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Incorporating Green Design into Teaching Aircraft Preliminary Design

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FORUM

[1]*INCORPORATING GREEN DESIGN INTO TEACHING AIRCRAFT PRELIMINARY DESIGN*

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ABSTRACT

Incorporating green design principles into a senior capstone aircraft design course may be an effective way to accomplish a number of objectives desired for ABET accreditation including the coverage of contemporary issues, global awareness, and ethics. The overwhelming environmental issues in designing an aircraft appear to be operating emissions - either combustion by-products or noise - but material selection and disposal are not insubstantial and should be considered. This paper is an initial look into what tools and guidelines exist for designing "green" aircraft as well as the policy and regulatory issues that will help motivate a culture shift to more environmentally friendly air transport.

INTRODUCTION

The senior capstone design course in engineering education is viewed by many faculty as a fit all course to include all of the ABET (Accreditation Board for Engineering and Technology) mandated material not yet covered by any other required course (ABET, 2001). Thus, a design instructor may be put upon to instill a knowledge of contemporary issues, global awareness, ethics, and project management; give the students the opportunity to employ communication and teamwork skills; and, by the way, teach the synthesis of design and while relaying practical methods for applying the knowledge and skills obtain in other courses. This combination of tasks can easily overwhelm the students and detract from the development of decision making skills very prized in industry. However, the introduction of "green design" principles presents an opportunity to cover three of these topics – contemporary issues, global awareness and ethics – with material closely related to the decision processes already being developed as part of design. The goal of this paper is to examine the topics and instructional needs necessary to introduce green design principles into a particular senior design course, Aircraft Preliminary Design.

In teaching students the basics of aircraft preliminary design, it is emphasized that 80% of the life cycle cost associated with an aircraft is determined during this initial phase of aircraft development. However, the traditional texts for aircraft design only emphasis the monetary cost, not the environmental. Fortunately in aviation, monetary costs and environmental costs often run in parallel. For example, the purchase price of an aircraft correlates very well with its gross weight - as does its fuel consumption and thus overall emission. Thus, the industry has shown a steady trend in improved specific fuel consumptions (SFCs) engines, decreased structural weight, and higher aerodynamic efficiency. However, as will be discussed, this is not always the case and graduating students should be aware when the search for performance runs counter to environmental compatibility just as they should be aware when it runs counter to profit.

The bulk of this paper is concerned with considerations most relevant to the commercial aircraft industry which has a much larger environmental impact that that of general aviation (GA). However, much as commercial aviation is growing rapidly, GA has been targeted for growth in the US with a NASA target of 10,000 aircraft sales by the year 2010 (NASA, 2000).

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Applying green design principles to GA aircraft will also be more challenging since there are fewer environmental regulatory restrictions in place. Thus, a culture of environmental consciousness is much weaker in the field.

GREEN AIRCRAFT DESIGN

The goals of green design as put forward by Hendrickson, Conway-Schemph, Lave, and McMichael (2001) are a good starting point in developing priorities in teaching environmental consciousness. These are:

1. Reduce or minimize the use of non-renewable resources
2. Manage renewable resources to insure sustainability; and
3. Reduce, with the ultimate goal of eliminating, toxic and otherwise harmful emissions to the environment, including emissions contributing to global warming

The current trend in transportation would support the reverse ordering of the goals, however, placing emissions on top of the list. While the aviation sector is not a large contributor to global emission with only 2-3.5% of the total impact on global warming, this transportation sector has received a disproportional amount of interest due to its large growth rate - an increase of up to 300% is expected in total aviation miles flown by the year 2020. In addition, the bulk of commercial aircraft emissions occur in the 10-12 km altitude range where NOx and H2O emissions have an enhanced green house effect compared to equivalent bulk emissions from surface transportation.

