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**COST-EFFECTIVENESS STUDY OF PREFABRI-
CATED AIRPLANE LANDING MATS**

G. R. Bierman, et al

Booz-Allen Applied Research, Incorporated

Prepared for:

Army Engineer Waterways Experiment Station

August 1971

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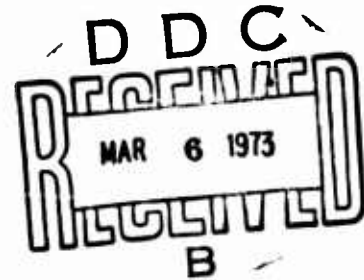
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FINAL REPORT

COST-EFFECTIVENESS STUDY OF PREFABRICATED AIRPLANE LANDING MATS

by

G. R. Bierman, C. T. deLorimier, K. Behari



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August 1971

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Under Contract No. DACA39-70-C-0010

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13. ABSTRACT Results are presented of a Cost-Effectiveness Study to determine the expedient airfield surfacing systems required in a theater of operations during the 1970-75 time frame to support the U. S. air mobility concepts, and to meet the Army approved Qualitative Materiel Requirements (QMR) for prefabricated airfield surfacings. Available data were used to develop the theater of operations scenario, airfield and aircraft mixes, traffic rates, and landing mat cost and performance information. Models were developed to measure the cost and effectiveness of hypothetical mats, as described in the QMR, and of existing mats currently in the inventory or under development. The results of the analysis are presented as recommendations in a Landing Mat Development Plan. As a result of the findings and conclusions, it was recommended that: the current requirement for a landing mat family consisting of three duty classifications (heavy, medium, and light) be discontinued and replaced by requirements for one landing mat system to surface tactical airfield and another for all logistics support airfields; since the current Truss-Web and XM19 systems meet the essential QMR specifications, they should be type classified as standard A items of the two family system for the 1970-75 time frame; and integrally water-proofed landing mats should be developed in order to provide the most cost-effective systems.		

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FOREWORD

The study reported herein was performed by Booz-Allen Applied Research Inc., Bethesda, Md., for the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under Contract No. DACA39-70-C-0010, during the period September 1969-July 1970. The principal investigators were Messrs. G. R. Bierman (Project Engineer), C. T. deLorimier (Project Scientist), and K. Behari (Senior Engineer), functioning under the supervision of Mr. C. S. Young (Vice-President).

WES personnel directly concerned with this project were Messrs. H. L. Green (Project Engineer and Chief, Mat Section); G. L. Carr (Assistant Project Engineer); W. L. McInnis (Chief, Expedient Surfaces Branch); R. G. Ahlvin (Assistant Chief, Soils Division); and James P. Sale (Chief, Soils Division). COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of the WES, and Mr. F. R. Brown was Technical Director during the project. The aforementioned WES personnel, along with Messrs. G. R. Kozan and W. R. Barwick of the U. S. Army Materiel Command (AMC), constituted the Project Advisory Group (PAG) for the study.

The authors acknowledge the invaluable contributions made by the WES and PAG personnel to the study through their cooperation, comments, advice, and constructive criticism. The cooperation and comments received from the industrial companies contacted are also acknowledged and appreciated.

The findings of this contract study do not automatically become doctrine, and do not necessarily represent the views of the WES or AMC. Final evaluation of the results presented in this study will be made in the next In-Process Review (IPR) to be held on landing mat.

The contract under which this report was prepared was monitored by Messrs. Green and Carr. The Contracting Officer was COL Brown.

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ABSTRACT

Results are presented of a Cost-Effectiveness Study to determine the expedient airfield surfacing systems required in a theater of operations during the 1970-75 time frame to support the U.S. air mobility concepts, and to meet the Army approved Qualitative Materiel Requirement (QMR) for prefabricated airfield surfacings.

Available data were used to develop the theater of operations scenario, airfield and aircraft mixes, traffic rates, and landing mat cost and performance information. Models were developed to measure the cost and effectiveness of hypothetical mats, as described in the QMR, and of existing mats currently in the inventory or under development. The results of the analysis are presented as recommendations in a Landing Mat Development Plan.

As a result of the findings and conclusions, it was recommended that:

- . The current requirement for a landing mat family consisting of three duty classifications (heavy, medium, and light) be discontinued and replaced by requirements for one landing mat system to surface tactical airfield and another for all logistics support airfields.
- . Since the current Truss-Web and XM19 systems meet the essential QMR specifications, they should be type classified as standard A items of the two family system for the 1970-75 time frame.
- . Integrally waterproofed landing mats should be developed in order to provide the most cost-effective systems.

I. BACKGROUND AND OBJECTIVES OF THE STUDY

On 25 September 1969, the U. S. Army Engineer Waterways Experiment Station (WES) awarded Contract No. DACA39-70-C-0010 to Booz, Allen Applied Research, Inc. The contract calls for a cost-effectiveness study of aircraft landing mats; and it contains a specific requirement for preparation and delivery of a final technical report. This document is the required report.

1. BACKGROUND

The U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Army Materiel Command (AMC) has a continuing program for the development of prefabricated materials for airfield surfaces (runways, high-speed exit lanes, taxiways, parking strips, etc.) in forward areas. Thus far in the program, emphasis has focused on the development of mats and membranes as expedient airfield surfacings. The mats are intended to provide a bearing surface capable of supporting specified aircraft loadings on low strength soils; the membranes to provide a means of waterproofing and dust-proofing runways and taxiways in areas where soil strength is adequate and for waterproofing subgrades beneath landing mats.

(1) Prior To Initiation Of This Study, The WES Had Already Demonstrated Technical Feasibility Of A New And Improved Family Of Airplane Landing Mats

The WES prefabricated surfacing program has demonstrated that the development of mats and membranes is technically feasible and a Qualitative Materiel Requirement (QMR), "Pre-fabricated Airfield Surfaces" has been approved by the Department of the Army. (A copy of the QMR is contained in Annex A of the report.) The QMR delineates the performance, physical, maintenance and human engineering characteristics which both the mats and membranes must possess in order to provide the Army with improved capability to produce aircraft landing facilities in theaters of operations essential for support of the air mobility concepts of the 1970-1975 time frame.

(2) After The Demonstration Of Technical Feasibility, USAMC Headquarters Directed That WES Explore Certain Implications Of A Decision To Proceed Further With The Mat Development Program

Having demonstrated technical feasibility, the WES has now reached an important milestone in the prefabricated surfacing development program. A number of key technical, economic, operational and logistical questions must be addressed before the program can proceed. These include, but are not

limited to, questions such as:

- . Is it more cost-effective to employ mats with integral waterproofing in lieu of those which require separate membranes to waterproof subgrades?
- . What is the status of current mat development in meeting the 1970-1975 air mobility concepts?
- . Are the current mat configurations; i.e., size, weight, dimensions; operationally and logistically effective?
- . Is it more effective from a cost and operational effectiveness perspective to have three mat types, i.e., light, medium, and heavy duty instead of only one or two duty types?

AMC Headquarters directed that these questions be addressed and authorized WES to engage contractor assistance for their resolution.

2. THE STUDY OBJECTIVE

As stated in WES Contract No. DACA39-70-C-0010, the objective of this study is to determine the composition of the airfield surfacing equipment set for the 1970-1975 time frame that will efficiently and economically provide the required aircraft landing facilities for support of air mobility concepts. (The Work Statement for the study is contained in Annex B.) That is, the study will identify, on a cost-effective basis, an optimum individual or mix of mats and membranes and/or waterproof

mats from among the current or proposed designs.

Additionally, in order to gain insights on the cost and effectiveness implications of building mat systems to the specifications delineated in the QMR, a tradeoff analysis was conducted. The analysis will determine the effects on landing mat cost and mission effectiveness which derive from specific changes to the QMR and if existing systems will meet the QMR requirements.

A landing mat system for expedient surfacing of airfields in a theater of operations is defined as one or more types of landing mats, by duty class, with subgrade waterproofing either integral to the mats or provided by a membrane underlay.

The basic purpose of this study is to develop a body of information concerning types, weights, and mixes of landing mat systems that will support subsequent value judgments regarding the continued development of these systems. The next chapter describes the methodology that was employed in carrying out the study.

II. THE TECHNICAL APPROACH

In the previous chapter, we presented a summary of the objectives of the cost-effectiveness study for which the WES issued Contract No. DACA39-70-C-0010, and of the background circumstances which gave rise to the requirement for the study. In this chapter, we present a summary of the technical approach to the study and certain critical assumptions that were made.

1. A SUMMARY OVERVIEW OF THE TECHNICAL APPROACH

Exhibit II-1, following this page, is a diagrammatic representation of the technical approach employed during the study. It depicts the sequence and interrelationships among the tasks that were performed. As suggested in the Work Statement for the study, the overall technical approach was comprised of three main elements:

- . Cost-Effectiveness Analysis
- . Tradeoff Analysis
- . Landing Mat Development Plan.

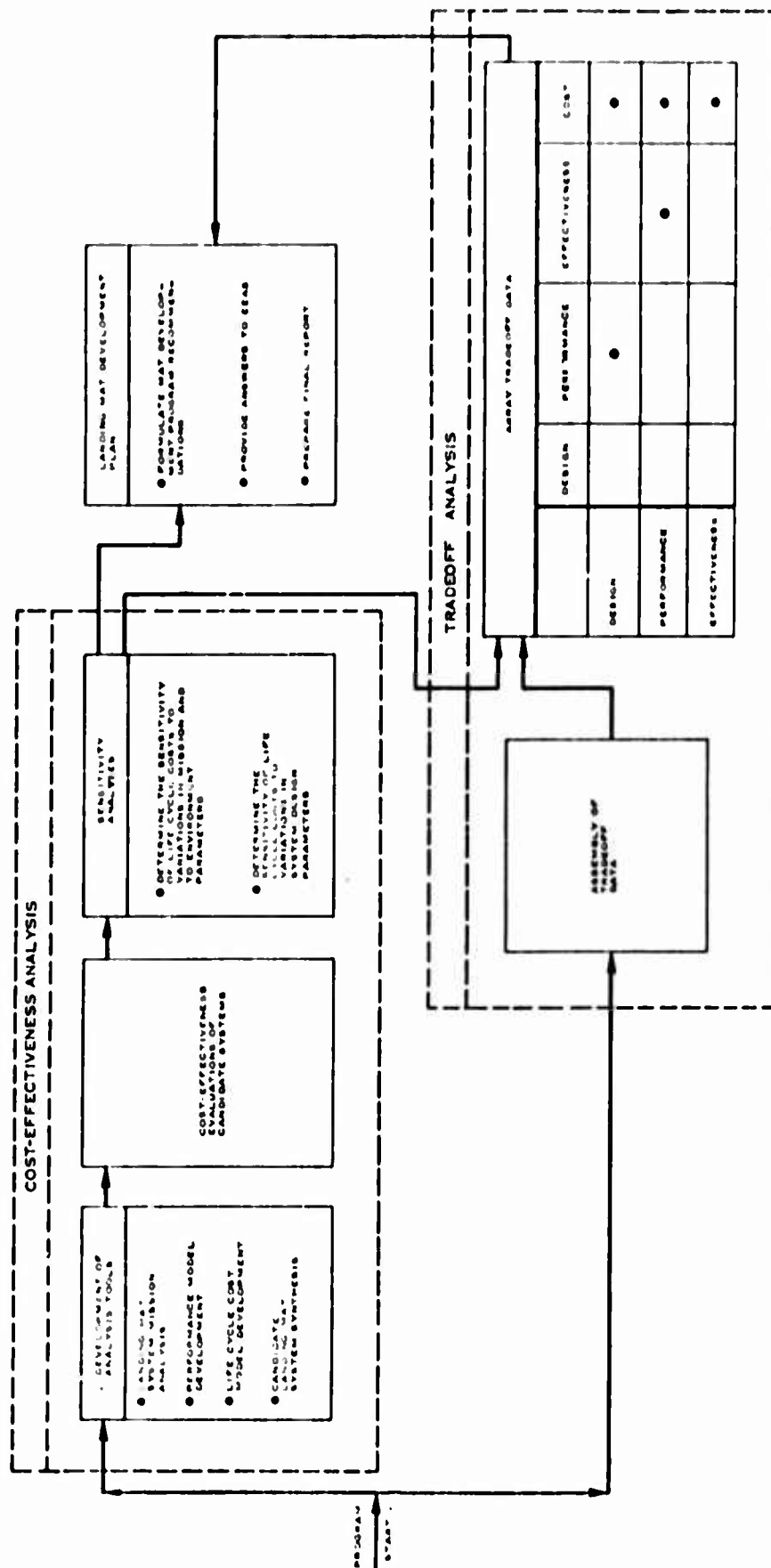
As shown in the exhibit, the cost-effectiveness and tradeoff analyses started simultaneously at the outset of the project and the results of both analyses were used in formulating Landing Mat Development Plan recommendations.

Exhibit II-1 also indicates that, overall, eight major tasks were performed during the study:

- . Landing mat system mission analysis (i. e. , scenario development)
- . Performance model development
- . Landing mat system life-cycle cost model development
- . Candidate landing mat system synthesis
- . Cost-effectiveness evaluations of candidate systems
- . Sensitivity analyses
- . Tradeoff analysis
- . Formulation of Landing Mat Development Plan.

The first six of the above tasks comprise the cost-effectiveness analysis portion of the study. The next chapter of this report describes the thinking that resulted in selection of the technical approach pictured in Exhibit II-1 and provides summary descriptions of the objectives and content of the various tasks. Complete, detailed presentations of critical elements of the methodology (e. g. , scenarios, models, etc.) are contained in the annexes to this report which are referenced at appropriate points in the text.

EXHIBIT E-1
An Overview of the
Technical Approach



2. ASSUMPTIONS

Early in the study, certain ground rules and assumptions were developed to focus the study effort on resolution of the issues of primary concern to the Army. These ground rules and assumptions were considered necessary and appropriate within the scope of the study. They are documented here in Exhibit II-2, following this page.

**EXHIBIT II-2
Study Ground Rules
And Assumptions**

- **SUBGRADE PREPARATION REQUIRED IS COMPARABLE FOR ALL EXPEDIENT-SURFACED AIRFIELDS, AND WILL NOT BE CONSIDERED AS A VARIABLE IN THIS STUDY**
- **PERFORMANCE STANDARD FOR LANDING MATS AND MEMBRANES (E. G. , 100% COVERAGES FOR ACCEPTANCE) IN EFFECT AS OF 1 OCTOBER 1969 WILL BE APPLICABLE FOR THE PERIOD OF THIS STUDY**
- **DESIGN CHARACTERISTICS FOR THE VARIOUS MATS AND MEMBRANES CONSIDERED IN THIS STUDY WILL BE THOSE IN EFFECT AS OF 1 OCTOBER 1969**
- **EMPLACEMENT RATES FOR ALL MATS AND MEMBRANES ARE INDEPENDENT OF EMPLACING PERSONNEL AND AIRFIELD LOCATION**
- **LANDING MAT SYSTEM REQUIRED FOR RUNWAYS, AS DICTATED BY CHARACTERISTICS OF USING AIRCRAFT, WILL ALSO BE REQUIRED FOR TAXIWAYS AND PARKING AREAS.**
- **COVERAGE DISTRIBUTION ON TAXIWAYS AND PARKING AREAS WILL BE THE SAME AS ON RUNWAYS**
- **TIME REQUIRED FOR DELIVERY OF A LANDING MAT SYSTEM TO POINT-OF-USE IS INDEPENDENT OF MAT TYPES (I. E. , IT IS THE SAME FOR ALL TYPES OF MATS AND MEMBRANES)**
- **ALL MODES OF TRANSPORTATION (LAND, SEA, AIR) CAN BE USED FOR ALL MAT SYSTEMS**
- **ENVIRONMENTAL EFFECTS ON LANDING MAT SYSTEMS WILL NOT BE CONSIDERED IN THIS STUDY**

- ALL MATS AND MEMBRANES INCLUDED IN THIS STUDY ARE CONSIDERED TO BE PRODUCIBLE BY MASS PRODUCTION TECHNIQUES (I. E., READILY PRODUCIBLE IN VERY LARGE QUANTITIES)
- REQUIREMENT WILL CONTINUE TO EXIST FOR SEVERAL DIFFERENT DUTY CLASSES OF AIRFIELDS, TO WIT:
 - LIGHT LIFT
 - MEDIUM LIFT
 - HEAVY LIFT
 - TACTICAL
- AIRFIELDS ASSIGNED THE SAME MISSION, SUCH AS MEDIUM LIFT, WILL SERVICE THE SAME AIRCRAFT MIX AND SORTIE RATES REGARDLESS OF WHERE THEY ARE LOCATED IN THE THEATER OF OPERATIONS
- THE RATIO OF THE NUMBER OF ANY ONE TYPE AIRCRAFT TO THE TOTAL AIRCRAFT INVENTORY IS THE SAME RATIO AS EXISTS IN ANY THEATER OF OPERATIONS
- ANY AIRCRAFT CAN USE ANY TYPE AIRFIELD IN AN EMERGENCY WITH USE CONSTRAINED ONLY BY RUNWAY SIZE
- STANDARD COST CATEGORIES WILL BE USED IN THE STUDY:
 - RDT&E COSTS
 - INITIAL INVESTMENT COSTS
 - OPERATING COSTS
- SHIPPING COSTS BY MODE OF TRANSPORTATION WILL BE STANDARD COSTS CURRENTLY IN USE BY THE ARMY

