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The Challenge of Maintaining or Replacing an Aging Airlift Fleet: A Cost/Capability Analysis for the Brazilian Air Force Mobility System

Julio C. Messias

AFIT/GLM/LAL/99S-9

THE CHALLENGE OF MAINTAINING OR REPLACING AN AGING AIRLIFT FLEET: A COST/CAPABILITY ANALYSIS FOR THE BRAZILIAN AIR FORCE MOBILITY SYSTEM

THESIS

Julio C. Messias, Captain, BAF

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THESIS

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Julio C. Messias, B.S.

Captain, Brazilian Air Force

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Abstract

Despite the high Operational and Support costs incurred, the Brazilian Air Force's (BAF) declining budget has led to the establishment of conservative policies that favor short run solutions for a critical BAF airlift problem of operating an aging fleet. As a result of this policy, service life extensions of older airlift aircraft are the preferred solution. Due to the lack of a well-defined cost analysis structure, studies concerning selection of alternatives capable of providing substantial cost savings in the long run for the BAF are not included in the early phases of a new aircraft acquisition program.

Using an equal airlift capacity approach to examine the Brazilian Air Force mobility system, this research performs a cost comparison analysis between two aircraft currently in operation at Brazilian's airlift command: C-130 Hercules and C-95 Bandeirante. To accomplish the cost analysis, this research develops an Operation and Support aircraft cost model adapted to the Brazilian's airlift system requirements.

Assuming the same level of annual flying hours for the next 20 years, the research cost analysis concludes that the proposed alternative of acquiring C-130 aircraft to replace the older C-95 fleet could result in savings of at least 25 percent, without reducing the BAF mobility capacity.

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I. Introduction

General Issue

For several years, the Brazilian Air Force (BAF) has been engaging in various programs to modernize and increase the capacity of its aging airlift fleet. While the range and diversity of transportation missions are expanding, lack of financial resources has been delaying any initiatives to improve the mobility system. Furthermore, Brazilian Air Force Mobility Command, the command responsible for the airlift transportation of cargo and personnel throughout the Air Force, has been operating aircraft that are currently reaching their initial projected operational life, as determined by the manufacturers.

Given the actual military budget reduction occurring not only in the Brazilian Air Force, but also in several other Air Forces, principally developing countries, extending the service life of an aging fleet could be an appropriate alternative solution to maintain the mobility capability. Nevertheless, such decisions may not be supported by studies concerning the increasing operation and support costs incurred by an aging airlift fleet in a long run.

Nowadays, several studies concerning aging airlift replacement alternatives are underway within Brazil's Air Force Materiel Command. In the same way, the Air Force Staff has been developing a near-term plan to improve the air transportation capability with the establishment of acquisition programs for a next generation of airlift aircraft that could replace some the current aging aircraft fleet. Studies in this area show that three lines of actions are conceivable (Menezes, 1999):

(1) To extend until 2010 the life of aircraft in service today through modernization or refurbishing.

(2) To introduce into service, as a complement to the present fleet, a given quantity of aircraft compatible with the type in use, to replace losses or rate of attrition.

(3) At the same time, discuss the replacement of the present fleet by a new-generation aircraft, starting in 2010.

In the same way, some of the aircraft in operation are also beginning to show severe aging problems, like corrosion and structural fatigue, which threaten the flight safety and result in decreasing aircraft availability. Futhermore, increasing Operational and Support (O&S) costs have been exceeding financial resources available to maintain an acceptable level of reliability in these aircraft. Besides these concerns, safety inspections, repair, and modification costs, when combined with other maintenance costs are reducing the availability levels of the Brazilian Air Force fleet.

Although the current aging fleet could be kept in service for another 20 or more years, some groups in the Brazilian Air Force believe that it would be more economical to replace these aircraft, rather than operating an aging fleet. However, no research has yet been conducted to evaluate if the cost of operating the actual BAF airlift fleet in fact exceeds the cost to acquire and operate new airlift aircraft.

Unfortunately, current projects for estimating the O&S cost impact over an aging fleet have not satisfied the Brazilian Air Force needs. The lack of a reliable cost database capable of providing more accurate predictions of future aircraft costs inhibits Air Force decision-makers from establishing a realistic timetable to phase-out an old system, and to begin planning for replacement of the aging aircraft in operation.

To investigate this issue, the BAF mobility system needs an overall economic service life estimation model capable of estimating all operational O&S cost elements incurred by its aging aircraft fleet. Nevertheless, procurement of a new airlift aircraft or in-house acquisition program that would attend the mobility system requirements represents a major challenge to the Air Force. Moreover, possible aircraft alternatives for the mobility system must demonstrate minimum levels of performance capabilities, and ability to operate in adverse environments found in some areas of the Brazilian territory, in addition to lower O&S costs throughout their operational life-cycle.

Brazilian Air Force Airlift Fleet

Currently, the BAF airlift fleet is composed of several aircraft models dedicated exclusively to military missions. If completely utilized, this fleet would have a total theoretical cargo capacity of approximately one million ton-miles per day (MTM/D). To accomplish its missions, the Brazilian Air Force Mobility Command operates four primary airlifter's:

(1) C-130 Hercules that performs a variety of missions ranging from cargo and troop transportation to aerial refueling. The actual fleet has an average age of approximately 24 years. For airlift missions, one C-130 can carry up to 43,000 pounds of cargo with a maximum operational range of 4,882 miles.

(2) C-115 Buffalo, transport aircraft produced by De Havilland (Canada), used for cargo and personnel transport primarily in the Amazon region. This aircraft has a cargo capacity of 18,000 pounds with an operational range of 791 miles.

(3) C-95 Bandeirante, light transport aircraft produced by EMBRAER (Brazilian Aeronautical Co.), performs missions of cargo and troop transport, reconnaissance and SAR (Search and Rescue). It has 5,630 pounds of cargo capacity with a maximum operational range of 1,266 miles.

(4) KC-137, military version of Boeing 707 that is used as tanker and cargo aircraft. The KC-137 has a maximum payload of 60,000 pound and a range of 4,100 miles.

One problem, which is commonly encountered by the BAF, is that of aging transport aircraft. The C-95, C-115, and KC-137 have an average life of more than 25 years. This aging fleet is increasing the airlift aircraft average age throughout the years, with some aircraft operating beyond the operational life in a near future (see Figure 1).

Although the current airlift fleet is serving BAF transportation requirements in a satisfactory manner, most of these aircraft are beginning to suffer problems of technological obsolescence and increasing O&S costs. Furthermore, these aircraft are beginning to show structural fatigue along with, increasing corrosion problems and flying fewer hours than in past years due to the lower availability.

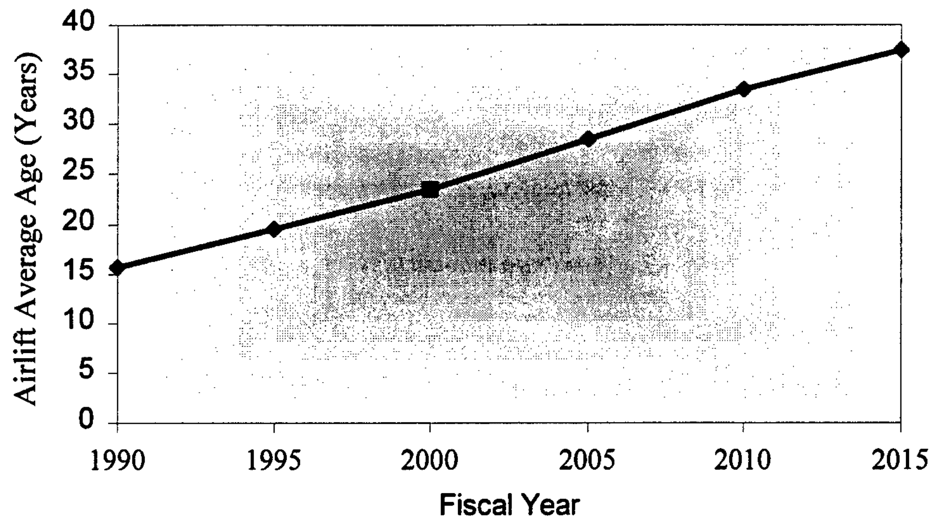


Figure 1. BAF Average Airlift Fleet Age

In view of this adverse situation, BAF studies show that an acquisition program of new airlift aircraft capable of increasing the mobility system capability seems to be the more reasonable solution (BAF DMA 400-6, 1992). Besides that, the decision between replacing or upgrading the current aging aircraft shows that the retirement of the C-95 and C-115 fleet in the near future is inevitable. Today, these aircraft not only are reaching their expected operational life but also begin to present high O&S costs to performs the BAF required mobility missions.

Furthermore, since 1995, the Brazilian Air Force started to question the feasibility of keeping the KC-137 and other aging aircraft in operation (Bonasser, 1995). Nevertheless, the appropriate methods and database necessary for computing O&S costs for these aircraft were not yet designed, which has been delaying the decision about the adoption of a more feasible airlift replacement program.

Research Objectives

This research has two main purposes. The first purpose is to conduct a review of principal issues affecting the actual aging airlift fleet to determine cost-effective options to improve the BAF mobility system performance. The second purpose, and more important, is the development of a new methodology to evaluate the airlift operational effectiveness, and present a new approach to estimate O&S costs and mobility capacity of the BAF airlift fleet.

To achieve these objectives, this research will use a constant airlift capacity approach to perform cost comparisons between two possible prospective scenarios to the Brazilian mobility system: (1) extend the operation life of the actual airlift fleet; or (2) acquire C-130 Hercules to replace the C-95 Bandeirante fleet. Besides that, this study will analyze the impact of each alternative on the BAF mobility system and validate a new tool to predict O&S costs of aging aircraft.

Since the proposed alternative to improve the mobility system would involve major financial investments along with future mobility capability implications, this research aims to provide the BAF with an independent study based upon in a in-depth analysis of its airlift system, exploring feasible solutions to evaluate the BAF mobility system.

Research Approach

To establish a common framework to analyze aircraft replacement program alternatives to the BAF Mobility System, this study includes an interactive approach between the research phases and the Air Force. Figure 2 presents a general guideline and the major research phases of this research as well as the respective Brazilian Air Force needs to improve its mobility system.

