either of the following:

- **Malleability.** The material is capable of undergoing plastic deformation without rupture, especially metals.
- **Ductility.** The ability of a material to be plastically deformed by elongation without fracture.

All materials have some degree of elasticity and plasticity, but when a material fractures easily it is said to be brittle. A material is brittle if it is liable to fracture when subjected to stress. It has little tendency to deform (or strain) before fracture. This fracture absorbs relatively little energy, even in materials of high strength, and usually makes a snapping sound.



Show the cadets Figure A-3 located at Attachment A.

APPLIED FORCE

The effects of applying force can be illustrated on a cube of material. The side view of the cube is shown as the shape of a square. When no external forces are present the cube is considered in a neutral state.



Show the cadets Figure A-4 located at Attachment A.

When external forces are applied while the cube remains stationary (eg, the cube does not accelerate under the application of the applied force) it is said to be in a non-neutral condition of which there are several possibilities.

Compression. If the cube is supported from below so that it is unable to move, while a downward force is applied on the top of the cube, the cube is said to be in a state of compression. In this state, the cube tends to deform, becoming slightly shorter and wider.



Show the cadets Figure A-5 located at Attachment A.

If the material from which the cube is made is elastic, it will return to its original shape when the compressing force is removed. If the material from which the cube is made is plastic and non-elastic, it will undergo permanent deformation. When the material is long and thin, compressive forces can cause buckling, where the material fails due to elastic instability.



Show the cadets Figure A-6 located at Attachment A.

Tension. If the cube is securely fastened at its lower surface (perhaps glued to the surface upon which it is sitting) and an upward force is applied to its upper surface, the cube is said to be in a state of tension. The effect is to make the cube stretch upward while contracting inward around its sides.

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Show the cadets Figure A-7 located at Attachment A.

If the material from which the cube is made is elastic, it will return to its original shape when the tensile (stretching) force is removed. If the material from which the cube is made is plastic and non-elastic, it will undergo permanent deformation.



Show the cadets Figures A-8 and A-9 located at Attachment A.

Shear. If the cube deforms as illustrated in Figure A-8, it is called shear. If the material from which the cube is made is elastic, it will return to its original shape when the shearing force is removed. If the material from which the cube is made is plastic and non-elastic it will undergo permanent deformation.

Shear stress. When forces are applied in such a way that the different parts of the cube try to slide with respect to one another, the effect is also called shearing. If parts of the cube try to slide, it is called shear stress.



Show the cadets Figure A-10 located at Attachment A.

Torsion. Torsion is the twisting of an object due to an applied torque. If the top of the cube is rotated while the bottom is fixed, the cube will twist.

CONFIRMATION OF TEACHING POINT 1

QUESTIONS:

Q1. What is a static load on a structure?

Q2. What happens to an object under tension?

Q3. What will torque do to an object?

ANTICIPATED ANSWERS:

A1. A load that remains constant.

A2. The object will stretch while contracting inward around its sides.

A3. It will twist the object.

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Teaching point 2 **Have the cadets, in pairs, design a truss.**

Time: 15 min Method: Practical Activity

Truss. Any of various structural frames based on the geometric rigidity of the triangle and composed of straight members connected at joints referred to as nodes, subject only to longitudinal compression, tension, or both. At a minimum, a truss will have three members and three nodes. Trusses offer the most strength using the least weight: an important factor in spacecraft design.



Show the cadets Figures B-1 and B-2 located at Attachment B.

A planar truss is one where all the members and nodes lie within a two dimensional plane. A space truss has members and nodes extending into three dimensions.

When designing a truss, consider the following:

- effect of tension versus compression on member sizes and lengths;
- approaches to preventing potential buckling failure modes;
- potential for stress reversal; and
- overall lateral stability (lateral-torsional buckling).

The first step in constructing a truss is to understand what the truss will be used for and what forces will be placed on the truss. When the parameters have been established, putting the design on paper or using computer aided design (CAD) software will save time and material.

The truss will be tested by applying weight at its centre via the suspended container mount. Weight will be added until the truss fails. This test will demonstrate one aspect of truss design as it is an application of only one force on the truss.



Distribute the handout of Attachment C to each cadet.

ACTIVITY

Time: 10 min

OBJECTIVE

The objective of this activity is to have the cadets, in pairs, design a truss to be constructed out of uncooked spaghetti and hot glue.

