10/28/2019

EML4551-2

Team 519: Composite Airframe Life Extension

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Chapter One: EML 4551C

Project Scope

Project Description.

The objective of this project is to evaluate replacing aluminum with a composite material for use as a C channel in an E-2 Hawkeye, by designing and performing experiments, according to MIL-STD-810, comparing aluminum with various composite materials.

Motivation.

The E-2 Hawkeye is a carrier borne airborne early warning and control (AEW&C) aircraft. The E-2 family of aircraft have been in service since the 1960s; the modern variant is the E-2D Advanced Hawkeye produced by Northrup Grumman, shown below.

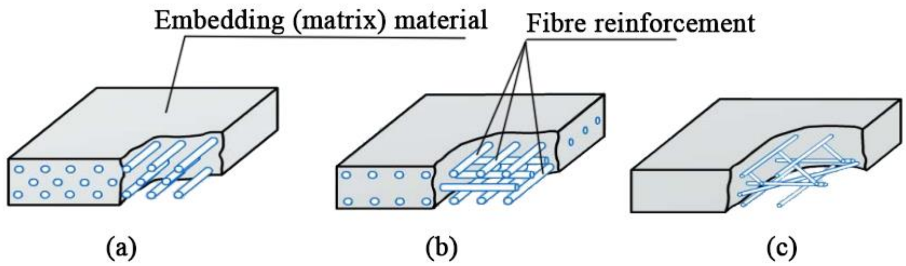
Figure 1: Northrup Grumman E-2D Advanced Hawkeye

Naval aviation has paradoxical size and weight requirements: the aircraft need to have large wings to decrease landing speed on short carrier flight decks and increase handling at low speed; however, the aircraft also need to be as lightweight as possible. (Wikipedia, 2019) Reducing airframe weight by using composites is a worthwhile goal because it reduces the lift required and therefore the size of the aircraft. In addition to improving flight characteristics, the weight saved by using lighter airframe materials can be allocated towards increasing the mission capability of the aircraft. In the case of the E-2, this could be more weight for sensory and communication equipment or fuel.

The second principle advantage composites offer is corrosion resistance; naval aircraft are continuously exposed to a corrosive environment while deployed. A composite material may need less maintenance than traditional materials, reducing operation costs and increasing readiness

Composites Background.

The Principle of Combined Action states that two materials with different properties can be combined to create a composite that incorporates the best parts of each material. Most composites are two phase materials with a distributed phase and a matrix phase. The distributed phase is generally a fibrous material with good tension strength which is enclosed in a matrix material with good shear strength. The result is an anisotropic material which is very strong in the direction of the fibers (the longitudinal direction) but significantly less strong in the direction perpendicular to the fiber direction (the transverse direction).



In figure 2a, the fibers are aligned in a single direction, resulting in an anisotropic material which is very strong only in a single direction (the direction of the fibers). Figure 2b, shows fibers going in two directions, resulting in a material which is strong in two directions. Figure 2c, shows fibers which are oriented randomly, resulting in a material that is approximately isotropic along the longitudinal and transverse planes. (Callister, 2014)

Composites are categorized by the matrix phase material. A ceramic matrix would be too brittle for a structural part of an airframe and would be far too heavy. A metal matrix would be extremely expensive and probably heavier than aluminum. This leaves polymer as the matrix material of choice. Polymer composites are extremely light, offer superior mechanical properties, and are used extensively in new airframe design. (Hale, 2006)

The distributed phase of polymer matrix composites are generally aramid fibers, glass fibers, or carbon fibers. Each type of fiber has a different use; carbon fibers see the most use in aerospace components; this family of composites are called Carbon Fiber Reinforced Polymers (CFRP). A more detailed discussion of distributed phase materials will occur later.

C Channel Background.

The C channel is a structural beam that is designed to hold a load. The C channel consists of two flanges attached to a web that allows for greater strength in bending. These structural channels have many applications, including in the airframes for many aircraft. These C channels can be manufactured from a variety of materials including steel and aluminum. These beams come in many standard sizes with varying cross-sectional dimensions and lengths. The back side of the web can often be mounted onto other structures. Two identical C channels may also be mounted back to back in order to form an I beam. Since developing a mold for composite I beams could be difficult, it common two see two composite C channels mounted back to back.

Insert a picture of it.

The governing equations are: bending y, bending x, moments of inertia, neutral axis. Its meant to be loaded in bending y because the most material is placed in the areas of highest stress. Explain St. Vennants principle and how tension will depend primarily on the attachment methods

Key Goals.

The key goals of this project are to find a lightweight composite material to replace an aluminum C channel with. From here, the phrase "the part" will be used in reference to the C channel. The team will validate the composite as structurally sound with at least five types of tests. The part holds a load and contributes to the structural rigidity of the airframe in general.

Determine Forces.

The stresses on the part must be determined so that the team can design the best material. The stresses will be determined by running a finite element analysis (FEA) on the part along with the governing equations. The FEA will show the areas of highest stress, which will be used to determine the most important tests to run and to design a composite system that will be appropriate to replace aluminum with.

