ROYAL CANADIAN AIR CADETS

PROFICIENCY LEVEL FOUR

INSTRUCTIONAL GUIDE

SECTION 1

EO M440.01 – IDENTIFY AEROSPACE MATERIALS

Total Time:	30 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 the figures located at Attachments A and B.

PRE-LESSON ASSIGNMENT

Nil.

APPROACH

An interactive lecture was chosen for this lesson to introduce aerospace materials and to generate interest in the subject.

INTRODUCTION

REVIEW

Nil.

OBJECTIVES

By the end of this lesson the cadet shall be expected to identify materials used in aerospace construction.

IMPORTANCE

It is important for cadets to learn about materials used in aerospace construction, as it will enhance their understanding of the materials used to build spacecraft and why they are chosen.

Teaching Point 1	**Discuss metals used in aerospace construction.**
Time: 15 min	Method: Interactive Lecture

METALS USED IN AEROSPACE CONSTRUCTION

During this TP, pass around samples of small pieces of components made from aluminum, magnesium, titanium, and stainless steel.

Aluminum

Pure aluminum lacks sufficient strength to be used for aerospace construction. However, its strength increases considerably when it is alloyed, mixed with other compatible metals. For example, when aluminum is mixed with copper or zinc, the resultant aluminum alloy is as strong as steel, with only one-third the weight. As well, the considerable corrosion resistance possessed by the aluminum carries over to the newly formed alloy. Aluminum is the most commonly used metal for spacecraft structure.

Magnesium

Magnesium is one of the lightest metals with sufficient strength and suitable working characteristics for use in aerospace structures. That is, in its pure form it lacks sufficient strength but, like aluminum, mixing it with other metals to create an alloy produces strength characteristics that make magnesium useful.

Titanium

Titanium and its alloys are lightweight metals with very high strength. Pure titanium weighs only half as much as stainless steel and is soft and ductile. Titanium alloys have excellent corrosion resistance, particularly to salt water.

Stainless Steel

Stainless steel is a classification of corrosion-resistant steel that contains large amounts of chromium and nickel. It is well suited to high-temperature applications such as firewalls and exhaust system components.

MATERIAL TESTS

The study of materials used in aerospace construction is vast and growing rapidly as scientists and engineers gain experience using materials, both new and old, in frontier applications and environments. All materials represent opportunity, but they must be correctly used. Space includes a variety of environments, each with different challenges, such as the Low Earth Orbit (LEO) environment encountered by the International Space Station (ISS) and space shuttle missions. Materials are selected for use in applications after careful study in laboratories, including laboratories in orbit such as the Long Duration Exposure Facility (LDEF).

LDEF was deployed in orbit on April 7, 1984 by the Shuttle Challenger. The nearly circular orbit was at an altitude of 275 nautical miles. LDEF remained in space for about 5.7 years and completed 32,422 Earth orbits. It experienced one-half of a solar cycle, as it was deployed during a solar minimum and retrieved at a solar maximum. LDEF was retrieved on January 11, 1990 by the Shuttle Columbia. By the time LDEF was retrieved, its orbit had decayed to 175 nautical miles and was a little more than one month away from re-entering the atmosphere.

The Long Duration Exposure Facility (LDEF) Archive System, maintained by NASA Langley Research Center, is designed to provide spacecraft designers and space environment researchers with a single point access to all available resources from LDEF. It is found at http://setas-www.larc.nasa.gov/LDEF/index.html

ORBIT ENVIRONMENT

The characteristics of a spacecraft's orbit are determined by its mission. Some spacecraft travel between worlds and must be capable of functioning in a variety of conditions. Most spacecraft, however, are used in an application that restricts them to a narrow range of space environments. The relative impact of any of the space environments' effects on materials depends on the type of mission the spacecraft has to perform (eg, communications, defense, Earth observing) and, more important, the orbits in which the spacecraft is placed.

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

Figure A-1 shows the variations in the space environment as a function of orbit altitude. LEO extends up to 1000 km. Mid-Earth Orbit (MEO) is above 1000 km and extends up to 35 000 km. Geosynchronous orbit (GEO) is 35 000 km and higher.

Show the cadets the slide of Figures A-2 and A-3 located at Attachment A.

Major space environment hazards in LEO include atomic oxygen, ultraviolet radiation, frequent cycling between hot and cold temperatures, micrometeoroids, debris and contamination.

