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Developments and Challenges for Aluminum – A Boeing Perspective

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Abstract

Aluminum has long been the material of choice for commercial aircraft primary structure. Aluminum suppliers have steadfastly improved products to support performance needs. Selection of composites for Boeing's 7E7 challenges aluminum's predominant position. Composites must prove their abilities; but improvements in manufacturability, performance, and affordability supported their selection for the 7E7 program to enable operating efficiency improvements. To win future airframe applications, aluminum must compete with and/or be compatible with composites. Recently demonstrated improvements in aluminum product properties suggest further advances are feasible. Research supporting improved performance and cost reductions is needed to meet the composite challenge and keep aluminum flying.

1. Introduction

During the 100 year history of powered flight, aircraft have evolved from the initial wood and fabric structures to robust structures of aluminum alloys; the world has witnessed the growth of the commercial airline industry and the evolution of aircraft design, production, and operating philosophies under competitive market pressures. Historically, the airframe industry has relied on new and improved structural materials to meet competitive challenges by implementing material options that increase performance, support reliability, reduce weight, lower costs, and/or solve problems.

Boeing currently has a safe, reliable fleet of revenue generating commercial airplanes that are produced using aluminum primary structure. We have years of experience in the design, production, operation, and maintenance of aluminum airframes. The operating history of our fleet provides guidance for decision making and contains many examples of lessons learned, both positive and negative. The infrastructure and knowledge base necessary to support the current commercial fleet, the airline customers, and ultimately, the flying public, is complex and has evolved over many years.

Through a long history of sustained development activities, the aluminum industry has supported Boeing and the airframe industry via the development and introduction of new products. Figure 1 provides a timeline highlighting the introduction of several aluminum structural materials on new and derivative airplane programs. Each of these new aluminum materials provided a performance, weight, and/or cost benefit to help the airplane program meet its objectives. Each successfully commercialized product represents the culmination of years of committed research and development activities.

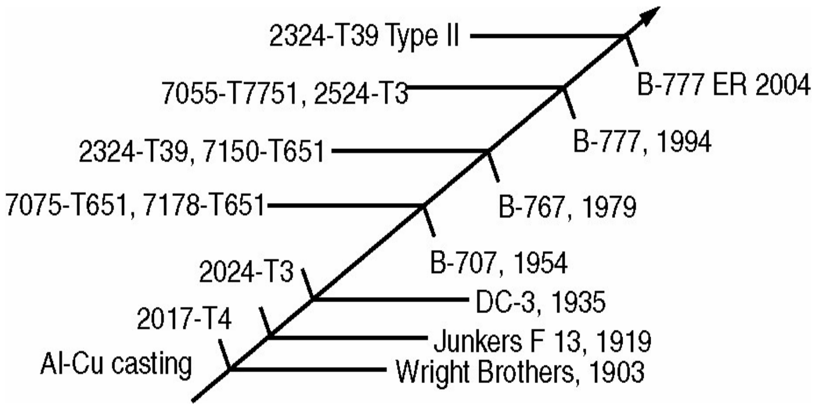

Figure 1: Timeline highlighting introduction of new aluminum alloys.

Aluminum product development efforts have been successful in improving the static strength and fracture toughness of aluminum alloys either through composition design and control, or through development of thermal mechanical practices and tempers which allow retention of high strength with acceptable corrosion performance. New aluminum product options with improvements in both strength and toughness are still of interest in current development programs, particularly for upgrades to existing aluminum designs. Figure 2 shows several significant aluminium sheet and plate product improvements implemented for production airplanes, and highlights the desired improvements that will allow us to build on these successes.