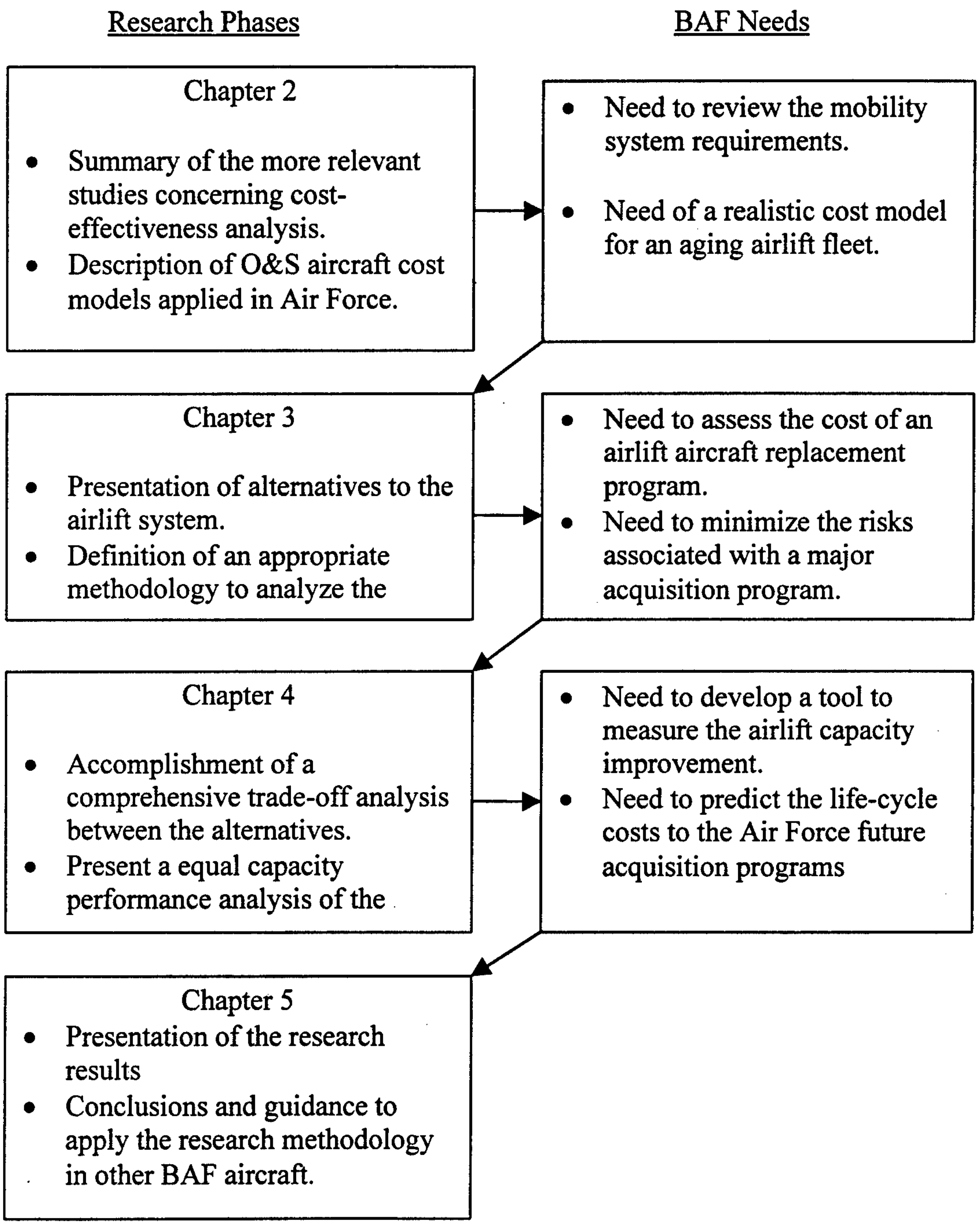


Figure 2. BAF Mobility System - Research Process Structure

Research Criteria and Assumptions

Despite of the actual uncertainty of future mobility needs along with increasing reduction of available resources, the BAF Mobility Command must decide how to invest its available resources to meet the mobility system requirements. Furthermore, defining and evaluating efficient mobility requirements constitute complex and hard work. Comparing cost/capacity estimates on feasible alternative scenarios seem to be an appropriate way to evaluate mobility capacity alternatives to the BAF mobility system. This approach would help the Air Force decision-makers in providing the optimal balance between cost and operational capability to the Air Force in the coming years.

A successful analysis of the viable alternatives to improve the BAF airlift capacity must attempt to control financial resources available within the constraints of cost and capability. For this reason, this research attempts to evaluate the BAF airlift requirements using a quantitative approach based on cost and capability rate as the primary variables to analyze the mobility system. In addition, this research will utilize a constant capacity performance approach to examine the O&S costs incurred in the scenarios/alternatives presented, providing the Air Force a tool capable of:

(1) Identifying the best cost-effective alternative based on some rational assumptions about each scenario.

(2) Identifying the critical cost factors affecting aging systems.

(3) Supporting the BAF decision-makers in performing trade-off analysis of new system acquisition programs.

The estimation of the actual BAF airlift aircraft costs will be performed with data collected from various O&S databases found at the BAF Galeão Depot, responsible for the C-130 program, and BAF Afonsos Depot, responsible for the C-95 program.

Moreover, O&S data from Galeão Air Force Base, the primary C-130 operator, and BAF Air Transportation Squadrons (ETA), the primary operators of the C-95 fleet, are used to complement the research cost analysis. The estimation, along with the predicted costs, will be adapted to fit in the proposed O&S cost model, due to lack of a comprehensive database available for some cost elements.

Related Definitions

MTM/D (Million Ton Miles/Day). The standard units of measure of theoretical airlift capacity.

Ton-Miles. It is the unit of measure that considers both the weight of cargo and the distance over which it must be carried.

Cost. The LCC (Life-Cycle Costing) approach has been developed and broadly used in military systems (Kerzner, 1997). As key factor in the LCC methodology, the O&S costs may be considered the most important factor included in the ownership costs of an aircraft program. The O&S costs may include: cost of sustaining personnel and maintenance support; spare and repair parts; test and support equipment maintenance; transportation and handling and; facilities and inventory.

II. Literature Review

Introduction

In order to illustrate feasible options to ensure a superior mobility capability for the Brazilian Air Force, an initial review of the issues concerning the cost effectiveness and trade-off incurred with a decision of extending the service life of aging airlift's or acquiring a new airlift aircraft must be presented. To accomplish this purpose, this chapter presents a summary of studies focusing on the problem of ownership costs of Air Force aging aircraft fleets. Moreover, this chapter discusses the challenge of sustaining the operational readiness of a mobility fleet that requires special attention due to the high O&S costs to operate its aging equipment, in a time when the military budget is continuously declining.

In addition, this chapter reviews some representative Air Force's O&S cost models for aircraft systems to provide a broad view of the more frequent O&S cost models that are commonly used in an Air Force environment. Since a broad description of all O&S available cost models is beyond the scope of this research, the models presented in this review were selected due to their ability to include the entire life cycle cost elements of a system. Moreover, fitting the existent O&S cost data in these models can be extremely advantageous, since they can significantly simplify the cost estimation process by avoiding time spent in developing highly complex models that are unable to provide reliable results in a dynamic environment (AFLC, 1989).

The Aging Aircraft Problem

The aging aircraft problem and the O&S costs associated with its operation are important issues that currently deserve critical consideration in the Brazilian Air Force mobility system. Achieving high reliability to maintain the operational capacity with adequate safety levels using an aging airlift fleet is extremely expensive.

Most aircraft systems eventually reach a point at which they should be replaced due to technical obsolescence, high O&S costs, or technology evolution (Patton, 1988). The need for more frequent inspection and maintenance activities in an aging aircraft has been addressed by several studies, such the USAF Aging Aircraft Program (Hellwig, 1998), and the BAF F-5 Modernization Program (Menezes, 1999). The commonly found problems in older aircraft are the large amount of maintenance actions to control structural corrosion, and overhaul of its main systems. Consequently, these maintenance activities also increase all the operational costs throughout the expected aircraft life cycle, along with the overhead costs of more complex facilities, spare parts, consumables and support equipment to attend an aging aircraft.

The first problem found in the mobility system is the tendency to place a higher priority on the operational availability rather than costs. The Air Force established concept of "fly to fail mentality" for all of its operational systems is a source of many controversial opinions when applied to an older airlift aircraft's with serious structural problems. Usually, maintenance of aircraft components has been scheduled on the basis of flight hours. Nevertheless, a high degree of deterioration in aging systems may lead to an underestimate of the maintenance schedules leading to higher O&S costs (Hopp and Kuo, 1998).

Likewise, some related research concluded that reliability and maintainability have strong effects on the O&S costs (Levine et. al., 1989). In some modern aircraft, the O&S costs may comprise as much as 60 percent of total ownership costs. For some aged aircraft these costs may approach 75 percent of the total support costs.

Some studies concerning the effect of reliability and maintainability over O&S costs of US Air Force F-4, C-130, F-15, and C-141, and the Navy F-18 systems, show a high degree of correlation among these factors (Levine et al., 1989). Such studies revealed evidences of an inverse relationship between reliability and costs with high degree of correlation.

Moreover, statistical analysis showed that a reduction of one percent in equipment reliability could cause an increase of two percent in maintenance costs (Levine et al., 1989). Such studies warn about the higher maintenance costs incurred by an aging aircraft in the wear-out phase, since the reliability levels are continuously decreasing in such systems. Likewise, higher costs of maintenance are associated with low increases in maintainability, since a ten-percent increase in cost may lead to a one-percent increase in equipment repair time. This results reveal that maintenance investments in aging aircraft do not necessary improve their maintainability or improve the aircraft availability levels.

Additionally, the pattern of failures rates for aircraft reparable items vary with time, and important implications can be derived from these trends (O'Connor, 1992). For aging aircraft, an increasing failure rate in reparables is expected during the wear out phase, that is, the phase near the end of the expected operational life of a system. These patterns of failure for reparable components are explained through a close look at "bathtub curve" theory as presented in maintenance and reliability studies (Ebeling, 1997).