- LABOR COST TO EMPLACE MATS AND MEMBRANES ONLY WILL BE CONSIDERED, I. E., SUBGRADE PREPARATION COSTS WILL NOT BE CONSIDERED
- ROUTINE MAINTENANCE INSPECTION COSTS WILL BE THE SAME FOR ALL LANDING MAT SYSTEMS AFTER AIRFIELD SURFACE IS INSTALLED, AND WILL NOT BE CONSIDERED IN THIS STUDY
- ALL COSTS WILL BE IN CONSTANT 1969 DOLLARS, I. E., NO INFLATION WILL BE CONSIDERED
- AIRFIELD SURFACING MATERIAL REQUIREMENTS WILL BE PER TM 5-366 (BY AIRFIELD LIFT CLASSIFICATION)
- RDT&E COSTS ARE CONSIDERED TO BE CONSTANT FOR ALL TYPES OF MATS
- SINCE UNIT COSTS FOR LARGE VOLUME BUYS TEND TO BOTTOM OUT AT APPROXIMATELY 10MILLION SQUARE FEET, THE PROCUREMENT COST FIGURES ARE BASED UPON THE BOTTOM PRICE WITH ONLY A BUY OF 10 MILLION SQUARE FEET CONSIDERED
- AN AVERAGE PRICE FOR EACH DUTY CATEGORY OF MATS WAS DEVELOPED TO ACCOUNT FOR THE VARIATION IN UNIT COSTS WHICH ARE PROCESS ORIENTED. CONSIDERING A MEDIUM DUTY COST AS A BASE LINE, THE UNIT COST OF HEAVY DUTY EXTRUDED MATS DECREASES WHILE THAT OF HEAVY DUTY SANDWICH TYPE MATS INCREASES. THE REVERSE IS TRUE OF LIGHT DUTY MATS
- CONUS SHIPPING COSTS ARE CONSIDERED TO BE A PORTION OF THE PROCUREMENT CONTRACT AS FIRST DESTINATION COSTS

- THE COST OF ANCILLARY ITEMS IS CONSIDERED TO BE COMMON TO ALL TYPES OF MATS AND IS NOT COSTED AS A SEPARATE ITEM
- THE STUDY ASSUMES THAT INTRA-THEATER SHIPMENT OF MATS WILL BE ACCOMPLISHED BY AIR TRANSPORTATION AND USES C-130 COSTS AS A MEAN, SO AS NOT TO PENALIZE MATS BECAUSE OF WEIGHT EXTREMES. (IT IS RECOGNIZED THAT ALL MODES OF TRANSPORTATION WILL BE USED)
- MAT PLACEMENT COSTS ARE BASED UPON SQUARE FOOTAGE PER MAN HOUR AND DO NOT CONSIDER MULTIPLE EMPLACEMENT CREWS.

III. METHODS AND TOOLS OF THE ANALYSIS

The previous chapter provided a summary overview of the technical approach employed in the study and identified the eight major tasks that comprised the:

- . Cost-Effectiveness Analysis
- . Tradeoff Analysis
- . Landing Mat Development Plan

elements of the study. This chapter discusses the rationale that supports the technical approach and provides a summary description of the objectives and content of the eight major tasks.

To provide a firm basis for understanding of the material that follows in this section, it is appropriate to define the terms "tradeoff analysis" and "cost-effectiveness analysis" in the context of this study.

The term "tradeoff analysis" is used herein to describe the steps necessary to define the impact of variations in one landing mat system parameter on other system parameters. In particular, in this study we are interested in defining:

- . The impact of variations in certain landing mat system design characteristics on system performance, mission effectiveness, and cost
- . The impact of variations in QMR specified performance characteristics on system mission effectiveness and cost
- . The impact of variations in system effectiveness on system costs.

It is clear from this definition that the study methodology should be structured to produce relationships (or data) that illuminate the impact of variations made in the independent variables (named above) on the dependent variables.

The term "cost-effectiveness analysis" is used herein to describe steps required to make quantitative comparisons of the life-cycle costs and mission effectiveness of various candidate landing mat systems.

When considered together, the definitions of the terms "tradeoff analysis" and "cost-effectiveness analysis" suggest that portions of the data that are required to illuminate tradeoff options of interest (as enumerated above) will be developed as a natural consequence of performing the cost-effectiveness analysis.

1. LANDING MAT SYSTEM MISSION ANALYSIS

The essence of a cost-effectiveness study is the quantitative comparison of life-cycle cost and mission effectiveness of a set of

alternative, candidate system configurations. Cost-effectiveness analyses can be conducted in either of two ways:

- . Candidate systems can be configured such that all are equally effective and then comparisons of their life-cycle costs are meaningful, or
- . Candidate systems can be configured such that their life-cycle costs are equal and then comparisons of their effectiveness are meaningful.

In this study, it proved convenient to choose the former course, i. e., a quantified landing mat system mission was postulated. Noting that the QMR contains a requirement that landing mats provide 6 months of operational life, the landing mat system mission was stated as follows:

"Provide at least 6 months of operational life (with no more than 10% mat replacement) on all airfields in a typical foreign theater of operations, under typical aircraft traffic loads."

Candidate systems were configured that would meet this mission requirement, and their life-cycle costs were then compared. The techniques employed in implementing this procedure are discussed in later sections of this chapter.

(1) The System Mission Scenario Defines Theater Airfield Environmental and Traffic Load Factors That Bear on Landing Mat System Operational Life

Given the above statement of landing mat system mission, it is apparent that a complete and definitive description of the mission environment should contain answers to the following questions:

- . How many different types of airfields are found in a typical foreign theater of operation?
- . What are the configuration and dimensions of each type?
- . How many fields of each type are found in a typical foreign theater, where in the theater are they located, and what is the soil strength at the site of each field?
- . What kinds of aircraft can be expected to operate from each field in the theater, and how frequently do they land and take off?

A principal product of the mission analysis task of this study is the Landing Mat System Mission Scenario. The scenario, presented in Annex C, does provide the answers to all these questions. It also indicates the sources of the various data elements.

In summary, the scenario describes a foreign theater of operations, patterned after the "typical" theater concept described in TM 5-366. It is assumed to be located at a distance of 8000 miles from a source of landing mats in CONUS. The theater contains fifteen (15) expedient surface airfields of four types:

- . Heavy lift
- . Medium lift
- . Light lift
- . Tactical.

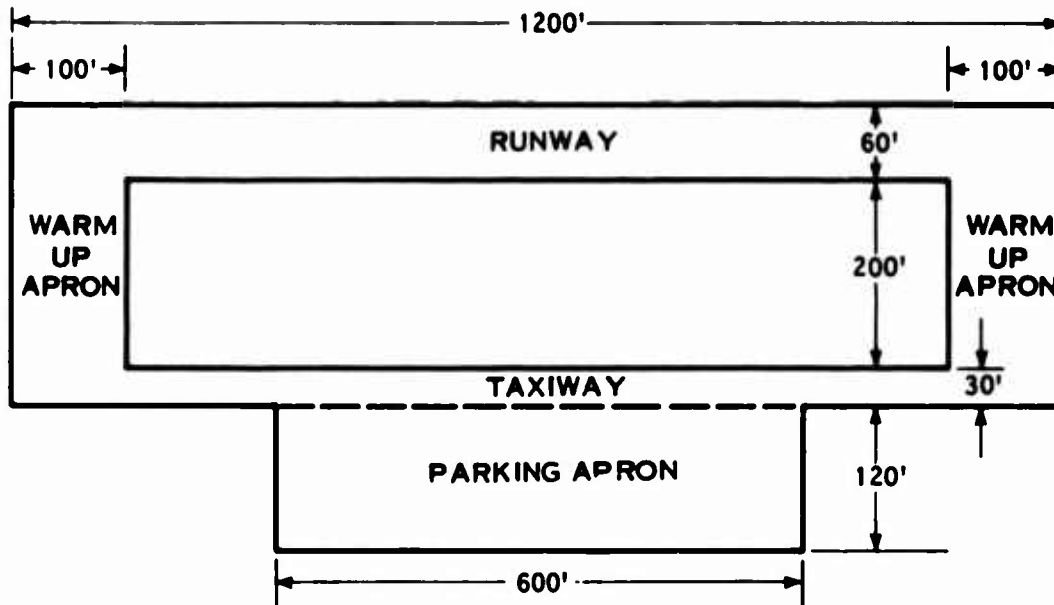
Exhibit III-1, following this page, indicates how the 15 airfields are distributed among the battle area, forward area, support area, and rear area of the theater. The configuration and dimensions of each type airfield are described in Annex C in a format similar to that of Exhibit III-2 of this chapter. From data such as those of Exhibit III-2, the required landing mat area was calculated for each airfield type and the last two columns of Exhibit III-1 were developed.

The theater descriptor data of Annex C also indicate the aircraft traffic that is postulated for each airfield type. It was assumed in the study that the traffic load would be imposed by a fleet containing only 7 aircraft types:

EXHIBIT III-1
Airfield Types in the
Theater of Operations

Airfield Type	No. of Airfields in Theater Area				Total No. Airfields	Total Surface Area By Type Of Airfields	% of Total Surface Area By Type Airfield
	Battle	Forward	Support	Rear			
HEAVY LIFT	-	-	1	1	2	5,347,000	38.2
MEDIUM LIFT	2	1	1	1	5	3,928,500	28.3
LIGHT LIFT	4	1	1	-	6	1,653,000	11.8
TACTICAL	-	-	1	1	2	3,050,000	21.7
TOTAL					<u>15</u>	<u>13,978,500</u>	<u>100%</u>

EXHIBIT III-2
Typical Presentation Of
Airfield Configuration and Dimensions
(Light Lift, Forward Area Field)



AIRFIELD TRAFFIC AREA REQUIREMENTS

RUNWAY	72,000 SQ. FT.
TAXIWAY	48,000 SQ. FT.
PARKING APRON	72,000 SQ. FT.
WARM-UP APRON	28,000 SQ. FT.

TOTAL -- 220,000 SQ. FT.

- . C-7
- . C-123
- . C-130
- . C-5A
- . C-141
- . F-4C
- . F-111B.

Of course, expedient surfaces airfields will be called upon to support the operations of other aircraft types in the 1975 time frame. These could include any U.S. military or commercial aircraft now in operational inventory, in production, or in development. They might also include aircraft of allied nations.

However, the single wheel load, tire pressure, and ground contact area characteristics of the 7 aircraft types listed above are representative of the full spectrum of loadings that could be imposed on airfield surfaces by 1975 time frame aircraft.

Regarding the volume of traffic postulated at each airfield type, Annex C contains a detailed presentation of the sources used and the assumptions made in developing these data.

(2) The Cost-Effectiveness Evaluation Procedure Provides
For Sensitivity Analysis of Critical Mission Assumptions

It was recognized during the study that one key element of the quantified landing mat mission statement (above) is quite arbitrary. We refer to the mission requirement for 6 months of airfield operational life.

Moreover, the Landing Mat System Mission Scenario of Annex C describes a "typical" foreign theater of operations for the 1975 time frame. It is recognized that, in reality, no theater description can really be called typical. The number of airfields (of each type) in a foreign theater will vary from theater-to-theater with the size, configuration, and composition of the theater itself and of the deployed force; and the soil strength at the site of each airfield in the typical theater is virtually unpredictable. Nevertheless, the cost-effectiveness analysis required that some estimate be made of the airfield composition and soil strength of the typical theater.

Accordingly, the implications of these selections and estimates of mission and theater environmental factors were explored in sensitivity analyses described later in this chapter.

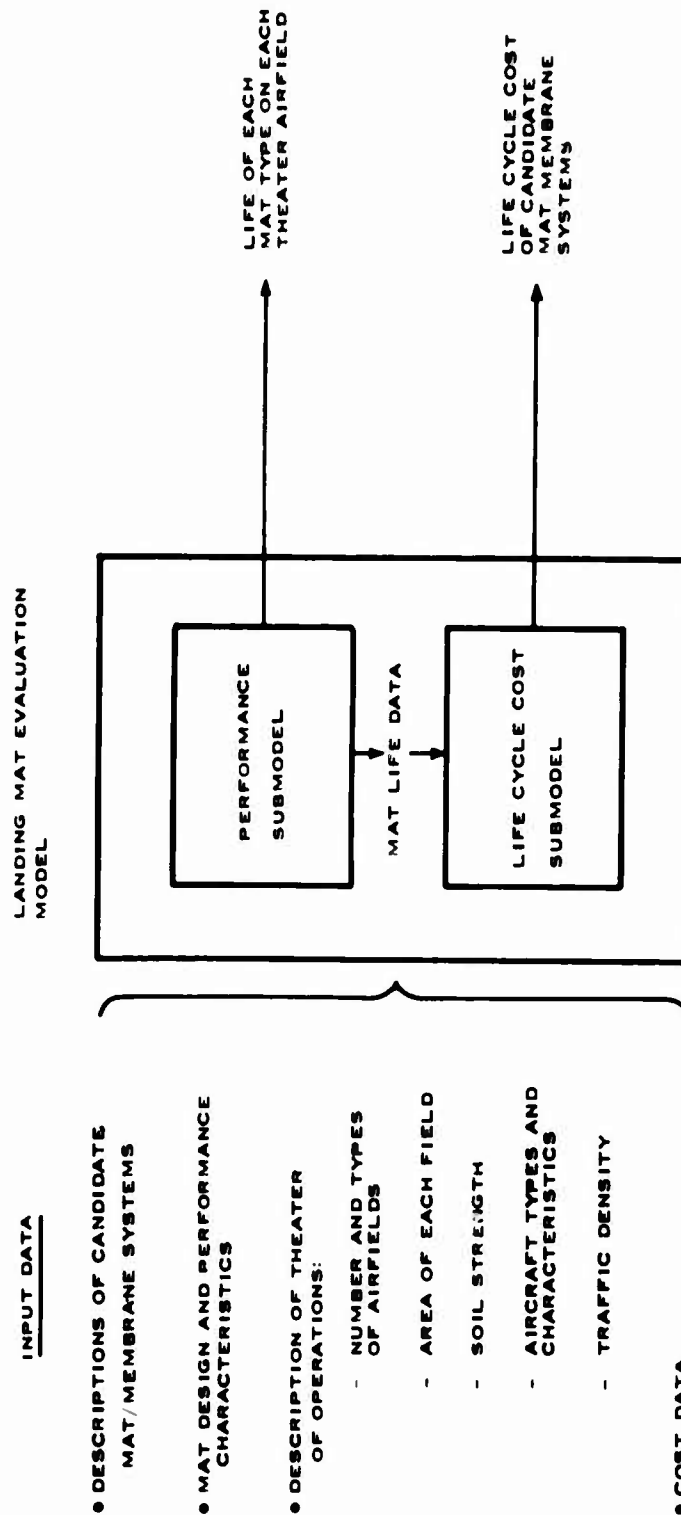
2. LANDING MAT EVALUATION MODEL DEVELOPMENT

As stated earlier in this chapter, it was convenient in conducting the cost-effectiveness analysis of this study to compare life-cycle costs of candidate landing mat systems that had been configured to be equally effective. More specifically, a cost estimate to sustain at least 6 months of aircraft operations at all airfields in the theater of operations was developed for each candidate landing mat system. Thus, all candidate systems were evaluated against a common effectiveness requirement, i.e., a requirement for 6 months of operational life. ⁽¹⁾

To accomplish these evaluations, it was necessary to develop a Landing Mat Evaluation Model comprised of two independent, but integrated, submodels. These are called the Performance model and the Life-Cycle Cost model. Exhibit III-3, following this page, is a pictorial representation of the Landing Mat Evaluation Model showing the interrelationship of the Performance and Life-Cycle Cost models.

(1) Later in the study, the sensitivity of the results of these evaluations to variations in the 6-month criteria were also examined. This sensitivity analysis is further discussed later in this chapter.