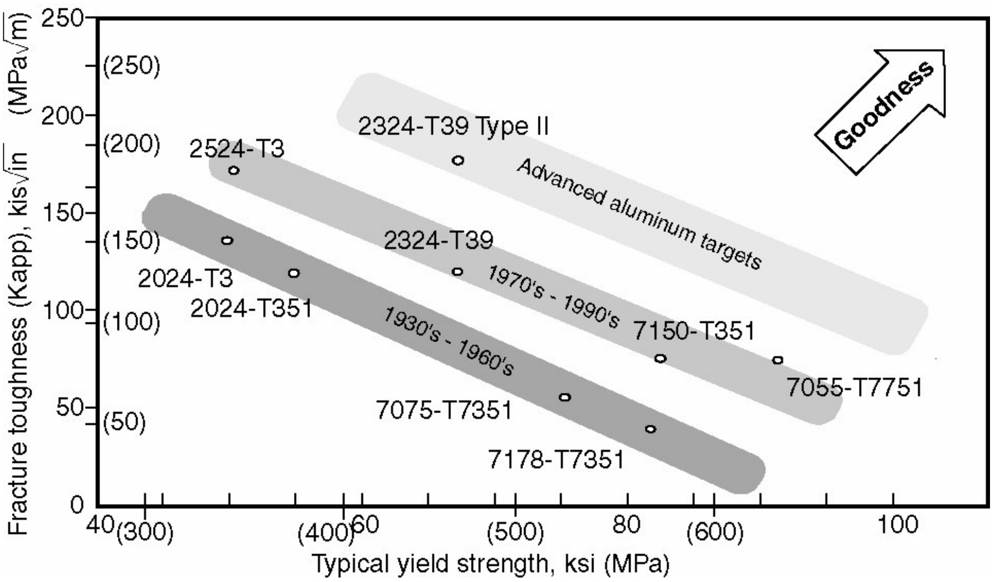

Figure 2: Illustration of continued strength-toughness development in aluminum alloys.

There is active engineering research and development work to support new aluminum products that offer benefits to Boeing's derivative airplane product development efforts for improvement of current airplane models. Boeing is interested in aluminum products that can be used to improve airplane performance via improved material properties, as well as aluminum products which provide the ability to reduce weight and/or reduce production costs.

Current advanced aluminum development at Boeing is working with the global aluminum industry to develop targeted technical solutions to support derivative models of current programs.

Additionally, we are working to position aluminum to compete with composites for future new airplane programs. Our materials development approach is integrated with airplane needs to provide advanced options for airframe design [1]. Our current aluminum product performance goals are challenging suppliers to develop and demonstrate aluminum alloys with significant increases in static strength, fracture toughness, fatigue performance, and corrosion behavior. In addition to the technical challenges, the competitive industry environment and the economic environment are creating significant cost pressure that cannot be ignored.

2. Current Commercial Airplane Market

Airplane development programs and related material development activities are influenced by the larger context of the commercial airplane market; current market conditions are marked by global issues which have created unprecedented times of uncertainty for the world economy. Airlines are facing the economic impact of a series of disruptive world events, as summarized in Figure 3, and many must develop new business models in order to survive and compete.

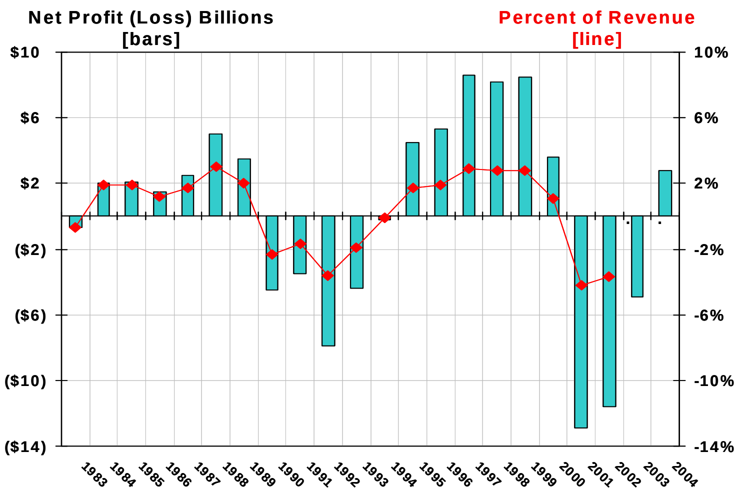

Figure 3: Airline profitability

While recent times have not been favorable for airline profitability, in the long view, the world economy will improve and grow, and a strong transportation network will be required to support that growth. Boeing's 20 year forecast [2] anticipates long term growth for air travel with increases in both passenger and cargo traffic based on worldwide economic growth, as shown in Figure 4.