The Intergovernmental Panel on Climate Change report on the impact of aviation (IPCC, 1999) on the global atmosphere is an excellent reference on the impact of aviation gaseous emissions. Some of the information presented in that report has a wide margin of error due to an inexact knowledge of atmospheric chemistry and the role of clouds in global warming. However, as agreed to in the 1992 Rio Declaration (UN, 1993), " lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." This principle should be considered applicable to aviation due to the long life span of aircraft programs – typically 30 years – and the time delay associated with propagating design changes into the civil fleet (Guynn, 1998 and 2001).

The Kyoto Protocol (UN, 1998) for reducing greenhouse gas emissions includes those from domestic aviation operations and charges the signing parties to work through the International Civil Aviation Organization (ICAO) for establishing limitations or reductions in international aviation emissions. Similarly, the scope of research into environmentally friendly aircraft may be described succinctly as emissions, emissions and emissions - whether considering noise, CO_2 or NOx. In setting their visions for civil aviation, both the European Commission (2001) and NASA (2000) set goals for dramatic reduction in the noise and gaseous emissions in the 10 to 20 year framework. And significantly, neither plan supports the concept of sustained development since they project air traffic capacity increasing faster than emission reductions (for CO_2 and noise).

Finally, under the concepts of green engineering, an aircraft designer should also be fully aware of the impacts on reuse, recycle and disposal of their decisions. If a designer makes the choice of using composite materials to save weight he is buying into a material with a very low recyclability and a potential disposal problem. However, on a typical 150 passenger aircraft flying a block range of 1,000 nm, one pound weight savings will save approximately 0.18 pounds of fuel per flight. For a typical utilization of 1,200 flights a year over a 20 year life, this equates to a life cycle savings of 4,300 pounds of fuel for each pound of structural weight saved. Thus, current trades would push towards the use of more weight saving materials regardless of other considerations.

IMPACT OF AIRCRAFT PURPOSE AND MISSION

The first opportunity an aircraft designer has to influence the environmental impact of a new concept is in deciding its appropriate purpose and mission. In general, there are three main reasons for a new commercial airplane program:

1. exploiting changing market opportunities,
2. responding to new regulatory action, or
3. exploiting new technologies

Engineering students need no prodding to understand the last topic - the application of new technologies - but are much more reluctant to become involved in the two former which arguably play a much larger role in deciding the total environmental impact of the aviation industry.

The current competition between Boeing and Airbus about the future of high capacity versus high-speed aircraft illustrates the market impact (Sparaco, 2001). The trend has been for larger aircraft to show better seat mile fuel economy than smaller aircraft. These large aircraft will of necessity operate only from the larger airports at major cities. Traveler's originating or destined for other cities would require secondary surface or air transportation. Thus, Boeing's vision of a "pacific fragmenter" aircraft that carries fewer passengers directly between smaller cities may have an overall lower impact just as it would reduce total travel time. However, this argument assumes the smaller aircraft does not suffer tremendous efficiency penalties and has similar utilization rates.

Another example or differences in vision, is the sharp contrast between the European Union's (EU) vision for short-range transportation and that of NASA. The EU sets the goal of effectively incorporating intermodal transportation (air/train/bus) as means of reducing short haul flights of 500 nm or less (EC, 2001). In contrast, NASA's proposed Small Aircraft Transportation System (SATS) concept would provide a similar service (Holmes, 2001) using the multitude of small, underutilized public use airports to provide faster point-to-point service for business travelers. At first glance, the SATS idea does not seem very environmentally compatible since aviation in general, and low capacity aviation in particular, would have a hard time competing with surface transportation for efficiency. However, from a system viewpoint that includes the reduced use of large aircraft carriers and the environmental impact of running high-speed rail to small municipalities, this concept may show merit. Instead, the selling point is the reduced travel time. The ethical responsibility of engineers would be to implement this concept without an added environmental burden.

