T-56 TURBOPROP ENGINE OVERHAUL ALTERNATIVES FOR THE INDONESIAN AIR FORCES

Setyo Siswanto

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FOR THE INDONESIAN AIR FORCES

by

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The Indonesian Air Force currently maintains and overhauls its aircraft structures and piston engines. However, turbo-prop and jet engines are shipped overseas for overhaul. Under this policy a large number of spare engines are needed due to long turn-around times. In addition, the costs of overseas overhaul was done in Indonesia. Finnaly, overseas overhaul compromises Indonesia's independence. This report studies the feasibility of overhaul of the T-56 turboprop engine within-the-country and

presents a preliminary estimation of the costs for setting up overhaul capabilities for that engine. A cost comparison is then made between within-the-country overhaul and overseas overhaul. Based on this comparison, the within-the-country alternative appears to be the most economical. Refinement of the cost analysis is needed and, in addition, because of economics of scale the establishment of overhaul capabilities for all military jet engines in Indonesia should probably be considered before any decisions are made to establish any overhaul capability.

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ABSTRACT

The Indonesian Air Force currently maintains and overhauls its aircraft structures and piston engines. However, turbo-prop and jet engines are shipped overseas for overhaul. Under this policy a large number of spare engines are needed due to long turn-around times. In addition, the costs of overseas overhaul appear to be higher than they would be if the overhaul was done in Indonesia. Finally, overseas overhaul compromises Indonesia's independence. This report studies the feasibility of overhaul of the T-56 turboprop engine within-the-country and presents a preliminary estimation of the costs for setting up overhaul capabilities for that engine. A cost comparison is then made between within-the-country overhaul and overseas overhaul. Based on this comparison, the within-the-country alternative appears to be the most economical. Refinement of the cost analysis is needed and, in addition, because of economics of scale the establishment of overhaul capabilities for all military jet engines in Indonesia should probably be considered before any decisions are made to establish any overhaul capability.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. LOGISTICS SUPPORT FOR AN AIRCRAFT WEAPON SYSTEM

Every activity or mission needs its own composition of logistics support. In an aircraft weapon system, a primary mission equipment is obviously the aircraft. And the requisite logistics support is the composite of all considerations necessary to assure the effective and economical support of the aircraft throughout its programmed life cycle. Logistics support must be planned and developed as a part of the aircraft weapon system development process to assure maximum system effectiveness. The considerations requiring support management attention through all phases of the life cycle, will be grouped as follows and described in detail below.

1. Test and support equipment;
2. Supply support (spares & repair parts);
3 Transportation and handling;
4. Maintenance facilities;
5. Personnel and weapon system training;
6. Technical data and publications.

B. TEST AND SUPPORT EQUIPMENT (T & S E)

All tools, monitoring and check-out equipment, calibration equipment, maintenance stands and handling equipment to support scheduled and unscheduled maintenance actions on the aircraft are included in test and support equipment.

Some test equipment is built in the aircraft instrument panel (for example the instruments showing engine temperature

and speed). This internal test equipment is usually considered as components of the aircraft (prime equipment), and is acquired as a part of the supply (described below).

The external test and support equipments are acquired based on:

1. The rate at which aircraft components wear or fail;
2. The time required to perform repairs and overhauls;
3. External or environmental factors such as personnel effectiveness and length of work day.

C. SUPPLY SUPPORT

Under the category of supply support are included all reparable spares (units, assemblies, modules, etc.) and all repair parts, consumables, special supplies and related inventories needed to support scheduled and unscheduled maintenance actions associated with the prime equipment and the external test and support equipment. Management of supply support includes considerations of the maintenance levels (echelons), the geographical locations from which spares and repair parts are distributed, the locations of storage points, and the methods of material distribution.

D. TRANSPORTATION AND HANDLING

Transportation and handling includes the actions and requirements necessary to transport, preserve, package and handle all prime and test & support equipment. These functional requirements and actions are developed from operation and maintenance analyses, equipment specifications, and other

documentation defining handling equipment, procedures, packaging and preservation needs.

Elements which must be considered include:

1. Transportability and packaging details such as time, locations, duration, frequency, volume and safety;
2. Desired locations for transportation equipment and facilities;
3. Planned availability of existing system capabilities by quantity, volume and location.

E. MAINTENANCE FACILITIES

Maintenance facilities for an aircraft weapon system are: the physical plants that consist of: hangar, intermediate shops, depot facilities and housing required to support the operational and maintenance functions associated with the air-crafts and its test and support equipment.

F. PERSONNEL AND TRAINING

The personnel which are needed include those required for the maintenance of the prime equipment, and the operation and maintenance of the support equipments. Personnel needed can be identified in terms of quantity and skill level requirements for each operational and maintenance function.

Training includes both initial training for system/equipment familiarization and replenishment training to cover attrition. Training is also needed to upgrade current personnel to the skill levels defined for the system. Personnel training

requirements are initially derived through:

1. Operation and maintenance functional analyses;
2. Detailed task analyses (identifying the quantity and skills required);
3. Comparison of the personnel requirements for the system with the personnel quantities and skills currently available.

G. TECHNICAL DATA AND PUBLICATIONS

Under this heading are included:

1. Engineering drawings, microfilms, technical and performance descriptions of the prime and support equipments;
2. Operating instructions/procedures, maintenance worksheets; special test procedures, installation instructions, and training manuals;
3. Inspection and calibration procedures for the prime and support equipment.

II. AIRCRAFT MAINTENANCE IN THE INDONESIAN AIR FORCE

A. AIRCRAFT TYPES

Most of the types of aircraft in use by the Indonesian Air Force are from the United States of America, and the rest are from France (Helicopters: Bourog, Aluete) and other western countries. The current aircraft types from the U. S. are:

1. Training aircraft:

   T-33 (T-birds) jet engined,

   T-34A (Mentor) piston engined,

   T-41D (Cessna) piston engined.

2. Transport air craft

   C-47 (Dakota) piston engined,

   C-130B (Hercules) turbo-prop, heavy transport,

   Cessna series (for light transport),

   S-55 (Sikorsky) turbo engined helicopters.

The Indonesian Air Force currently has enough equipment and skilled personnel to completely maintain its piston engined aircraft. However, the maintenance capabilities for jet engine aircraft are not as complete; in particular, engine overhaul capabilities do not exist.

B. MAINTENANCE ORGANIZATION

The maintenance system in the Indonesian Air Force has been organized on a parallel with the rest of the air force organization. Maintenance is performed in three levels, they are organizational, intermediate and depot.

1. Organizational Maintenance

Organizational maintenance is usually performed at the site. The maintenance tasks are performed by personnel of the squadron involved with the operation and use of equipment. They should not spend time on detailed maintenance. They are limited to:

a. Pre-flight and visual inspections/functional checks;

b. Periodic checks of equipment performance (after every 25, 50 and 100 hours of operation);

c. External adjustments (such as fuel regulation system adjustments);

d. Removal and replacement of some components (such as tires); and

e. Cleaning and some servicing.

The personnel assigned to this function are usually not skilled in specialized maintenance. They do not repair any removed equipment, but forward it instead to the next higher maintenance level.

2. Intermediate Maintenance

Maintenance tasks that cannot be performed by organizational levels due to limited personnel skills and test equipment are performed at this intermediate level. The maintenance personnel are better equipped and more skilled than those at the organizational level.

Equipment may be repaired by the removal and replacement of major modules, assemblies or unit parts. Scheduled maintenance requiring equipment disassembly may also be accomplished. The shops are usually located within specified geographical areas. As a consequence, the turn-around times are not as rapid as in the organizational maintenance units. The tasks include:

a. Detailed inspection and system check out;

b. Major servicing (after every 300 and 1,000 hours in operation);

c. Complicated adjustments; and

d. Limited calibrations.

For emergency purposes, semi-mobile units can provide close support to the operational site. The mission of such units is to provide close on-site maintenance, beyond that accomplished by organizational units, to facilitate the return of the aircraft to its full operational status on an expedited basis.