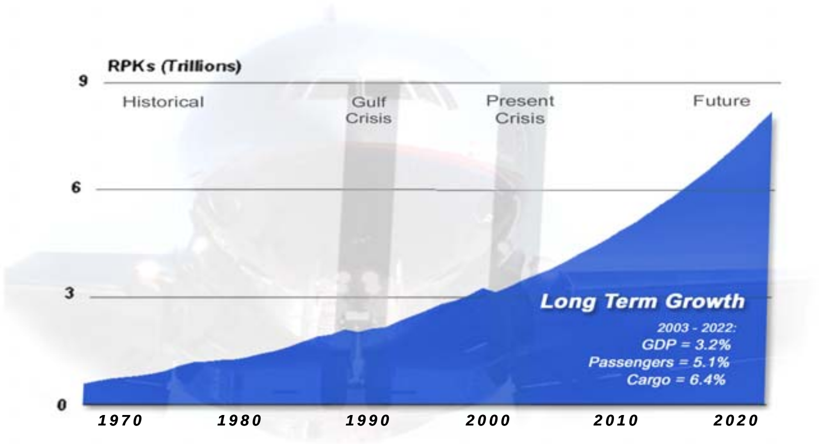

Figure 4: Growth trends in passenger traffic as measured in revenue passenger kilometers (standard industry unit = number of passengers x kilometers they fly).

Within the overall global forecast, expectations for growth by region vary and strategic decisions reflect differing interpretations of the data. The airline industry will continue to respond to the changing business and regulatory environment, and will continue to adapt their strategies to take advantage of developments in airplane capacity and range capabilities.

3. Boeing Commercial Airplane's Strategy and the 7E7

Boeing's strategy continues to be based on the view that the flying public wants safe, reliable service with the shortest trip times possible, a wide variety of flight choices direct to multiple destinations, low fares, and comfortable surroundings. The cornerstone of the Boeing strategy is that passengers generally prefer point-to-point service rather than routing through connecting hubs. This leads to the expectation that the world market will demand more non-stop flights and increasing flight frequency to meet increased air traffic needs. Boeing refers to this as "fragmentation", and believes that this philosophy is supported by airplanes that serve the middle of the market in the 200 – 300 seat range.

Boeing's newest airplane, the 7E7 is being designed with airline input to support needs in the middle of the market. The 7E7 program is using technical advances in a number of areas in addition to materials, including: aerodynamics, systems, and engines. Advances in these technology areas are interdependent and are expected to work together synergistically to provide targeted performance benefits, most notably improved operating efficiency.

There have been systematic increases in the application of composite materials on Boeing commercial aircraft [3, 4], as illustrated in Figure 5. The growth of composites applications began in secondary structures (i.e. cowlings, fairings, spoilers) on the 757 and 767, and later moved into the empennage and primary control surfaces for the 777. These commercial applications have provided design, manufacturing, and operational experience with composites which have, in turn, guided additional developments in material properties, cost reductions, and manufacturability.

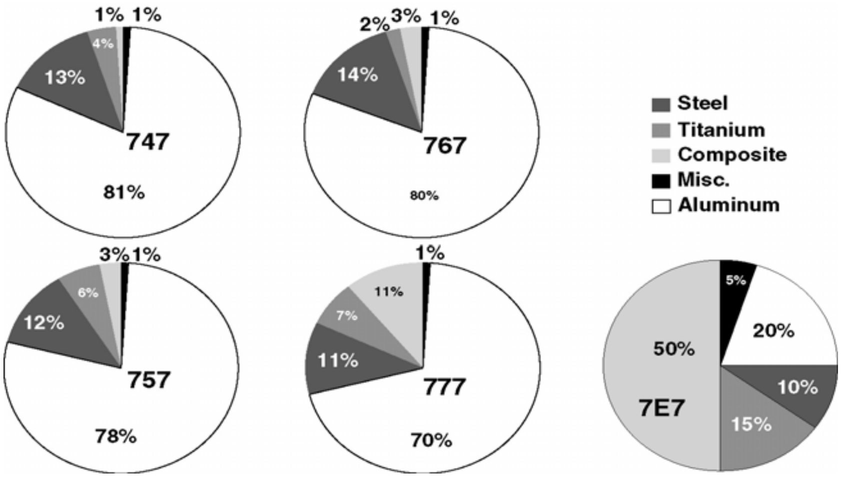

Figure 5: Approximate primary structure material usage by weight on several Boeing programs.