Finally, government regulation may be expected to play an increasing role in directing the scope of aircraft programs. Current regulations already limit the emission of noise, NOx and CO from commercial aviation around airports. However, these regulations have never been excessively challenging and most new aircraft designs easily exceed current and planned regulations (Guynn, 2001). In the near future, however, the type of regulatory control may change dramatically. ICAO's Committee on Aviation Environmental Protection (CAEP) will recommend the use of market based tools (charges or taxes) to effect changes in total emission rates (ICAO, 2001 and EC, 2000). Such charges already exist for noise emissions at selective airports around the world, and gaseous emission charges are currently in effect in Sweden and Switzerland. The details of how these new charges are eventually accessed can be expected to have a strong influence on the direction of civil aircraft development.

NECESSARY DESIGN TOOLS

In order to apply green design to aircraft design, a suitable set of design tools for environmental compatibility must be available. These tools range might from a collection of qualitative design rules based upon prior experience to historical trends showing technological trends to methods and data for quantitative analysis and comparison. This section examines some of these design rules and identifies further needs.

Gas Emissions

The push towards improved fuel efficiency has moved commercial aviation towards larger by-pass engines driven by hot, high-pressure ratio cores. While reducing total CO_2 emissions by improving SFC's, the combination of high pressures and temperature in the combustion section results in an increase in the production of NOx. Some turbofan engines may be purchased with a low NOx combustor section option - with an added penalty in purchase price, fuel efficiency and maintainability. The benefit of such a trade must then be based upon the relative harmfulness of CO_2/H_2O versus NOx.

While engine technology is important, there is a limit on how much reduction can be obtain while still using kerosene burning engines. Other technologies like alternate fuels are not projected for the near or mid (< 20 years) term and aircraft designers are limited by what engines are currently produced or can be delivered (and certified!) when the airframe is ready. Fortunately, the aircraft designer does have the ability to strongly effect engine emissions through improved aerodynamics and lighter weight structures. Quinn (1998) has shown results indicating that the total benefit from better airframe design will exceed that of kerosene engine technology gains alone. Thus, clean external lines to reduce profile drag, innovative lifting surface design to reduce induced drag, and synergistic structural design coupled with advanced materials are as important as ever.

To estimate aircraft emissions, the Federal Aviation Administration (FAA) has already produced a useful tool (FAA, 2001) for the calculation and comparison for existing aircraft during the landing and takeoff (LTO) phases of operation. While the program is useful, the included engine emission data obtained by the Environmental Protection Agency (EPA) and ICAO, is immensely valuable due to the great difficulty in obtaining any engine performance data from the manufacturers. In preliminary design, this database would be useful for establishing baseline emissions standards from which to compare. This tool exists due to the need to calculate LTO emissions to demonstrate compliance with regulatory requirements and does not address cruise emissions. While improving LTO emission probably has a collateral effect on cruise, the cruise phase, where the bulk of the greenhouse gasses are emitted, should be addressed directly.

To this end NASA has begun work at compiling data and estimating fleet wide gaseous emissions for aircraft (Dagget, Sutkus, Dubois, and Baughcum, 1999) and the FAA is expected to beings it's SAGE program (Locke and Morales, 2001) in late 2001. Similarly, De Lauretis, Gaudioso, and Romano (2001) have compared different methods of calculating aircraft missions during the entire flight operation but they note the inadequacy of the available database. With the prospect of future operational charges based upon cruise emissions, a definitive methodology and database may be expected at some time through the FAA or ICAO.

Noise

While older low by-pass turbojet suffered from high levels of jet noise – that associated with the high-energy wake - modern high by-pass may also suffer a penalty due to fan noise - associated with the high tip speed and high fan blade loadings (Gliebe, 2000). Unfortunately, engine noise is difficult to predict from a preliminary design and actual noise levels seen in operation are strong influence by operation procedures. In fact, one of the more effective means of local airport noise control is in modifying aircraft operating procedures during take-off and landing. Thus aircraft with improved low speed performance and handling characteristics may have noise advantages in practice.