3. Depot Maintenance

The depot level is the highest level of maintenance. This level of maintenance includes:

a. Complicated "factory" adjustments;

b. Complex equipment repair and modifications;

c. Overhaul and rebuilding;

d. Detailed calibration; and

e. Work overloads from intermediate levels of maintenance.

Depot facilities exist only at certain locations and equipment requiring this level of maintenance must be transported to those locations. Each depot maintains its own inventories (called depot level stock). In addition, there is one logistics depot whose sole mission is supply support for the entire air force including the transportation and distribution to the maintenance depots and other unit organizations.

C. THE PRESENT MAINTENANCE CAPABILITY

By maintenance capability is meant: availability of tools, test and support equipment, facilities and skilled personnel to do the aircraft maintenance tasks considered appropriate for that level.

All maintenance facilities and equipment at the organizational and intermediate levels belong to the air force because it is virtually impossible to efficiently and independently operate any type of aircraft without them. These capabilities are considered enough since all types of aircraft operated are already supported with facilities (hangars), tools, minor test and support equipments and skilled personnel to perform the organizational and intermediate level maintenance.

The Indonesian Air Force does not yet have the depot level capabilities for all types of aircraft operated. In particular the new types (C-130B, F-86, T-33, etc.) were not procured together with complete logistics support at the depot level.

The current depot level capabilities include:

1. Plants that are dedicated to all types of current conventional aircraft and their engines. These depots are capable of overhaul and repair of air frames, and its system and piston engines;
2. Plants that are dedicated and capable of overhaul and repair of jet aircraft bodies and IRAN for C-130B. (IRAN = Inspection and repair if necessary).
3. A plant that was initially dedicated to overhaul and repair of jet engines of the MIG series and IL-28 Ilynsin. This unit is currently almost idle because all types of these aircraft are grounded, waiting for phase out policy since their supply support was cut for political reasons.

Parts of this last unit that could be converted to another use are:

1. Buildings (≈ 10 buildings). The largest three building comprises approximately 7200 m^2 . Few modifications would be required of the shops and warehouses; and
2. Some support equipment may be common enough for use on other type of jet aircraft.

D. CURRENT POLICY FOR TURBO-PROP AND JET ENGINE OVERHAUL

The current policy for overhauling and major repair of turbo-prop and jet engines is to send them back to the foreign overhaul shop in the United States. The distance between

Indonesia and the United States is approximately one half of the circumference of the earth. And, obviously, such a long distance requires a long lead time. The advantages are:

1. No large capital fund needed for investment in a physical plant; and
2. More flexible in future decision for type of aircraft to be purchased.

The disadvantages are due primarily to long lead time. They include:

1. The long "pipe line" of the engine circulation cycle between Indonesia and the United States requires a large number of spares be available. If there are not an adequate number of spare engines, then the readiness requirement will be compromised;
2. The cost for packaging and shipping are high because of the distance;
3. The costs of overhaul in the United States are higher than they would be in Indonesia because of higher labor wage rates, the contractor profits, and taxes; and
4. The dependence on foreign overhaul compromises the need for independence of the Indonesian Air Force from any other military power.

III. OBJECTIVES AND SCOPE

A. OBJECTIVES

The primary objective of the Indonesian Air Force is to maintain a specified readiness level and to be independent of foreign countries for aircraft maintenance. To accomplish the first part of this objective, the maintenance system should provide a specified number of annual flying hours from all aircraft so that they could accomplish certain specified missions. Independence requires that they have overhaul and repair capabilities for turbo-prop and jet engines in terms of hardware (facilities) and software (experience, system and skill).

The objective of this report is to establish a structure for making a decision as to whether to continue to rely on foreign overhaul capabilities for existing aircraft or to establish now such capabilities inside Indonesia. In particular, this report develops a general procedure for determining the costs. The general benefits have been described above and their relative importance must be weighed against the resulting costs by ultimate decision makers.

B. SCOPE

The cost analysis presented in this report to illustrate the general procedure addresses only the question of the overhaul of the T-56 engines from a C-130B. The alternatives that will be considered are:

1. The current policy of sending the engines for overhaul and repair to the United States of America;
2. Overhaul and repair in Indonesia including the establishment of overhaul facilities.

Both alternatives are to provide the same level of aircraft operational capabilities.

The costs of the two alternatives will be compared and the pay-back period for within-the-country overhaul will be determined.

C. METHODS AND PROCEDURES OF ANALYSIS

The data used in this report are not accurate but can serve as a starting point towards obtaining more refined data for the critical components of the analysis. The two major data sources were the Naval Air Rework Facility (NARF), Alameda, California and Kelly Air Force Base (AFB), San Antonio, Texas. With the exception of the cost of overhaul, the costs and resources analysis data from NARF, Alemeda, were taken from internal reports on feasibility studies done in 1974 for expanding the NARF facilities to handle increased work loads. The cost estimates from Kelly AFB are approximately one year old and represent costs paid by Indonesia at that time for T-56 engine overhaul. No resource analysis data was obtained from the U. A. Air Force. The first step of this analysis will be the estimation of the expected numbers of engine removals per year due to scheduled overhaul and random failure in the Indonesian Air Force.

The next step will be to compare this expected number of overhauls with the number of engines overhauled at NARF, Alameda, to provide a basis for estimating the resources required to perform overhauls in Indonesia. These are identified by work station of an overhaul facility. The floor space, test and support equipment, and personnel and training needs will then be estimated. Initial training is assumed to take place in the United States. The engine spares problem is also examined. An estimate of the turn-around time for overseas and with-the-country overhauls will be made and the necessary spare engines to avoid shortages will be determined.

The initial investment and variable costs for each of the alternatives will be then estimated. Finally, comparisons of the relevant overseas and within-the-country overhaul costs over an estimated lifetime of ten years will be made.

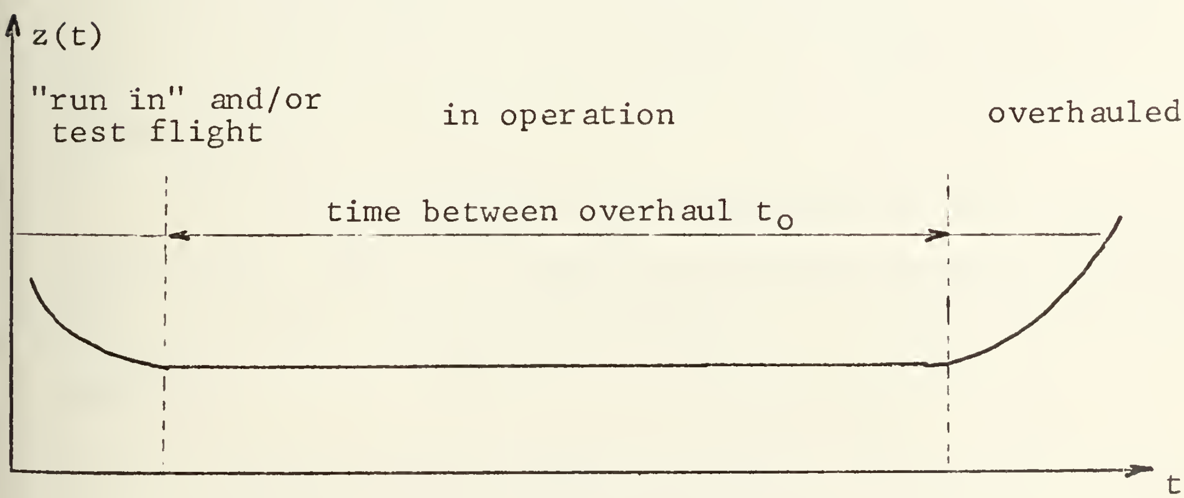
IV. OVERHAUL RESOURCES ESTIMATION

A. EXPECTED NUMBER OF ENGINE OVERHAULS

Jet engine performance generally is not allowed to degrade gradually until failure occurs. If a policy of waiting until failure before replacing an engine is used, the associated hazards to the aircraft and its occupants are severe. For this reason, a policy of preventive maintenance (including overhaul) has been common.