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RESOURCES

Material required by each pair of cadets:

- Photocopy of Attachment C,
- One legal size graph paper pad,
- Two mechanical pencils,
- One eraser,
- One 30-cm ruler,
- One plastic protractor, and
- 24 unbroken strands of uncooked spaghetti.

ACTIVITY LAYOUT

Nil.

ACTIVITY INSTRUCTIONS

1. Distribute the required material to each pair of cadets.
2. Have each pair of cadets design a truss.



The truss will be constructed out of uncooked spaghetti and hot glue. When designing the truss keep these factors in mind:

- The truss will be assessed on its strength to weight ratio. A light truss that supports the same weight as a heavy truss will be assessed a higher value.
- The buckling point of a member is related to its length. The longer the member, the greater the chance of buckling. Shorter pieces of spaghetti are better in compression. Long strands of spaghetti are stronger in tension than they are in compression.
- The suspended container mount consists of a block of plywood with a screw eye in its centre and is used to hold the suspended container of marbles. Be precise with the suspended container mount position and dimensions. All the weight that the truss will carry is supported by this mount.
- Truss members can be made up of more than one strand of spaghetti.
- The truss will be supported on each end by an abutment, represented by tables set 45 cm apart.

SAFETY

Nil.

CONFIRMATION OF TEACHING POINT 2

The cadets' participation in the activity will serve as the confirmation of this TP.

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Teaching point 3 **Have the cadets, in pairs, construct and test a truss.**

Time: 50 min Method: Practical Activity



The truss testing is a competition between the pairs of cadets and not an assessment.

The truss construction should follow the design as closely as possible. Points will be lost for trusses that do not follow the original design or that waste material. Points will be gained for construction technique and neatness.

The suspended container will be filled with marbles. When the truss fails, the amount of marbles in the suspended container will be counted and divided by the weight of the bridge. This ratio will be used in the total score.

Neatness counts!

ACTIVITY

Time: 45 min

OBJECTIVE

The objective of this activity is to have the cadets, in pairs, construct and test a truss.

RESOURCES

Material required by each pair of cadets:

- Suspended container mount,
- Glue gun,
- Hot glue sticks,
- Hobby knife, and
- Uncooked spaghetti.

ACTIVITY LAYOUT

Nil.

ACTIVITY INSTRUCTIONS

1. Distribute the materials to each pair of cadets.
2. Have the cadets, within 35 minutes, use their truss designs from TP 2 to construct the truss.
3. Have the cadets test their trusses for the remaining 10 minutes.
4. Use the scoring sheet at Attachment C to record the test results.

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Hot glue is hot enough to cook the spaghetti, which will result in a weakened node or member. Apply only a small amount of heat and glue to connect the members.

SAFETY

Use caution with the hot glue gun and glue. The glue and gun can reach 120–195 degrees Celcius. This is hot enough to burn flesh.

CONFIRMATION OF TEACHING POINT 3

The cadets' participation in the activity will serve as the confirmation of this TP.

END OF LESSON CONFIRMATION

This lesson should be taught in three consecutive periods.

The cadets' construction of a truss will serve as the confirmation of this lesson.

CONCLUSION

HOMEWORK / READING / PRACTICE

Nil.

METHOD OF EVALUATION

Nil.

CLOSING STATEMENT

Although the International Space Station is made largely of aluminum instead of spaghetti, it is an application of the material science of trusses, using the same principles as any truss.

INSTRUCTOR NOTES / REMARKS

Cadets who qualified Advanced Aerospace may assist with this instruction.