EXHIBIT III-3
The Landing Mat
Evaluation Model



(1) The Performance Model Calculates the Life of Each Expedient Surface Airfield in its Operational Environment

The principal problem that had to be solved in development of the Performance model was the formulation of a set of equations and relationships that would support calculation of the operational life of each candidate landing mat type when employed on a particular type airfield and stressed by the scenario-prescribed aircraft traffic.

The mathematical model that was developed to accomplish these calculations requires five types of input data:

- . Aircraft traffic load, i.e., specification of the number of sorties (landing and takeoff operations) that will be executed by each aircraft type on each airfield type, each month
- . Characteristics of each aircraft type
 - Single wheel load
 - Tire pressure
 - Tire contact area
 - Coverages per sortie conversion factor for each aircraft type
- . Landing mat performance characteristics
 - Weight per square foot
 - Placement rate

- . Descriptions of theater landing fields
 - Area
 - Soil strength
- . Description of candidate landing mat systems, i. e. , specification of the mat and membrane type employed on each airfield.

Definitions of the form and content of each of the above data items are contained in Annex F. The data values that were actually used in each exercise of the model are presented in Annex G.

The model operates on these input data to calculate the elements of a matrix that states the expected life (in months) of each candidate landing mat type on each airfield type when stressed by the aircraft traffic expected at that field. The equations and relationships associated with these calculations are described in detail in Annex F.

The expected life matrix developed by the Performance model is a primary input to the landing mat system Life-Cycle Cost model.

(2) The Life-Cycle Cost Model Calculates the RDT&E, Initial Investment, and 6-Month Operational Costs of Each Candidate System

For the purpose of this cost-effectiveness analysis, the mission to be performed by the candidate landing mat systems was to surface the airfields in the selected theater for 6 months. This was a fixed effectiveness level. Therefore, total system life-cycle cost became the selection criterion. The purpose of the Life-Cycle Cost model is to compute this total life-cycle cost for each of the candidate systems. The cost computations are based on a variety of inputs:

- . System Descriptions
 - Numbers and types of mat required at each airfield in the theater
 - Locations of theater airfields
- . Technical Characteristics
 - Weight of mat
 - Weight of membrane
 - Placement rates
 - Bundle sizes
- . Cost Characteristics
 - Purchase cost of mats
 - R&D cost per mat system

- Accessory costs
- Membrane costs
- . Support System inputs
 - Overseas shipping costs
 - Man hour costs
 - Intratheater shipping speeds
 - Intratheater shipping vehicle operational costs
 - Intratheater vehicle payload.

Definitions of the form and content of each of these input data items are contained in Annex F. The data values actually used are presented in Annex G. These input data items are combined with the wear rate and active life data derived from the Performance model to compute the seven elements of life-cycle cost:

- . Research and Development Cost
- . Procurement Cost
- . Transportation Cost
- . Placement Cost
- . Maintenance Cost
- . Replacement Cost
- . Value Remaining.

These seven elements are computed by the Life-Cycle Cost model and summed algebraically to produce the total life-cycle

cost for each candidate landing mat system. The details of these calculations and the assumptions on which they are based appear in Annex E.

3. CANDIDATE LANDING MAT SYSTEMS SYNTHESIS

To assure that the cost-effectiveness and tradeoff analyses of the study would produce meaningful and useful results (in the context of the study objectives), it was necessary to define a set of alternative candidate landing mat systems whose characteristics span the range of interest of critical systems design variables. This required consideration of the following factors:

- . The study seeks quantitative, cost-effectiveness comparisons of systems comprised of different mixes of mat duty classes (i. e. , heavy duty, medium duty, and light duty classes). The list of candidates should include systems that are representative of each possible mix of duty classes. Thus, seven families of systems were synthesized for analysis:
 - Heavy duty mats only
 - Medium duty mats only
 - Light duty mats only
 - Heavy and medium duty mats only
 - Heavy and light duty mats only
 - Heavy, medium, and light duty mats
 - Heavy, and light duty mats only

Exhibit III-4, following this page, lists the constituent elements of landing mat systems analyzed in the study in the seven families above.

- . The study seeks comparisons of the cost effectiveness of landing mats now in development, production, or operational inventory; with hypothetical mats that meet the requirements of the QMR. The mat systems of Exhibit III-4 were structured to facilitate these comparisons.
- . Comparisons of landing mat systems with integrally waterproofed mat systems are also required. The systems of Exhibit III-4 accommodate this requirement also.

Each of the mat systems, defined in Exhibit III-4, was evaluated using the models described in Annex F of this report. The results of the evaluations are presented in detail in Annex G, and summarized in Chapter IV.

Exhibit III-4 indicates only the identification of landing mat types included in the candidate systems whose cost effectiveness was analyzed. Further design details concerning each mat and membrane type are presented in Annex D of this report.

4. COST-EFFECTIVENESS EVALUATIONS OF CANDIDATE SYSTEMS

Once the Landing Mat Evaluation Model had been developed, candidate landing mat systems had been identified, and needed input

data had been assembled, the next step was exercise of the models to evaluate the cost-effectiveness of the candidate systems.

It was necessary to conduct only a single run of the Performance model (which is entirely deterministic) to produce a complete matrix of expected life data. As indicated earlier, this matrix defined the expected life (in months) of all mat types represented in the candidate landing mat systems on every type of airfield in the typical theater.⁽²⁾ The calculated, expected life matrix is presented in a later chapter of this report and in Annex G.

The life-cycle cost model was exercised once for each candidate landing mat system against a stated mission requirement of 6 months of operational life for each airfield. For purposes of life-cycle cost calculation, any field which failed before the 6-month requirement was met was assumed to be refurbished⁽³⁾ at the time of failure through as many iterations as were required to provide 6 months of operational life.

(2) An assumption was made in this model exercise that the soil strength at each airfield was CBR 4.

(3) In refurbishing an airfield, the landing mats comprising the center 1/3 of all runways and taxiways are replaced.

EXHIBIT III-4
Candidate Landing Mat
Systems Analyzed

Landing Mat System No.	Airfield Type			
	Tactical	Heavy Lift	Medium Lift	Light Lift
1	HDM	HDM	HDM	HDM
2	MDM	MDM	MDM	MDM
3	LDM	LDM	LDM	LDM
4	HDM	HDM	MDM	MDM
5	HDM	HDM	LDM	LDM
6	HDM	MDM	MDM	MDM
7	HDM	LDM	LDM	LDM
8	HDM	MDM	MDM	LDM
9	MDM	MDM	LDM	LDM

Systems Nos. 1 through 9 include T-17 type membrane for waterproofing.

Systems Nos. 10 through 18 are the same as Systems Nos. 1 through 9 except that they are integrally waterproofed.

Notes

1. The 18 base candidate systems shown at left are comprised of

- Heavy duty mats (HDM)
- Medium duty mats (MDM)
- Light duty mats (LDM)

as indicated in the table

2. In conducting the cost effectiveness evaluations of candidate systems, five sets of systems (designated from the 18 base systems designated at left) were evaluated. The five sets of systems were synthesized as follows:

In Set No. 1, all mats were assumed to be hypothetical mats meeting the requirements of the QMR and the set includes all 18 base systems.

Set No. 2 includes only System No. 2 and the mat type evaluated in the A M 2

Set No. 3 includes all 18 base systems and the mat types evaluated were

- HDM, Dow True Web
- MDM, Dow NM 18
- LDM, Hypothetical mat

Set No. 4 includes all 18 base systems and the mat types evaluated were

- HDM, Dow True Web
- MDM, Kerner KM 19
- LDM, Hypothetical mat

Set No. 5 includes all 18 base systems and the mat types evaluated were

- HDM, Dow NM 20
- MDM, Dow NM 18
- LDM, MSAI

Thus, these model exercises produced a life-cycle cost estimate for each candidate landing mat system when challenged by a mission requirement for 6 months of operational life.

5. SENSITIVITY ANALYSES

Earlier in this chapter, it was noted that certain selections and estimates of mission and environmental factors were made in setting up the model exercises described above:

- . The QMR requirement for 6 months of operating life was assumed to be valid
- . The soil strength at each field in the theater of operations was assumed to be CBR 4.

To explore the effects of these assumptions on the conclusions of the study, two sets of sensitivity tests were conducted.

In the first set of tests, the full set of model exercises described in Paragraph 4 above was repeated twice, in each repetition, a different value was used as the operational life requirement. The values used were 3 months and 24 months.

In the second set of tests, the full set of model exercises was repeated three times using a different soil strength assumption each time. Values used included CBR's of 2, 6, and 8. Although CBR 2

was used, it is considered unlikely that expedient surfaces airfields would actually be layed on such soil without preconditioning to improve the soil strength.

6. TRADEOFF ANALYSIS

An earlier paragraph of this chapter described the scope of tradeoff interest in this study. The tradeoffs of interest can be summarized more graphically as in Table 1, below.

Table 1
Tradeoffs of Interest

	Landing Mat Systems			
	Design	Performance	Effectiveness	Cost
Design		*		*
Performance			⊛	*
Effectiveness				⊛

Each asterisk in the table represents an interest in tradeoff information between the row and column paired by the asterisk.

Data required to define tradeoff options between system parameters paired by circled asterisks were developed during the cost-effectiveness comparisons of candidate landing mat systems. Development of relationships and data required to define tradeoff options

between system parameters paired by the uncircled asterisks were developed during this task.

Data required to support development of tradeoff possibilities were assembled from:

- . Waterways Experiment Station
- . U. S. Army Materiel Command, Headquarters
- . U. S. Army Combat Developments Command, Headquarters
- . U. S. Army Combat Developments Command, Engineering Agency
- . U. S. Army Deputy Chief of Staff, Logistics
- . U. S. Air Force Logistics Command, Headquarters
- . Harvey Aluminum Company, Torrance, California
- . Kaiser Aluminum and Chemical Company, Oakland, California
- . Dow Chemical Company, Midland, Michigan
- . Goodyear Aerospace Corporation, Akron, Ohio.

A complete list of the companies contacted and the reference documents used is presented in Annex I. Results of the tradeoff analysis are presented in the next chapter of this report.

7. FORMULATION OF THE LANDING MAT DEVELOPMENT PLAN

This final task of our study methodology had a threefold objective as follows:

- . To provide answers to the Essential Elements of Analysis (EEA) that are enumerated in the contractual work statement
- . To formulate recommendations that will guide the future course of the landing mat development plan
- . To document the findings, conclusions, and recommendations of the study in a final technical report.

Accomplishments of these objectives required interpretation and integration of the work of all prior tasks of the study. The substantive results of this task are presented in the next two chapters of this report.

IV. FINDINGS AND CONCLUSIONS

As stated in the last two chapters, the key elements of the study approach included a tradeoff data collection effort, a landing mat system cost-effectiveness analysis, and several sensitivity analyses.

The discussion of the findings and conclusions of the study is organized under four major headings:

- . Landing Mat Performance
- . Landing Mat System Cost-Effectiveness
- . Sensitivity Analyses
- . Analysis of the QMR.

In each of these topic areas, the results of all the efforts of the study are integrated as required to permit presentation of a logical and coherent discussion of the study findings.

1. LANDING MAT PERFORMANCE

The primary objective of this study was to determine the composition of the airfield expedient surfacing equipment set for the 1970-75 time frame that will most efficiently and economically provide the required aircraft landing facilities for support of air mobility concepts. It was assumed that these requirements could be satisfied by landing

mats described by the QMR, and a set of hypothetical mats was defined which represent the performance characteristics as stated by Enclosure 1 to the QMR (Annex A). To achieve the objective, it was necessary to evaluate the capabilities of not only the hypothetical mats, but of existing landing mats as well, to meet the 1970-75 expedient surfaces mission requirements.

The mission requirements (i. e. , support of 1970-75 aircraft operations on the various types of airfields in a foreign theater of operations) are defined and documented in the Landing Mat System Mission Scenario (Annex C). The various types of hypothetical and existing mats were evaluated against these mission requirements in the Performance Submodel (Annex F). The first step was to evaluate the performance of the various mats, in terms of their life expectancy on airfields in the theater of operations, against the fundamental requirement for 6 months operational life given by the QMR. Exhibit IV-1, following this page, presents the results of the life expectancy evaluation.

Several significant conclusions can be drawn from the data of Exhibit IV-1:

- . Based on the aircraft types, traffic densities, and the QMR sortie rates employed in the performance submodel, and assigning the QMR mat duty classes as follows:

EXHIBIT IV-1
Landing Mat Performance
(Life in Months)
at CBR 4

Landing Mat Type	Airfield Type			
	Tactical	Heavy Lift	Medium Lift*	Light Lift*
<u>Heavy Duty:</u>				
QMR Mat	39.50	59.89	63.46	111.61
Dow Truss Web	59.17	61.73	63.46	111.61
XM-20	25.01	56.75	63.46	111.61
<u>Medium Duty:</u>				
QMR Mat	3.15	23.30	63.46	111.61
XM-19	5.95	32.69	63.46	111.61
XM-18	3.66	24.94	63.46	111.61
AM-2	2.38	18.68	63.46	111.61
<u>Light Duty:</u>				
QMR Mat	0.09	0.59	2.78	111.61
M8A1	0.08	0.42	2.16	111.61

* Identical life values in these columns represent 25,000 coverage limit of aircraft using these fields.

- Heavy duty mats on tactical airfields
- Medium duty mats on heavy and medium lift airfields
- Light duty mats on light lift airfields,

then the performance capability of the hypothetical (QMR) mats substantially exceeds the operational requirement for a 6-month mat life.

- . On the same basis, it is also apparent that a family of landing mats which substantially exceeds the 6-month life requirement can be assembled entirely from mats already in existence.
- . Heavy duty mats and medium duty mats can satisfy the operational mission requirements for a variety of airfield types.
- . Light duty mats are the least desirable type for inclusion in any landing mat system because of their short life on all but light lift airfields.

Finally, it is noted that the identical mat life values appearing in the last two columns of Exhibit IV-1 are the result of restricting mat life to a limit of 25,000 coverages of certain types of aircraft, even though estimates by the WES have indicated that much greater coverage levels might be achieved with those aircraft. Exhibit G-9 of Annex G displays the calculated longer life values. The longer life values were not used in obtaining results in this study for two reasons. First, many of the values are so large as to unduly bias the results in favor of nonfailure and unrealistically low life-cycle costs. Second,

the extremely long life values obtained by calculation have not been verified by actual test results.

2. LANDING MAT SYSTEM COST EFFECTIVENESS

As described previously, the cost effectiveness of the candidate landing mat systems was evaluated against a mission requirement for 6 months of airfield life at all fields in the theater of operations. The candidate systems themselves are defined in detail in Annex D.

Any expedient surface that failed prior to 6 months was refurbished and the refurbishment costs were added to the candidate system's life-cycle cost.

In this type of a cost-effectiveness analysis, the system life-cycle cost (LCC) itself is the principal measure of system cost effectiveness.

The results of the cost-effectiveness evaluations of the candidate landing mat systems are displayed in Exhibit IV-2, following this page, which includes LCC data for all 18 mat systems in all 5 sets run in the model exercise.

Analysis of the results portrayed in Exhibit IV-2 leads to the following conclusions:

- . Comparing the life-cycle costs of Systems Nos. 1 through 9 (all with membrane underlay) with costs of Systems Nos. 10 through 18 (all with integral waterproofing), it is evident that in every case the integrally waterproofed system has a lower LCC than does its counterpart system with membrane underlay. That is, the cost effectiveness of integrally waterproofed systems is superior to that of systems with membrane underlay. The reason for this superiority is that integrally waterproofed mat systems have a cost advantage over those using membrane underlay. Performance of landing mat systems, as calculated in this study, is identical for any system using membrane underlay and its counterpart integrally waterproofed system.
- . With the exception of Mat Set No. 2 (the AM-2 mat used on all fields), the LCC of all mat sets is either comparable to, or less than, the LCC of counterpart sets of hypothetical QMR mats. This indicates that development and ultimate type classification of 3 new mats to meet the requirements for all 3 QMR duty classes will result in no significant improvement in overall cost effectiveness.

Along with the LCC results for each landing mat system, Exhibit IV-2 includes data indicating the least life expectancy for any mat in each system, and denotes those systems which do not meet the 6-month life criterion given by the QMR. Applying this criterion to eliminate all systems containing a mat (or mats) not expected to live 6 months in the operational environment, a final listing of 4 candidate systems is obtained.