Preventive maintenance is based primarily on the number of operating hours and hence is periodic. Engine inspection is a major part of each periodic maintenance. Regular engine removal for overhaul occurs after a specified number of operating hours. However, removal may occur sooner than the time for scheduled overhaul because inspection of the engine suggests that failure could occur before the next inspection.

Typically, the rate of failures of a large population of engines follows the bath tube shaped curve sketched below.



In this sketch, we denote the failure rate (also called "the hazard function") by $z(t)$. The initial period of decreasing $z(t)$ can be explained by the fact that the engine is often initially defective or is subject to start-up failures. Such failure rates occur immediately after overhaul as well as when a new engine is first placed in service. During this period engines are "run-in" on the ground in the aircraft and are flown on test flights. Failures occuring during this period are repaired and counted as part of the previous overhaul.

The second period, where $z(t)$ remains fairly constant, corresponds to the operational period of an engine. The third period shows a time increasing $z(t)$ corresponding to an increasing failure rate resulting from engine components wearing out. If scheduled overhauls take place at the start of this period, then this increasing failure rate with its associated hazards to the aircraft and its occupants can be avoided.

The ideal time "t_o" between overhauls corresponds to the length of the period when $z(t)$ is constant. A longer period of time would result in a greater probability of failure. A shorter period of time would result in overhauls which are unnecessary.

If $z(t)$ = a constant as is assumed for the second period and we let $z(t) = \lambda$ then the probability density function for the time "t" between failures is assumed to be exponential; that is:

$$f(t) = \lambda e^{-\lambda t} \quad . \tag{1}$$

The expected time between failures (MTBF) is λ^{-1} and, over a period of length T, the expected total number of failures is λT and the probability mass function is Poisson [2].

The values of λ and t_o for a given engine may be obtained from the manufacturer (assuming his assumptions about operation are true) or may be determined from experience and statistical analyses by user organization. The values used by the Indonesian Air Force for the T-56 engine are $\lambda = 0.00033$ failures per hour of operation and $t_o = 2000$ hours.

The determination of the expected number of engine removals per year due to random failure during period II and to scheduled overhaul at the end of period II is complicated by the fact of the scheduled overhaul. The distribution of time between overhauls when both random failures and scheduled overhauls are considered is given by equation (2).

$$f(t) = \begin{cases} \lambda\, e^{-\lambda t} & \text{for} \quad 0 \le t \le t_o \\ e^{-\lambda t_o} & \text{for} \quad t = t_o \end{cases} \tag{2}$$

The expected value of time between overhauls is given by equation (3) and takes advantage of the properties of the exponential distribution [2].

$$\text{MTBO} = \int_0^{t_o} t \cdot f(t)\,dt = \int_0^{t_o} e^{-\lambda t} dt = \frac{1}{\lambda}\left(1 - e^{-\lambda t_o}\right) \tag{3}$$

Now, if

h = annual number of flying hours per aircraft,

n = number of engines per aircraft, and

m = number of aircraft which are operational;

then the total number of hours of engine operation T per year is given by equation (4)

$$T = h \cdot m \cdot n \quad . \qquad (4)$$

The mean total number of overhauls X per year can now be estimated from equation (5)

$$X = \frac{T}{MTBO} \quad . \qquad (5)$$

The data for the Indonesian Air Force pertaining to the C-130B aircraft powered by the T-56 engine are:

h = 1000 hrs., m = 15 aircraft, n = 4 engines,

λ = 0.00033 failures per hour, t_o = 2000 hours.

The mean time between overhaul is, from equation (3).

$$MTBO = \left[\frac{1}{\lambda} \quad 1-e^{-\lambda t_o}\right] = \frac{1}{3.3\times10^{-4}} \left[1-e^{-3.3\times10^{-4}\times2000}\right]$$

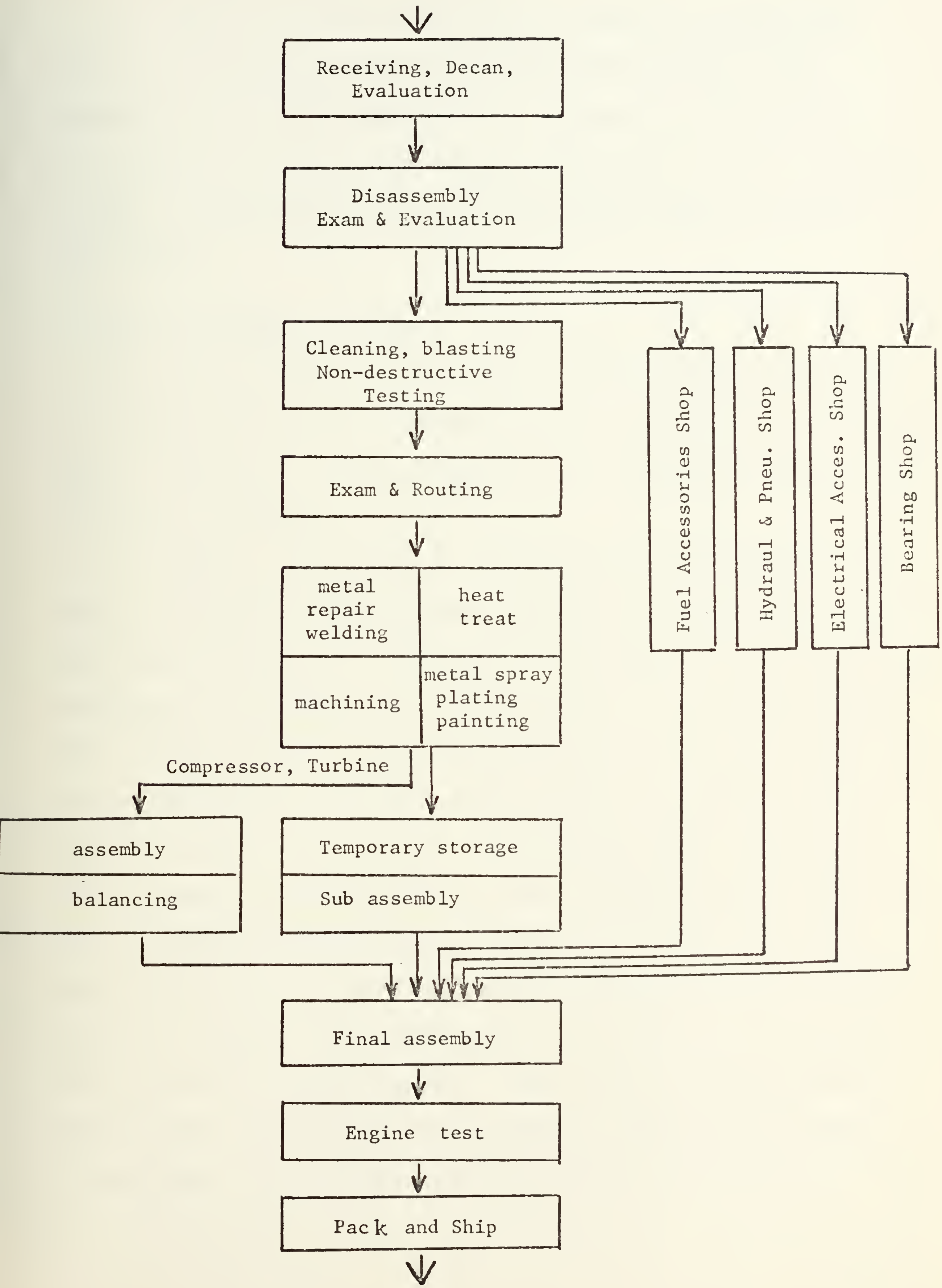
$$= 1464 \text{ hours.}$$

The mean number of overhauls per year is, from equation (4) and (5)

$$X = \frac{h \cdot m \cdot n}{MTBO} + \frac{1000\times15\times4}{1464} = 41 \quad .$$

Thus, a mean number of 41 overhauls of the T-56 engine can be expected. If, in addition, similar assumptions are made about all parameter values but n for the other jet engine aircrafts (F-86, T-33, and S-55) in the Indonesian Air Force, then approximately 200 jet engine overhauls per year would be needed in total.