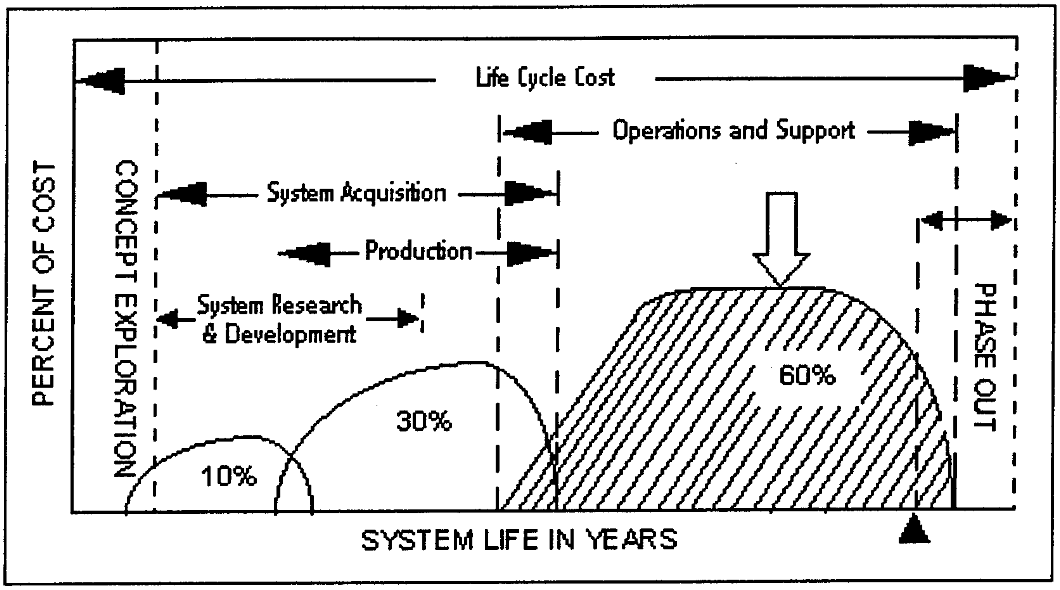
To analyze and investigate aging aircraft issues, as well as developing technologies to help predict aging aircraft impacts, the USAF maintains the Aging Aircraft Program Office, which provide means and support to extend aircraft service life. This office investigates ways to reduce the total costs associated with the aging fleet. Furthermore, this program funds projects that address the critical needs to ensure cost savings and continued safety of flight of the aging fleet, focusing on seeking common solutions for multiple aircraft systems rather than concentrating in specific problems of individual aircraft (Hallwig, 1998).

Life -Cycle Cost Overview

This section is divided in three main parts. First, it presents a brief description of the Life Cycle Cost fundamental concepts for the Acquisition System. Second, it reviews issues concerning the O&S cost estimations, along with a comprehensive description of the more common USAF O&S cost models. Finally, this review assesses some guidelines for developing reliable cost analysis using the appropriate O&S cost model.

First, Life Cycle Cost (LCC) is defined as the total cost of a system over its full life, which includes a research and development phase, an investment or procurement phase, an operating and support phase, and final disposal or phase out (Gill, 1999). These program phases may overlap considerably, in particular, the R&D phase may not be completed before procurement begins (Acquisition Logistics Handbook, 1997), or O&S phase may start during the production phase.

Moreover, a typical distribution of costs over a system's life cycle shows that O&S phase is the largest components of LCC and represents almost 60% of all costs incurred in a system program as shown in Figure 3:



Source: Adapted from Ulysses O. Bonasser in Estimating KC-137 Aircraft Ownership Costs in the Brazilian Air Force (1997).

Figure 3. Typical System LCC Distribution

For purposes of cost estimating, the following descriptions provide a brief summary of the costs associated with each phase of the system life cycle:

1. Research and Development Costs. Cover the conceptual, validation, and development phases. They include feasibility and engineering design, development, testing, prototype fabrication and testing, system test and evaluation, operations and support planning, manufacturing planning and documentation (Acquisition Logistics Handbook, 1997).
2. Production or Procurement Costs. Incurred during the production phase for acquisition programs. They include industrial engineering and operations analysis, process development, facility construction, manufacturing, quality

control, operation and maintenance of the production capability, and initial logistic support requirements (Bonasser, 1997).

3. Operation and Support Costs. O&S costs are those incurred by the DoD for the peacetime operations and maintenance of a system throughout its life cycle (Acquisition Logistics Guide, 1997). In the U.S. Air Force, many cost models are used to perform O&S cost estimates to fulfill a particular need (AFLC, 1995) based upon determinants such as: design characteristics, reliability, maintainability, and mission requirements.
4. Disposal or Phase-out Costs. These costs capture costs associated with deactivation or disposing of a system at the end of its useful life.

The above described O&S costs also include sustaining operation, personnel, maintenance, provisioning, transportation and handling, test and support equipment maintenance, training, technical manuals, some system modifications, and facilities. Operating and support (O&S) costs are usually the largest part of LCC. These costs depend basically on the system design, on how the system is used, and on the concepts and policies that drive its operation and support. The parameters that comprise O&S costs, however, are the same regardless of such policies.

While operation costs are functions of the number of crew members, flight hours, number of bases, and frequency of missions; support costs comprise the costs of maintaining each of the separate components of a system, including full system maintenance, engine overhaul, and repair of components or support equipment (Marks, 1978).

Air Force Aircraft O&S Cost Models Review

In an economic sense, cost analysis is the process to developing and applying techniques for assessing costs of proposed alternative under conditions of uncertainty (Gill, 1999). To provide an initial basis to accomplish an O&S cost analysis, this section reviews several of cost models used for military aircraft systems.

At the initial stage, the cost estimating analysis requires a varied range of guidance prior to proceeding. Many of these issues are available from various cost analysis publications. In the USAF there is a great variety of sources in manuals, pamphlets, and papers that discuss most of the general cost analysis policies and procedures (AFLC, 1989). In this context, many cost models are used to perform analyses for the USAF and its allies. In general, these cost models are designed to satisfy particular needs and they are primary based on:

Cost Accounting Models. A set of equations used to aggregate elements of operating and support costs (AFLC, 1989). Costs may be obtained by applying factors to system parameters, gross costs, and requirements.

Cost Estimating Relationship (CER) Models. A model which uses CER based on analysis of data of analogous systems (AFLC, 1989). This model is appropriate for new aircraft programs where the cost data is not yet available. On the other hand, these models may present problems in their internal construction validation and reliability of the sources used to develop the CER used.

Simulation Models. These models consider the interactions of all support resources in a simulation of logistics support operations (Gill, 1999). They are useful for cost sensitivity analysis of aircraft logistics support plans.

Among the selected O&S cost models currently available, the most commonly O&S cost analysts at the AFMC (US Air Force Materiel Command) are:

1. SABLE (Systematic Approach to Better Long Range Estimating) model that was designed to provide aircraft O&S cost estimates in Air Force programs.
2. CORE (Cost-Oriented Resource Estimating) model that provides aircraft squadron annual O&S cost estimates (ASC, 1995),
3. LSC (Logistics Support Cost) model that is used in analysis of support costs of alternative aircraft designs, and
4. CASA (Cost Analysis Strategy Assessment) model that performs LCC analysis using both the accounting and simulation techniques.

Systematic Approach to Better Long Range Estimating (SABLE) Model

The SABLE model, which is described by the U.S. Aeronautical System Center (ASC) as being designed to provide O&S cost estimates for aircraft programs, is one of the most widely utilized models in the Air Force environment. This cost model has been primarily employed to compute aircraft annual O&S cost estimates in several program reviews. In addition, this model is used for life cycle comparisons of alternate aircraft systems and determination of the O&S cost portions of independent cost analysis (AFLC, 1989).

The O&S cost estimates used in a SABLE-based structure are based on the projected aircraft operational use and logistic support throughout the equipment life cycle. In general, these costs are among the most difficult to estimate due to uncertainties inherent to the military operation environment. Table 1 presents the commonly used SABLE cost breakdown structure.

Table 1. SABLE O&S Cost Model Structure

* *

1. Unit Pay

2. Personnel Pay

3. Indirect Personnel Support
   3.1 Overhaul and Maintenance
   3.2 Permanent Change of Station (PCS)

4. Personnel Acquisition and Training
   4.1 Acquisition and Training
   4.2 Aircrew Training System

5. Operating and Support Consumables
   5.1 Petroleum, Oil, and Lubricants (POL)
   5.2 Base Maintenance Supplies

6. Depot Level Maintenance
   6.1 Airframe Rework
   6.2 Engine Rework
   6.3 Ground Support Equipment

* *

During early program phases, SABLE model data inputs may be obtained from analogous systems. On the other hand, systems that are already in operation may take advantage of the SABLE model since it may collect input factors based on cost assessment, analogy or CER sources. In addition to the basic features, the SABLE model is capable of using different techniques along with an aircraft-level estimate orientation. (AFLC, 1989).

Cost-Oriented Resource Estimating (CORE) Model

The CORE model was designed to provide a cost-estimating technique to be used to develop all common aircraft O&S cost estimates through the standard USAF data systems (Acquisition Logistics Handbook, 1997). The CORE cost element structure and procedures are generally used to support acquisition milestone briefings. Moreover, this cost model was primarily designed to provide aircraft squadron annual O&S cost estimates (ASC, 1995).

Additionally, the CORE model allows the element estimating techniques to vary as the program progresses through the phases of acquisition. The user may select the most adequate level and method by which an element is estimated at each phase (Bonasser, 1997). Table 2 shows the basic CORE structure for aircraft systems.

Logistics Support Cost (LSC) Model

Initially developed for use in analysis of support costs for alternative aircraft designs, the LSC model is a generic accounting model that forecasts operating and support costs of spare parts, transportation, and depot maintenance (Gill, 1999). LSC addresses only superficially cost elements related to manpower, support equipment, and training (Acquisition Logistics Handbook, 1997). This model is also used to compute key SABLE input factors such spare parts and depot maintenance costs.

Table 2. CORE O&S Cost Model Structure

* *

1. MISSION PERSONNEL
   - 1.1 OPERATIONS
     - Aircrew
     - Non Aircrew
   - 1.2 MAINTENANCE
     - Organizational Maintenance
     - Intermediate Maintenance
     - Ordnance Maintenance
     - Other Maintenance Personnel
   - 1.3 Other Mission Personnel
     - Unit Staff
     - Security
     - Other

2. UNIT LEVEL CONSUMPTION
   - 2.1 POL/Energy Consumption
   - 2.2 Consumable Material/Repair Parts
   - 2.3 Depot Level Reparable
   - 2.4 Other Unit Level Consumption

3. INTERMEDIATE MAINTENANCE
   - 3.1 Maintenance
   - 3.2 Consumable Material/Repair Parts
   - 3.3 Other Intermediate Maintenance

4. DEPOT MAINTENANCE
   - 4.1 Overhaul/Rework
   - 4.2 Other Depot Maintenance
     - General Depot Support
     - Second Destination Transportation
     - Contracted Unit Level Support
     - Miscellaneous Depot

5. CONTRACTOR SUPPORT
   - 5.1 Interim Contractor Support
   - 5.2 Contractor Logistics Support
   - 5.3 Other Contractor Support

6. SUSTAINING SUPPORT
   - 6.1 Support Equipment Replacement
   - 6.2 Modification Kit Procurement.
   - 6.3 Other Recurring Investment
   - 6.4 Sustaining Engineering
   - 6.5 Software Maintenance Support
   - 6.6 Simulator Operations
   - 6.7 Other Sustaining Support

7. INDIRECT SUPPORT
   - 7.1 Personnel Support
     - Medical Support
     - Special Training
     - Permanent Change of Station
   - 7.2 Installation Support
     - Base Support Personnel
     - Property Maintenance Personnel
     - Installation Support Non-Pay

* *

Cost Analysis Strategy Assessment (CASA) Model

Considering the entire system life cycle except for disposal, the CASA model is based on accounting and simulation techniques to generate data files and perform LCC analysis. Although the Air Force has used this model for maintenance analysis such as examining two or three level logistics support, CASA has not been used for LCC estimates or trade-off analysis because of more specialized logistics models available in the Air Force (Gill, 1999).

