Chapter One

INTRODUCTION

BACKGROUND AND PURPOSE

Good cost estimates for military aircraft can play an important role in developing sound budgets and in contributing to effective acquisition policy. RAND has a long tradition of developing cost estimation techniques and has published a number of widely used reports on the topic. As the methods and materials used in aircraft production change and as new information becomes available, however, these techniques should be updated. This report presents the results of a research project on the determinants of military airframe costs and offers a methodology for projecting future costs.

This work is part of a larger research project on military aircraft costs. Two other publications from this project are relevant to the work described here. One is on the impact of lean manufacturing and other advanced manufacturing techniques on airframe costs,[1] and the other is on the effect of acquisition reform on these costs.[2] This report also discusses how the results described in those reports can be integrated into an overall methodology for projecting future airframe costs. Appendix E presents a complete list of subjects addressed in all three reports.

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[1]Cook and Graser (2001).

[2]Lorell and Graser (2001).

RELATION TO PREVIOUS WORK

This report updates two RAND reports that dealt with different aspects of estimating the cost of aircraft production: Hess and Romanoff (1987) and Resetar, Rogers, and Hess (1991).[3] The Hess and Romanoff work is itself an update of traditional airframe cost-estimating methodologies that were based on historical cost data of various aircraft, usually annual data on cost and quantity produced by aircraft type. In traditional cost estimation methodology, costs are sometimes expressed in dollars and sometimes in labor hours and are disaggregated in various ways. These costs are then used as the dependent variables in statistical regression analysis. Explanatory variables typically include factors such as cumulative production quantity, annual production rate, aircraft characteristics (e.g., weight and speed), and the like. The resulting estimated equations are referred to as cost-estimating relationships, or CERs. The Hess and Romanoff study estimated CERs for a wide range of military aircraft. This study updates that work by using a new aircraft cost data set called MACDAR.[4] This data set includes information on the AV-8B, F-14, F-15, F-16, and F/A-18 aircraft for the years 1971 to 1991.

Resetar, Rogers, and Hess (1991) factor the new materials used in aircraft construction into cost estimates. An important technical development in military airframe manufacturing over the past 50 years has been the increasing use of materials other than aluminum. The most important of these are the metals titanium, steel, and aluminum-lithium and the composite materials carbon-epoxy, carbon-bismaleimide (BMI), and carbon-thermoplastic. Resetar, Rogers, and Hess (1991) pioneered the analysis and measurement of the cost implications associated with the use of these materials. That report, hereafter called RRH, estimates the ratio of the cost (per pound) of airframe structure made of any given material to the cost of structure

[3]Hess and Romanoff (1987) and Resetar, Rogers, and Hess (1991) included total recurring and nonrecurring cost estimates for airframes. This report addresses only recurring labor and raw material cost in the main body and nonrecurring engineering and tooling labor in Appendix D.

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

made of aluminum.[5] Separate ratio estimates were made for the following cost categories:

- Nonrecurring engineering labor
- Nonrecurring tooling labor
- Recurring engineering labor
- Recurring tooling labor
- Recurring manufacturing labor
- Recurring manufacturing material
- Recurring quality assurance labor.

For the six labor categories, the measure of cost was labor hours per pound. Thus, the ratio in question was hours per pound required to manufacture airframe structure from the given material divided by hours per pound required to manufacture airframe structure from aluminum. For manufacturing material, the measure of cost was dollars per pound.

All the estimates were based on a survey of companies in the military aircraft industry. The cost ratio estimates thus derived were then integrated with the Hess and Romanoff CERs. The Hess and Romanoff CERs did not include material composition as an explanatory variable. In the integrated structure proposed in RRH, for each aircraft–cost category combination a weighted-average overall material cost ratio is calculated, with weights proportional to the share of each material in the aircraft structure. This weighted-average cost ratio is then used as a multiplicative adjustment factor for the appropriate CER. RRH also included some "primer" material on the properties and manufacturing techniques for composite materials as well as metals.

We are updating these earlier studies for several reasons. First, the RRH report gives only one cost ratio for each material–cost category

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[5]In that report, the cost ratios were referred to as "complexity factors" with the connotation that the increased costs were due to the increased complexity of the production process. Since this research introduces part geometric complexity as a cost determinant, we simply use the term *cost ratios*.

combination, representing typical part geometry and manufacturing technique at that time. This was appropriate in that composite materials at the time of the RRH study were generally used for simple parts such as surfaces and panels rather than for more complex applications.[6] In addition, one manufacturing technique then dominated composite material fabrication: hand layup.[7] Since then, a wider variety of part types have been made from composite materials, and new manufacturing techniques have become much more common, especially automated fiber placement and resin transfer molding (RTM). In addition, new manufacturing techniques for metals are becoming more common, especially high-speed machining (HSM) for aluminum and hot isostatic press (HIP) investment casting for titanium. Thus, the cost-estimating community has called for a more detailed set of cost ratio estimates in which cost ratios are a function of part geometry and manufacturing technique as well as of material type and cost category. This approach would allow cost estimators, for example, to make their projections sensitive to what manufacturing technique was planned for each part—an approach that was not possible with earlier estimates.

Second, the RRH results were based on estimates provided by a group of military aircraft companies with no detailed backup data. This occurred because at the time of that work, relatively little systematic data were available on the cost of individual parts as a function of material type. As a result, the RRH estimates were based on engineering judgment informed by the experience to date. Since then, some systematic data have become available, and this study has been able to take advantage of those data. We present cost ratio results based both on a new survey of industry estimates and on statistical analysis of data that we obtained.

Third, as mentioned above, the MACDAR database has become available, offering some additional data that were not available to the earlier studies.

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[6]We say "generally" because there were in fact limited applications to relatively complex parts—for example, sine wave spars in the AV-8B.

[7]Again, there were some exceptions, such as pultrusion and early tape-laying machines for the B-2.

Fourth, as was discussed in RRH, their two-step integration procedure did not account for the fact that the airframe CERs estimated in the Hess and Romanoff study—and incorporated into the RRH study—did not factor in material composition. Thus, as RRH clearly pointed out, there was a possibility that material composition effects were biasing the coefficient estimates in the CERs, as a result of which the integration process proposed therein might have misestimated the net effect of material composition. RRH noted that with the limited data available at the time, these effects could not be reliably disentangled. With the new data, however, they now can, and our CER estimation thus includes an explicit material composition variable that should improve the quality of the estimates.

HOW THIS REPORT IS ORGANIZED

This report is divided into two parts. The first part, made up of Chapters Two and Three, presents a primer on aircraft materials and manufacturing techniques that is intended to provide background information for cost analysts who may not be familiar with some of the technical aspects of aircraft construction that influence aircraft cost. Discussed herein are the properties of various materials and considerations that are important in choosing material for different applications. Also described are alternate manufacturing techniques. Those familiar with these areas can skip over the primer material and move to the second part of the document, which consists of Chapters Four, Five, and Six. Chapter Four presents estimates of how costs vary by material mix, manufacturing technique, and part geometric complexity, with estimates based both on our industry survey and on data analysis. Chapter Five presents a statistical analysis of historical production cost data on five recent fighter-attack aircraft. Chapter Six integrates all the estimates to develop an overall methodology for projecting future airframe costs.