FIGURE 1 Engine Overhaul Process Flow Diagram



B. COMPARISON WITH NARF ALAMEDA

The Naval Air Rework Facility at Alameda, California annually overhauls approximately 200 T-56 engines (predominantly for the P-3 aircraft). Because of similarities to facilities needed by Indonesia, an analysis of the resources at NARF, Alameda will be made in the next several sections of this report.

C. ENGINE OVERHAUL PROCESS

An understanding of the details of the process of engine is a prerequisite for a resource analysis of an overhaul facility. Figure 1 presents a flow diagram of the overhaul process as it is done at Alameda.

In summary, the engine is removed from its shipping container, undergoes a preliminary inspection, is then disassembled and further inspected to determine the extent of overhaul needed. Depending on the part, it is either sent to a specialty shop (for example a fuel system component goes to the fuel accessories shop) or to the more basic cleaning, sandblasting and non-destructive testing (the turbine and exhaust components are typical). Parts falling in this latter category then receive another inspection to determine the extent of repair required and the appropriate routing to other shops to accomplish the repair. The compressor and turbine receive particular attention in this process. The stages are separated and their blades are removed and examined, replaced if necessary or replated. The turbine housing interior is replated and

machined. The compressor and turbine are then reassembled and balanced. Final assembly follows after all components have been repaired. The assembled engine is then test run and repacked in its container for shipment.

D. FLOOR SPACE (BUILDING) REQUIRED

A listing of the floor space dedicated to T-56 overhaul at NARF Alameda is shown in the first column of Table 1. In column two are listed the floor space that are prorated for the T-56 engine which is shared with overhaul of other types of jet engine. These prorated values represent lower bounds on areas needed; in fact, they may be too small to be feasible. The third column shows the total shop areas by building number for all types of jet engines, included that floor space which is prorated for the T-56 engine. The sum total of all floor space represents an upper bound needed area.

The total of the first two columns of Table 1 sum to approximately 70,000 square feet or around 6,300 square meters. This represents the bare minimum area for overhaul of 200 T-56 engines.

The current buildings in Indonesia which have been idled by the grounding of the MIG series type of jet aircraft have a total floor area in excess of 6,300 square meters and should, therefore, be sufficient for T-56 and other types of jet engine overhaul. The expense needed is for rework and/or minor modification, before the new support and test equipment can be installed. The common rate including labor and material cost for this type of job is \$100 per m^2, therefore, the 6,300 m^2 area would cost \$630,000.

TABLE I Building Flor Areas (in square feet) Associated with the Various Overhaul Shops at NARF Alameda

WORK STATION	Area For T-56		Total Building Areas	
	Dedicated	Prorated	Bldg No.	Area
Disassembly (includes for exam and evaluation)	1,400	385		
Cleaning		2,880		
Non-distructive testing (NDT)		720		
Exam and Routing		1,240		
Welding		2,805		
Metal Repair		1,155		
Plating		2,520		
Painting		1,835		
Blade and Vane		2,200		
Compressor	1,900	935		
Turbine		525		
Machining		4,830		
Component Assembly		1,000		
Assembly	3,820			
Support (parts inventory)		13,548		
Total area	7,120	36,578	Bldg 360	106,000
Auxiliary electrical power		1,355	Bldg 398	5,000
Bearing Shop		4,245	Bldg 5	5,000
Test Assembly		9,475	Bldg 14	33,000
Fuel Accessories		8,335	Bldg 66	30,000
Hydraulic and pneumatic Accessories		2,180	Bldg 162	8,500
Electrical Accessories		320	Bldg 400	1,200
Total, all stations	7,120	62,488		

E. TEST AND SUPPORT EQUIPMENT (T & SE) REQUIRED

The first column in Table 2 lists the estimated costs for specialized equipment at Alameda. Total costs of this equipment are $750,500. Column two lists the costs of common equipment in each work station, not all of which is used for T-56 overhaul. Prorated costs of this equipment are listed in column 3 and were calculated based on floor space proration in Table 1. For example, for the fuel accessories work station:

Floor space prorated for T-56 = 8,335 sq. ft. (Table 1)

Total shop areas = 30,000 sq. ft. (Table 1)

Total common test & support equipment = $1,739,000 (Table 2)

$$\text{Common Test \& Support eq. prorated for T-56} = \frac{8335}{30000} \times \$1,739,000 = \$483,000.$$

Total of the prorated costs of test and support equipment for the T-56 engine from the third column are approximately $2,637,000.

All of the costs listed in Table 2 represent installed costs at Alameda. Assuming similar equipment could be purchased in the United States, additional costs would be incurred to ship it to Indonesia. Based on statistical analysis [3], the transportation costs are estimated to be 12% of the purchase costs. Therefore, the estimated installed costs in Indonesia are the sum of installed costs in the United States plus transportation costs. The breakdown of these costs are listed in Table 3 by specialized and prorated equipment.

TABLE 2 Support equipment cost at NARF Alameda

Work Station/Equipment	Specialized for T-56	Total Common	Common Prorated for T-56
Main Overhaul building			
a. Common Cleaning, blasting, NDT, E&R, welding, metal repair, plating, machining, painting, etc.		$4,320,000	$1,490,000
b. Dedicated/Peculiar			
dolly engine test	$ 7,700		
fixture checking safety	9,375		
fixture milling inlet case	6,575		
fixture inspect turbine rotor	4,625		
fixture for turbine disassembly	2,450		
spring tester	4,375		
stand for turbine section	3,650		
fixture for compr. vane	3,175		
temperature test set	3,000		
adapter test oil	2,575		
c. Building total	47,500		
Fuel accessories repair	221,000	1,739,000	483,000
Propeller system (gear box)	74,000		
Rework auxilliary electrical power		600,000	156,000
Hydr. & Pneu. accessories	42,000	650,000	166,000
Electrical accessories	29,000	36,000	10,000
Bearing overhaul	12,000	114,000	90,000
Test cell	325,000	850,000	242,000
Total, all buildings	$750,000		$2,637,000

TABLE 3 Installed Costs of overhaul equipment in Indonesia

Equipment Types	Installed Costs at Alameda	Transportation Costs from U.S. to Indonesia	Installed Costs in Indonesia
Specialized Equipment	$ 750,000	$ 90,000	$ 840,000
Common Prorated Equipment	$2,637,000	$ 316,000	$2,953,000
		TOTAL =	$3,793,000

F. PERSONNEL AND TRAINING REQUIREMENT

Table 4 presents the number of personnel required by work station at Alameda (in column 1) and estimated requirements for Indonesia (in column 2).

The estimated number of personnel required in Indonesia was determined by assuming the following formula:

$$N_I = N_A \left(\frac{n_I \; e_A}{n_A \; e_I} \right) \qquad (6)$$

where N_I = number of personnel in Indonesia,

N_A = number of personnel at Alameda,

n_I = mean number of T-56 engines overhauled per year in Indonesia,

n_A = mean number of T-56 engines overhauled per year at Alameda,

e_I = average personnel efficiency at Alameda,

e_A = average personnel efficiency in Indonesia.

Calculations earlier in this report indicate that $N_I = 41$. Information from Alameda indicates that $N_A = 200$. If e_A is assumed to be 1.0 then the current lack of efficiency and skills in Indonesia suggest that $e_I \simeq 0.5$. Finally, N_A is given in column 1. For the fuel accessories repair for example:

$$N_I = 46 \ \frac{41 \times 1}{200 \times 0.5} \ = \ 18.86 \ \text{or} \ 19 \text{ people.}$$

The number of personnel to be initially trained from each work station is difficult to determine. Obviously, all personnel must be trained eventually but the procedure to efficiently initiate the process is not clear. Two factors dominate, they are;

1. Costs to receive training overseas; and
2. The time required for most of the personnel to become proficient enough for the facility to be able to handle an average overhaul rate of approximately four engines per month.