The 7E7 decision to use graphite epoxy composites as primary structure reflects belief that composite technologies have advanced sufficiently to meet the new performance, cost, and weight targets necessary to support stated goals of delivering 20% better fuel efficiency than current similarly sized models, while reducing overall operating costs for the airline and improving passenger comfort.

Working in concert with other technical advances, composite materials are expected to meet weight reduction goals, support reduced maintenance based on reductions in corrosion and fatigue, and support program cost objectives.

For example, the improved fatigue and corrosion resistance of composites will help to enable a cabin environment equivalent to a lower altitude with a more comfortable cabin pressure and improved humidity.

Composite materials still face considerable challenges as their applications expand into primary structure, but composites are also expected to provide significant development potential for the future. Current composites work is focused on optimization of structural designs to make the best use of unique composite capabilities and reduce manufacturing costs for new structure, and on development of in service repairs necessary to support dispatch reliability for the airlines.

4. Challenges for Aluminum Research and Development

The selection of composite materials for the primary structure of the 7E7 is a significant, immediate, and direct challenge for aluminum [5]. Composite materials are considered disruptive technology by members of the aluminum industry who have long discussed the “composite threat”.

The current focus of materials development activities for both composites and aluminum includes: further demonstrated improvements in material performance, ability to support optimized structural designs, continued lowering of manufacturing costs, and ability to perform reliably in service. In terms of airplane design drivers, there are significant cost and weight challenges for both aluminium and for composites as shown schematically in Figure 6.

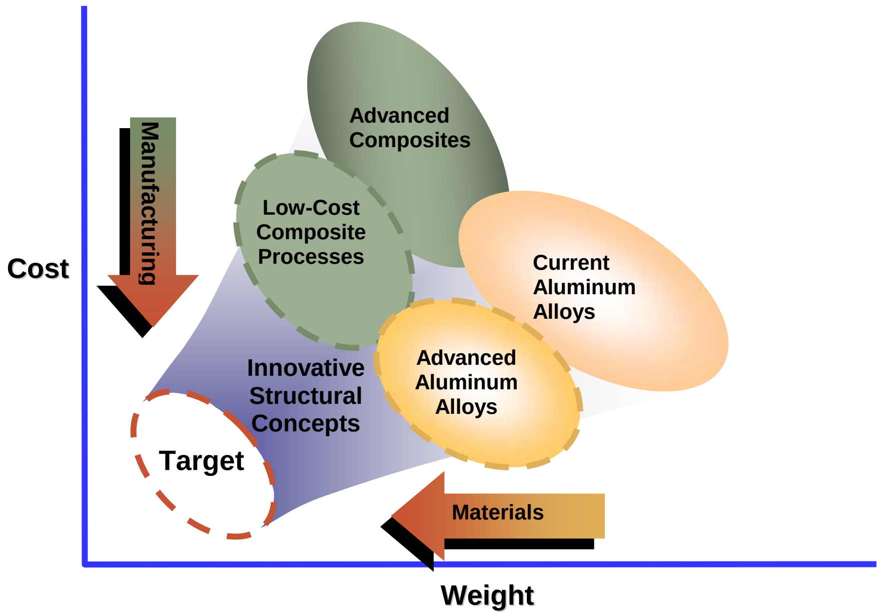

Figure 6: Schematic view of cost weight considerations for material selection.

The perception is that composites have significant potential for performance and producibility improvements as they continue to mature technically. Additionally, as applications increase, composite material costs are expected to continue to moderate.

The infrastructure necessary for production and support of composite airframe structure is developing in a time where lean manufacturing principles can be readily applied to allow efficiency and flexibility to be built into these new processes. The challenge faced by composites is that they must prove their capabilities and cost effectiveness in both production and in service as they expand their role into primary structure.
For aluminium, the focus of our active development work is two fold. For existing airplane programs, the focus is on improving the design values to support improved structural performance and weight reductions on existing aluminum designs. For future new airplane programs, the desire is to provide aluminum options that can compete favorably with graphite epoxy composites, or be compatible with next generation composite materials.