Exhibit IV-3, following this page, lists Systems Nos. 10, 13, 15, and 17 as the candidates for final consideration. When the ranking of these candidates is considered together with other facts known about

EXHIBIT IV-2
Candidate Landing Mat System
Life Cycle Cost
For 6 Month Mission Requirement
On CBR-4

System Number	Set - 1				Set - 2		Set - 3		Set - 4		Set - 5	
	LCC Extruded (\$/sq. ft.)	LCC Sandwich (\$/sq. ft.)	LCC Average (\$/sq. ft.)	Least Life of the Mat in the System	LCC (\$1000,000)	Least Life of the Mat in the System	LCC (\$1000,000)	Least Life of the Mat in the System	LCC (\$1000,000)	Least Life of the Mat in the System	LCC (\$1000,000)	Least Life of the Mat in the System
1	40.5	41.0	40.7	39.5	64.2	2.38 (N)	3.5	59.17	37.5	59.17	36.7	25.01
2	44.5	45.3	44.9	3.15 (N)			43.2	3.66 (N)	26.3	5.95 (N)	43.2	3.66 (N)
3	571.9	512.2	542.0	0.09 (N)			542.6	0.09 (N)	542.6	0.09 (N)	399.6	0.08 (N)
4	371.7	381	379	39.5			34.4	59.17	33.0	59.17	34.2	25.01
5	40.3	37.7	39.0	2.78 (N)			56.3	2.78 (N)	56.3	2.78 (N)	47.3	2.16 (N)
6	39.0	35.4	35.2	23.3			31.5	24.94	28.7	32.69	33.0	24.94
7	174.6	158.1	166.3	0.59 (N)			164.3	0.59 (N)	164.1	0.59 (N)	135.0	0.42 (N)
8	35.5	35.8	35.7	23.30			31.8	24.94	29.4	32.69	34.1	24.94
9	68.5	66.3	67.4	2.78 (N)	63.2	2.38 (N)	51.8	2.78 (N)	49.6	2.78 (N)	56.3	2.16 (N)
10	38.4	38.5	38.6	39.5			35.1	59.17	35.1	59.17	34.3	25.01
11	42.1	43.0	42.5	3.15 (N)			40.8	3.66 (N)	23.9	5.95 (N)	40.8	3.66 (N)
12	560.7	501.0	530.8	0.09 (N)			531.4	0.09 (N)	531.4	0.09 (N)	388.3	0.09 (N)
13	35.5	35.9	35.7	39.5			32.0	59.17	30.6	59.17	31.9	25.01
14	32.8	35.2	34.5	2.78 (N)			53.7	2.78 (N)	53.7	2.78 (N)	45.2	2.16 (N)
15	32.8	33.1	33.0	23.3			29.1	24.94	26.3	32.69	30.7	24.94
16	170.3	154.0	162.3	0.59 (N)			160.1	0.59 (N)	160.1	0.59 (N)	130.8	0.42 (N)
17	33.3	33.6	33.4	23.3			29.4	24.94	27.1	32.69	31.8	24.94
18	67.9	64.2	65.3	2.78 (N)			51.1	2.78 (N)	49.0	2.78 (N)	58.4	2.16 (N)

NOTE: (N) - denotes the system not meeting the 6 month QMR life criterion.

EXHIBIT IV - 3
Life Cycle Cost Of
Acceptable Systems
On CBR-4

System Number	Set - 1 (Average)		Set - 2		Set - 3		Set - 4		Set - 5	
	LCC (\$x10 ⁶)	Rank	LCC (\$x10 ⁶)	Rank	LCC (\$x10 ⁶)	Rank	LCC (\$x10 ⁶)	Rank	LCC (\$x10 ⁶)	Rank
10	38.6	4			35.1	4	35.1	4	34.3	4
13	35.7	3	NONE		32.0	3	30.6	3	31.9	3
15	33.0	1			29.1	1	26.3	1	30.7	1
17	33.4	2			29.4	2	27.1	2	31.8	2

these systems, the following conclusions can be drawn:

- . As indicated by the cost-effectiveness analysis, System No. 15 of Set No. 4 is identified as the most cost-effective system. This system includes the following two specific mats:
 - Dow Truss Web as heavy duty mat, for tactical airfields
 - XM-19 as medium duty mat, for heavy lift, medium lift, and light lift airfields.
- . The analysis identifies System No. 17 of Set No. 4 as the second most cost-effective system. This system includes the following three specific mats:
 - Dow Truss Web as heavy duty mat for tactical airfields
 - XM-19 as medium duty mat for heavy lift and medium lift airfields
 - Hypothetical (QMR) light duty mat for light lift airfields.

It is recognized that the difference between the LCC estimates (approximately \$800,000) for these two candidate systems is so small as to be insignificant when estimating inaccuracies are considered. This could lead to the conclusion that the two systems are essentially equal. When certain undetermined cost factors are considered, however, the difference could easily increase. For example, no attempt was made in estimating the LCC of System No. 17 to quantify the cost penalty associated with carrying three, rather than two, mat duty classes in the

inventory. Nor was any attempt made to quantify the risk cost associated with the development of a new light duty mat meeting the QMR specifications.

For these reasons, it is concluded that System No. 15 of Set No. 4 remains the least risk, most cost-effective of the candidate systems evaluated.

To summarize the desirable features of the selected system:

- . It provides a heavy duty mat for tactical airfields. Use of the heavy duty mat will assure (with a good margin of safety) that the operational life requirements of such airfields can be met with minimum downtime and under traffic loads imposed by any mix of U. S. or Allied tactical aircraft of the 1970-75 time frame.
- . It also provides for use of medium duty mats on all logistical support airfields in the theater of operations. This will enhance operational flexibility in that the capability of forward logistical support airfields can be readily upgraded by lengthening of runways and by precluding any necessity for replacement of all mats to accomplish upgrading.
- . The selected system will also permit logistics and operational planners to develop landing mat requirements for tactical airfields separately from those for support airfields; thus simplifying procurement, storage, shipment, and deployment actions by the logistician, engineer, and commander.

Having identified System No. 15 of Set No. 4 as the system of choice by reason of low risk and high cost-effectiveness, it is appropriate to examine the sensitivity of that choice to variations in required airfield life and subgrade strength.

3. SENSITIVITY ANALYSIS

It should be noted that the conclusions reached in the preceding paragraphs were based upon the QMR requirements for a subsurface CBR factor of 4 and for an airfield life criterion of 6 months. In order to determine landing mat system requirements under different criteria, sensitivity analyses were conducted by varying CBR's and airfield mission life requirements.

(1) CBR Sensitivity Analysis

The CBR sensitivity analysis investigates the following at various CBR's:

- . Expected mat system life
- . Life-cycle costs for 6-month mission requirements.

Exhibit IV-4, following this page, displays the expected mat lives resulting from the CBR sensitivity analysis. The analysis considered only hypothetical QMR mats at CBR values

EXHIBIT IV-4
Sensitivity Analysis -
Mat Life VS CBR
(Hypothetical Mats)

Field	Months of Mat Life														
	Heavy Duty Mat					Medium Duty Mat					Light Duty Mat				
	CBR					CBR					CBR				
	2	4	6	8		2	4	6	8		2	4	6	8	
Tactical	2.46	40	334	2008		.38	3.2	17	67		.028	.09	.25		.55
Hvy. Lift	23.5	670	9489	95,850		2.7	34	235	1279		.099	.56	1.8		4.7
Med. Lift	2,968	3.2×10^6	1.1×10^9	2.4×10^{11}		47	7,739	5.5×10^3	2.8×10^7		.2	2.8	25		190
Lt. Lift	1.9×10^9	2.8×10^{18}	5.3×10^{21}	5.2×10^{26}		5.2×10^6	1.7×10^{11}	1.2×10^{15}	5.7×10^{18}		99	20,610	2×10^6		1.5×10^3

*Note: For the purposes of this exhibit the coverage capability of the Mats on fields is not limited artificially to 25,000 coverages so that the true impact of CBR on life of the Mat can be shown.

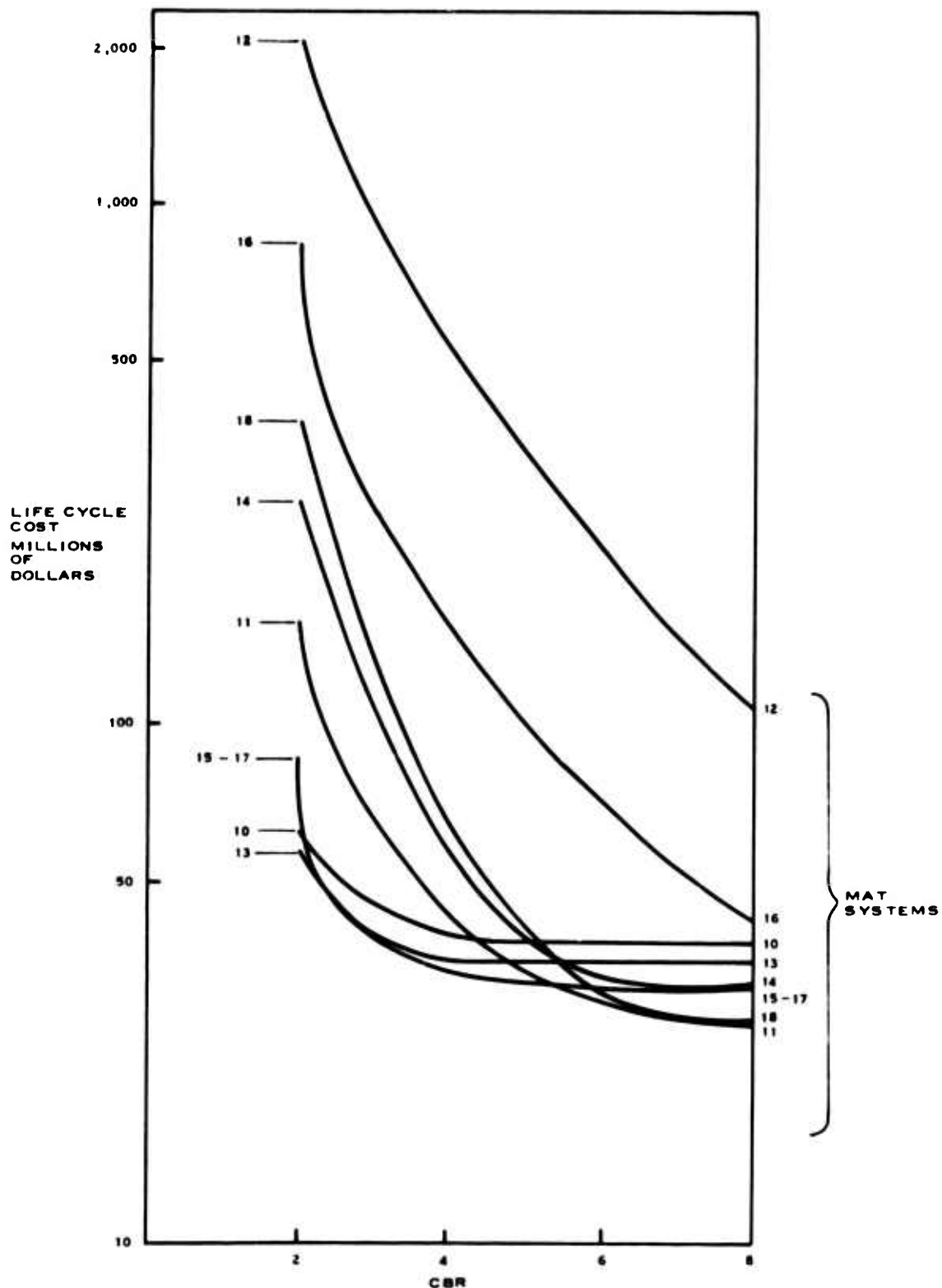
of 2, 4, 6, and 8. Although not shown in the exhibit, the same results would apply to existing mats.

These results indicate that landing mat life increases significantly as subgrade strength increases above CBR 4. A similarly dramatic decrease in mat life is evident when the CBR drops to 2. Consequently, mat system requirements are altered considerably as the CBR level changes. For example, at CBR 2 none of the candidate systems meet the full QMR requirement of six months for all airfield types since the heavy duty mat will fail on a tactical field in 2.5 months. At CBR 4, only the heavy duty mat meets the six-month requirement on all fields. At CBR 6, however, the medium duty mat will fulfill the QMR field life requirement for all fields.

Exhibit IV-5, following this page, displays the life-cycle cost of each of the 18 systems at varying CBR's and assumes a mission life requirement of 6 months. (An LCC and mat life comparison between the hypothetical, XM18, XM19, and AM2 medium duty mats at various CBRs is shown in Exhibit G-15 and G-16, Annex G.)

Those systems showing rapidly increasing costs as the CBR is reduced contain light duty mats in each case, while the systems showing relatively constant costs regardless of the CBR contain predominantly heavy and medium duty mats. For example:

EXHIBIT IV-5
Sensitivity of CBR VS
Life Cycle Cost At
6 Month Mission Life
(Hypothetical Mats)



- . At CBR 2, System 13, which is composed of heavy duty mats on tactical and heavy lift fields and medium duty mats on medium and light duty fields, is the better system.
- . At CBR 4, System 15, composed of a heavy duty mat on tactical fields and medium duty mats on all other fields, is superior.
- . At CBR 6, System 11, composed of medium duty mats for all fields, appears to be the best system.

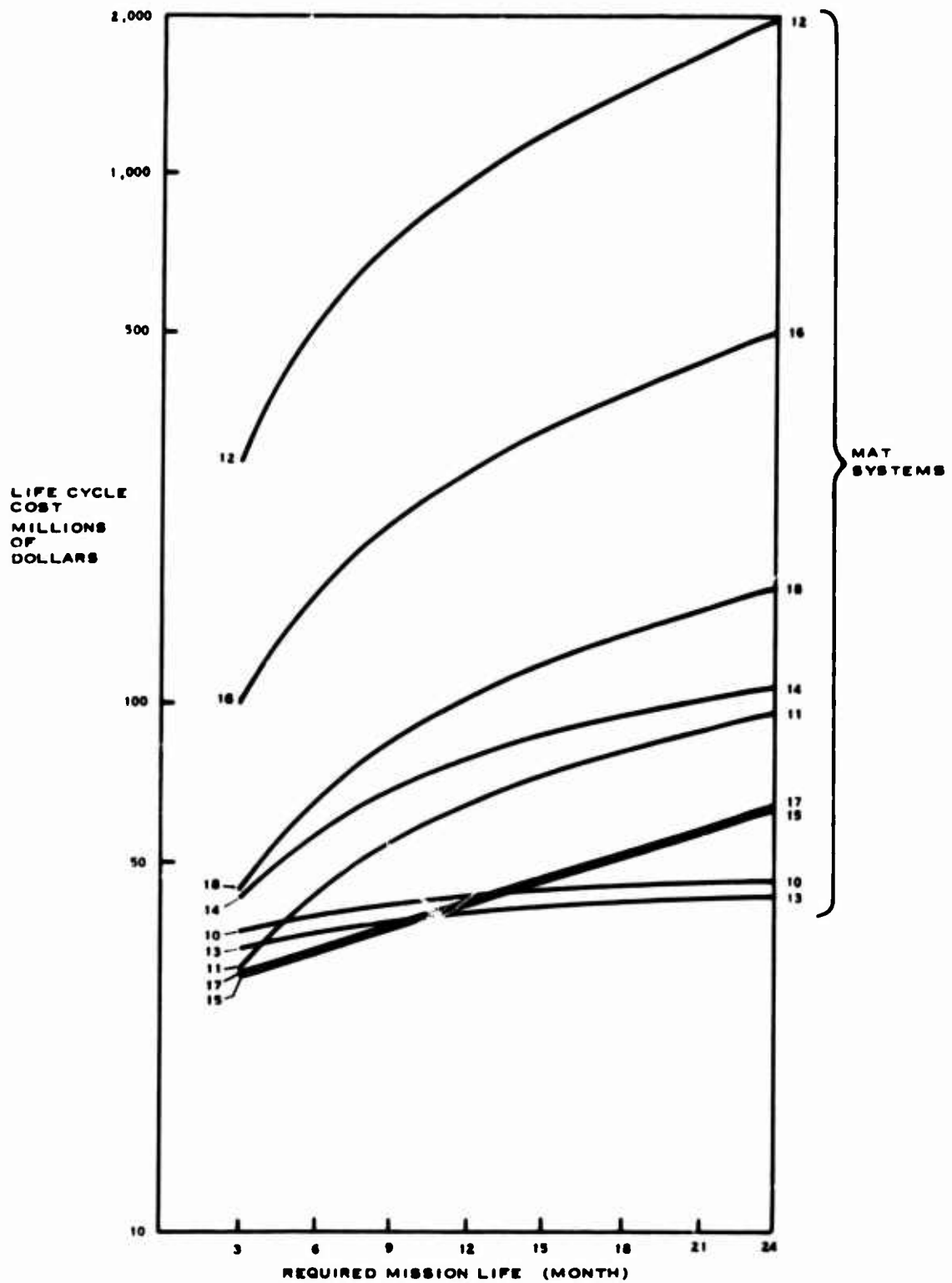
It is evident from the sensitivity data that, should the CBR criterion be changed to a bearing ratio of 2, the Army would be faced with a major development effort. The requirements established in the QMR will not provide expedient airfield surfacing materials capable of adequately servicing existing aircraft under such subsurface conditions.