The following approach is a crude attempt to resolve the problem. Suppose that it is desirable to have a minimum capacity to overhaul 4 engines per month after four months following the decision to develop an overhaul capability within the country. A minimum number of trained personnel can be approximated by workload analysis. If the monthly overhaul rate is 4 engines and each consumes 700 man-hours then the monthly work load is 2800 man-hours. An assumed total effective work hours per individual is 35 per week or

140 per month (excluded lunch and coffee breaks, etc.). Thus, the absolute minimum number of personnel to be sent for training is $\frac{2800}{140} = 20$ people.

According to information from NARF Alameda, the on-the-job training requirements to bring an individual up to 80 percent efficiency are:

1. 80 percent of the overhaul work requires 120 to 140 training hours per individual, and
2. 20 percent of the overhaul work which is highly specialized required 200 training hours per individual.

These values result in an average of approximately 140 hours for all types of work or one effective man-month. Due to language difficulties and the technical background of the Indonesian people it would probably be necessary to double (analogeous with $\frac{1}{e_I}$ above) the training hours to get 80 percent efficiency. Thus, approximately two months training time would be required. Now an 80 percent efficiency implies that a minimum of 25 people should be trained on-the-job to be ready to work alone by the end of two months of training. However, inspection of Table 4, column 2 requirements suggests that almost ten times this number of people would be ultimately needed. Dividing up 25 people equally over eight work stations results in only three people per work station. While three people might be able to handle the tasks of, say, the test cell, it is obvious that considerably more are needed to effect the main overhaul process (figure 1 shows eleven different steps

in the main process). Therefore, a more reasonable value of 50 will be assumed for trained personnel to be ready to work alone after on-the-job training.

Suppose next that each man trained abroad requires two months of training and, after returning home, devotes full time to training other men. If this were true, then a total of four months would be needed before the first in-country trained men would be ready to do efficient overhauls. The number of men sent abroad for training would not need to be in excess of 0.8×50 or 40 because one man can teach at least one other man during on-the-job training. In addition, the efficiency of the instructor improves as a consequence of his teaching efforts. Thus, a maximum of 40 out of the 215 work station personnel would need to be sent abroad for training. If we distribute these proportionally among the work stations, as is shown in column 3 of Table 4, then, for example, the fuel accessories repair personnel to be sent for training will be $\frac{19}{215} \times 40$ or approximately four people. Finally the selection of people from among those in one work station should be based on their command of the english language, and previous teaching experience. The importance of supervisors and managers suggests that at least ten people to be sent for initial training abroad.

Based on the fact that training at the Naval Postgraduate School for 18 months costs $36,000 to Indonesia, a first estimate would be that one month of overseas training will cost at least $2,000. Therefore, the costs to train 50 people for

two months would be at least $200,000. The intensity of training suggest that a cost of $2,500 per month may be more reasonable and 2 months training for 50 people would then cost $250,000. This latter value is assumed in the subsequent analyses of this report.

TABLE 4 Number of personnel required by work station

Work Station	NARF Alameda work force	Indonesian overhaul shop	
		Work Force	For Training
Disassembly, Exam & Eval, Overhaul process, Assembly	350	144	24
Fuel accessories repair	36	19	4
Rework auxilliary power	14	6	1
Hydroulic & Pneu. high pressure	25	10	2
Bearing shop	42	16	4
Test cell	17	7	2
Rework of gear box	25	10	2
Containerizing	6	3	1
Managers & supervisors		15	10
TOTAL	515	230	50

V. SPARE ENGINES IN THE SYSTEM

A. TURN-AROUND TIME FOR OVERSEAS OVERHAUL

The major disadvantage noted earlier (in Chapter II) of sending engines abroad for overhaul is the long turn-around time. This time is approximately 5 months, excluding the removal from the aircraft and canning which are done gradually (one by one) while accumulating enough engines to constitute one order to be shipped. Based on the author's experience, this 5 months is divided into:

1.	Preparation for shipping. (Administration, handling and loading)	¼ months
2.	Shipping and transportation to the overhaul shop in the United States (unloading, customs and receiving, and land transportation).	1¼ months
3.	In the overhaul system (waiting for schedule, decan, overhaul process and canning)	2 months
4.	Preparation for and shipping back to Indonesia (administration land transportation and loading)	1¼ months
5.	Unloading, customs and receiving, land transportation to the operational site.	¼ months

With the exception of the time in the United States in the overhaul system, the times shown above do not vary appreciably.

Time in the overhaul system could be expected to vary as the size of order (number of engines being processed) increases. However, past orders sent to the United States Air Force have been promised to be done within two months provided the order does not exceed 20 engines. An average order of ten has been sent by Indonesia in the past.

The order size has an impact on how often an order is sent. The time between sending of orders t_{po} can be computed by dividing the order size Q by the annual rate of engine removal X ; that is,

$$t_{po} = \frac{Q}{X} \quad . \tag{7}$$

If $Q = 10$, as in the past, and $X = 41$ (from Chapter IV), then $t_{po} = \frac{10}{41} = 0.244$ years $\approx$ 3 months.

B. SPARE ENGINES NEEDED FOR OVERSEAS OVERHAUL

Figure 2 illustrates the flow of engines between operations and overhaul. The mean rate of engine flow around the route shown is x , the mean number of overhauls required per month. As in the preceding section, Q is the order quantity shipped. This quantity is accumulated at the rate x and is then shipped to overhaul every t_{po} months. That quantity Q is not available then for 5 months. At any instant of time, an average of $5x$ engines are somewhere in the pipeline outside Indonesia. The average number waiting shipment is $\frac{Q}{2}$. The spare engine stock is assumed to fluctuate between $2Q$ and Q. If demand

were Poisson distributed, this would give at least 95 percent protection against running out of stock before the next order is received back into the operation. A uniform demand distribution having mean Q gives 100% protection under a policy of keeping a maximum level of 2Q in inventory. The actual demand distribution is convolution of a Poisson and a uniform distribution. Regardless of the demand distribution, the average number of engines in inventory is $\left(\frac{Q + 2Q}{2}\right) = \frac{3}{2} Q$. The average number of engines needed as spares at any instant in time is the sum of the individual averages given above, namely:

$$\frac{Q}{2} + 5x + \frac{3}{2} Q = 2Q + 5x \quad . \tag{8}$$

Since the annual number of overhaul was determined above to be 41 per year, then $x = \frac{41}{12} = 3.42$ engines per month, and 5x will total and rounded to 17 engines. Equation (8) then reduces to:

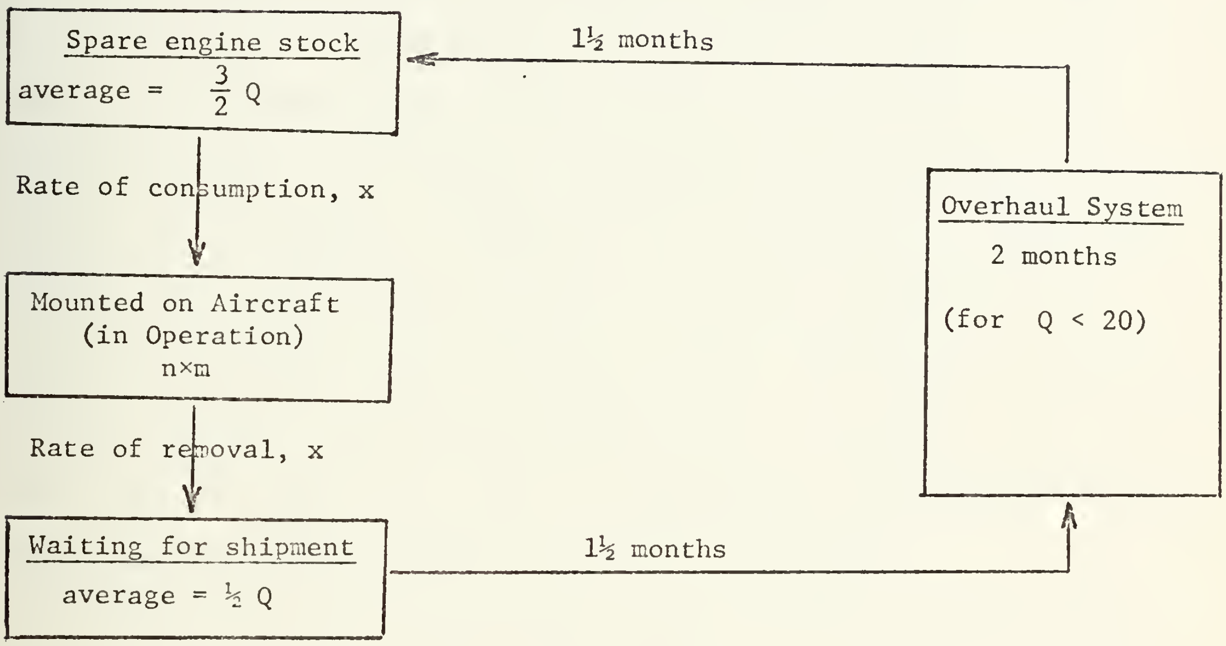
$$2Q + 17 \ .$$

If the engine unit price is C_{EA} then procurement of those engines will cost:

$$C_{EA} = (2Q + 17) C_E \quad .$$

Because the cost of spare engines C_{EA} is a function of Q , smaller Q (a smaller shipment at more frequent intervals) implies decreased C_{EA}.

FIGURE 2   Flow of engines for oversears overhaul



There is also another cost that is related to Q , and that is the annual order cost C_{oA}. If C_{po} is the cost of placing one order and t_{po} is the time between orders, then:

$$C_{oA} = \frac{C_{po}}{t_{po}} = \frac{41}{Q} C_{po} \quad .$$

The final form is the result of equation (7) with $X = 41$. In contrast to the procurement cost of spare engines, the annual order cost will increase as the Q decreases.

Considering the time value of money, the total of all annual order costs that will be incurred in the future over the remaining engine lifetime should be discounted to the

present value. According to the longrange plans of the Indonesian Department of Defense (considering political, economical, and technical development aspects), the C-130B aircraft will be operational for the next 10 years. Therefore, the present value of the order costs of the next 10 years is needed. The latest information obtained established the rate of interest in Indonesia at 24 percent per year and an inflation rate of 19 percent per year[1], therefore the effective interest rate is five percent. The discount rate for the present value of an annuity at a 5 percent interest rate over 10 years is 7.7 [5]. Therefore, the present value of 10 years worth of order cost is $7.7\left(\frac{41 \cdot C_{po}}{Q}\right)$.

Adding procurement and order costs gives the following:

$$C_t = C_{EA} + 7.7\ C_{oA} = (2Q + 17)C_E + 7.7\left(\frac{41}{Q} \times C_{po}\right) ;$$

and C_t represents the total variable cost due to Q for overseas overhaul. The base cost per engine according to the United States Air Force is \$91,000, and the cost of placing one order is \$850 based on the author's past experience. Substituting these values into the total equation, we now have:

$$\begin{aligned} C_t &= (2Q + 17)91{,}000 + 7.7\left(\frac{41}{Q} \times 850\right) \\ &= 182{,}000Q + 1{,}547{,}000 + \frac{2{,}747{,}000}{Q} \end{aligned} \qquad (9)$$

---

[1]Pikiran Rakyat, The daily newspaper of Bandung, Indonesia, January 1976.

The value of Q which minimizes equation (9) is obtained from taking its derivative with respect to Q and setting it to zero.

$$\frac{dC_t}{dQ} = 182{,}000 - 2{,}747{,}000\ Q^{-2} = 0$$

so that $Q^2 = \frac{2{,}747{,}000}{182{,}000} = 15.3$; the minimizing integer value of Q is four. Therefore, based on the previously stated total annual flying hours and mean time between overhauls, the optimum number of spare engines needed under the overseas overhaul policy, from equation (8) will be $(2\times4+17) =$ 25 engines. The total procurement costs would then be:

$$25 \times \$91{,}000 = \$2{,}275{,}000.$$

C. SPARE ENGINES NEEDED FOR WITHIN-THE-COUNTRY OVERHAUL

The flow of engines in a within-the-country overhaul system is similar to that of overseas overhaul policy, but the turn-around time is much shorter. Transportation time from the operation site to the overhaul shop is approximately three days; as is the return trip. Process flow time in the overhaul shop based on information from NARF Alameda could be expected to be 28 days. Thus, the total turn-around time would be 34 days or 1.13 months. Therefore at any instant of time an average of 1.13x or 4 engines will be in overhaul or in transit.

Under the within-the-country overhaul policy, the engines will constantly be under the control of the Indonesian Air Force, and therefore, the order cost would be expected to be very small and should not significantly influence the order size. Analysis with equation (8) the formula for average number of engines needed as spares will be $2q + 4$, where q is the order size for within-the-country overhaul. To minimize the number of spare engines required, the engines should be transported as frequently as possible. However, the presently established schedule for this route is monthly. Under this schedule average $q = 3.4$ engines, (some of the orders are three and some are four), and four T-56 engines are approximately a full load for a truck. Therefore the number of spare engines needed is:

$$2 \times 3.4 + 4 \approx 11 \text{ engines.}$$

The total procurement costs for spare engines under a within-the-country overhaul policy would be:

$$11 \times \$91,000 = \$101,000.$$

VI. IDENTIFICATION OF RELEVANT COSTS

A. COST ITEMS OF WITHIN-THE-COUNTRY AND OVERSEAS OVERHAUL

The overseas overhaul and within-the-country overhaul policies involve both investment (initial) and variable costs. For the overseas overhaul policy, spare engines are the only investment cost. However, the within-the-country overhaul policy includes the costs of the overhaul facility and personnel training as investment cost in addition to spare engines. The variable costs for both policies involve: labor, material, transportation and handling, overhead and administration costs. The various investment and variable costs are listed below under their respective headings.

1. Cost Items Under Within-the-Country Overhaul
    - a. Investment (initial) cost:
        1. overhaul facility, includes: building rework/modification,
        2. peculiar and common test and support equipment procurement cost;
        3. personnel training costs; and
        4. spare engines procurement costs.
    - b. Variable costs:
        1. labor costs;
        2. material and its transportation and handling costs; and
        3. overhead costs.

2. Cost Items Under Overseas Overhaul

a. Investment (initial): spare engines procurement costs;

b. Variable costs:

1. overhaul costs (which includes: labor, material, and overhead costs); and

2. engine transportation and handling costs.

B. COST DATA

The cost data obtained for this report originated from two sources: San Antonio Air Material Area (SAAMA) at Kelly Air Force Base, San Antonio, Texas and NARF, Alameda, California. As shown in Table 5, the data from these two sources do not agree. Since the Indonesian Air Force purchased the T-56 engines via the United States Air Force through the foreign military sale procedure, the engine unit price was assumed to be $91,000. For an overhaul, the NARF reported 700 man-hours are required, while SAAMA reported 360 man-hours. The NARF value seems more appropriate because it was based on a "complete overhaul." The SAAMA value did not include accessory overhaul and/or replacement. To obtain an estimate of various costs hidden in the United States Air Force value of $28,000 of additional charges, the following analysis was made.

Since T-56 engines of the Indonesian Air Force were overhauled by SAAMA, the labor and overhead costs were recomputed for a base of 700 man-hours to be:

1. labor cost at $9/man-hour = 700 × $9 = $6,300, and

2. overhead cost at $10/man-hour = 700 × $10 = $7,000.

and therefore, the material cost would be determined from the "non USAF" engine overhaul cost minus the cost of labor and overhead, that is $36,500 - $6,300 - $7,000 = $23,200.