The CASA model is basically a management decision tool based on LCC. Actually, a new CASA version includes many new features improving its capability to assign operational availability and describing maintenance levels more accurately (Acquisition Logistics Handbook, 1995). Table 3 presents CASA cost breakdown structure:

Table 3. CASA O&S Cost Model Structure

ACQUISITION COSTS:	OPERATION AND SUPPORT COSTS:
Tooling	Operation Labor
Start Up	Repair Labor
System Acquisition	Support Equipment Maintenance
Shipping Containers	Recurring Training
Pre-Production Engineer Changes	Repair Parts
Installations	Consumables
Support Equipment	Condemnation Spares
Hardware Spares	Technical Data Revisions
Spares Reusable	Transportation
Initial Technical Data	Recurring Facilities
Initial Training	Recurring Item Management
Training Devices	Contractor Services
New facilities	Engineer Changes
Initial Item Management	Miscellaneous O&S Costs
Miscellaneous Acquisition Costs	
Warranty	

Guidelines for Selecting Appropriate O&S Cost Model

The process of developing O&S cost estimates has been based on specific cost elements structures developed in the U.S. Air Force cost analysis centers. In fact, over 50 Life Cycle Cost work breakdown structures associated with different O&S cost models are available to all-military services and government programs (AFLC, 1995) of U.S. Department of Defense (DoD). Since the O&S cost elements structure is a compound of a hierarchical breakdown of items and sub-items of a system's operations and support costs, the Air Force O&S cost models follow primarily some general guidelines. Such guidelines defines the four major categories of systems operated and supported by the U.S. Air Force (AFLC, 1995):

a) Aircraft systems

b) Electronic systems

c) Missile systems

d) Alternate mission equipment.

In this context, after defining the system category and appropriate cost breakdown structure, the analyst must select a current cost model or develop a new particular model or series of models to facilitate the life cycle economic evaluation process. Such models may be a simple series of parameter relationships or a complex set of computer subroutines (Blanchard, 1991). In performing a cost estimating analysis, one must choose a cost model that primarily presents:

a) Comprehensiveness and include all relevant factors.

b) Be reliable in terms of consistency of results.

c) Be flexible to the extent that it provides capability to perform not only overall system evaluations but also individual relationships among the various subsystems.

d) Be simple enough to allow a timely implementation.

e) Be designed such that it can be easily modified to incorporate additional capabilities.

In addition to these issues, to perform a feasible LCC analysis, subsequent cost analysis phases must include a comprehensive data cost treatment using some essential analytical procedures such as: (1) Development of cost profiles; (2) Incorporation of inflationary factors in the data results; (3) Inclusion of learning effects; and (4) Determination of cost equivalence (Blanchard, 1991).

Summary

This chapter reviewed the major issues concerning O&S cost estimating models and their suitable application at the BAF airlift fleet. Moreover, the reviewed literature presented a general framework not only for cost estimating methodology but also the basic knowledge to perform a cost/capability analysis at the BAF airlift system. In the next chapter, this study will present the methodology to analyze the potential alternatives to the BAF mobility system using a realistic cost model appropriate for its aging airlift fleet.

III. Methodology

Introduction

As previously presented, the feasible options available to improve the BAF mobility system analyzed in this research are:

(1) Extend the operation life of the actual airlift fleet, or

(2) Acquire new C-130 Hercules aircraft to replace the C-95 Bandeirante aging fleet while maintaining the same BAF airlift capacity.

To assess the BAF airlift needs in estimating O&S costs for an airlift aircraft upgrade/replacement program studies, this research performs a preliminary data collection that will capture O&S costs of the actual Brazilian airlift C-130 and C-95 fleet. Based on the available aircraft O&S data, a model to predict the O&S costs as a function of the number of annual flight hours allocated to the aircraft estimates will be developed.

In addition, sensitivity analysis will be performed to analyze the effects of flying hours or maintenance costs variation on the O&S estimated costs, providing a more consistent cost comparison analysis between the available alternatives.

Cost Analysis Methodology and Assumptions

The BAF airlift system is fairly flexible in serving the Air Force mobility requirements in the majority of its operational missions. However, retirement of the fleet of C-95 Bandeirante will reduce the airlift capacity by at least 30%. This reduction in BAF airlift capacity in the short run shows an urgent need of new aircraft programs to replace that aircraft.

These issues raise serious questions concerning the real costs incurred not only by the actual airlift fleet, but also by the proposed acquisition programs under study. In addition, the airlift capacity changes impact over the BAF mobility flexibility must be also considered in a trade-off analysis. Therefore, this research analyzes the BAF mobility system by examining a proposed alternative, while maintaining the actual airlift capability levels considering the C-95 fleet retirement.

As the O&S cost estimates should extend beyond the full life expectancy of C-95 aircraft, the research will assume the actual steady-state operation and the performance of upgrading programs to extend the life cycle of this aging aircraft. In addition, the forecasting period, which range from FY2000 to FY2020, will assume that the mobility system will maintain the actual annual flying hours per aircraft and discount rate of 10% for future O&S financial expenses. Since DoD (U.S. Department of Defense) traditionally uses such discount rates in cost estimating processes, this study will consider the value of 10% as the baseline for the cost estimating process.

Furthermore, this research also address some important issues to accomplish the data analysis:

(1) The cost analysis needs to addresses the cost data uncertainties due to lack of consistent data records of the BAF airlift fleet.

(2) Estimates of future BAF mobility O&S costs are subject to some degree of uncertainty due to economic and political factors.

(3) The identification and bound of the scope of variables that contribute to uncertainty in ground rules and assumptions, as well as the impact of cost drivers on the research results.

(4) Given the number of variables that affect O&S costs, the trade-off analysis will perform sensitivity analysis to identify explicitly the nature and magnitude of the uncertainty.

(5) The attrition rates, which allocates the probability of aircraft lost, are not considered in the estimates, since this data has not been available at the Brazilian Flight Safety Department.

BAF Airlift O&S Cost Structure Description

An independent cost analysis will provide a comprehensive view of all elements of O&S costs including in this model assuming a period of 20 years of operation that covers the period FY2000 through FY2020. The O&S cost model structure comprises of the following cost elements described in Table 4.

Table 4. BAF Airlift Aircraft O&S Cost Model Structure

****

1. POL (Petroleum, Oil, and Lubricants)
1.1 Fuel
1.2 Oil and Lubricants

2. MAINTENANCE
2.1 Support Equipment
2.2.Airframe
2.3 Engine
2.4 Reparable
2.5 Contract Support
2.6 Depot Overhaul
2.7 Squadron Maintenance

3. SUPPLIES
3.1 Aircraft Material
3.2 Replenishment Spares
3.3 Base Supplies
3.4 Depot Level supplies

OTHER COSTS:
4. MILPAY
5. Permanent Change of Station (PCS)
6. Training

****

The cost breakdown structure along with the cost estimating model structure are developed in Excel spreadsheet format (Appendices A and B) using this basic structure to provide the cost elements estimates, along with program and logistics factor related to each cost component.

Cost Elements Definitions

In accomplishing the proposed O&S cost analysis, the model cost breakdown structure (CBS) is defined at its elements levels to facilitate the allocation of the O&S costs incurred and subsequent collection of such input parameters on a functional basis. The cost breakdown description is presented through a description of the Cost estimate contents of each element along with the estimating method used to gather the data values and apply in the proposed cost model. The primary cost elements are defined as follow:

<u>POL (Petrol, Oil, and Lubricants)</u>

a. <u>Cost Estimates Contents</u>. POL comprises primary fuel (JP4 or 100/130) and miscellaneous oils, lubricants, and hydraulic fluids. The primary fuel cost is the average price allocated for C-130 and C-95 aircraft, which takes into account fuel consumption rates and fuel prices procured at several locations with PETROBRAS, the principal BAF fuel supplier.

b. <u>Estimating Method.</u> The primary fuel costs per hour was collected based on weighted fuel consumption for the C-130 and C-95 using data from historical flying hour consumption in transportation missions under normal conditions of operation.

Maintenance

a. Cost Estimates Contents. Estimated costs of materials and repair work at depot level to inspect, repair, overhaul, or perform other aircraft maintenance not performed at base level. These costs includes those required to repair base-generated Depot Level Reparables and are based on a long run average of maintenance costs due to:

1. Organic Repair parts provided by the Brazilian Materiel Department, division responsible for the Air Force depots. Organic refers to maintenance performed by the Air Force using government-owned or controlled facilities, equipment, and military or civilian government personnel. Organic depot costs include civilian labor, military labor, material expense, and overhead expense.
2. Commercial repair and overhaul costs, which include service, labor, and repair parts provided through outsourcing.

b. Estimating Method. The maintenance cost data are collected from two sources: (1) the BAF Galeão Depot, responsible for the C-130 depot level maintenance, and (2) BAF Afonsos Depot, responsible for the C-95 depot level maintenance. Such collected data comprises:

1. Expenditure data from the most recent fiscal year for the average number of hours of repair including estimated maintenance per flying hour and,
2. Depot average labor rate, including salaries and contributions of direct maintenance personnel allocated to each aircraft.

Supplies

a. Cost Estimates Contents. Include the costs to replace reparable or consumable items needed to maintain a required stock level to attend the maintenance system at base or depot level. This item also includes the costs of replenishing the inventory of support equipment needed to perform the required maintenance activities.

b. Estimating Method. The BAF Central Depot of Aeronautics (DCA) manages general support consumable items, other services or purchased through local purchase authority such AFB commandants or Supply and Maintenance Squadron managers. The Supply Division of the DCA and the Depot division responsible for each aircraft project provided data of annual average consumable items.

MILPAY (Military Pay)

a. Cost Estimates Contents. MILPAY totals by fiscal year from FY2000 to FY2020 assuming steady-state for the total of officers and enlisted in operational units at organic, training and active missions. Also, the total includes crew, maintenance, and staff personnel involved in the squadrons operations.

b. Estimating Method. MILPAY inputs were multiplied by the average pay for officer and enlisted to achieve the annual unit pay for each aircraft fleet on a yearly basis. Moreover, all increases and decreases in number of personnel for each particular year were not considered at the total estimates.

Permanent Change of Station (PCS)

a. Cost Estimating Contents. This item includes the cost associated with personnel transfer between BAF base and depot units as well as cost associated with retirement of personnel.

b. Estimating Method. The average costs of PCS are multiplied with turnover rates commonly used at base or BAF depot units.