Should the criterion remain at CBR 4, or be increased to CBR 6 or higher, it is apparent that the hypothetical (QMR) and existing landing mats will be more than adequate to meet the expected traffic load during the anticipated life spans of theater of operations airfields.

(2) Airfield Mission Life Sensitivity

The impact of varying airfield mission life from 3 through 24 months upon life-cycle cost is displayed at Exhibit IV-6, following this page. The exhibit is based upon a constant CBR 4

EXHIBIT IV-6
Sensitivity of Mission
Life Requirement
CBR = 4
(Hypothetical Mats)



since the same relationship between cost and mission life applies to all other CBR's. It also considers only the QMR hypothetical mat systems because the results would also apply to the existing mat systems.

Those systems showing rapidly rising costs as the mission life is increased include light duty mats in each case. Mat systems having predominantly heavy and medium duty mats show relatively stable costs throughout the mission life spectrum.

- . For a mission life from 3 to 10 months, System 15, consisting of heavy duty mats on tactical fields and medium duty mats on all others, has a slight cost advantage over System 17, which is composed of heavy, medium, and light duty mats.
- . From 10 to 24 months, System 13, consisting of heavy duty mats on tactical and heavy lift fields and medium duty mats on medium and light lift fields, has a slight cost advantage over System 10, which consists of all heavy duty mats.

(3) Conclusions

In addition to indicating landing mat system requirements under changing criteria, the sensitivity analyses performed during the study appear to further validate the selection of System 15 as the most cost-effective system.

Although other systems appear to have slight advantages at either ends of the CBR and mission life spectrums, system 15 is in a consistently favorable position throughout the sensitivity analyses.

4. ANALYSIS OF THE QUALITATIVE MATERIEL REQUIREMENT (QMR)

Since the QMR for prefabricated airfield surfacings constitutes the basic framework under which the study was conducted, it is appropriate that requirements established by that document be reviewed for validity and current applicability. This section presents a discussion of the principal requirements stated by the QMR in relationship to the status of landing mat system development.

(1) Service Life

The QMR states that: "The surfacing will have a service life of not less than six months or equivalent sorties with not more than a 10 percent replacement of materiel due to failures."

The general conclusion has been reached that existing operational and developmental landing mats satisfy the overall requirements of the QMR, and will support current air mobility concepts. This conclusion is supported by the selection, through cost-effectiveness analysis, of a landing mat system composed

of existing mats as the first choice for use in the 1970-1975 time frame. The selection was made on the basis of the least cost system that would live more than six months on the theater airfields.

Moreover, the mat life data presented previously by Exhibit IV-1 indicates that additional mat systems could be assembled using existing mats, and which would fulfill the 6-month life requirement given by the QMR, but at higher costs.

With respect to the limitation of 10 percent materiel replacement due to failure, insufficient field test data is available to determine whether the existing mats will satisfy this requirement. However, the cost model accommodated the lack of data, in part, by assuming a 10 percent materiel replacement cost for all mats considered.

(2) Performance

The desired landing mat performance is stated by the QMR in terms of the coverage level (1,000 coverages or subgrade with CBR-4) at the specified aircraft wheel loads for each mat duty class, and the expected aircraft sortie rate (500 for each two-week period, or 1,000 per month).

When the theater airfield traffic loads were estimated (Annex C) and applied to specific mats, the result for existing mats was generally long life, particularly in the heavy and medium duty classes. In each case, the performance model applied the monthly sortie rate (distributed among the aircraft types considered) until the coverage limit for each mat was reached, and the mat was considered to have failed.

The coverage limits for each mat are given by Exhibit D-2 (Annex D) for the aircraft wheel load which identifies each mat duty class, and demonstrates that in the heavy duty and medium duty classes, existing mats have been developed which exceed the 1,000 coverage level specified by the QMR. Equally important, however, the mat life results shown by Exhibit IV-1 demonstrate that life in excess of the 6-month QMR requirement can be obtained on theater airfields from existing mats which have not met the 1,000 coverage level for their respective duty classes. For example, the XM20 mat has achieved only 620 coverages under heavy duty test, yet has been calculated to yield a life of some 25 months under the estimated traffic on a tactical airfield, and more than 56 months on a heavy lift airfield. Similarly, the AM2 mat has achieved only 950 coverages

under medium duty test, yet yields a life of some 18 months on a heavy lift airfield, and more than 63 months on a medium lift airfield.

Recognizing that the 1,000 coverage level for a mat duty class is an engineering test function, and which cannot be adequately measured in the operational environment, it is concluded that more emphasis should be given to methods of estimating airfield traffic loads (sortie rates). Thus, mats which might actually prove valuable in field operations would not be eliminated from consideration on the basis of engineering test results alone, i. e., the 1,000 coverage level requirement for engineering test should not be made the sole factor in determining mat acceptability.

(3) Landing Mat Duty Classes

The QMR specifies three duty classes, i. e., heavy, medium and light duty mats, with the classes defined, as noted above, by specific aircraft wheel loadings, tire pressures, and tire contact areas. While these aircraft loading characteristics may remain valid for engineering test purposes, the results of the study performance model have indicated, in terms of mat

life, that arbitrarily assigned duty classes tend to lose their meaning when the more realistic situation of mixes of aircraft (with their associated wheel loading characteristics) on the mats is considered.

The mat system demonstrated to be most cost-effective includes a single mat type for all logistics support airfields. Further, that same mat (XM19) falls only marginally short of meeting the 6-month life requirement for tactical airfields, at 5.95 months (Exhibit IV-1). Therefore, it can be concluded that rather than limiting mat applications by duty classes, the more desirable and practical approach would be to employ mats which perform best under the greatest variety of aircraft types, and do so at acceptable costs. While this conclusion might seem to favor heavy duty mats, since they are the only type which perform satisfactorily on all types of airfields, it is recognized that for logistics support airfields, these mats would represent an "overkill" in terms of performance, and would also impose a cost penalty.

In further consideration of mat duty classes, it is noted that no light duty mat has yet been developed which will meet the 1,000 coverage level for the 30,000-pound single wheel load at

100 psi tire pressure and 300 square-inch tire contact area which define this duty class. However, the need for such a mat is considered questionable, since from both cost-effectiveness and practical applications viewpoints, mats classed as medium duty not only satisfy the performance requirements, but do so at a favorable cost as well.

(4) Mat Weight

The QMR specifies the following unit weights for mats:

<u>Mat Classification</u>	<u>Essential Weight (lb. per sq. ft.)</u>
Heavy Duty	6.5
Medium Duty	4.5
Light Duty	3.0

In addition, the QMR specifies an essential limit of 120 pounds per mat panel, to promote ease of handling by two men.

While the two-man handling restriction appears valid, the review of mat design data documents (Annex I) and discussions with the WES engineering staff indicate that too much emphasis has been given to unit weight (pounds per square foot).

For example, the 3 pounds per square foot essential unit weight for a light duty mat has proven to be a most elusive goal, yet a great variety of materials and mat configurations have been employed toward achievement of this goal. At the same time, mats have been successfully developed (XM18 and XM19) whose unit weights are approximately 50 percent above the 3-pound goal, but whose panel weights are substantially under the 120-pound limit.

It is concluded that the key factor should be panel weight rather than unit weight, to insure ready mat handling by a minimum number of personnel and precluding the need for special panel handling equipment. The QMR implies that weight per square foot controls the placement rate (discussed below) capability; however, assuming a mat reasonably configured and capable of being handled by two men, this would not hold true.

It is further concluded, therefore, that the mat unit weights should be eliminated from the QMR as fixed constraints, and be retained only as recommended engineering design goals.

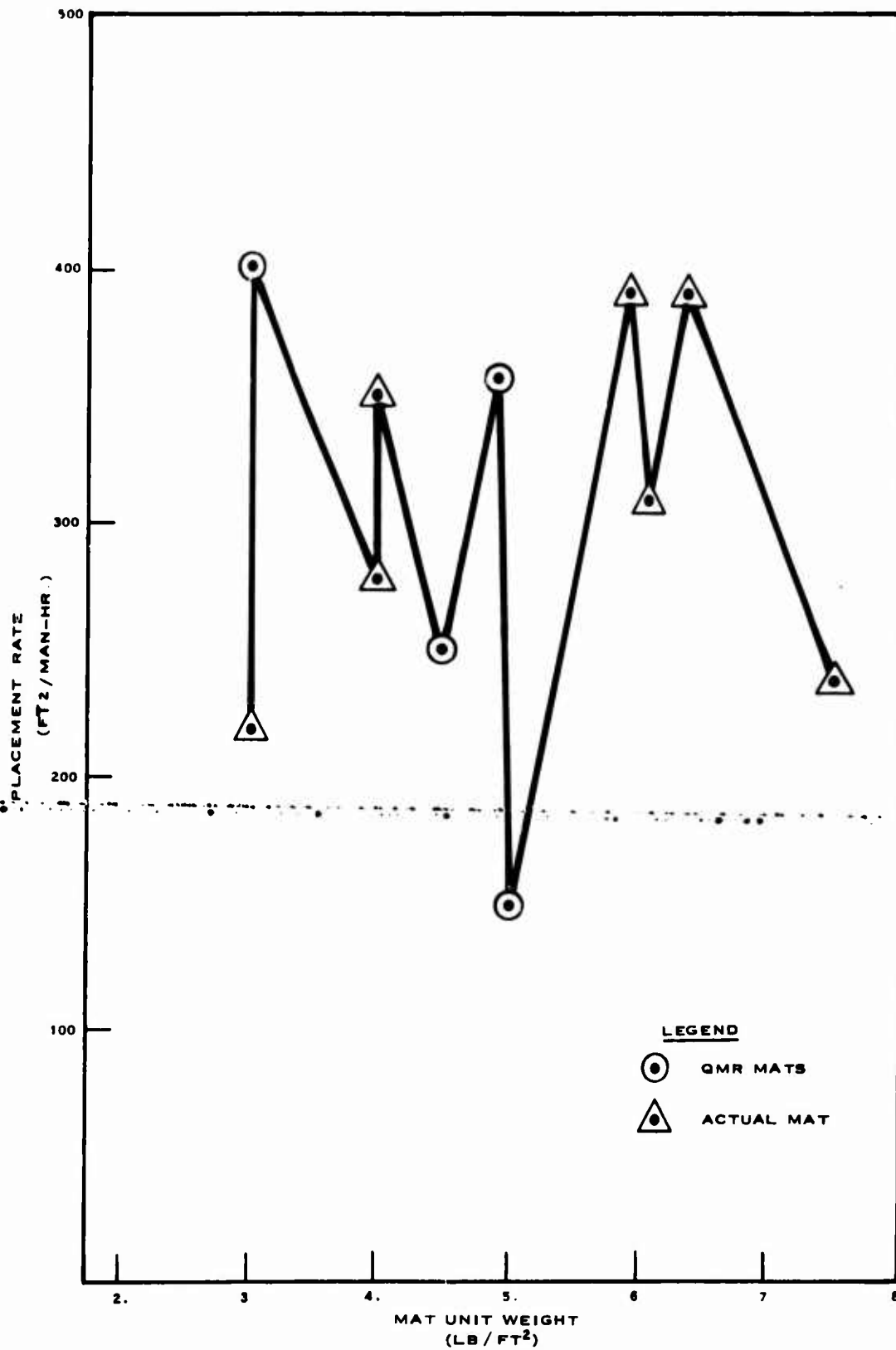
Finally, it is noted that in view of the unsuccessful efforts to date to develop a satisfactory mat weighing no more than 3 pounds per square foot, the continued risk cost of such a development might be unnecessarily high.

(5) Placement Rate

The placement rates of existing heavy and medium duty mats exceeds the essential QMR rates (see Exhibit D-2, Annex D), and approach the desired level given by the QMR. It is interesting to note that the rates for the existing heavy duty mats at least equal those of the medium duty mats. This tends to negate the QMR implication that placement rates are controlled by mat weight per square foot. Exhibit IV-7 , following this page, graphically demonstrates the lack of direct relationship between unit weight and placement rate, since these two factors generate a sawtooth curve rather than a smooth curve.

Placement rates represent a cost element, in terms of labor cost to surface an airfield, and it is noted that the least cost (i. e. , the most cost-effective) mat system developed by this study is one in which all mats are integrally waterproofed. This is true despite the fact that placement rates for integrally

EXHIBIT IV-7
Mat Unit Weight VS
Placement Rate



waterproofed mats were assumed to be one-half the rates for the same mats using membrane underlay. (The assumption was based on limited WES experience with integrally waterproofed mats.)

The QMR contemplates only mats which would be placed over membranes, but in light of the foregoing discussion, it is concluded that the QMR should be revised to include integrally waterproofed mats and their associated placement rates.

V. LANDING MAT DEVELOPMENT PLAN

The findings and conclusions discussed in Chapter IV lead to the principal product of the study effort; a Mat Development Plan in the form of recommendations to be considered for implementation by the U. S. Army Corps of Engineers, Waterways Experiment Station (WES), which are discussed below.

1. MODIFICATION OF THE QMR

As indicated in the report, currently available mat systems have met the specifications established by the current QMR. Briefly stated, WES and industry are now capable of producing expedient airfield surfaces for the 1970-1975 time frame. The development goal must continue to be the refinement of existing landing mat capability in order to provide increased performance at reduced cost and weight. Since the prime objective must always be the enhancement of U.S. air mobility capability, aircraft safety, and combat effectiveness, it is recommended that the QMR be updated to meet the objectives of the 1975-1980 time frame.

2. LANDING MAT DEVELOPMENT

Considering existing and near range technology and current testing activities, it is recommended that a two-landing-mat family be established in the U.S. Army inventory, and that the current designation of landing mats by three duty classifications be discontinued. Airfield expedient surfacing requirements could be met by one mat type for tactical airfields and another type for all logistical support airfields. To meet the above requirements, it is further recommended that action be taken to type classify the following mat systems:

- . A tactical airfield system having the Truss Web design, such as the existing Dow Truss Web currently undergoing testing at WES. This system should be modified to incorporate an integral waterproofing capability comparable to that available with the Kaiser XM-19 waterproofed mat.
- . A logistical support airfield system having a sandwich or honeycombed design such as the current waterproofed version of the Kaiser XM-19 system, or one comparable to it.

3. MEMBRANE DEVELOPMENT

During the conduct of the study, membranes were not addressed as a major component for analysis and evaluation but only as a cost alternative for waterproofing and dustproofing. Consequently, there is no discussion of future membrane development actions. The study considered the square foot procurement cost of membranes and

waterproof seals to be equal. The favorable cost advantage of waterproofed mats resulted from the shipping and placement cost accrued to the membrane requirements and in spite of the reduced placement rate for the waterproofed mats when compared with nonwaterproofed mats. Should the study's recommendation be acceptable -- that inherently waterproofed mat systems be utilized as the primary means for waterproofing and dustproofing of the mat surfaced area of an airfield -- it is recommended that the requirements for membrane procurement and stockage be reviewed. This is not meant to imply that membranes are no longer required in the system since there may be other uses such as emergency surfacing on high CBR, short-lived fields.

4. IMPROVED SUBSURFACE CONDITIONS

As evidenced by the results of the sensitivity analysis in Chapter IV, the initial and continuing stability of an airfield's subsurface has the most significant single effect upon the increased performance of expedient surfacing materials. The degradation of the subsurface is the major cause of mat failure. Priorities should be given to improving the means of rapid subsoil preparation and possible ways of ensuring a constant bearing surface under anticipated weather conditions.

5. IMPROVED WATERPROOFING CAPABILITY

The study displayed the cost advantages of inherently waterproofed landing mats over the use of membranes as a waterproofing device. In addition to the cost advantage shown, the reduction of another item from the logistics inventory will result in substantial savings. Conversations with interested personnel during the study revealed that inherent waterproofing also appears to increase mat life and enhance subsurface stability. Since there has been comparatively little testing done to date with inherently waterproofed mats upon which to base conclusions, it is recommended that WES increase its R&D effort to improve waterproofing techniques. One of the major goals should be the reduction of placement time for waterproofed systems.

6. REDUCED WEIGHT/INCREASED BEARING RATIO

Improved weight/bearing ratio may, of course, be achieved by improving the light metal alloys such as aluminum and magnesium. However, an excessive cost penalty must be avoided since expedient surfacing is already relatively expensive when compared to permanent type surfaces.