Some design concepts to reduce noise do exist. Since the major issue is ground noise levels, any engine installation that shields the fan and/or engine wake from the ground will reduce the aircraft noise signature. Examples include extended nacelle designs, over-wing engine installations or the scarf inlet concept (Berton, 2001 and Shivashankava, 1998). Penalties here may include aircraft drag or increase cabin noise. Oversizing an engine may also be effective since it shifts the normal operating range away from the engines maximum conditions. However, higher thrust engines are also more expensive and, if physically larger, may result in increase cruise drag and thus fuel burn.

Another source of noise that is gaining more attention is that due to airframe noise. Turbulent, swirling flow around landing gear and high lift systems (flaps and slats) can produce a sizeable amount of noise that can be reduced by cleaning up the aerodynamics of these components. Unfortunately, accurate prediction of noise emissions during the preliminary design phase is not likely to happen - at least not with the tools and knowledge base available in a university setting. Thus, qualitative design guidelines such as those above may have to suffice.

Materials

Ashby (1999) presents useful methods for comparing the environmental suitability of different materials based upon either their associated energy content or their "eco-indicator" as is currently been implemented in European industry. While these methods are interesting, to be useful in aviation, a comparison of materials should include not just the energy and/or environmental impact of production, but also that of usage over the life span of an aircraft since, as mentioned in the introduction, the potential lifetime fuel savings from lighter weight materials would indicate their use almost all the time.

Economically this might not be true. The cost of fuel is only approximation 9.5% of the operating cost of a Boeing 777 aircraft (Cuthbertson, 1999) while the cost of ownership is 49.5%. Since the cost of ownership is closely tied to the acquisition cost of the aircraft, lighter weight materials must not carry an excessive monetary burden due to either material or labor cost. The cost of certifying new materials for aviation use is also very high and carries a risk in itself. Thus, while the aerospace sector has been in the forefront of material research, civil application of these materials in airframes has been a slow process.

End-of-Life Disposal

While the use of low weight materials may reduce the total environmental impact of a design, this fact is not much consolation when faced with the disposal of non-recyclable production or end-of-life wastes. It is very unlikely that you would ever see an existing aluminum aircraft in a landfill – but what about a next generation all-composite aircraft? The final issue remaining is the disposal of an aircraft at the end-of-life.

The European community has already enacted several take-back initiatives that require manufacturers to bare responsibility for final end-of-life disposal of their products. These include the automotive industry despite the fact that automobiles were already highly recycled (Ref. 24). It should be expected that eventually aircraft will be similar targeted, either directly or included as part of an all-encompassing legislation. It is also possible that requiring the aircraft manufacturer to take back older aircraft may be seen as a effective policy to encourage aircraft operators to routinely upgrade and increase the fleet turnover rate to newer aircraft designs with lower emissions.

The metal components of current aircraft should be easily recyclable although care should be taken to ensure that some exotic alloys or specially treated metals with potentially toxic components should not be placed into the consumer recycling chain. As the use of composites becomes more prevalent, particularly fiber reinforced epoxy composites, the issue of disposal becomes more important. For the designer, selection criteria and guidelines for these materials that take into account their disposal impact should be developed.

CONCLUSIONS

In teaching aircraft design, emphasizing the goal of improved efficiency is largely compatible with reducing the environmental impact of aviation. However, adopting the goals of green design would include efficiency as part of a larger environmental framework and necessitate a more systemic approached to design. In addition, teaching the regulatory and policy aspects of environmental issues like greenhouse gas emissions helps satisfy additional educational objectives for engineering.

The tools necessary to include environmental trades into aircraft design do not current exist as such though some of the existing tools used in other engineering fields may be adapted to use. The same is true for some of the governmental impact assessment methods. Also, compilations of historical trends and projections of current technology will be useful to establish baseline comparisons for new green designs. However, the best start towards the goal of green aircraft design would simply be the collection of new anecdotal design rules and recasting existing guidelines for designing efficient aircraft into guidelines for designing environmentally friendly aircraft.❑

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