Accumulated past experiences with aluminum have created the perception that aluminum represents a mature technology. There is a general concern that performance improvements are typically incremental and that improved materials end up costing more, not less. While the cost of raw material may not appear large when viewed relative to the cost of the finished airplane, material costs and associated manufacturing costs are a large fraction of those for individual structural elements and there is strong pressure to demonstrate cost savings. Economic targets could be difficult to meet with the pricing structure traditionally applied to sole source, proprietary aluminium products. Research and bold thinking by the aluminum industry which could provide for breakthrough efficiencies in the energy intensive aluminium production process and enable a new aluminum product cost structure would be of great interest in meeting the competitive pressures from other material systems.

There is current active interest in improved aluminium alloy products to support needs for derivative airplane programs; goals of these product development activities include development of future passenger and freighter airplane models and require aluminum alloy products to support improvements in fuselage and wing applications. The primary design drivers for derivative aircraft remain static strength properties, fatigue behavior, damage tolerance and corrosion performance.

Alloy development activities are focused on supporting improvements in airplane performance as well as reducing the overall operating costs for the airlines. Related research and development work to support manufacturing efficiency and cost reduction via improved and/or novel processing is also of interest, but processing must be robust to support production and the data necessary to support implementation and business case development must be available.

For the 7E7, specific selection of carbon fiber reinforced plastic composites creates an additional challenge for application of aluminium on this airframe based on corrosion considerations. Direct coupling of graphite fiber composites to aluminium creates a galvanic cell which drives corrosion degradation of the aluminium. Available isolation techniques add weight, and create inspection and/or maintenance issues which can make them impractical. In many applications, composite and/or titanium components are selected to avoid potential galvanic corrosion issues with aluminum in service.

For the future, continued developments in composite materials where current graphite based fiber systems are replaced with emerging high modulus, chemically inert, organic fibers, such as M5™, may provide opportunities for increasing aluminium applications by removing the galvanic corrosion concerns. These new fibers also offer the potential for development of new hybrid materials, including the possibility for a new generation of fiber metal laminate materials.

In order to win future applications for aluminum on new and derivative airplane programs, aluminum will need to meet or exceed targets for performance and life cycle cost affordability. It is fully expected that future trade studies will compare aluminum solutions with new composite options. Aluminum must be well positioned to meet these technical and market challenges by being competitive with or compatible with composite design options.

5. Summary

Aluminum development for Boeing commercial airplanes is in a very unique position at the moment; recently demonstrated improvements in aluminum alloy properties have certainly captured the interest of those who work on developing derivatives of the existing airplane models. We continue to support improvements for these programs via active participation in exciting technical development with the global aluminum industry. At the same time, the selection of graphite epoxy based composites for the 7E7 represents a significant challenge to aluminum for the future.

Aluminum research that supports new aluminum alloy product development is of continued interest.

Challenging performance goals supporting airplane program needs are being worked with members of the global aluminium industry via alloy and temper design capabilities. Related research and development work ultimately contributing to support of manufacturing efficiency and cost reduction via improved and/or novel processing is also of interest and Boeing is engaged in continued technical discussions with the aluminum research and development community on these topics. Future developments of advanced hybrid materials could provide additional opportunities for aluminum and new material options for the airframe industry.

References

[1] S.E. Axter, et al, AIAA 2003-7879, Evolution of an Integrated Approach to Material Development, 44th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, April 7–10, 2003 Norfolk, VA, to be published 2004.
[2] R. Baseler, Boeing Commercial Airplanes Market Forecast, 2003.
[3] P. Harradine and J. T. Quinlivan “Composites and the Commercial Jet – A Boeing Viewpoint” AIAA-89-2126, Aircraft Design and Operations Conference, 1989.
[4] B.W. Smith “The Boeing 777” Advanced Materials and Processes, September 2003.
[5] American Metal Market Staff, Dreamliner Handed Boarding Pass to Composites, AMM 12/24/03.