SUMMARY

Good cost estimates can make important contributions to effective acquisition policy. RAND has a long history of producing cost-estimating methodologies. Two of its more recent studies are Hess and Romanoff (1987) and Resetar, Rogers, and Hess (1991).

This report both updates and extends these earlier studies, focusing on the effects of material mix, manufacturing technique, and part geometric complexity on cost. We collected two types of information on these effects. First, we surveyed the military airframe industry for estimates of how aircraft production costs vary with airframe structure material mix. Second, we analyzed a large set of actual part data from recent aircraft manufacturing efforts that we collected from industry. We also estimated a set of airframe cost-estimating relationships (CERs) for labor hours based on MACDAR, a historical airframe database.[1] We then integrated the effects of material mix into these estimates.

AIRFRAME MATERIALS

The first part of this report reviews material properties that are important in airframe applications. Chief among these properties are strength and stiffness, especially in relation to weight.[2] Many air-

[1]MACDAR stands for Military Aircraft Cost Data Archive and Retrieval, a database owned by the Air Force Cost Analysis Agency.

[2]As outlined in the body of the report, when a material is referred to as low weight, technically it is the material's density (pounds per cubic inch) that is being discussed.

frame parts require high strength and stiffness to withstand the loads (forces) placed on airframes during flight; low weight increases performance in such areas as range, payload, acceleration, and turn rate. Other important material properties, such as corrosion resistance, toughness, and service temperature, are also briefly discussed. We then discuss the properties of composite materials that are important in airframe applications: carbon fiber with epoxy, bismaleimide (BMI), and thermoplastic resins. In most cases, these composites have better strength and stiffness in relation to weight than do metals. In addition, composite parts can be designed and built with more strength and stiffness in some directions than in others and can thus be tailored to the directional loads the part is expected to bear. This leads to the more efficient design and use of material. Another advantage of composite materials is that they lend themselves to unitization—that is, to the substitution of one integrated part for several smaller ones that must be fastened into a subassembly.

However, composite materials have some drawbacks, the most significant of which is higher design and fabrication cost. Composites fail in ways that metals do not—e.g., through delamination—posing inspection and maintenance challenges. We discuss the pros and cons of individual composites and also review the properties—and pros and cons—of the metals aluminum, steel, and titanium.

This report also discusses part fabrication techniques. Toward this goal, it reviews the traditional composite hand layup process, in which workers manually stack individual plies on a tool to form the part. Two newer techniques are then discussed: automated fiber placement,[3] in which a machine lays down the plies, and resin transfer molding (RTM), in which the part is formed in a complex die. These techniques make it possible to fabricate highly complex parts less expensively and with significantly better tolerances than would be possible by hand layup. We then discuss two advanced techniques for producing metal parts. The first such technique is high-speed machining (HSM), which both lowers the cost and increases the complexity of parts that can be machined. The second is hot iso-

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[3]We use the term *automated fiber placement* in its generic sense to refer to automated tape placement, automated tow placement, and contour tape placement.

static press (HIP) investment casting of titanium, which greatly improves the properties of titanium-cast parts compared to more traditional processes.

AIRFRAME COST INFORMATION

The second part of the report presents our results on how costs—primarily labor hours—vary by material mix, manufacturing technique, and part geometric complexity. Results from both an industry survey and data analysis are shown, and the reasons behind the results are discussed. We also present estimates of learning rates, weight-sizing factors, and raw material prices in the year 2000. In Chapter Five we estimate recurring labor hour CERs from the MACDAR data set, which has production data on five recent fighter-class aircraft: AV-8B, F-14, F-15, F-16, and F/A-18. Material effects on cost are part of these CERs.

Finally, the report describes how all the cost estimates presented herein can be integrated to generate airframe cost projections, illustrating this by estimating the cost of a notional future fighter aircraft.