TABLE 5 Cost data from SAAMA, Kelly AFB and NARF Alameda

Items	SAAMA Kelly AFB		NARF Alameda	
T-56 engine unit price		$91,000		$195,000
Overhaul	excluded: accessories overhaul and/or replacement		"Complete overhaul"	
1. labor:				
number of man-hours	360		700	
wage rate/man-hour	$9		$18	
total labor costs		$ 3,300		$ 12,600
2. Material costs		$ 1,700	included in overhead cost.	
3. Overhead				
number of man-hours	360		700	
overhead rate	$10		$12	
total overhead costs		$ 3,600		$ 8,400
4. Total overhaul costs		$ 8,500		$ 21,000
Additional charge for "Non-USAF" engine overhaul and/or replacement)		$28,000		-
TOTAL COST for complete overhaul		$36,500		$21,000

C. RELEVANT COST ITEMS FOR COMPARISON ALTERNATIVES

For the comparison of alternatives not all of the costs listed in section (IV-A) need be considered. Some are dependent upon the policy selected while others remain essentially unchanged. The cost items that are not alternative dependent are called "wash costs" and they will therefore, be excluded from the comparison of alternatives [4]. The wash costs for this study are material order and procurement cost. These costs, regardless of where overhaul takes place, should be approximately the same.

The policy dependent cost items are listed in Table 6 along with their estimated dollar values as calculated in a previous section of this report. The transportation and handling cost for sending a T-56 engine having a weight of 1,800 lbs. [5] is $1,200 for the round trip. (source: Maersk Line, San Francisco). The material (estimated weight approximately by two-thirds of an engine) transportation and handling costs would be $400 (one way only). In Indonesia, the labor wage rate used is $3 per man-hour, while for overhead (educated personnel) it is $5 per man-hour.

D. SALVAGE VALUE

The time horizon in this study is ten years. After that time the engines will probably be obsolete because the aircraft is obsolete, and therefore, will have no salvage value. Further use of the peculiar support and test equipment and also the rework/modification on the building is not known, therefore, its salvage value according to accounting

principles [1] is estimated to be ten percent; that is, $147,000. However, the common S&TE is estimated to have a salvage value of 30 percent or = $886,000. Thus, the total salvage value would be $1,033,000; which has a present value of $692,000 under a five percent interest rate.

TABLE 6 Relevant cost items for comparison of alternatives

Investment (initial) costs		
1. Overhaul facility	$	$
Building (rework/ modification)	630,000	
Peculiar S&TE	840,000	
Common S&TE	2,953,000	
2. Personnel training	250,000	
3. Spare engines	1,001,000	2,275,000
	$5,674,000	$ 2,275,000
Variable Costs		
1. labor costs	$ 2,100	$ 6,300
2. overhead costs	3,500	7,000
3. transportation and handling costs	400	1,200
	$ 6,000	$ 14,500

VII. ALTERNATIVES ANALYSES

A. COST-TIME RELATIONSHIP

The cost-time relationship (CTR) describes how the total cost of overhaul C_{ot} varies as a function of the number of years (y) during which the C-130B is in operation.

1. Overseas Overhaul

In previous sections, it was calculated that the initial investment (as a fixed cost) needed for overseas overhaul policy was $2,275,000. The relevant variable cost for policy selection purposes was $14,500 per engine overhaul, and therefore the annual variable cost is 41 × $14,500 = $594,500 per year. Since this annual variable cost is incurred over several years in the future, it should be discounted to it's present value; and the cost-time relationship will be:

$2,275,000 + the present value at a series of y annual payments of $594,000 each.

2. Within-the-Country Overhaul

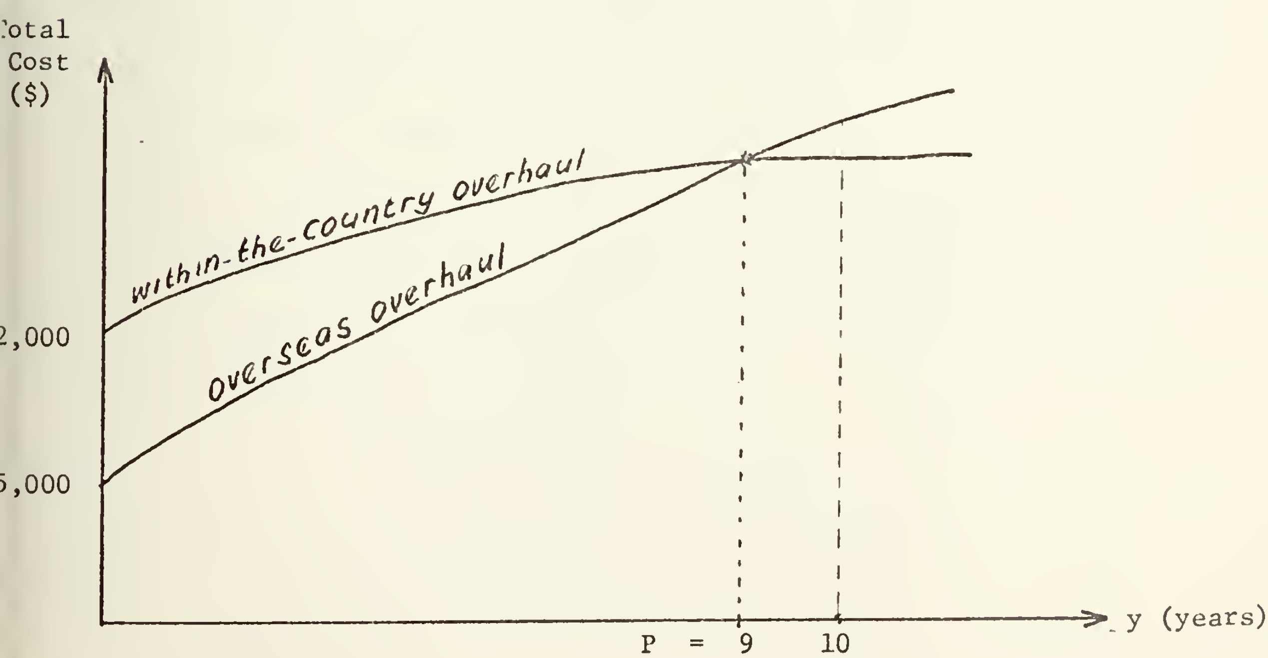
Previously calculated initial investment costs for within-the-country overhaul was $5,674,000. However, after ten years, part of this amount will be retained as a salvage value estimated at $1,033,000 which has present value of $692,000. Therefore, the net fixed costs for this cost-time relationship would be $5,674,000 - $692,000 = $4,982,000. Analogeous to the above derivation, the relevant annual variable cost of this plan is 41 × $6,000 = $246,000; and the cost-time relationship would be:

$4,982,000 + the present value of a series of y annual payments of $246,000 each.

B. BREAK-EVEN ANALYSIS

The break-even analyses in this report is concerned with determining the pay-back period point, which corresponds to point P in the sketch below (Figure 3). At this point, the difference of the fixed costs between within-the-country and overseas overhaul ($4,982,000 - $2,275,000 = $2,564,000) is balanced by the present value of the annual variable cost savings over P years. The annual variable cost saving is the difference of the annual total variable costs between the two alternatives in one year; that is: $594,500 - $246,000 = $348,500. The value of P was determined through the method of successive approximations. The pay-back period was found to be nine years. The additional annual cost savings flow after this pay-back point would then be an advantage to the within-the-country overhaul alternatives.