Atomic oxygen (AO) is an elemental form of oxygen that does not exist in the Earth's atmosphere. In space, however, it is common in the LEO area where satellites orbit the Earth. There, it reacts with other materials very easily and exposes satellites and spacecraft to damaging corrosion. Researchers at NASA's Glenn Research Center study these damaging effects in order to find materials and methods to extend the lifetime of communication satellites, the Space Shuttles and the ISS.

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

To prevent AO from damaging metal surfaces, protective coatings are applied to the metal's surface. AO flux and ultraviolet radiation interact in the degradation of silver and Teflon materials.

Cadets can explore Space Weather: Impact of the Orbital Environment on the MOST microsatellite mission at http://www.astro.ubc.ca/MOST/posters/WS-Kristy-poster.jpg

Orbital debris is another hazard for materials in LEO. This refers to man-made particles orbiting the Earth. Within about 2 000 km above Earth's surface there is an estimated 3 000 000 kg of man-made orbiting objects. These objects are in mostly high inclination orbits and sweep past one another at an average speed of 10 km / second. These particles are a result of standard launch and spacecraft operations as well as rocket and satellite breakups. Launch and spacecraft operations place both large particles (eg, greater than 1-cm diameter such as satellite shrouds, lens covers, and dropped tools) and small particles (eg, approximately 10-micron diameter solid rocket exhaust) in orbit.

Impacts can alter material states and expose underlying materials, allowing the space environments (eg, AO) to further increase the damage area and begin damaging previously unexposed areas. AO undercutting of polymer substrates under protective coatings is a phenomenon that can be a concern for space applications of multi-layer insulation.

CONFIRMATION OF TEACHING POINT 1

QUESTIONS:

Q1. Why is pure aluminum unsuitable for use in many applications of aerospace construction?

Q2. What three characteristics make titanium useful for aerospace components?

Q3. What two metals are mixed with steel to make stainless steel?

ANTICIPATED ANSWERS:

A1. Pure aluminum lacks sufficient strength for aerospace construction.

A2. Titanium alloys have high strength, are lightweight and are resistant to corrosion.

A3. Steel is mixed with chromium and nickel.

Teaching Point 2	**Discuss composite materials used in aerospace construction.**
Time: 10 min	Method: Interactive Lecture

COMPOSITE CONSTRUCTION

The term composite refers to a combination of two or more materials that differ in composition or form. Composite is sometimes used to mean any synthetic building material.

Composite structures differ from metallic structures in important ways: excellent elastic properties, high strength combined with light weight and the ability to be customized in strength and stiffness. The fundamental nature of many composites comes from the characteristics of a strong fibre cloth imbedded in a resin.

Pass around clearly marked samples of fibreglass cloth, aramid cloth and carbon fibre cloth.

Fibreglass

Fibreglass is made from strands of silica glass that are spun together and woven into cloth. Fibreglass weighs more and has less strength than most other composite fibres. However, improved matrix materials now allow fibreglass to be used in advanced composite aerospace applications.

There are different types of glass used in fibreglass: E-glass, which has a high resistance to electric current and S-glass, which has a higher tensile strength, meaning that the fabric made from it resists tearing.

Aramid

Aramid is a polymer. A polymer is composed of one or more large molecules that are formed from repeated units of smaller molecules.

Ask the cadets to name all the applications they are aware of for Kevlar® .

The best-known aramid material is Kevlar®, which has a tensile strength approximately four times greater then the best aluminum alloy. This cloth material is used in many applications where great strength is needed: canoes, body armour and helicopter rotors. Aramid is ideal for aerospace parts that are subject to high stress and vibration. The aramid's flexibility allows it to twist and bend in flight, absorbing much of the stress. In contrast, a metal part would develop fatigue and stress cracks sooner under the same conditions.

Carbon / Graphite

The term carbon is often used interchangeably with the term graphite; however, they are not quite the same material. Carbon fibres are formed at 1315 degrees Celsius (2400 degrees Fahrenheit), but graphite fibres are produced only above 1900 degrees Celsius (3450 degrees Fahrenheit). As well, their actual carbon content differs—but both carbon and graphite materials have high compressive strength and stiffness.

Carbon molecules will form long strings that are extremely tough (this is what makes diamonds so strong). These minute hair-like strands of carbon (a very common and inexpensive element) are, per unit of weight, many times stronger than steel. Individual carbon fibres are flexible, rather than stiff, and bend easily despite having high tensile strength. To stiffen the fibres, cross-directional layers are immersed in a matrix material such as epoxy plastic. A matrix is any material that sticks them together.