Training

a. Cost Estimating Contents. This item includes the costs of training personnel at technical skills, flying training for aircrew members, and general training related to the aircraft operation. Also, training includes costs to acquire and train personnel to execute assignment at operational squadron, base supply and maintenance unit or depot

b. Estimating Method. The training costs are based on the estimates provided by the BAF technical schools estimates for courses related to maintenance and support training courses which includes the Aeronautical Institute of Logistics (ILA) and Depot internal training programs. Aircrew training uses data from instruction division localized in the respective transportation squadrons.

In addition, the average training costs for aircrew are provided for the BAF training programs of airlift units and the costs for non aircrew personnel (administrative and support personnel) are provided by some BAF training program publications.

Description of BAF O&S Cost Model Factors

In this research, Flying Hours (FH) are assumed to change with defined operating flying hours established annually by the BAF operational command and Primary Aircraft Authorization (PAA) factors are assumed to change with the number of assigned aircraft. The program and logistics factors along with manpower and personnel cost factors applied in the cost model are structured as follow:

(1) PROGRAM FACTORS. Aircraft Qty and Annual Average Flying Hours/Aircraft.

(2) LOGISTICS FACTORS. Fuel Consumption (Liter/FH), Oil Consumption (Liter/FH), System Support/FH, Support Equip/Aircraft, Depot Maintenance/Aircraft, Depot Maintenance/FH, Aircraft Material/FH, Depot Level Reparable/FH, Fuel Price (Liter), Oil Price (Liter).

(3) MANPOWER FACTORS. Squadron Personnel, Supply & Maintenance Personnel, Depot Personnel, Average Annual PCS (Permanent Change of Station), and Average Annual Training.

(4) PERSONNEL COST FACTORS. Average Officers Pay, Average Enlisted Pay, Average Civilian Pay, Average PCS Costs, and Average Training Costs.

Program and Logistics factors are correlated to the primary O&S cost elements in a way that such factors represent typical values which provides a common basis for the estimation, and are annually reviewed considering inflation rates or budget changes. Logistics factors are a common value for both alternatives in study while the Program factors vary according to the Air Force operational requirements.

While the cost elements comprises the primary input for the cost estimate process, logistics and program factors are the external modifier factor that affects the cost estimates process as showed in Figure 4:

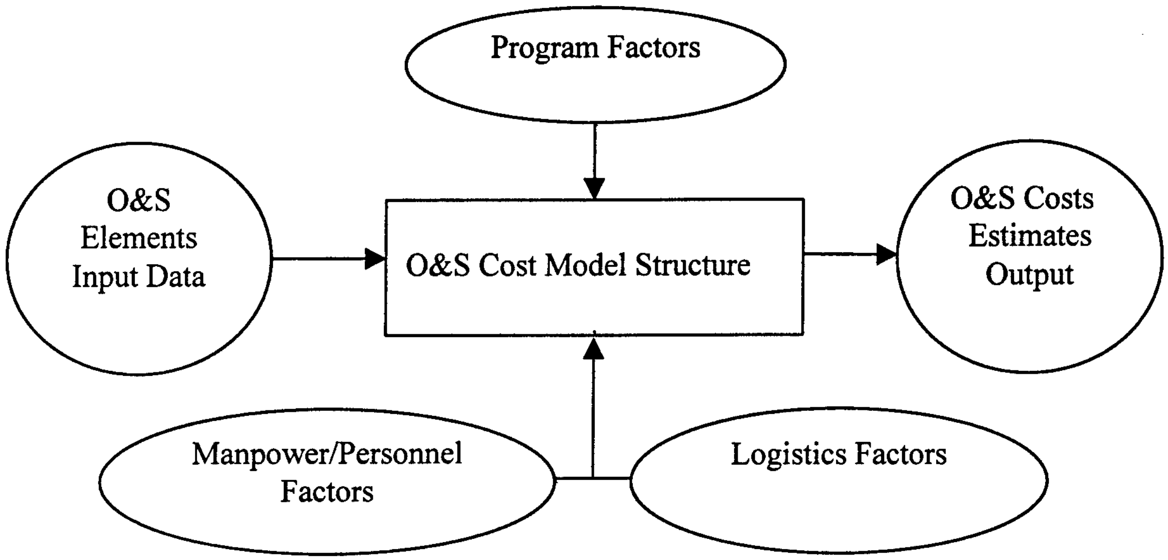


Figure 4. Research O&S Cost Estimating Process

As previously defined, program factors values will be subjected to variations in the programming and budgeting process that increment and decrement the baseline program as a result of force structure changes. They are a result of command inputs and Air Staff analysis. These logistics cost factors are especially useful in estimating incremental O&S costs based on Flying Hour (FH) and Primary Aircraft Program (PAA) programming changes.

Through analysis of depot maintenance historical cost data, a cost factor per flying hour and a cost factor per PAA are estimated. These factors do not include fixed costs, such as depot facility related costs that reflect general and administrative expenses.

Depot maintenance factors are used in the process to increment and decrement depot maintenance budgets due to changes in flying hours and/or PAA. Depot Level Repair factors represent both repair and surcharge costs associated with aircraft and engine component sent to a depot to execute maintenance actions.

BAF Airlift Capacity Methodology

Airlift questions in the Air Force include choices among alternative aircraft or program candidates to improve a mobility system (Robinson, 1995). Such choices include an in-depth identification of the current and predicted operational capacities allied with an optimal combination of candidates and concepts to select the appropriate fleet size with minimum O&S costs.

Since the military airlift capability requires the use of tools to measure the relative contributions the available airlift fleet, the US Department of Defense (DoD) currently uses aircraft characteristics to estimate the aggregate contributions of different types of aircraft. Capability estimates for an aircraft depend on several factors: (1) cargo capacity, (2) mix of cargo being carried, (3) speed of the aircraft, (4) utilization rate, and (5) availability of spare parts and maintenance facilities (Gebman, 1994).

The Brazilian Air Force's current fleet of transport aircraft has unique characteristics that provide some advantages over a civilian airlift fleet. The military-style transports are designed to operate in adverse environments through their unique capability of using airfields with no infrastructure with high damage tolerance.

The military airlift capability requires the use of tools to measure the relative contributions the available airlift fleet. The formula used to estimate the BAF airlift capacity by aircraft fleet is defined as:

* *

$$\underline{MTM/D} = (\underline{ABS} * \underline{DUR} * \underline{AAP} * \underline{NAA}) / 1{,}000{,}000 \qquad (1)$$

Where:

MTM/D: Millions of Ton Mile/Day

ABS: Aircraft block speed (Kts)

DUR: Daily utilization rate (Hours/Day)

AAP: Aircraft Available Payload (Ton)

NAA: Number of Available Aircraft

* *

The mobility factors used to estimate the relative contributions of the actual types of airlift aircraft to the total assessed capacity are defined as:

(1) Aircraft block speed (ABS). The average speed maintained in normal flight.

(2) Daily utilization rate (DUR). The number of hours per day that the available aircraft is expected to fly daily.

(3) Aircraft Available Payload (AAP). The average quantity of cargo carried in each flight.

(4) Number of Available Aircraft (NAA). Average number of aircraft available for airlift missions.

To apply this formula, we assume that the variables are scenario sensitive and the daily utilization rate implies that the maintenance actions per flight hour are constant in all scenarios. Moreover, some restriction may occur in annual flying hours estimates for some aircraft's fleet due to reallocation of financial resources or adjustments in the federal budget that may also affect the ton-mile capability levels in specific periods within a year. Because of these uncertainties, the estimated values are dependent of the following assumptions:

(1) Due to the aging process of aircraft such C-115, C-95, and KC-137, the availability may be less than the number of aircraft allocated to each wing or squadron. To overcome this problem, the lower operational availability computed in a given year will be used to show the number of aircraft in the formula above.

(2) Due to delays in operations in airfields without adequate support equipment to load and unload an aircraft, the productivity factor may present great variability for the same aircraft allocated to operate in diverse missions.

(3) Since the KC-137 is primarily allocated to perform air refueling missions, its achieved utilization rate and productivity factor to accomplish air cargo missions are the lowest among the airlift fleet.

(4) To estimate the average availability of aircraft, this research includes only the aircraft pertaining to airlift squadrons that are exclusively allocated to cargo transportation.

(5) An achieved availability of 75% is used to provide a reasonable estimate of the number of available aircraft in typical transportation missions which represents the required achieved availability rate defined by BAF airlift squadrons.

Eventually, the great sensitivity of the ton-mile measures to changes with the specified assumptions suggests that this tool may not present satisfactory measures of mobility effectiveness. Nevertheless, the capability requirements must be translated into a single measure to facilitate the interpretation of a decision-maker in selecting alternatives to improve the BAF mobility system.

Summary

Until this point, this research had already presented the alternatives to the BAF airlift system problem and the related methodology used to perform the cost/capacity analysis. The next chapter will develop the comprehensive trade-off analysis between the BAF airlift alternatives using the equal capacity approach.

IV. Analysis

Equal Capacity Approach – Cost Analysis Results

The presentation formats described in this section provide a standard framework for displaying, documenting, and reviewing O&S estimates. Although these reports establish an adapted format for presenting O&S costs for the BAF, they should not preclude good judgment in providing additional cost information that may be pertinent to the research. Furthermore, the results can easily be selected and/or modified for those formats that are most appropriate for posterior analysis.

Following the defined data collection methodology, this chapter present an evaluation and analysis of the O&S costs incurred by the C-130 and C-95 followed by a cost comparison analysis between the proposed alternatives.

The cost estimate validity will be tested through three likely scenarios to test the effects in the O&S cost model results. In addition sensitivity analysis will be performed to determine the robustness of the model to variable levels of flying hours and maintenance costs.

BAF Airlift - Capacity Estimates

The total BAF theoretical capacity of 1.03 million ton-miles per day is constrained by several factors such as aircraft availability, maintenance schedule, and airfield availability. Table 5 illustrates the relative contributions of the actual and alternative BAF capacity estimates according to available BAF airlift aircraft and the total assessed mobility capacity.

Table 5. Estimate of Current BAF Airlift Capacity

Aircraft	Avg. Speed (Kts)	Utilization Rate	Payload (Ton/Aircraft)	Aircraft Qty.	Airlift Rate (MTM/D)
C-130	290	7	12.2	12	0.30
C-115	250	9	8.2	9	0.17
C-95	180	6	4.0	58	0.25
KC-137	350	8	28.0	4	0.31
			BAF Theoretical Airlift Capacity		1.03

Based on these BAF airlift capacity estimates, the C-95 fleet operation, which is distributed among seven Air Transportation Squadrons (ETA), provides approximately 25% of the BAF airlift capacity. The C-130 fleet provides almost 30% of the BAF airlift capacity.