Industry has indicated that means do exist to accomplish comparable or increased durability at decreased weight by reconfiguring the current mats. For example, it appears that a 4' x 4' sandwich mat weighing approximately 4 pounds per square foot may be reconfigured to dimensions of 5' x 5' or 6' x 6' and still meet current medium duty load requirements with a decrease in weight per square foot. This is made possible by a relatively small increase in the length of the extruded edging material which imposes the major weight penalty on such a mat when compared with the increase in square footage of coverage of the mat panel. A mat panel covering 25 to 36 square feet would also provide an increased placement rate capability.

* * * * *

The above discussion represents the major recommendations resulting from the study. Less salient points are incorporated throughout the report.

ANNEX A

QUALITATIVE MATERIEL REQUIREMENT (QMR) FOR PREFABRICATED AIRFIELD SURFACINGS

Section I - Statement of Requirement

1. Statement of Requirement

Prefabricated or expedient airfield surfacings are required to provide the Army with improved capability to produce the required aircraft landing facilities, in theaters of operations, which are essential for support of air mobility concepts. Economy in logistics and costs and flexibility in design of landing facilities can best be provided by development of mats and membranes. The landing mats will provide a bearing surface capable of supporting specified aircraft loadings on low strength soils. Use of the matting will greatly reduce the time and engineer effort required to construct airfields by substantially reducing the need for subgrade preparation and by providing a surface which can be rapidly emplaced. The membranes will provide a rapid means of waterproofing and dust-proofing runways and taxiways in areas where soil strength is adequate and of waterproofing subgrades beneath landing mats. Use of the membranes will enable in-situ soil strength to be maintained, reducing airfield construction and maintenance effort required, and provide dust control, reducing safety hazards to

aircraft operation and airfield detection. It is desirable that these membrane requirements be met by a single membrane. All surfacings will be lightweight, consistent with meeting operational requirements, reusable without rehabilitation if undamaged, and packaged for ease of handling. The landing mats and membranes will be of such superiority to warrant replacement of current standard items. Army engineer units or groups of indigenous personnel under Army engineer supervision will use the surfacings to improve existing airfields or to construct new airfields in all areas of the world where operations require airfield support. (TF: 70) (CDOG para 639b (2)) (Approved 14 Apr 66)

Section II - Operational, Organizational and Logistical Concepts

2. Operational Concepts

a. Requirements.

The proposed airfield surfacings will provide rapid means for preparing and/or improving airfields and landing areas capable of accommodating all types of aircraft in support of military operations including strategic and tactical lift (inter-theater and intra-theater), and tactical air support. The surfaces must provide all-weather operational capability and be capable of installation during all times except when the proper subgrade conditions cannot be

obtained or maintained. The landing mat must be capable of providing operational surfacing for two weeks or 500 sorties (sortie - one takeoff and one landing) without failure. A typical daily 24-hour mission for an airfield is 36 sorties. The membrane must be capable of providing operational surfacing for two weeks or 100 sorties without failure. A typical daily 24-hour mission for a membrane surfaced airfield is seven sorties. The method of construction and materials used will provide for the suppression of dust to the extent that visual detection and adverse effects on aircraft maintenance will be reduced.

b. Operational Information.

(1) Planned deployment.

The proposed materiel is essential to the successful conduct of air operation within any theater of operations. The airfield surfacings may be utilized to support air operations in any land area of the world; however, primary use is expected to be in the underdeveloped areas where airfields are either nonexistent or inadequate. The surfacing will also be used to repair damage of existing airfields with like surfacings. Adoption of this materiel will provide significant reduction in logistical tonnages and manhours of installation and maintenance effort required. The proposed surfacings will be installed

primarily by Army engineer combat and construction battalions or trained indigenous personnel, under supervision of Army engineers.

(2) Turnaround time.

Predicted turnaround time is unknown. Turnaround time is the time needed to remove, inspect for reuse, reprovision, and install at another site.

(3) Reaction time.

Reaction time is the time needed to inspect the airfield surface to determine if an aircraft can take off or land without damage. The reaction time will not exceed ten minutes per landing or takeoff. Normally, the suitability of the airfield to perform a typical 24-hour mission will be determined during a daily (1 hour essential) (30 minutes desired) visual inspection of the runway surface. The daily visual inspection will be performed from a moving ground vehicle driving up one side and down the other side of the runway with intermediate steps as necessary.

(4) Service life.

The surfacing will have a service life of not less than six months or equivalent sorties with not more than a 10 percent replacement of materiel due to failures.

(5) Availability.

It is desired that operational availability be at least 93 percent, with 15 percent replacement parts (AR 700-19).

(6) Reliability.

The materiel shall demonstrate a Mean Time Between Failures (MTBF) of not less than two weeks or equivalent sorties. A failure is defined for the purposes of computing MTBF as a repair necessary to restore performance to within limits indicated herein and requiring greater than 24 manhours of total effort by personnel from an Engineer Platoon of the Airmobile Divisional Engineer Battalion.

(7) Durability.

Surfacing materiel shall without failure complete the following initial operations requirement of 500 sorties for mat and 100 sorties for membrane.

3. Organizational and Logistical Concepts

- a. The size and numbers of the installing crews will be consistent with construction requirements and the time factors dictated by operational requirements.
- b. The proposed surfacings will be Class IV supply items.

c. Specific quantities required will be determined after completion of the current US Army Combat Developments Command Study, Airfield Construction Requirements, Theater of Operations 1967-1970.

Section III - Justification, Feasibility and Priority

4. Reason for the Requirement

The requirements for air support to ground combat operations have increased significantly and are continuing to grow. Present planning in both general and limited war situations, and for sustained ground, airborne and airmobile operations, call for an unprecedented volume of Air Force and Army aircraft for such air missions as inter-theater strategic lift, close tactical support, air assault operations, intra-theater airlift in an air line of communications (ALOC), and intra-division airlift to front line units. Additionally, the concept of total air mobility as developed by the Army Tactical Mobility Requirements Board will create many new aircraft missions within the front line division area. Current Army construction capabilities in support of these concepts are not compatible with requirements in terms of time and geographical areas of employment. Concepts dictate that airfields be readied in the early stages of troop deployment in airmobile operations and that airfields be located in proximity to the supported forces thereby

ensuring that the mobility of the Army force is consistent with strategic and tactical objectives. Current airfield surfacing methods require either the selection of a site where the California Bearing Ratio (CBR) of the soil will sustain aircraft loadings or the extensive preparation of the subgrade to achieve necessary soil strengths. In many areas of the world where deployment of US airmobile forces is foreseen, required airfields do not exist, are too few in number, or cannot sustain the loadings of supporting aircraft. Also, construction materials for preparation of airfield subgrades and surface are not available or necessitate disproportionate demands for time and effort to locate, process, transport, emplace and compact granular materials for airfield base construction. Current military systems (PSP, M6, M8, and M9 mats) due to weight and load bearing characteristics and conventional methods of constructing airfields do not permit the development of air landing facilities for airborne and airmobile forces throughout the world on a selective basis within envisioned time parameters. Without the construction capability to support airborne and airmobile forces their employment is seriously jeopardized if not totally prevented. This proposed system will facilitate the construction envisaged.

- a. The time phasing of this requirement is immediate in relationship to present material and capabilities. The requirement

satisfies immediate and long-range objectives.

b. The requirement for this type materiel is supported in CDOG paragraph 639b(2).

c. References which support this requirement are:

(1) US Army Tactical Mobility Requirements Board Final Report, August 1962.

(2) Final Report of Joint Exercise SWIFT STRIKE III, 20 November 1963.

(3) Army Air Mobile Evaluation, Headquarters, US Army Combat Developments Command, 15 February 1965.

5. Technical Feasibility

It is technically feasible, as stated Appendix I, to develop the airfield surfacings which will satisfy the requirements of this QMR.

6. Priority

This QMR is assigned Priority I, functional group 4 Tactical Movement, Appendix C, CDOG.

Section IV - Characteristics

7. Performance Characteristics

a. It is essential that the landing mats for the various classifications:

(1) Be capable of being directly installed upon graded subgrades.

(2) Be capable of withstanding the aircraft loading conditions shown on Incls 1 and 2.

(3) Be capable of withstanding coverages and loads shown on Incls 1 and 2, with maximum of 10 percent replacement.

(4) Be capable of:

(a) Heavy duty mats will withstand aircraft operations to include maximum takeoffs using afterburner. These mats shall withstand blast effects of 700° F for 10 seconds.

(b) Medium duty mats will withstand aircraft operations to include maximum takeoffs using afterburner. These mats shall withstand blast effects of 300° F for 5 seconds.

(c) Light duty mats shall withstand C-130 aircraft assault landings utilizing maximum wheel braking and reverse thrust procedures.

(d) Surfacing at locations of arresting cables and arresting hook impacts are subject to unusual loadings and impact effects and are considered critical areas. Special surfacing will be provided when heavy and medium duty mats do not meet the requirements listed below for critical areas of runways surfaced with heavy or medium duty mats.

1. Surfacing for critical areas of heavy duty mat surfaced runways will withstand five F4 tailhook impacts of 80 knots at equivalent 18 feet per second (FPS) sink speed at the same location without structural failure due to rupture of the top surface of the mat.
2. Surfacing for critical areas of heavy duty mat surfaced runways will withstand 20 roll-over loadings on a one inch diameter arresting cable with a 50,000-lb wheel load, having a nominal tire contact area of 200 sq. in. and a tire-inflation pressure of 250 psi, without structural failure due to rupture of the top surface of the mat.
3. Surfacing for critical areas of medium duty mat surfaced runways will withstand two F4 tailhook impacts of 80 knots at equivalent 18 FPS sink speed at the same location without structural failure due to rupture of the top surface of the mat.
4. Surfacing for critical areas of medium duty mat surfaced runways will withstand 20 roll-over loadings on a one inch diameter arresting cable with a 25,000-lb wheel load, having a nominal tire-contact area of 100 sq. in. and tire-inflation pressure of 250 psi without structural failure due to rupture of the top surface

of the mat.

- (5) Be so designed so as to not cause damage to waterproofing or dustproofing treatment applied to the subgrade, or desirably, inherently provide waterproofing and dustproofing of the underlying soil surface.
- (6) Be capable of withstanding ambient temperature variations in accordance with paragraph 7c of AR 705-15, change 1, without deformation of such magnitude as to interfere with assembly and operations.
- (7) Possess a surface which provides effective braking with a Runway Condition Reading (RCR) of 13-25 for aircraft landings and control during all ground operations, under conditions specified in AFR 60-13 and in paragraph 7a, b, and c of AR 705-15, change 1.
- (8) Resist adverse effects, when installed operationally, resulting from exposure to POL spillage, downwash from helicopters, and wheel vehicle traffic.
- (9) Be capable of storage and air transit under conditions stated in paragraph 7.1a, b, and d of AR 705-15, change 1: for closed storage, ten years; for open storage, five years without adverse effects upon the system components.
- (10) Possess a service life of not less than six months or 6000 sortie with not more than a 10 percent replacement of material

due to failures.

(11) Possess an operational availability of at least 93 percent, with 15 percent replacement parts (AR 700-19).

(12) Possess reliability that the Mean Time Between Failures (MTBF) shall be not less than two weeks or 500 sorties. A failure is defined for the purpose of computing MTBF as a repair necessary to restore performance to within limits indicated herein and requiring greater than 24 manhours of total effort by personnel from an Engineer Platoon of the Air-mobile Divisional Engineer Battalion.

(13) Possess a durability which will enable the mate to sustain 500 sorties of initial operations without failure.

b. It is essential that the membranes:

(1) Be capable of being directly installed upon graded subgrades.

(2) Possess a surface which provides effective braking with a Runway Condition Reading (RCR) of 13-25 for aircraft landings and control during all ground operations, under conditions specified in AFR 60-13 and paragraph 7a, b, and c of AR 705-13, change 1.

(3) Be capable of withstanding wheel loads without destruction of waterproof properties when laid on

soils capable of supporting these wheel loads, or when placed underneath landing mat, see Incl 3.

(4) Resist adverse effects, when installed operationally, resulting from exposure to POL spillage, helicopter downwash, and wheel vehicle traffic.

(5) Be capable of storage and air transit under conditions stated in paragraph 7.1a, b, and d of AR 705-15, change 1: for closed storage, five years; for open storage, three years without adverse effects upon the system components.

(6) Be capable of withstanding ambient temperature variations in accordance with paragraph 7c of AR 705-15, change 1, without elongation or contraction of such magnitude as to interfere with assembly and operations.

(7) Be readily repairable in the field under conditions as specified in paragraph 7a and b of AR 705-15, change 1.

(8) Possess a service life of not less than six months or 1200 sorties with not more than 10 percent replacement of material due to failure.

(9) Possess an operational availability of at least 93 percent assuming adequate logistical support.

(10) Possess reliability that the MTBF shall be not less than two weeks or 100 sorties. A failure is defined for

the purposes of computing MTBF as a repair necessary to restore performance to within limits indicated herein and requiring greater than 24 manhours of total effort by personnel from a Engineer Platoon of an Airmobile Divisional Engineer Battalion.

(11) Possess a durability which will enable the membrane to sustain initial operations of 100 sorties without failure.

8. Physical Characteristics

a. It is essential that the landing mats:

- (1) Be as lightweight as possible consistent with other requirements, and weigh as shown on Incls 1 and 2.
- (2) Be capable of installation by trained personnel at the rates shown on Incl 1, Table 3.
- (3) Permit replacement of an individual mat panel within two hours essential, one hour desirable.
- (4) Be capable of placement with a minimum number of accessories and special tools.
- (5) Be provided with a simple method of transition and laying from runway to taxiway and parking aprons.
- (6) Be provided with an adequate system of anchoring runways and taxiways to prevent movement, lift, and not cause damage

to aircraft tires.

(7) Be capable of being installed directly on graded subgrades with maximum crowns of 3 percent, longitudinal grades of 5 percent, and a maximum longitudinal grade change of 2 percent in 100 ft.

(8) Individual mats be of such size, shape, and weight to be handled by two men (desirable maximum weight - 100 lb, essential maximum weight - 120 lb).

(9) Be packaged so as to compliment ground transportation and installation and for ease of aircraft transportation in accordance with para 5a of AR 705-35.

(10) Be provided with a capability which will allow rapid replacement of buckled (forced together) and forced apart panels in the center of the runway from bomb or other damage.

(11) Be provided with components which will permit joining light duty panels to medium duty panels, and medium duty panels to heavy duty panels.

(12) (Desirable) Be provided with 45-deg transition connector panel which will allow construction of high speed taxiways.

b. It is essential that the membranes:

(1) Be as lightweight as possible as shown in Incl 1, Table r.

(2) Be capable of being installed by trained personnel at the

rates shown on Incl 1, Table 5.

(3) Withstand locked-wheel braking action and maximum wheel braking procedures of critical aircraft.

(4) Be packaged to facilitate hand laying so as to compliment ground transportation and installation and for ease of aircraft transportation in accordance with para 5a of AR 705-35.

(5) Be provided with suitable anchoring devices which will not damage the membrane or tires.

(6) Be capable of being installed directly on graded subgrades with maximum crowns of 3 percent, longitudinal grades of 5 percent, and a maximum longitudinal grade change of 2 percent in 100 ft.

9. Maintenance Characteristics

a. The mats and membranes shall be designed to minimize maintenance. It is essential that maintenance be as follows:

(1) Be designed to facilitate maintenance accessibility in the field environment at all categories so that required maintenance will be performed in the minimum practicable time with a minimum degree of skill, variety of tools, test equipment, and other supplies.

(2) Be designed towards minimization of maintenance by utilization of the most reliable components; modular construction;

built-in, simple, failure indicators; and other technological advances in components and/or methods.

(3) Be designed so that individual and/or damaged sections of materials may be removed and replaced.

b. Typical maintenance to restore performance specified herein will consist of but not necessarily be restricted to the following: cleaning, inspecting for repairs, alignment, tightening of anchors, patching, replacement of damaged mat panels, and repair of nonskid surface. Maintenance performed shall not exceed 150 manhours per month by personnel from an Engineer Platoon of the Airmobile Divisional Engineer Battalion for the service life of the materials. (Subgrade failures are not included in this paragraph.)

10. Human Engineering Characteristics

Human factors engineering characteristics of the system will include consideration of the intellectual, physical and psychomotor capabilities of the intended user.

11. Priority of Characteristics

- a. Performance
- b. Weight
- c. Reliability and Durability
- d. Transportability

e. Maintainability

Section V - Personnel and Training Considerations

12. Quantitative and Qualitative Personnel Considerations

a. The system will be installed primarily by Army engineer units. However, its simplicity of emplacement will require a minimum of training whereby any Army unit, or indigenous personnel, could install and maintain the system.

b. No new MOS will be required.

c. Although a savings in personnel strengths normally associated with airfield construction may not be effected, with this system the troop effort required to prepare base courses can be diverted to other tasks, and the overall airfield construction time reduced.