FIGURE 3 Total cost curves of overseas and within-the-country overhauls



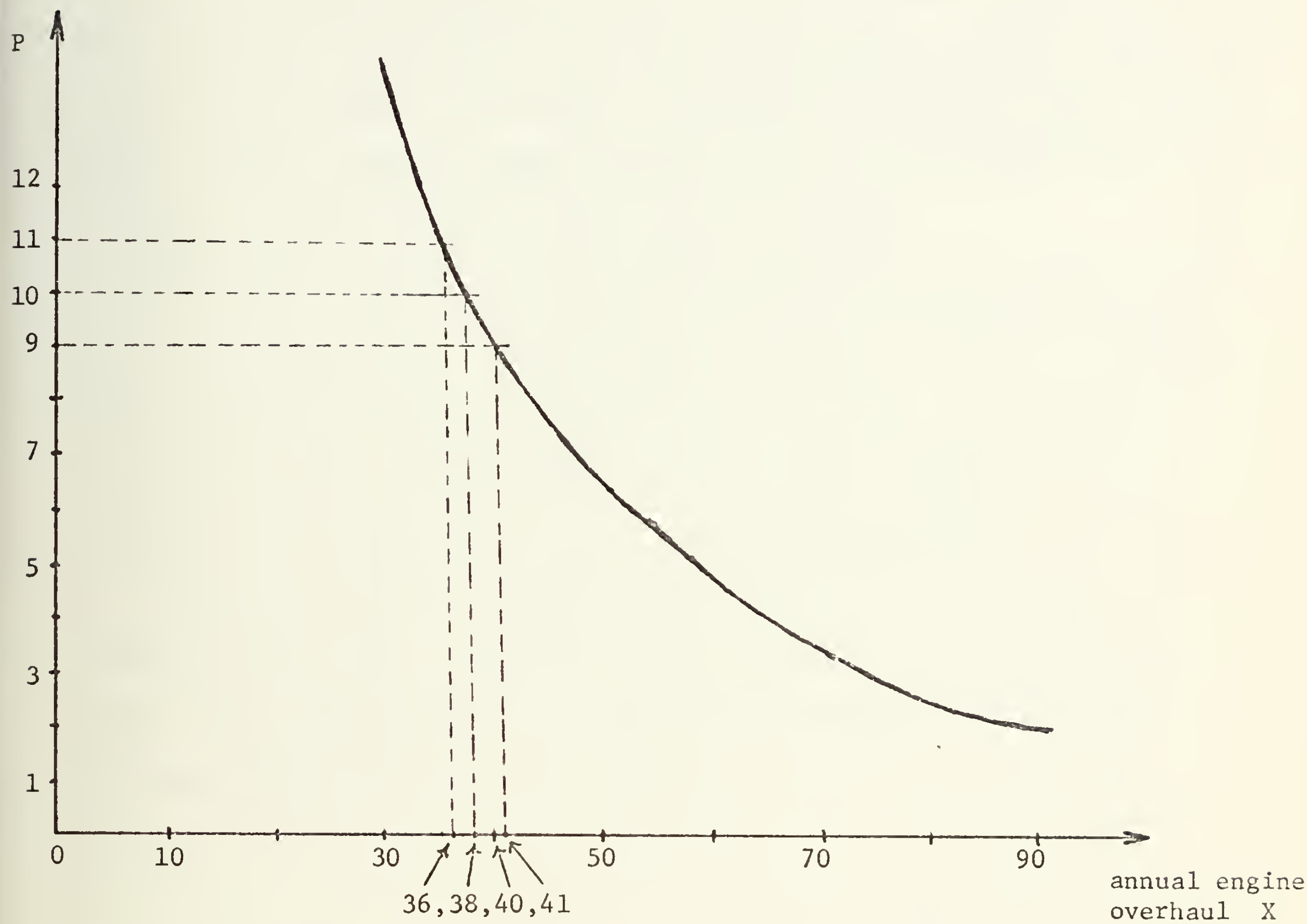
C. SENSITIVITY ANALYSIS

Some factors (such as: annual engine removal, engine unit price, training costs, etc.) may not be accurate, or may vary over time. To see how policy selection is influenced by such variations, it is necessary to do sensitivity analyses. In this study, we will first examine how the variation of annual engine removal X influences the pay-back period P . This analysis is presented in Table 7. The first column presents a range of X values. In calculating the associated number of spare engines needed in column 2 for overseas and in column 5 for within-the-country overhaul, the formulas from sections V-B and C, respectively were used. The associated procurement costs (columns 3 and 6) were obtained by multiplying columns 2 and 5 by an engine unit price of $91,000. The reader will recall that the spare engines costs (in column 3) are the total initial investment costs for the overseas overhaul plan. Column 7 is the sum of spare engines costs and net investment costs ($3,865,000) associated with overhaul facilities. The annual variable costs in column 4 and 8 were obtained by multiplying X by the respective variable cost per overhaul for each alternative. To calculate the payback period in column 9, the same method was used as in section VII-B. Figure 4 is a plot of the pay-back period P (in years) as X varies.

TABKE 7 Calculation for the pay-back period P for various values of annual engine removal rate X

X (annual engine removal)	OVERSEAS OVERHAUL			WITHIN-THE-COUNTRY OVERHAUL				P
	# Spares engines	Spare engine cost	annual variable costs	# Spare engines	Spare engine cost	Total Investment	Annual Variable cost	
1	2	3	4	5	6	7	8	9
24	18	$1,638,000	$ 348,000	9	$ 819,000	$5,492,000	$ 144,000	18
36	23	2,093,000	522,000	10	910,000	5,583,000	216,000	11
41	25	2,275,000	594,500	11	1,001,000	5,674,000	246,000	9
60	33	3,003,000	870,000	13	1,183,000	5,856,000	360,000	5
72	38	3,458,000	1,044,000	14	1,274,000	5,947,000	432,000	3

FIGURE 4 Pay-back period versus annual engine overhaul rate



D. DISCUSSION

Under the annual engine removal rate of 41 engines, the pay-back period was nine years. The minimum possible annual engine removal is 36 (if only one scheduled overhauls are needed) under which the pay-back period was 11 years. Obviously, random failures will result in an annual overhaul rate in excess of 36 and the higher the rate, the more favorable is the within-the-country alternative.

The engine purchase costs of $91,000 used in this study may be too small. The T-56 engine costs should be more than $91,000 according to NARF Alameda. An increased engine cost

also favors the within-the-country alternative, because the overseas overhaul needs a larger number of spare engines. With the use of formulas in previous sections, it was found that if the engine unit price increased to $140,000 then, even under minimum annual engine removal rate of 36 engines, the pay-back period is still less than ten years.

The above discussion has assumed equal benefits from each of the alternatives. Realistically, however, even if the pay-back period is slightly larger than ten years, the benefits of training and establishment of an overhaul capability may justify the within-the-country overhaul alternative.

Finally, experience with other aircraft in the past suggests that the C-130B will be in use in Indonesia well beyond the ten years live assumed and perhaps a 15 year or 20 year horizon is more realistic.

VIII. ENVIRONMENTAL DIMENSIONS AND RECOMMENDATIONS

A. ENVIRONMENTAL DIMENSIONS

The period of 1974-1978 is the second five year development plan (FYDP) for Indonesia. During this FYDP, defense is one of the major areas which is to be strengthened. As a consequence, this is the period when the budget allocated for defense is the largest. Therefore, it is an opportune time to establish the overhaul capability for turbo-prop and jet engine. In addition, Indonesia is a recipient of the United States Military Assistance Program (MAP), from which Indonesia may get aid in the form of technical advisers and/or replacement training needed for overhaul within-the-country.

The present Indonesian economic condition is still weak. However, consideration should be given to allocating funds for this project, since an overhaul facility would help with employment of people.

Because Indonesia has developed closer political ties with the United States and other western countries, the continuity of the supply support within the next ten years seems to be assured. Sustaining supply support is important to prevent aircraft from deteriorating and the associated maintenance facilities from being idled.

B. RECOMMENDATIONS

The preliminary cost analysis presented in this report suggests that the establishment of an overhaul capability within Indonesia for the T-56 turbo-prop engine is desirable.

However, the decision to implement this alternative should await a more refined analysis, especially of costs from Indonesia and more up-to-date overhaul costs from the United States Air Force are obviously needed. Actual equipment estimates instead of "prorated" estimates are needed. Actual building space estimates to house this equipment should then be made. Finally, new equipment procurement, transportation and installation costs are needed.

The estimation of personnel and training needs deserves very serious consideration. Training costs, in particular were very crudely estimated in this report. The economics of training in the United States versus training in Indonesia by a United States team should be examined.

Finally, the analysis presented in this report addresses only the overhaul of the T-56 engine. Analyses of the within-the-country overhaul of all of Indonesia's military turbo-prop and jet engine should probably be conducted before any decision or within-the-country overhaul is made. Economics of scale would be an obvious benefit because of the large amount of test and support equipment which can be used to overhaul not only the T-56 engine but pure jet engines as well. The NARF at Alameda is a good example of such a multi-engine overhaul facility.

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