Most important, the estimated capacity indicates that a fleet of only 10 C-130 can provide the same airlift capacity of the all BAF C-95 fleet on a daily basis. Such conclusions may suggest that the retirement of a aging airlift fleet with low airlift capability like the BAFC-95 fleet would be feasible if lower long run O&S cost associated with a proposed alternative (C-130 acquisition program) could justify such a decision.

BAF Airlift - Cost Analysis Summary

The cost analysis provides a comprehensive view of all elements of O&S costs included in this model, assuming a period of 20 years of operation, that covers the period FY2000 through FY2020 as showed in Table 6.

The cost estimates are derived from the full version of BAFOS (Brazilian Air Force Operation and Support) cost model whose basic structure is presented in Appendix A and B. The data included in the cost model are based on BAF airlift program and cost factors and adjusted for FY99 dollars.

This summary compares the annual BAF expenditures with each cost element to the actual BAF C-130E and C-95 units. For the BAF C-130 Program, the estimates represent annual expenditures with each cost element based on C-130 squadron at Galeão AFB and Galeão Depot. For the BAF C-95 Program, the estimates represent the annual expenditures with each cost element based on ETA's (Air Transportation Squadrons) and Afonsos Depot. Besides that, this table shows that 20 years of O&S costs at a 10% discount rate are approximately $14.4 millions for each C-95aircraft, and $ 27.4 millions for each C-130 aircraft.

Initially, as pointed out earlier, the analyze the total costs of acquiring and operating additional 10 C-130 Hercules in comparison to maintain 58 C-95 in Air Force inventory, assuming stead-state operation for the next 20 years and discount rate of 10%. Such alternative follows the equal capacity approach defined previously since it provides a capacity of 1.02 MTM/D to the BAF mobility system.

Table 6. BAF Airlift O&S Cost Estimates Summary

Aircraft		C-95	C-130
Flying Hours		500	600
Lifecycle years		20	20
Flying Hours Related Factors:			
Depot Maintenance/FH		562	825
Supplies/FH		318	713
Depot Reparable/FH		1,150	1,083
	Subtotal	2,030	2,621
Aircraft Related Factors:			
Depot Maintenance/Aircraft		43,555	84,700
Support Equipment/Aircraft		11,352	12,700
	Subtotal	54,908	97,400
POL (Liter/FH)*(S/Liter):			
AVFUEL		418,950	1,152,480
Lubricants		12,218	19,548
	Subtotal	431,168	1,172,028
Crew and Personnel ($/Aircraft):			
Mission Personnel (Squadron)		99,336	176,147
Support Personnel (Base/Depot)		41,206	122,804
Permanent Change of Station (PCS)		27,703	35,200
Personnel Acquisition & Training		18,883	45,400
	Subtotal	187,128	379,551
Aircraft O&S Costs ($/yr./Aircraft)			
Annual O&S Costs/Aircraft		$ 1,688,203	$ 3,221,579
Twenty Year O&S Costs @ 10%		$14,372,685	$27,427,234

Nevertheless, procurement costs of new C-130 may be determined to provide a well-drawn comparison analysis between the alternatives. Procurement costs, for this cost analysis, includes not only the purchase of new C-130 but also the estimated expenditures with military construction and initial provisioning for the aircraft operation.

Since the C-130 aircraft is available in a varied range of models and prices, this study considers the procurement of C-130H, a new model in the US Air Force that is replacing the aging E models in operation. This model is available at $22.9 million per unit (USAF Fact Sheet 92-93, 1999). Besides the procurement costs, an additional twenty percent is added to cover estimated costs of initial spare part and support equipment. Table 7 provides a total cost summary for both alternatives including procurement and provisioning costs of C-130 aircraft.

Table 7. BAF Airlift Total Cost Estimates Summary

(In thousands of US$)

	Alternative 1 C-95	Alternative 2 C-130
Number of Aircraft	58	10
Airlift Capacity Provided (MTM/D)	1.03	1.02
Aircraft Procurement	x	229,200
Initial Acquisition Provisioning	x	45,840
Twenty Years O&S Costs @ 10%	833,616	274,272
Total Cost Incurred	$833,674	$549,323

As a result, the O&S cost estimates from FY2000 to FY2020 shows that to maintain the actual fleet of 58 C-95 in operation would incur in O&S costs of US$ 833.7 millions. On the other side, the proposed alternative of acquiring 10 C-130, with the retirement of all C-95 fleet, would reduce the total O&S costs to US$ 549.3 millions (FY99 in dollars)

Sensitivity Analysis

The accuracy of estimates with respects to future predictions is, to some extent, inversely proportional to the span the time between the estimate and the event (Blanchard, 1992). Because of this uncertainty, a final step for cost estimating process involves the application of sensitivity analysis to assess the risks associated with a given decision (Blanchard, 1991). In this case, the goal of the sensitivity analysis is to evaluate the effect of flying hour variation on the total costs along with the impact of maintenance costs on the O&S estimates for both alternatives.

A sensitivity analysis was performed on the data results considering initially variations in the flying hours levels for both alternatives (see Figure 5). This graph indicates that the C-130 alternative is more cost effective if increasing flying hours are expected the next years. The Figure 5 indicates that increasing flying hours for both alternatives would intensify the gap between the alternatives providing more bases to decide for Alternative 2 (Acquire C-130 aircraft). However, a reduction in flying hour, which could change the decision between the alternatives, would modify the BAF airlift capacity too. In this case, the alternative of acquiring the aircraft C-130 would still be the preferred for reductions up to 50% in flying hours.

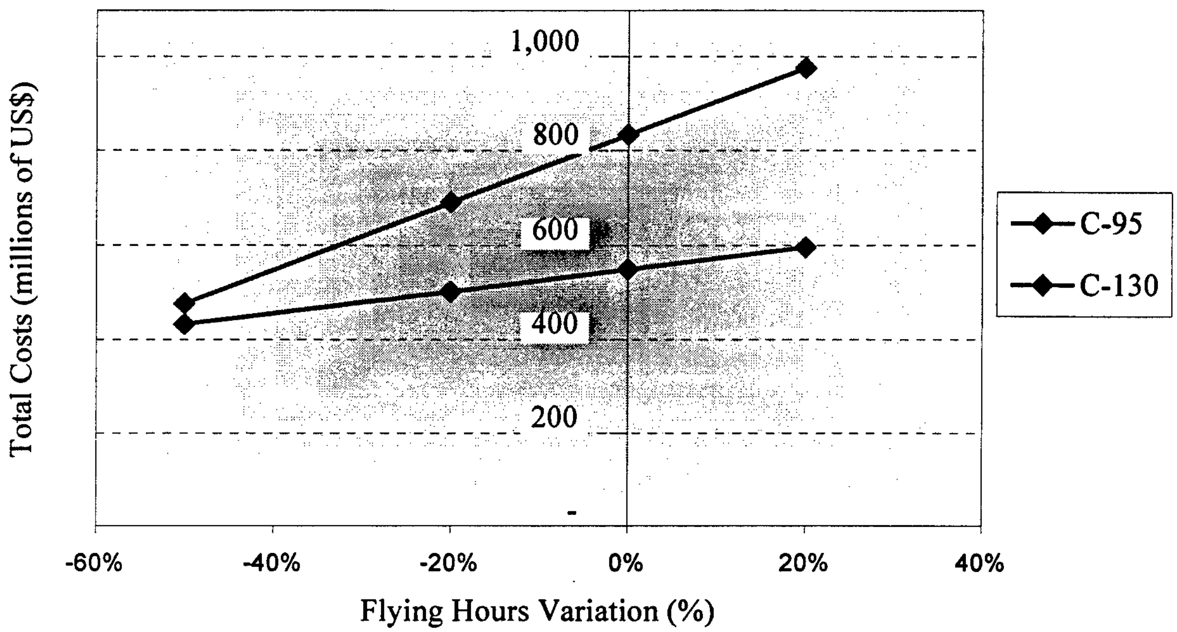


Figure 5. Effect of Flying Hours Changes on Total Costs

Another area of concern in this cost analysis refers to the estimates of maintenance costs incurred at depot level that includes the Depot maintenance costs/FH and Depot maintenance/Aircraft. As showed in Figure 6, maintenance cost variations up to 50 percent does not alter significantly the total cost of either alternative. This fact suggests that changes in maintenance costs would not affect the decision between the alternatives.

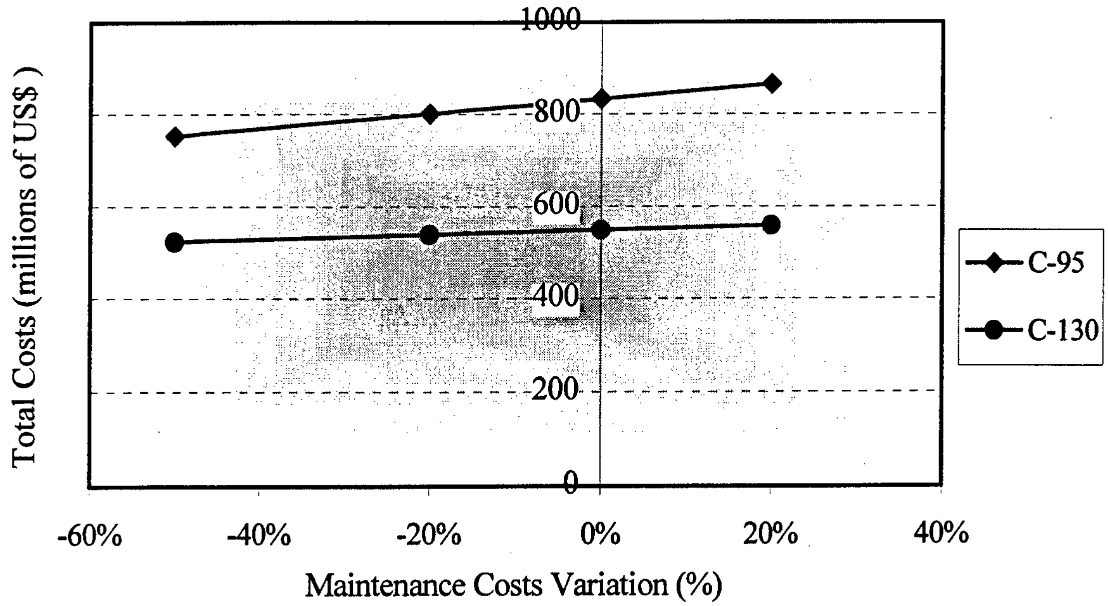


Figure 6. Effect of Maintenance Costs Changes on Total Costs

Cost Break-even Analysis

A break-even evaluation was used to identify the expected time for which the alternatives incur equal cost providing basis for evaluating the most desirable alternative considering the time span considered. Prior the final decision, the research analysis needs to determine the point in time when the alternative of acquiring C-130 for the BAF becomes more economical. As showed in Figure 7, the break-even point for the alternatives is around year 2006, after which time the savings of the C-130 over the C-95 alternative increases over time.