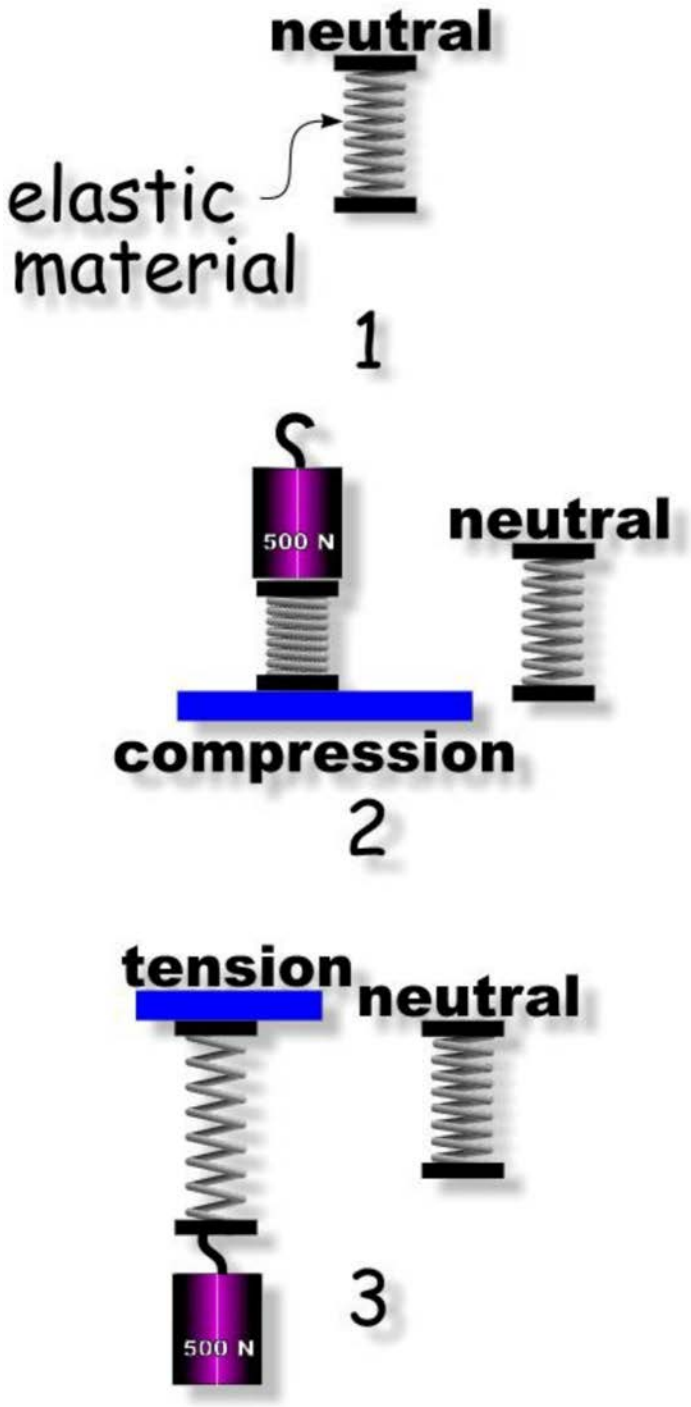
REFERENCES

C3-331 McMaster University YES I Can! Science Team. (2009). *How forces act on structures*. Retrieved February 19, 2009, from http://resources.yesican-science.ca/sts115/aboutforces.html