13. Training Considerations

Training for actual installation and maintenance of this system will be negligible. Preparation of the ground for installation of this system will normally be by Army engineer units which already have this capability. Training literature on the repair and reuse of prefabricated airfield surfacing materials is required. This literature should cover the factors to be considered in evaluation of surfacing for reuse, evaluation methods and procedures, repair techniques and methods, repackaging information, and a basis of classification of prefabricated

airfield surfacing materials for future use.

Section VI - Associated Considerations

14. Training Devices

None required. Components of the system will be utilized for training.

15. Related Materiel

No change in present items of supply is anticipated. Similar items of supply already in the Army supply system may still be required to support Army aircraft operations. It is not intended that this system be capable of inter-mix usage with current standard, similar items of supply, although this would be desirable if it could be done with no compromise of capability in the proposed system. Ancillary equipment and special tools to emplace, use, and maintain prefabricated airfield surfacings must be developed as required.

16. Concealment and Deception

Normal camouflage considerations apply; reduction in light reflectivity is required. No disguise or simulation devices are required.

17. Interest

This system will probably be of interest to British, Canadian, and

Australian Armies.

18. Current Inventory Items

There are no existing items, and no items are under development by other services or allied armies which can fulfill this requirement.

19. Communications Security

None.

20. Additional Comments

a. If, during the development phase, it appears to the developing agency that the characteristics listed herein require the incorporation of certain impracticable features and/or unnecessarily expensive and complicated components or devices, costly manufacturing methods or processes, critical materials or restrictive specifications which will prove excessively expensive or serve as a detriment to the military value of the unit, such matters shall be brought to the immediate attention of the Chief of Research and Development of the Army, and Headquarters, US Army Combat Developments Command for consideration before incorporation into a final design.

b. This materiel requirement is identified by USACDC Action Control Number 7494 and supports the following:

- | | |
|--|--|
| (1) Army CD Program | Army 75 (70-75) |
| (2) Study "Engineer 75";
USACDC Action Control No. 6493 | |
| (3) Army Tasks | 1: High Intensity Conflict
2: Mid Intensity Conflict
3: Low Intensity Conflict,
Type I
4: Low Intensity Conflict,
Type II
5: Military Aid to US Civil
Authorities
6: Complementing of Allied
Land Power |
| (4) Phase | Materiel |
| (5) Function | Service Support |

3 Incl
Tables

Table 1

<u>Mat Classification</u>	<u>Single-Wheel Load</u> lb	<u>Tire Pressure</u> psi	<u>Nominal Contact Area</u> sq. in.	<u>Coverage Level</u>	<u>CBR</u>
Heavy duty	50,000	250	200	1000	4
Medium duty	25,000	250	100	1000	4
Light duty	30,000	100	300	1000	4

Table 2

<u>Mat Classification</u>	<u>Desirable Weight</u> lb per sq ft.	<u>Essential Weight</u> lb per sq ft.
Heavy duty	5.0	6.5
Medium duty	4.0	4.5
Light duty	2.5	3.0

Table 3

<u>Mat Classification</u>	<u>Desirable Placing Rate</u> sq ft per man-hour	<u>Essential placing Rate</u> sq ft per man-hour
Heavy duty	400	150
Medium duty	400	250
Light duty	600	400

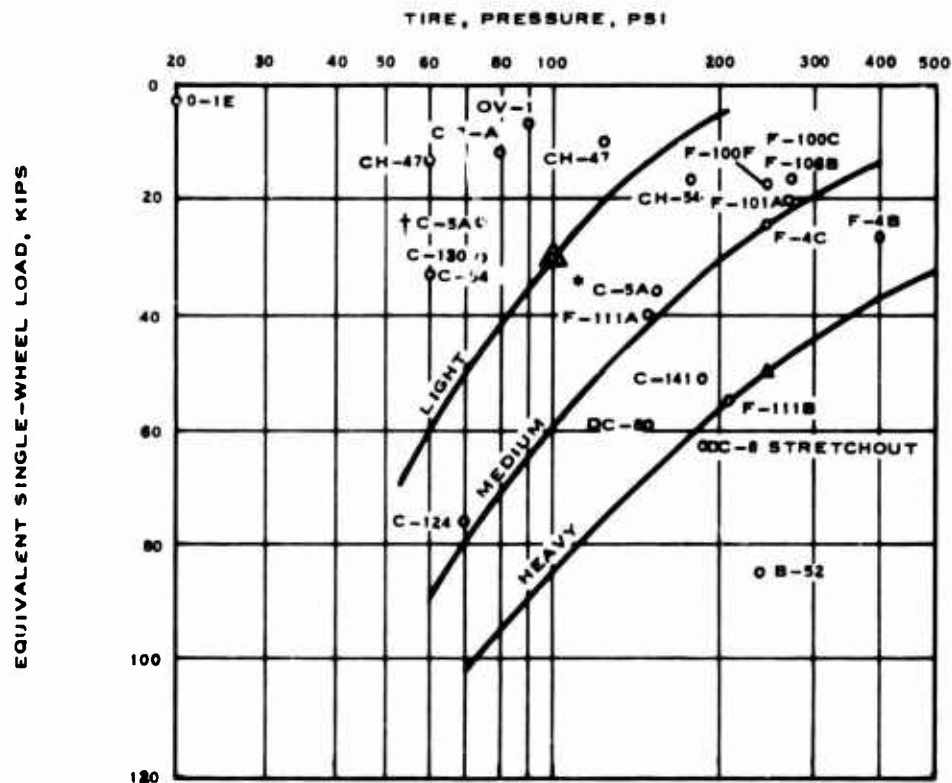
Table 4

<u>Membrane Classification</u>	<u>Desirable Weight</u> lb per sq yd.	<u>Essential Weight</u> lb per sq yd.
Heavy duty	5.0	6.0
Medium duty	3.0	4.0
Light duty	1.0	2.0

Table 5

<u>Membrane Classification</u>	<u>Desirable Placing Rate</u> sq ft per man-hour	<u>Essential Placing Rate</u> sq ft per man-hour
Heavy duty	300	200
Medium duty	400	300
Light duty	600	400

Incl 1 to QMR



LEGEND

- △ MAT CATEGORY DEFINITION
- AIRCRAFT REQUIREMENT
- ✦ MAXIMUM TAKEOFF WEIGHT
- ✧ THEATER OF OPERATIONS WEIGHT

NOTE THESE CURVES DO NOT INDICATE MAT CAPABILITY FOR ARRESTING GEAR LANDINGS WITH TAILHOOKS.

THE PURPOSE OF THIS FAMILY OF CURVES IS TO ILLUSTRATE THE APPROXIMATE LOAD-CARRYING CAPABILITY OF A PROPOSED FAMILY OF MATS WITH RESPECT TO LOADINGS OF SOME CURRENT AIRCRAFT. THE CURVES HAVE ONLY BEEN PARTIALLY VALIDATED AND SHOULD NOT BE USED FOR DESIGN PURPOSES.

EACH MAT WILL SUPPORT ALL AIRCRAFT PLOTTED IN A POSITION ABOVE THE CURVE REPRESENTING THAT MAT CATEGORY.

INCL 2 TO QMR

PROJECTED RELATIVE LANDING MAT CAPABILITY

1000 COVERAGES 4 CBR
(SUBJECT TO REVISION)

PROJECTED PERFORMANCE OF MEMBRANES FOR PERIOD OF SIX MONTHS (1200 SORTIES #)

(THIS IS A PRELIMINARY TABLE SUBJECT TO REVISION)

OPERATION							REMARKS
AIRCRAFT	LANDING	MAX ENGINE RUN-UP FOR TAKEOFF	LOCKED- WHEEL TURNS	TAXIING	LOCKED- WHEEL BRAKING	AUXILIARY USE WATERPROOFING BENEATH LANDING MATS	
HEAVY-DUTY MEMBRANE (5-6 LB PER SQ YD)							
F-111A	4	4	4	4	4	4	PERFORMANCE RATING
F-111B	4	4	4	4	4	4	SCALE FOR MEMBRANES:
F-4B	4	4	4	4	4	4	1 SATISFACTORY
C-141	4	4	4	4	4	1	2 BORDERLINE
C-5	4	4	4	4	4	4	3 UNSATISFACTORY
C-130E	1	1	1	1	1	1	4 NO TEST DATA AVAILABLE
C-7A	1	1	1	1	1	1	
CH-54	1	1	1	1	1	1	
CH-47	1	1	1	1	1	1	
UH-1	1	1	NA	1	NA	1	*SORTIE - ONE LANDING AND ONE TAKEOFF
OV-1	1	1	1	1	1	1	
O1-3	1	1	1	1	1	1	
MEDIUM-DUTY MEMBRANE (3-4 LB PER SQ. YD)							
F-111A	4	4	4	4	4	4	NOTE: THE PURPOSE OF THIS PROJECTED PERFORMANCE OF A FAMILY OF MEMBRANES IS TO INDICATE THEIR RELATIVE CAPABILITIES FOR SELECTED CURRENT AIRCRAFT AND HELICOPTERS.
F-111B	4	4	4	4	4	4	
F-4B	3	3	1	4	4	1	
C-141	4	4	4	4	4	4	
C-5	4	4	4	4	4	4	
C-130E	2	2	1	1	1	1	
C-7A	1	1	1	1	1	1	
CH-54	1	1	1	1	1	1	
CH-47	1	1	1	1	1	1	
UH-1	1	1	NA	1	NA	1	
OV-1	1	1	1	1	1	1	
O1-E	1	1	1	1	1	1	
LIGHT-DUTY MEMBRANE (1-2 LB PER SQ. YD)							
F-111A	4	4	4	4	4	4	
F-111B	4	4	4	4	4	4	
F-4B	4	4	3	1	3	1	
C-141	4	4	4	4	4	4	
C-5	4	4	4	4	4	4	
C-130E	3	3	2	1	2	1	
C-7A	3	3	2	1	2	1	
CH-54	1	1	1	1	1	1	
CH-47	1	1	1	1	1	1	
UH-1	3	3	NA	3	NA	1	
OV-1	3	3	3	1	1	1	
O1-E	1	1	1	1	1	1	

INCL 3 TO QMR

ANNEX B

WORK STATEMENT FOR COST-EFFECTIVENESS STUDY FOR PREFABRICATED AIRPLANE LANDING MATS

Airfield Landing Mats

BACKGROUND

Landing mat surfacings are required to provide the Army with improved capability to produce the required aircraft landing facilities, in the theaters of operation, which are essential for support of air mobility concepts. The landing mats are to provide a bearing surface capable of supporting specified aircraft loadings on low-strength soils. Use of the matting will greatly reduce the time and engineer effort required to construct airfields by substantially eliminating the need for subgrade preparation and by providing a surface which can be rapidly emplaced. The mats are to be of a design which is lightweight, consistent with meeting operational requirements, reusable without rehabilitation if undamaged, and packaged for ease of handling. The mats should inherently provide waterproofing and dustproofing of the underlying soil surface; however, prefabricated membranes can be used beneath mats to waterproof the subgrade. The landing mat surfacings may be utilized to support air operations in any land area

of the world; however, primary use is expected to be in underdeveloped areas where airfields are either nonexistent or inadequate.

OBJECTIVE OF STUDY

The objective of the study is to determine the composition of the desired airfield surfacing equipment set for the 1975 timeframe. Specifically, a determination is desired as to the optimum mix of mats and membranes compared to waterproof mats on a cost-effective basis. This should include a recommended size and weight for pannels with basic guidelines for ancillary equipment and the desirability of standardizing connectors, etc. A "systems approach" treating mats in conjunction with membranes is desired to define the most cost/effective mix. A copy of the Qualitative Materiel Requirement (QMR) for prefabricated airfield surfacings, which provides the requirements for landing mats and membranes, is Annex A.

WORK TO BE PERFORMED

The contractor will provide all labor, personnel, materials, facilities, and equipment required to conduct trade-off analyses of the major QMR requirements and a cost-effectiveness comparison of landing mat materials. The contractor will perform the three phases of work which are described in the succeeding paragraphs. The

phases which are described are required for the accomplishment of the study objective.

(a) Phase I - Trade-Off Analyses

(1) The contractor will identify and examine trade-offs in order to determine the effect on landing mat cost and mission effectiveness resulting from specific changes to the QMR requirements.

(2) These trade-offs should encompass all major physical and performance characteristics, operational, organizational, and logistical specifications, as given in the QMR. The trade-off analyses should include, but not necessarily be limited to, the following parameters:

- a. Performance (i. e. , operational capability)
- b. Weight
- c. Reliability and durability
- d. Transportability
- e. Maintainability
- f. Placement rate
- g. Producibility
- h. Logistical support
- i. Availability

(3) If warranted by the trade-off analyses of Phase I, the contractor will include in the study report recommendations for changes to the current QMR and will furnish justifications for each change. The parameters which are considered critical, with respect to landing mat cost and effectiveness, will be identified.

(b) Phase II - Cost-Effectiveness Analysis

(1) Phase II will determine the most cost-effective combination of mats and membranes (both current and proposed) that are capable of satisfying the requirements of the QMR.

(2) Cost Models

a. The contractor will develop and present the cost models used in the study. A detailed backup to include assumptions, raw data, sample calculations, and data sources will be required to justify all costs.

b. The cost models will include development, procurement, operational, and maintenance costs broken down to the detail necessary for cost-effectiveness comparisons.

c. Costs common to all landing mats will not be included in the cost models. However, these costs will be identified and their absence from the model explained in the backup narrative.

d. Costs will be developed for the 1970-1975 time frame, based on production quantities of 10, 25, 50, 75, and 100 million sq. ft. of each type of landing mat considered.

(3) Effectiveness

a. The contractor will develop and state the criteria for landing mat effectiveness used in the study. However, landing mat effectiveness should be expressed as a function of the parameters considered in the Phase I trade-off analyses (see subparagraph (a)(2)).

b. Effectiveness parameters will be weighed to reflect their relative importance and priority according to the general guidance contained in the QMR under Section IV - Characteristics, in paragraph 11 - Priority of Characteristics. However,

a sensitivity analysis of these weighing factors is required.

c. Effectiveness criteria and weighing factors must be approved by the Project Advisory Group (PAG) at the first contractor briefing to the PAG (see subparagraph g(1)(a)).

(4) Sensitivity Analysis

a. A sensitivity analysis will be performed on all important variables and parameters. This is required to determine what variations in effectiveness will result for small changes in the value of these parameters. Bounds will be given to show the range of values that the parameters can assume without influencing the results of the analysis. Confidence limits on these data will be specified.

b. The implications of the sensitivity analysis to landing mat trade-offs and cost-effectiveness will be discussed in detail in the report.

(c) Phase III - Landing Mat Development Plan

(1) In Phase III, the contractor will answer the basic

questions set forth in the study objective. Supplemental questions depicted as Essential Elements of Analysis (EEA's) are to be answered accordingly. Typical EEA's could include but not be limited to the following: Using the existing mats, is there an optimum mix? What influence would a hypothetical (QMR) mat have on the optimum mix solution? What influence will the optimum membrane have on the results?

Determine if one landing mat should be developed that will satisfy the military requirement (QMR) or should a family of landing mats (heavy, medium, and light-duty) be developed. What influence will the optimum membrane have on the results?

Waterproofing the underlying soil surface is a requirement of prefabricated airfield surfacings. Present practice is to use membranes under mats. Should mats be designed to provide inherent waterproofing? What effect will waterproof mats have on the optimum membrane solution? Determine the cost breakeven point for membranes vs. inherent waterproof mats.

Will standardization of mats affect cost, use, production, etc. ?

Will the optimum mat (family) be affected by a specific production method? What influence does size (w, l, h) or shape of mat have on production?

(2) The contractor will use the results of Phases I and II, plus any other considerations, to justify the answers to these questions.

(3) Technical characteristics for the landing mat(s) most suitable for military requirements will be recommended. The results of the trade-off and sensitivity analyses of Phases I and II should justify these recommendations.

(d) Study Plan

(1) Within 30 days of receipt of a fully executed contract, the contractor will submit to the contracting officer for approval, a study plan to include a schedule for the accomplishment of Phases I, II, and III. The scheduling information contained in the study plan must include sufficient detail for future use as a guide for evaluating the contractor's performance.

(2) Within 45 days after award of contract, all assumptions to be used in the study will be developed and will

constitute one of the items to be presented in the initial briefing of the PAG (see subparagraphs f and g(1)(a)).

(e) Contracting Officer's Representative.