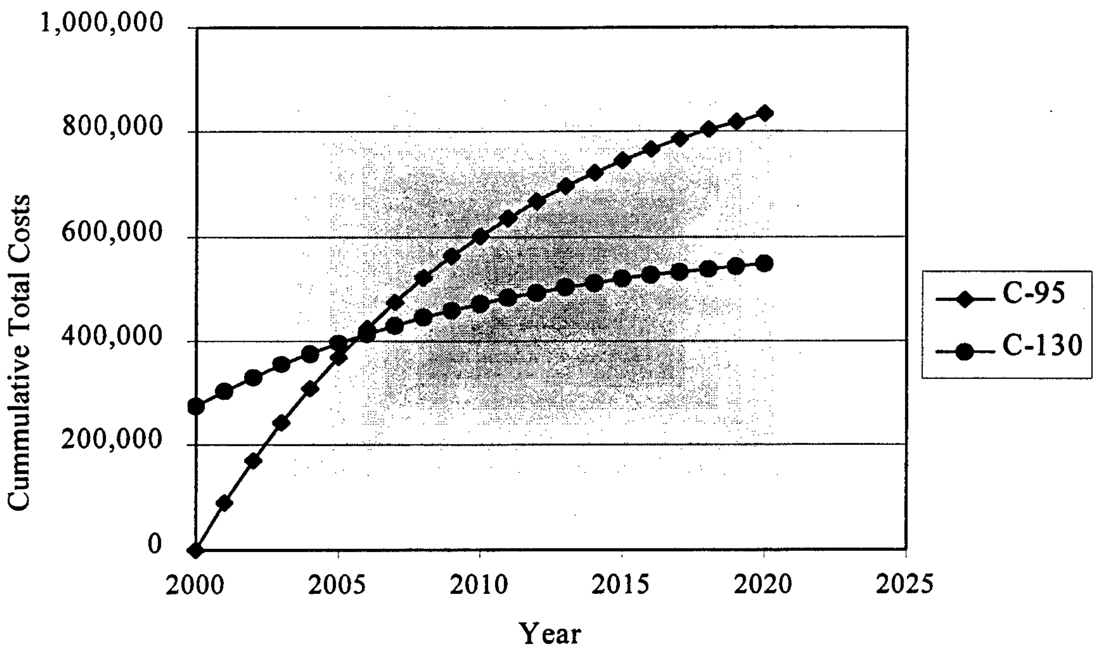


Figure 7. Break-even Analysis for the Alternatives

Analysis Summary

This chapter performed a comprehensive cost analysis using a O&S cost model proposed for the BAF mobility system. In addition, the allocation of each cost element on a functional basis along with estimates of airlift capacity was developed to achieve the total cost estimates of the proposed alternative. In addition a sensibility analysis based on flying hour and maintenance costs as independent variables was accomplished to verify the consistence of cost estimates. The next chapter will discuss the research findings providing some recommendations and necessary guidance capable of improving the Brazilian Air Force airlift capacity.

V. Findings and Conclusions

Evaluation of Alternatives

Up to this point, the research primary objective was to identify the better of the two alternatives, that is, the alternative that provides lower total costs in a long run, on the basis of present equivalent total costs. Using the discount rate of 10%, the cost/capacity analysis results support the alternative of acquiring new C-130 as the preferred alternative on the basis of present equivalent total costs. It is noted that the O&S costs for the aging C-95 fleet for an aircraft of low cargo capacity. Moreover, its expected that the O&S costs for these aircraft increases considerable due to operation beyond the life-cycle for these aircraft.

On the other hand, each additional C-130 can provide almost 6 time the capacity than the C-95 aircraft. In addition, O&S costs estimates for new C-130 units tends to be lower that estimated initially since this aircraft is assumed to operate within the expected life-cycle, which means they would incur lower O&S costs than with the current aging BAF C-130 fleet.

Cost/Capacity Analysis Findings

Assuming the same airlift capacity with a 10% discount rate, same levels of annual flying hours for the next 20 years, and the C-95 programmed retirement, this research found that:

(1) The proposed alternative of acquiring more 10 units of C-130 to replace the older C-95 fleet could result in savings of US$284.3 millions (FY99 in dollars) to the

Brazilian Air Force. This result implies that the BAF could achieve cost reductions of at least 25 percent, without reducing its mobility capacity in the long run.

(2) A sensibility analysis evaluation, based upon in variations of expected flying hours levels and maintenance costs indicates that no significant changes on the cost estimates results could favor the maintenance of the actual C-95 fleet.

(3) The break-even analysis indicates that the C-130 option would become more economical after 6 years in operation. This point may be considered early enough in the life cycle to support the decision toward the C-130 acquisition and C-95 fleet retirement.

These conclusions suggest that the expected lower costs incurred by the proposed alternative could be used for short term investments in procurement of additional C-130 aircraft, a new in-house airlift acquisition program, or similar airlifted in the international market.

Such investments could provide a higher mobility capacity and flexibility for the BAF for the future years rather than a continuous declining of mobility capability due to an aging fleet operation. Moreover, the estimated cost savings for the BAF mobility system may be preserved if the proposed investments could remain within some established limits based upon the results of this cost analysis.

Brazilian Air Force O&S Cost (BAFOS) Model Performance

The BAFOS model developed in this research, which was especially designed to performs O&S cost estimating for BAF airlift aircraft, presents a new approach to estimate aircraft O&S costs based in program and logistics factors in problems of evaluation of alternatives. A comparison of the BAFOS model characteristics with the current Air Force cost models characteristics (Twomey, 1991) shows that the simplified design of BAFOS can be easily accommodate to estimate other aircraft systems (see Table 8 below). Moreover, this model is also capable of providing reliable cost estimates for decision making purposes along with sensibility analysis capabilities and flexibility to upgrade variable data.

Table 8. BAFOS and Other Cost Models Characteristics

Model	LSC	CASA	CORE	SABLE	**BAFOS**
Microcomputer Based	Yes	Yes			**Yes**
Formally Validated	Yes		Yes	Yes	**No**
Operational Availability	Yes	Yes			**No**
Budget Estimates	Yes	Yes			**Yes**
Risk Analysis		Yes			**No**
Inflation Adjustments		Yes	No	No	**No**
Present Value Adjustments		Yes			**Yes**
Sensibility Analysis	Yes	Yes			**Yes**
Ease to Operate	No	Yes	No	No	**Yes**
Data Intensive	Yes	No	Yes	Yes	**No**

Source: Adapted from Mark Twomey in A Review of Selected USAF Life-Cycle Costing Models (1991).

Preferred Strategy to Improve the BAF Mobility System

In spite of fact that the BAF is implementing a new program called SILOMS to integrate all operational and maintenance data systems in a near future (PAMA-GL, 1998), a study focus in the Total Aircraft Ownership Cost concepts is expected to be established in each aircraft program.

If the Brazilian Air Force Mobility System would opt to establish a new Airlift Acquisition Program, the initial phase to develop such program is the definition of the mission needs and identification of deficiencies in the mobility system. Based in this framework, among the feasible alternatives carried out in air mobility studies, the acquisition of a new transport aircraft capable of increasing the mobility system capability seems to be the most reasonable solution.

A possible strategy for the BAF mobility system is the C-95 retirement due to higher O&S costs incurred. In their place, the C-130 Hercules would be a feasible option since it performs a variety of missions ranging from cargo and troop transportation to aerial refueling and in airlift missions can carry up to 43,000 pounds of cargo with maximum operational range of 4,882 miles. Moreover, new C-130 aircraft has the advantage of be easily incorporate within the actual fleet that has an average of approximately 24 years.

Concurrently with alternative definition, an review of the mobility system and Brazilian Air Force policies and procedures concerning the renew of its airlift fleet shows that the establishment of an acquisition program depends basically (DMA 400-1, 1992):

(1) Acquisition program definition according to the air mobility requirements.

(2) Justification to the Congress of the acquisition program costs estimates.

(3) Planning for the program activation,

(4) Test and evaluation followed to the system operation.

Since the accomplishment of all phases may take several years, the Air Force cost estimates must also include unexpected rising of costs out of the previously planned. Preliminary studies on a complex acquisition program must consider that early cost estimates may be lower than the real costs due to uncertainty normally found in programs of long run. Futhermore, possible delays in the program milestones on account of lack of financial resources or cuts in the military budgets.

In summary, the potential cost savings associated with successful airlift aircraft acquisition program to substitute an aging aircraft fleet, would occur due to:

(1) Small Airlift Fleet. Fewer aircraft with superior performance and larger freight capacity that can provide the same airlift capability that presents superior system reliability providing greater availability and less maintenance actions.

(2) Aircrew and Support Personnel Reduction. Less aircraft in service would cut the manpower requirements to execute the maintenance and support activities.

(3) O&S Costs Reduction. With the same airlift capability, the annual O&S costs for a fleet with smaller average years, would be lower due to better performance, fuel efficiency and manpower reductions.

Research Recommendations

Current aircraft O&S cost per flying hour is a rough capacity estimate that does not permit a more in-depth analysis to the real O&S cost incurred by an airlift fleet. On the other hand, a O&S cost estimating model capable to support the decision-maker in deciding the optimum level of the operation considering all costs elements incurred would be the most suitable for the BAF mobility system

Most importantly, the development of new methods for estimating the economic life limit of BAF aircraft fleet is a crucial subject to be included in future Air Force planning. Moreover, studies regarding tools capable of predicting the O&S costs to achieve an optimal performance level for aged aircraft fleets is the also a key issue in the current Air Force environment.

Nonetheless, to be successful, a new aircraft acquisition program must be take in account extensive exploratory researches relating to important issues such:

(1) ownership cost estimates projections,

(2) Cost-benefit analysis among the viable options, and exam of all support system required operating a new airlift fleet.

Futhermore, rely only in the " ton-miles concept" to perform an exam the mobility capability of an Air Force may lead to measures that not necessarily reflects the real cargo capacity of an airlift fleet as expected in the predicted required needs of the mobility system.

The performed analysis and estimates of the BAF airlift capability indicate that the single measure provide by the ton-miles approach should be improved by the inclusion of selected alternate scenarios. Such scenarios must also consider the average airlift cargo transported at different time intervals.

In addition, the inevitable trend of defense budget shrinking arises the need to drive down all O&S costs of the actual and future aircraft fleet. Among the remedies for this problem, a comprehensive economic service life estimation applied at the BAF aircraft fleet seems to be an important key to support important decisions concerning major aircraft acquisition programs or life extension of the aging aircraft at the BAF mobility system. In addition, further research must be accomplished airlift life-cycle costs models applied at other BAF operational commands. In particular, a representative O&S cost models should be developed and implemented to perform reliable economic service life estimation at other BAF aging aircraft fleets.