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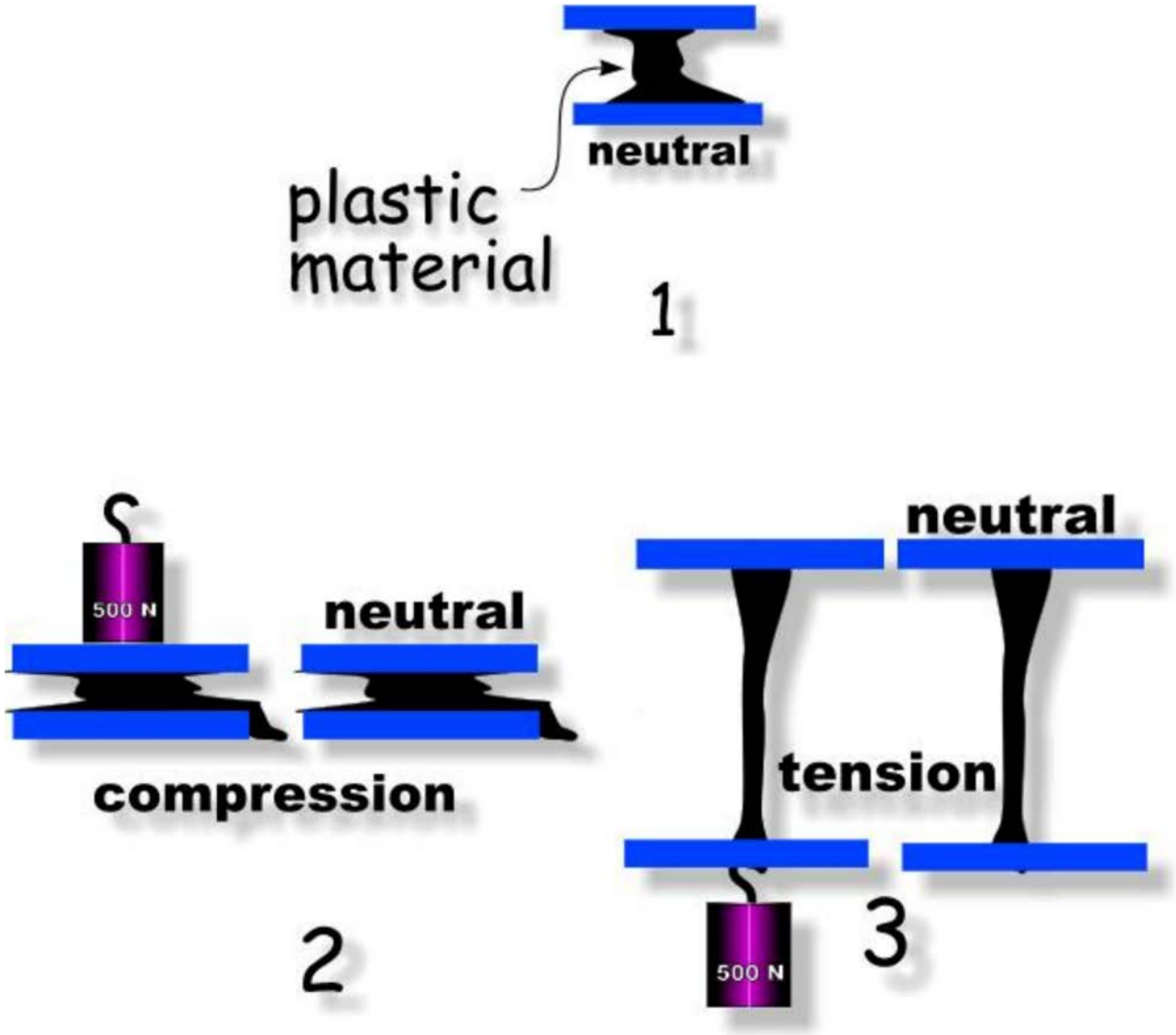
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Note. From "Materials, Structures, and Forces", 2008, Structures in Space. Retrieved November 20, 2008, from http://resources.yesican-science.ca/sts115/aboutforces.html