The term epoxy refers to a substance derived from an epoxide. An epoxide is a carbon compound containing an oxygen atom bonded in a triangular arrangement to two carbon atoms. So, an epoxy matrix is itself carbon-based, as are the fibres that it binds.

Ceramic

Ceramic fibre is a form of glass fibre designed for use in high temperature applications. It can withstand temperatures approaching 1650 degrees Celsius (3000 degrees Fahrenheit), making it effective for use around engines and exhaust systems.

Show the cadets the slide of Figure B-1 located at Attachment B.

Ceramic's disadvantages include both weight and expense, but sometimes no other known material will do the job. One of the most famous applications of ceramic is the Thermal Protection System (TPS) used on the space shuttle. The properties of aluminum demand that the maximum temperature of the shuttle's structure be kept below 175 degrees Celsius (350 degrees Fahrenheit) during operations. Heating during re-entry (in other words, heating caused by friction with the air) creates surface temperatures high above this level, and in many places will push the temperature well above the melting point of aluminum (660 degrees Celsius or 1220 degrees Fahrenheit).

Underneath its protective layer of tiles and other materials, the space shuttle has an ordinary aluminum construction, similar to many large aircraft.

Show the cadets the slide of Figure B-2 located at Attachment B.

A space shuttle's TPS is very complex and it contains highly sophisticated materials. Thousands of tiles of various sizes and shapes cover a large percentage of the space shuttle's exterior surface. There are two main types of silica ceramic tiles used on the space shuttle:

- **Low-Temperature Reusable Surface Insulation (LRSI).** LRSI tiles cover relatively low-temperature areas of one of the shuttles, the Columbia, where the maximum surface temperature runs between 370 and 650 degrees Celsius (700 and 1200 degrees Fahrenheit), primarily on the upper surface of fuselage around the cockpit. These tiles have a white ceramic coating that reflects solar radiation while in space, keeping the Columbia cool.

Show the cadets the slide of Figure B-3 located at Attachment B.

- **High-Temperature Reusable Surface Insulation (HRSI).** HRSI tiles cover areas where the maximum surface temperature runs between 650 and 1260 degrees Celsius (1200 and 2300 degrees Fahrenheit). They have a black ceramic coating, which helps them radiate heat during re-entry.

Both LRSI and HRSI tiles are manufactured from the same material and their primary difference is the coating.

A different and even more sophisticated material, Reinforced Carbon-Carbon (RCC), is used for the nose cone and leading edges of the space shuttle. It is a composite material consisting of carbon fibre reinforcement in a matrix of graphite, often with a silicon carbide coating to prevent oxidation.

CONFIRMATION OF TEACHING POINT 2

QUESTIONS:

Q1. What type of glass is used in fibreglass strands?

Q2. What is the best known aramid material?

Q3. What method is used to stiffen carbon fibre materials?

ANTICIPATED ANSWERS:

A1. Silica glass.

A2. Kevlar®.

A3. Immersing cross-directional layers of carbon fibres in a matrix compound such as epoxy plastic.

END OF LESSON CONFIRMATION

QUESTIONS:

Q1. What are the altitudes of LEO, MEO and GEO orbits?

Q2. What is the major gas found in LEO?

Q3. What is the most commonly used metal for spacecraft structure?

ANTICIPATED ANSWERS:

A1. LEO extends up to 1 000 km, MEO is above 1 000 km and extends up to 35 000 km, and GEO is 35 000 km and higher.

A2. The major gas in LEO is AO.

A3. Aluminum is the most commonly used metal for spacecraft structure.

CONCLUSION

HOMEWORK / READING / PRACTICE

Nil.

METHOD OF EVALUATION

Nil.

CLOSING STATEMENT

The study of materials used in aerospace construction is a rapidly growing field that holds immense opportunity for development. Space travel demands accurate and creative materials applications.

INSTRUCTOR NOTES / REMARKS

Cadets who are qualified Advanced Aerospace may assist with this instruction.

REFERENCES

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C3-294 Silverman, E. M. (1995). *Space environmental effects on spacecraft: LEO materials selection guide*. Hampton, VA: NASA Langley Research Center. Retrieved November 27, 2008, from http://see.msfc.nasa.gov/mp/NASA-95-cr4661pt1.pdf