Design Composite System.

Design a composite system that will withstand the stresses required, fulfills customer requirements, and is within the team's budget. The team will select the materials and design a custom composite system. This will include material selection and the design of the part. The composite system will be tested via FEA before manufacturing of test specimens.

Down-Select MIL-STD.

MIL-STD-810 details the environmental test methods for materials used by the Department of Defense (Department of Defense, 2019). There are far too many tests for the team to perform, so a small number of tests will be selected which will be tailored to the specific requirements of the part, as shown by the FEA. These tests will reflect the likely failure modes of composites and the operating conditions of the part. The tests the team runs will be heavily influenced by the team's budget and facility availability.

Perform Tests.

The team will design and perform a series of tests which will replicate maximum loading conditions of the part, as revealed by the FEA. All tests are to be done in accordance with MIL-STD-810 and any relevant ASTM standards.

Analyze Results.

Compare test results with values for aluminum alloys to determine if a composite will be a suitable replacement. Consider not just the mechanical properties, but also secondary advantages and disadvantages of composites. Also consider cost benefit of replacing aluminum with composite. Make a recommendation for further integration of composites into airframes.

Markets.

There are many applications of the techniques developed in this project.

Department of Defense.

Both the United States Navy and the United States Air Force are interested in replacing the aluminum and other airframe materials with composite components. (Milberg, 2015) Composites can offer superior strength, lifespan, electromagnetic properties, and weight savings.

Aerospace Companies.

Civilian aviation companies are also integrating composites in airframes, most notably the Boeing 787, which is 50% composite material. (Hale, 2006) The primary advantage composites offer in civilian aviation is fewer maintenance hours than aluminum, which means more profitable flight hours and less time grounded.

Secondary Markets.

Many allied militaries purchase systems from the US or develop their own systems. They may decide to use composite materials in the airframes of their aircraft as well.

Replacing metals with composites also has applications in the automobile industry where lighter cars will lead to fuel savings for the consumer. Not only are composites attractive because of their low weight, they can also offer more resilience than traditional metal parts.

Assumptions.

Several key assumptions are made to limit the possible scope of the project. It is assumed that part is to be mounted in an E-2D Advanced Hawkeye; the validation done on the composite material are assumed to reflect the specific operating conditions of this aircraft. The sponsor, Northrup Grumman, will be asked to provide information regarding the amount of force exerted on the part, the operating temperature of the part, vibration profiles, etc. If this information cannot be provided, the details in question will be studied further and assumed values will be assigned.

The two primary constraints on the project are budget and timeline. The project will be constrained by the delivery timeline. The available budget will be set at $2000. These assumptions are the primary limitations of the project scope and timeline. Under no circumstance will the project be allowed to surpass either of these constraints.

It is assumed that the facilities at the College of Engineering will be available to test specimens. In addition, these facilities need to perform the tests that are necessary to complete the selected tests. This assumption limits the possible scope of the project to only tests that can be done on campus, and within the team's budget. The team may be able to use facilities at the High-Performance Materials Institute (HPMI).

It is assumed that the test specimens obtained are reflective of the components used for the prototype. These specimens are assumed to behave in the same manner and have the same physical properties as the materials used in a full-scale prototype.

Stakeholders.

A stakeholder is anyone who has control, interest, or an investment in the project. This may be expressed as authority over the members of the project group, time allocated to the project in assisting the members of the project group, or financial investment in the project itself, among other things.

Northrop Grumman, Project Sponsor.

Northrop Grumman Corporation (NGC) sponsors the project; they invest time and money into the project and receive the product in the end. NGC has provided mentors to help guide the project.

Dr. Shayne McConomy, Senior Design Project Coordinator.

Dr. McConomy grades the deliverables for the project and will grade the student's performance in the Senior Design class. Along with the sponsor, Dr. McConomy invests time and can control the project in relation to what is required for the Senior Design course.

Dr. Lance Cooley, Faculty Technical Advisor.

Dr. Cooley is the faculty advisor for the project; he is interested in the success of the team. Dr. Cooley invests his time with the team by meeting with them on a biweekly basis and providing mentorship.

United States Navy.

The USN is the primary operator of the E-2, and it is also operated by other allied countries. The navy wants the lightest planes possible to catapult off of and land on carrier decks. Additionally, maintenance is more difficult on a ship, so a more durable part that requires less maintenance will lead to higher operational readiness rates and lower long-term cost.

United States Airforce.

The USAF is currently interested in switching out aluminum components for composite in many aircraft. Many airframes are undergoing life extension programs, and new designs make extensive use of composites. The Air Force Research Lab issued the Composite Airframe Life Extension (CALE) grant that this project is based off. (Air Force Research Lab, 2015)

High Performance Materials Institute.

HPMI is a multidisciplinary research institute at Florida State University with a primary technology research area in high-performance composite materials. Dr. Hao has graciously offered her expertise and facility access to the team.