Figure A-1 Elastic Material

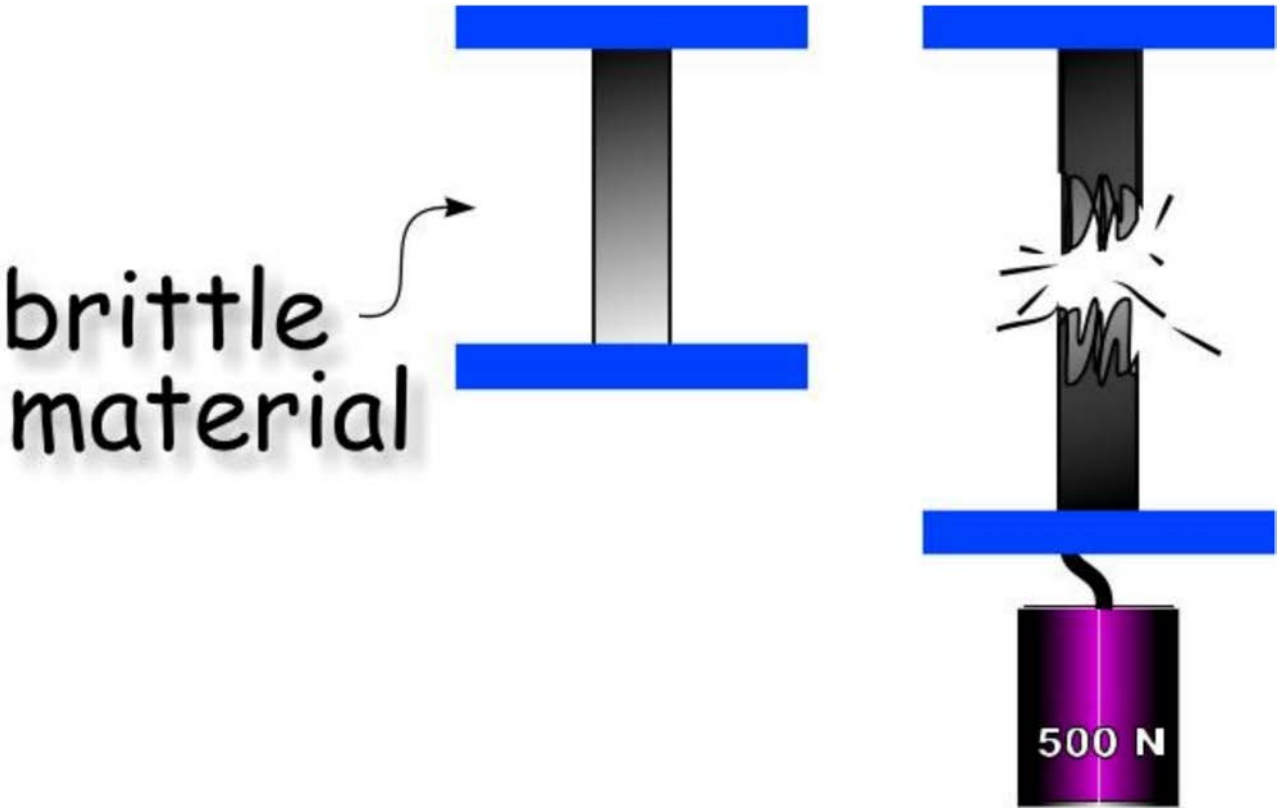
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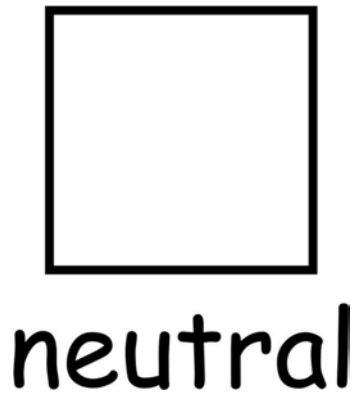
Figure A-2 Plastic Material

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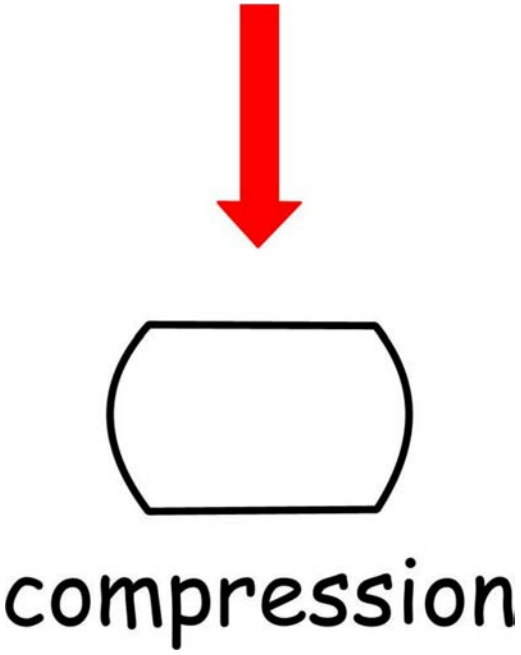
Figure A-3 Brittle Material



Note. From "Materials, Structures, and Forces", 2008, Structures in Space. Retrieved November 20, 2008, from http://resources.yesican-science.ca/sts115/aboutforces.html

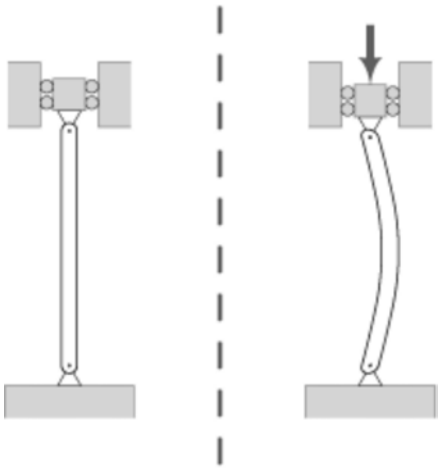
Figure A-4 Cube at Rest

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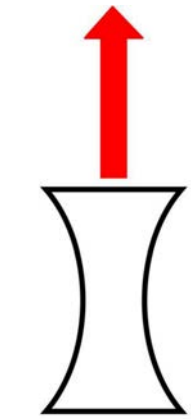
Figure A-5 Cube in Compression