In this context, a more comprehensive and validated version of BAFOS model could be extremely useful to perform cost estimates of other BAF aircraft systems and evaluation of system alternatives in major acquisition programs.

Final Comments

Cost growth on aging aircraft systems has been recognized as a long standing problem in the Brazilian but solutions for this problem are not properly addressed due to lack of an adequate aircraft cost structure along with inadequate database on cost estimate of critical elements.

To succeed in this adverse scenario of financial restrictions, the BAF needs to develop a cost estimating guidance handbook capable to gather all cost estimates documentation, procedures, and concepts available. Besides that, a successful program of improvement of BAF cost estimating capabilities can be achieved through:

(1) Additional cost estimating research.

(2) Use of computer-based technology to develop well designed cost models.

(3) Training of personnel in cost analysis techniques.

As a final point, cost analysis techniques are a powerful management tool when used for cost estimation at acquisition, development and operation of a major aircraft system, especially in a time of scarce military resources. As exhibited throughout this research, a comprehensive cost analysis study must be developed under consistent and precise guidance, which includes the cost estimate purposes, required assumptions, and an applied methodology.

Appendix A: C-130 O&S Cost Summary

BAFOS (Brazilian Air Force O & S Costs) Model

****

Report =	Cost Summary
Dollars =	FY99 (Millions)
Project =	C-130

****

Program Factors:		Estimating Method
PAA QTY	12	C-130 operating @ Galeão AFB
Avg. Annual Flying Hours/Aircraft	600	FY97 and FY98 Data
Manpower Factors:		
Galeão Squadron - Officers	35	
Galeão Squadron - Enlisted	47	
Galeão Supply & Maint - Officers	9	
Galeão Supply & Maint - Enlisted	34	
Galeão Depot Maint - Officers	12	
Galeão Depot Maint - Enlisted	96	
Base/Depot Civilians	45	
Total Personnel	278	
Squadron Allocation Factor	0.8	.8 @ Operations/ .2 @ Others
Supply & Maintenance Allocation Factor	0.6	.6 @Fleet Support/ .4 @ Base
Depot Allocation Factor	0.33	.33 C-130 / .66 KC137 & HS125
Base Turnover Rate	0.2	
Depot Turnover Rate	0.1	
Average Annual PCS	35	Total Personnel * Turnover Rates
Squadron/Base Training Rate	0.3	
Depot Training Rate	0.2	
Annual Average Training Qty	68.1	Total Personnel * Training Rates

Personnel Cost Factors

Avg. Officer Pay	36,364	Annual Avg. Basic Pay (0-1 to 0-6)
Avg. Enlisted Pay	17,894	Annual Avg. Basic Pay (E-1 to E-9)
Avg. Civilian Pay	13,560	Annual Avg. Basic Pay for Civilians
Avg. PCS/Personnel	12,000	Avg. based on rank or grade
Avg. Training/Personnel	8,000	Avg. Expense per Course

POL Factors

Fuel Price(Liter)	0.7
Fuel Consumption(Liter/Hr)	2,744
Oil Price(Liter)	16.29
Oil Consumption(Liter/FH)	2

Logistics Factors:

Depot Maintenance/FH

Depot Overhaul	610
Squadron Maintenance	215
Subtotal	825

Supplies/FH

Consumable Material	18
Depot Material	145
Replenishment Spares	550
Subtotal	713

Depot Reparable/FH	1,083

Depot Maintenance/Aircraft

Airframe Division	23,800	285,600/PAA QTY
Engine Division	14,400	172,800/PAA QTY
Transportation	9,000	36,000lb/yr @ $.25/lb
Contract Support	37,500	650,000/PAA QTY
Subtotal	84,700	

Support Equipment/Aircraft

GSE Maintenance		2,117	20%/yr of GSE systems/PAA QTY
GSE Replacement		10,583	2 GSE @ 63,500/PAA QTY
	Subtotal	12,700	

****

*Values in US$ (FY99)

**The values in this table represent estimates of the annual BAF expenditures with each cost element based on the BAF C-130E fleet at Galeão AFB and Galeão Depot

Appendix B: C-95 O&S Cost Summary

BAFOS (Brazilian Air Force O & S Costs) Model

****

Report =	Cost Summary
Dollars =	FY99 (Millions)
Project =	C-95

****

Program Factors:		Estimating Method
PAA QTY	58	C-95 operating @ ETA* Squadrons
Avg. Annual Flying Hours/Aircraft	500	FY97 and FY98 Data
Manpower Factors:		
ETA** Squadrons - Officers	145	
ETA Squadrons - Enlisted	163	
ETA Supply & Maint. - Officers	28	
ETA Supply & Maint. - Enlisted	118	
Afonsos Depot Maint. - Officers	12	
Afonsos Depot Maint - Enlisted	82	
Base/Depot Civilians	62	
Total Personnel	610	
Squadron Allocation Factor	0.7	.7@ Operations/ .3 @ Others
Supply & Maint Allocation Factor	0.5	.5 @Fleet Support/ .5 @ Base
Depot Allocation Factor	0.7	.7@ C-95 and .3 @ UH-1H
Base Turnover Rate	0.25	
Depot Turnover Rate	0.15	
Avg. Annual PCS	134	Total Personnel * Turnover Rates
Squadron/Base Training Rate	0.5	
Depot Training Rate	0.3	
Annual Avg. Training Qty	273.8	Total Personnel * Training Rates

Personnel Cost Factors

Avg. Officer Pay	26,364	Annual Avg. Basic Pay (0-1 to 0-2)
Avg. Enlisted Pay	11,894	Annual Avg. Basic Pay (E-1 to E-9)
Avg. Civilian Pay	9,560	Annual Avg. Basic Pay for Civilians
Avg. PCS/Personnel	12,000	Avg. based on rank or grade
Avg. Training/Personnel	4,000	Avg. Expenses per Course

POL Factors

Fuel Price(Liter)	0.7
Fuel Consumption(Liter/Hr)	1,197
Oil Price(Liter)	16.29
Oil Consumption(Liter/FH)	1.5

Logistics Factors:

Depot Maintenance/FH

Depot Overhaul	332
Squadron Maintenance	230
Subtotal	562

Supplies/FH

Consumable Material	16
Depot Material	136
Replenishment Spares	166
Subtotal	318

Depot Reparable/FH	659

Depot Maintenance/Aircraft

Airframe Division	21,034	1,220,000/PAA QTY
Engine Division	11,121	645,000/PAA QTY
Transportation	11,400	45,600lb/yr @ $.25/lb
Contract Support	x	No contract
Subtotal	43,555	

Support Equipment/Aircraft

GSE Maintenance	5,859	20%/yr of 32 GSE/PAA QTY
GSE Replacement	5,493	6 GSE @ 53,100/PAA QTY
Subtotal	11,352	

****

*Values in US$ (FY99)

**The values in this table represent estimates of the annual BAF expenditures with each cost element based on BAF C-95 fleet distributed at ETA's (Air Transportation Squadrons) and BAF Afonsos Depot.

Appendix C: O&S Costs Estimate Results

Aircraft		C-95	C-130
**************************************			
Flying Hours		500	600
Lifecycle years		20	20
Flying Hours Related Factors:			
**************************************			
Depot Maintenance/FH		562	825
Supplies/FH		318	713
Depot Reparable/FH		1,150	1,083
	Subtotal	2,030	2,621
Aircraft Related Factors:			
**************************************			
Depot Maintenance/Aircraft		43,555	84,700
Support Equipment/Aircraft		11,352	12,700
	Subtotal	54,908	97,400
POL (Liter/FH)*(S/Liter):			
**************************************			
AVFUEL		418,950	1,152,480
Lubricants		12,218	19,548
	Subtotal	431,168	1,172,028
Crew and Personnel ($/Aircraft):			
**************************************			
Mission Personnel (Squadron)		99,336	176,147
Support Personnel (Base/Depot)		41,206	122,804
Permanent Change of Station (PCS)		27,703	35,200
Personnel Acquisition & Training		18,883	45,400
	Subtotal	187,128	379,551
Aircraft O&S Costs ($/yr./Aircraft)			
**************************************			
Annual O&S Costs/Aircraft		$ 1,688,203	$ 3,221,579
Twenty Year O&S Costs @ 10%		$14,372,685	$27,427,234
**************************************			

Appendix D: BAF Total Cost Estimates

	Alternative 1 C-95	Alternative 2 C-130
Number of Aircraft	58	10
Airlift Capacity Provided (MTM/D)	0	0
Aircraft Procurement	x	229,200
Initial Acquisition Provisioning	x	45,840
Twenty Years O&S Costs @ 10%	833,616	274,272
Total Cost Incurred (thousand of US$)	$833,674	$549,323

Appendix E: Break-even Analysis Database

Year	Cumulative C-95 O&S Costs*	Cumulative C-130 Total Costs*	Cumulative C-130 O&S Costs*
2000	0	275,040	0
2001	89,005	304,324	29,284
2002	169,911	330,943	55,903
2003	243,455	355,140	80,100
2004	310,306	377,135	102,095
2005	371,074	397,129	122,089
2006	426,311	415,303	140,263
2007	476,522	431,823	156,783
2008	522,164	446,840	171,800
2009	563,653	460,490	185,450
2010	601,366	472,899	197,859
2011	635,647	484,178	209,138
2012	666,809	494,430	219,390
2013	695,134	503,750	228,710
2014	720,883	512,221	237,181
2015	744,288	519,922	244,882
2016	765,563	526,922	251,882
2017	784,902	533,285	258,245
2018	802,482	539,069	264,029
2019	818,461	544,326	269,286
2020	832,987	549,105	274,065

*Assuming 10% of discount rate

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Despite the high Operational and Support costs incurred, the Brazilian Air Force's (BAF) declining budget has led to the establishment of conservative policies that favor short run solutions for a critical BAF airlift problem of operating an aging fleet. As a result of this policy, service life extensions of older airlift aircraft are the preferred solution.

Using an equal airlift capacity approach to examine the Brazilian Air Force mobility system, this research performs a cost comparison analysis between two aircraft currently in operation at Brazilian's airlift command: C-130 Hercules and C-95 Bandeirante. To accomplish the cost analysis, this research develops an Operation and Support aircraft cost model adapted to the Brazilian's airlift system requirements.

Assuming the same level of annual flying hours for the next 20 years, the research cost analysis concludes that the proposed alternative of acquiring C-130 aircraft to replace the older C-95 could result in savings of at least 25 percent, without reducing the BAF mobility capacity.

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