Note. From "Buckling", 2008. Retrieved November 25, 2008, from http://en.wikipedia.org/wiki/Buckling

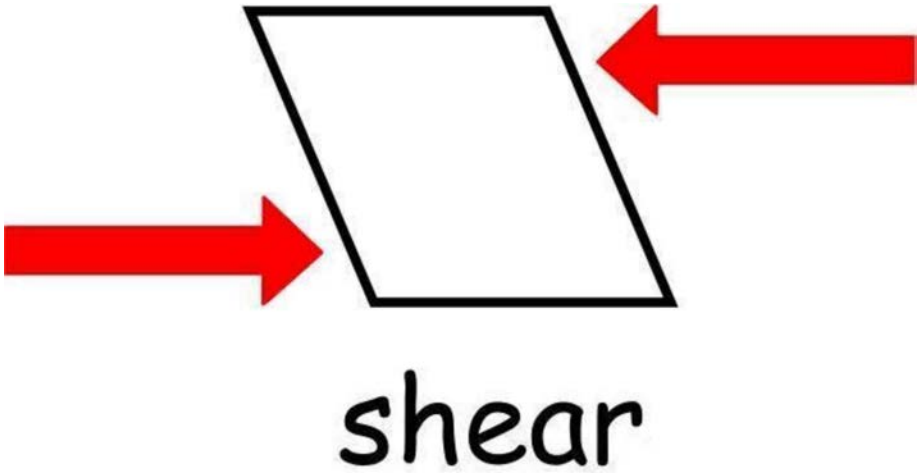
Figure A-6 Compression Causing Buckling

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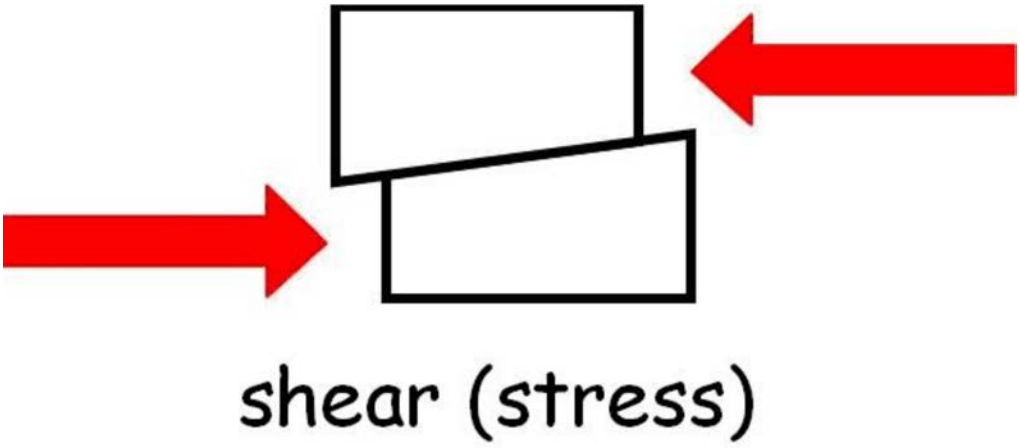
Figure A-7 Cube in Tension



Note. From "Materials, Structures, and Forces", 2008, Structures in Space. Retrieved November 20, 2008, from http://resources.yesican-science.ca/sts115/aboutforces.html

Figure A-8 Cube in Shear

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Figure A-9 Cube Shear Stress

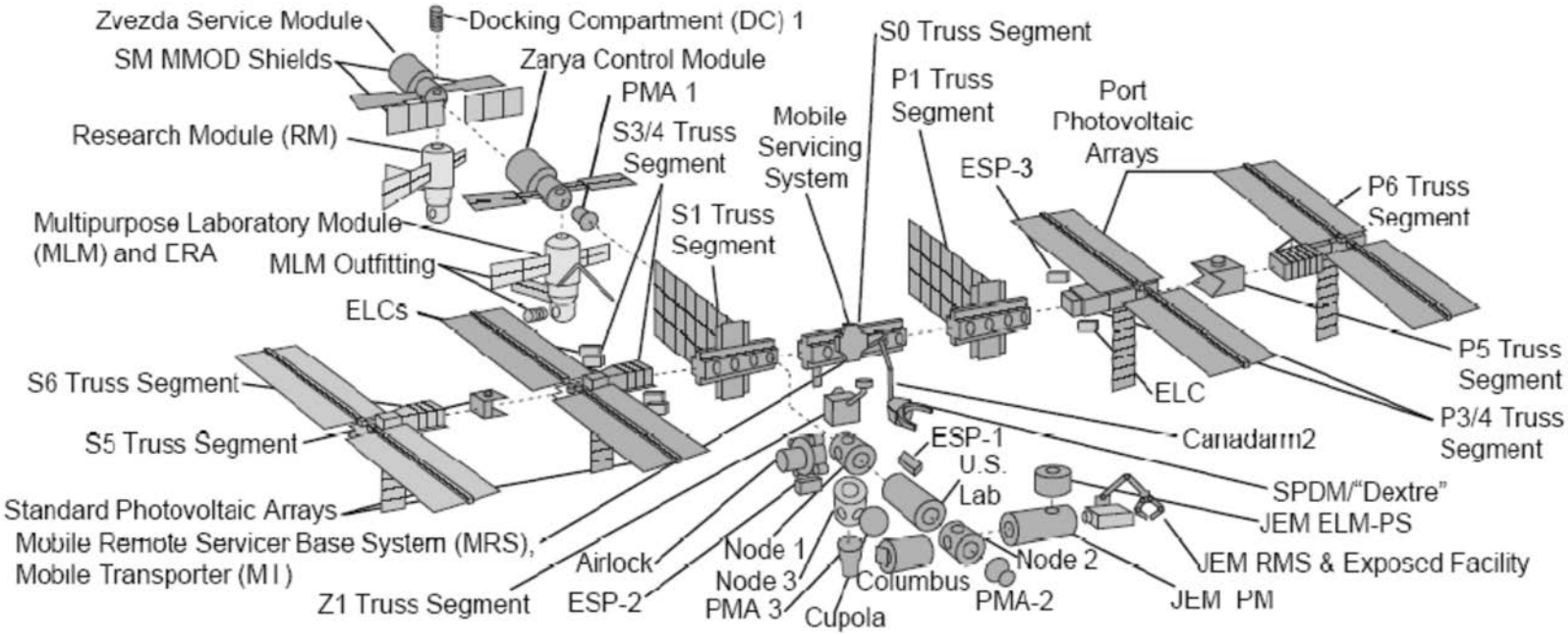


Note. From " Cube Twist", 2008. Retrieved November 25, 2008, from http://www.helleronline.com/fgfc1_main.php?&color=silver&view=front

Figure A-10 Cube in Torsion

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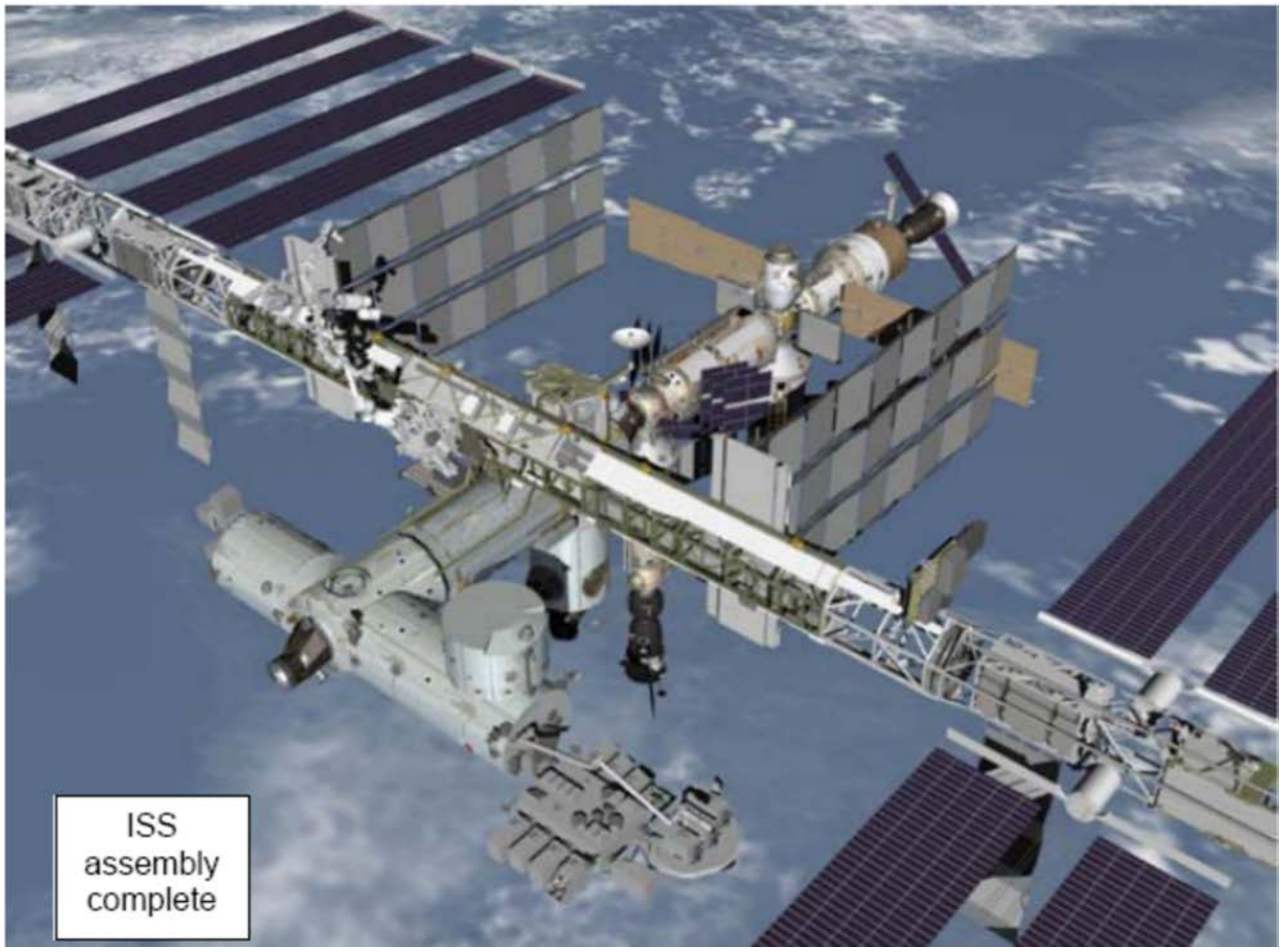
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Note. From "Space Exploration", Boeing, 2008, International Space Station Backgrounder, Boeing. Retrieved February 19, 2009, from http://www.boeing.com/defense-space/space/spacestation/docs/ISS_overview.pdf

Figure B-1 Exploded View of the ISS Truss Structure

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Note. From "Space Exploration", Boeing, 2006, International Space Station Backgrounder, Boeing. Retrieved November 25, 2008, from http://www.boeing.com/defense-space/space/spacestation/docs/ISS_overview.pdf

Figure B-2 ISS Truss Structure

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TRUSS COMPETITION

Rules and Regulations

Trusses must be constructed of materials provided by the squadron training office. No other materials may be used in the construction of the truss.

Material required by each pair of cadets includes:

- Spaghetti (uncooked, 25 cm long),
- Hot glue gun, and
- Glue sticks.

Parameters for the competition are:

- distance between the abutments: 45 cm,
- length: not less than 47 cm, not greater than 55 cm,
- width: not greater than 10 cm,
- height: not greater than 25 cm,
- no part of the truss will hang below the top of the abutments, and
- time: 40 min.

The provided suspended container mount (SCM) shall be incorporated into the truss. The SCM consists of the following materials:

- 2-cm eye bolt, and
- 8 cm by 8 cm birch plywood square, 4 mm thick.

The following criteria will be used for scoring:

- design,
- quality of construction,
- material use / waste, and
- amount of marbles divided by the weight of the truss.

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TRUSS TESTING SCORING SHEET

Cadet Pair	Follows Design [1]	Quality of Construction [2]	Material Use [3]	Length [4]	Width [5]	Height [6]	Amount of Marbles	Weight of Truss	Ratio [7]	Total
	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0				
	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0				
	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0				
	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0				
	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0	1 / 0				

Note:

1. One point for following design; no points for not following design.
2. One point for neat construction; no points for messy construction.
3. One point for minimum waste; no points for wasting material.
4. Subtract one point for over or under 47–55 cm.
5. Subtract one point for over 10 cm.
6. Subtract one point for over 25 cm.
7. Divide the number of marbles in the suspended container by the bridge weight for this ratio.

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