The contracting officer may designate and authorize a person to act as the contracting officer's representative (COR) under this contract. The COR will represent the contracting officer in the technical aspects of the work; however, he will not be authorized to issue change orders, contract supplements, or direct any contract performance requiring contractual modifications or adjustment.

ANNEX C

LANDING MAT SYSTEM MISSION SCENARIO

1. Purpose

The purpose of this annex is to describe a theater of operations and an operating environment typical of those in which expedient airfield surfaces will be employed in the 1970-1973 time frame. The annex describes aspects of geographic location and environmental conditions of the theater of operations that are pertinent to the cost-effectiveness analysis of landing mats, and defines the types and locations of specific fields and the anticipated aircraft loading on each field.

2. Landing Mat System Mission

For purposes of the cost-effectiveness analysis of this study, a quantified landing mat system mission was postulated. Noting that the QMR contains a requirement that landing mats provide six months of operational life, the landing mat system mission was stated as follows:

"Provide at least six months of operational life (with no more than 10% mat replacement) on all airfields in a typical foreign theater of operations, under typical aircraft traffic loads."

The remainder of this annex describes how the phrases "typical foreign theater of operations" and "typical aircraft traffic loads" are interpreted in the cost-effectiveness analysis.

3. Theater of Operations (TO)

In the real world, a potential exists for myriad scenarios describing all levels of intensity of warfare, numerous geographic locations, climatic and terrain conditions, and varying degrees of deployed troop levels.

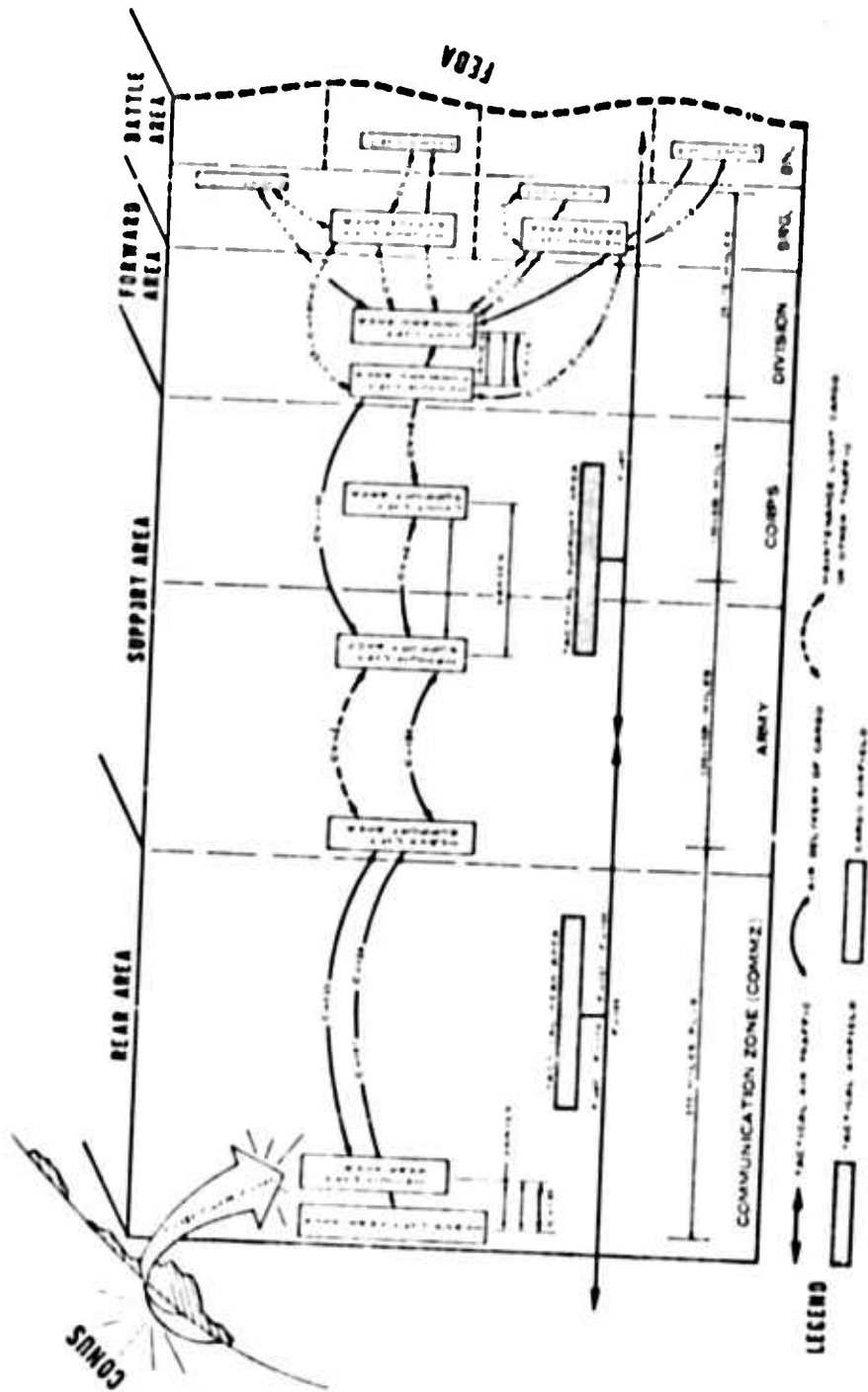
As a basis for the cost-effectiveness analysis of this study, the typical or standard TO description of TM 5-366 was selected. This selection avoids unnecessary proliferation of data requirements and yet provides a rational, realistic, and adequate setting for the analysis.

3.1 Theater Operational Areas

As shown in Exhibit C-1, following this page, the typical theater of operations is divided into four operational areas. Starting at the forward edge of the battle area (FEBA) and moving rearward to the communications zone, these include:

- . Battle area
- . Forward area

INVEST C:
Theater Operations
Aerial Concepts Typicals



- . Support area
- . Rear area.

A brief description of each of these areas is provided below.

3.1.1 Battle Area

The battle area represents that area occupied by combat and combat support forces in contact with the enemy along the FEBA and under the operational control of a brigade commander. Airfields in this area must accommodate medium and light lift aircraft for logistics operations. The air lines of communication (ALOC) are normally augmented by organic Army rotary wing aircraft (i.e., CH-47 and CH-54), as well as surface transportation, provided ground lines of communication are available and passable. Anticipated airfield life is relatively short (one week) in the battle area and runway and construction time requirements are minimal.

3.1.2 Forward Area

The forward area of the TO includes the area between the division rear boundary and the brigade rear boundary. Airfields in this area are also relatively short-lived (one month), require minimum construction time and effort, and are of relatively small size. It is anticipated that only medium and light transport aircraft will operate in the forward

area. Organic rotary wing aircraft and surface transportation augment the logistics function in the forward area.

3.1.3 Support Area

This area is normally occupied by combat support, combat service support, and command and control elements of the corps and field army. The area is sufficiently distant from enemy ground fire to permit the operational use of all types of airfields accommodating all types of aircraft. Fields meeting tactical aircraft and all sizes of transport aircraft requirements are constructed in the support area. The operational life of the airfields in the support area is expected to reach 6 months.

3.1.4 Rear Area

The rear area is considered to be in the communications zone and includes all types of airfields. These fields are expected to have an operational life of at least one year and have maximum operational surface. It is anticipated that many fields in the rear area would be permanently surfaced within one year.

3.2 Theater of Operations Airfield Requirements

The airfields in the TM 5-366 typical theater (pictured earlier in Exhibit C-1) are further described in Exhibit C-2, following this page. In addition to tabulating the numbers of the various airfield types in the theater of operational areas, this latter exhibit also describes the overall theater airfield surfacing requirements by airfield type. These requirements were developed from airfield configuration data derived from TM 5-366 and shown in exhibits as follows:

. Heavy Lift Field, Rear	Exhibit C-3
. Heavy Lift Field, Support	Exhibit C-4
. Medium Lift Field, Rear	Exhibit C-5
. Medium Lift Field, Support	Exhibit C-6
. Medium Lift Field, Forward	Exhibit C-7
. Medium Lift Field, Battle	Exhibit C-8
. Light Lift Field, Support	Exhibit C-9
. Light Lift Field, Forward	Exhibit C-10
. Light Lift Field, Battle	Exhibit C-11
. Tactical Field, Rear	Exhibit C-12
. Tactical Field, Support	Exhibit C-13

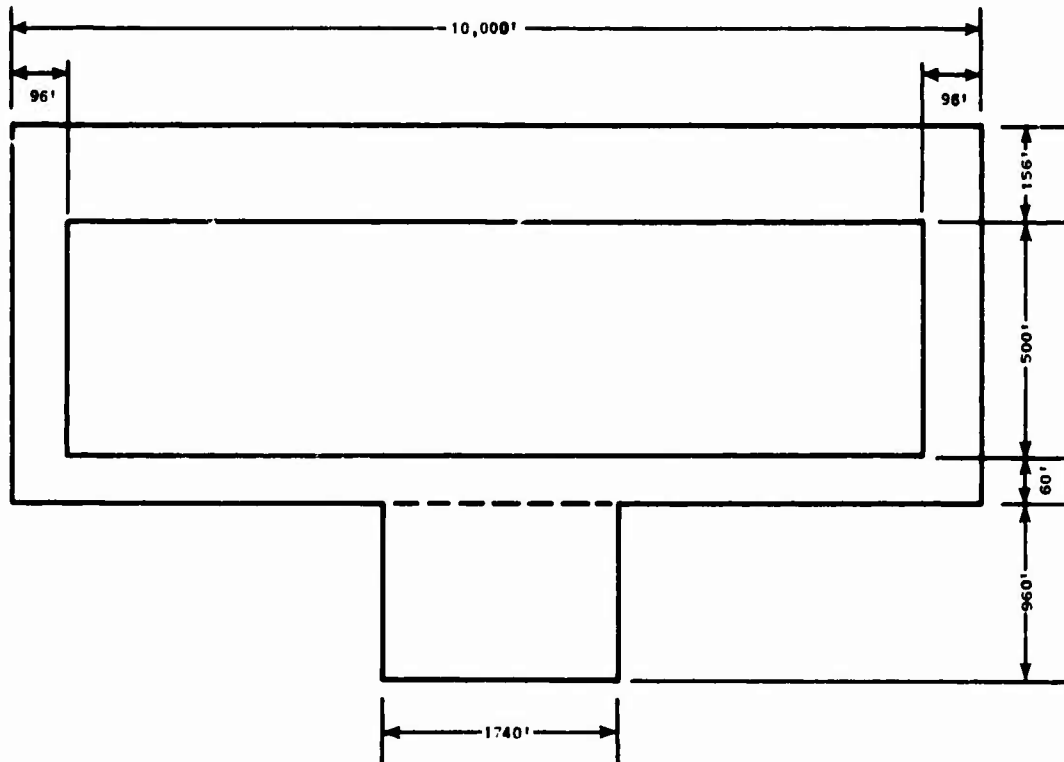
Although the various fields are categorized as heavy, medium, and light lift and tactical within the various operational areas, any of the aircraft considered in this study can land on any field in an emergency.

As it applies to logistics support fields, the designation of the field as heavy, medium, or light lift relates to the size and type of aircraft to be serviced by the field. The major significance of the

EXHIBIT C-2
Airfield Types In The
Theater of Operations

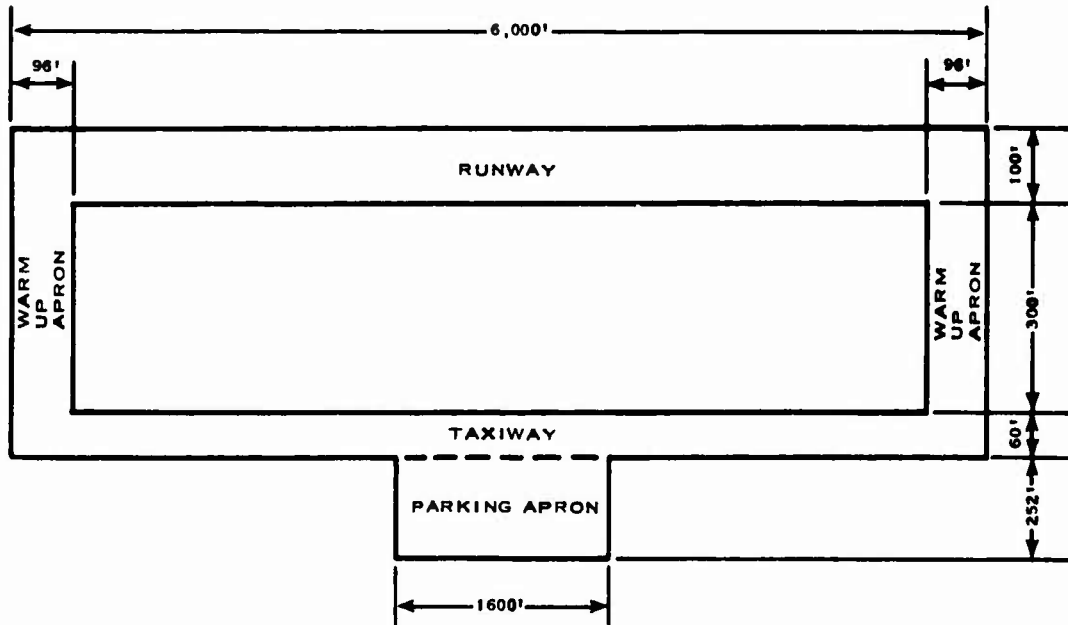
Airfield Type	No. of Airfields in Theater Area				Total No. Airfields	Total Surface Area By Type Of Airfields	% of Total Surface Area By Type Airfield
	Battle	Forward	Support	Rear			
HEAVY LIFT	-	-	1	1	2	5,347,000	38.2
MEDIUM LIFT	2	1	1	1	5	3,928,500	28.3
LIGHT LIFT	4	1	1	-	6	1,653,000	11.8
TACTICAL	-	-	1	1	<u>2</u>	<u>3,050,000</u>	<u>21.7</u>
TOTAL					<u>15</u>	<u>13,978,500</u>	<u>100%</u>

EXHIBIT C-3
Heavy Lift Rear Area Airfield



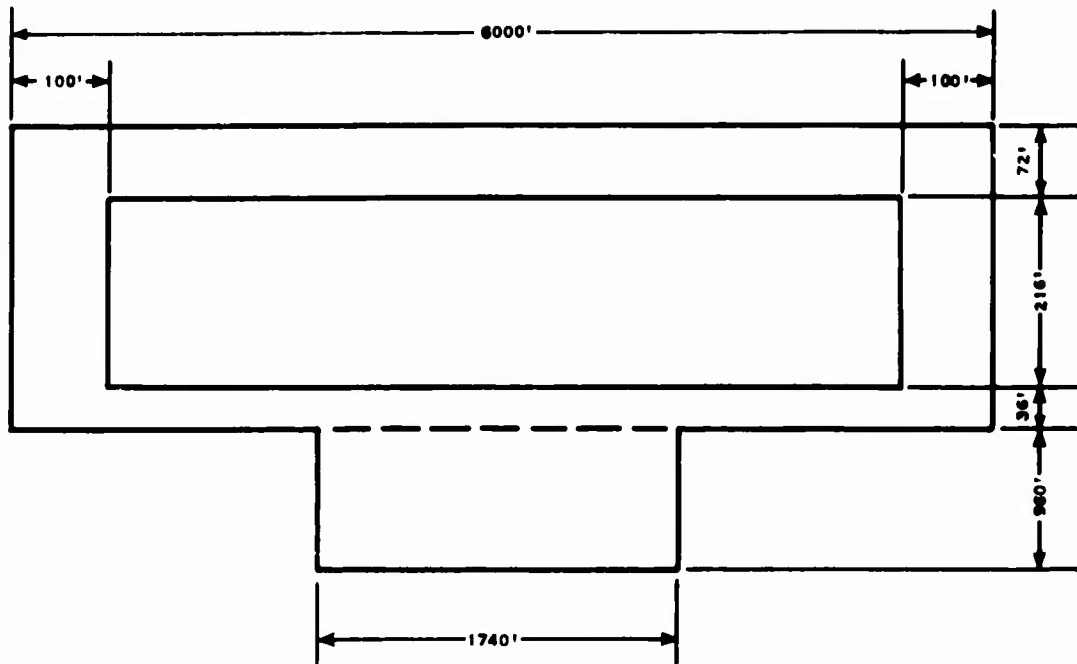
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	1,560,000 SQ. FT.
TAXIWAY	660,000 SQ. FT.
PARKING APRONS	1,670,000 SQ. FT.
WARM-UP APRONS	36,000 SQ. FT.
TOTAL	3,926,000 SQ. FT.

EXHIBIT C-4
Heavy Lift Support Area Airfield



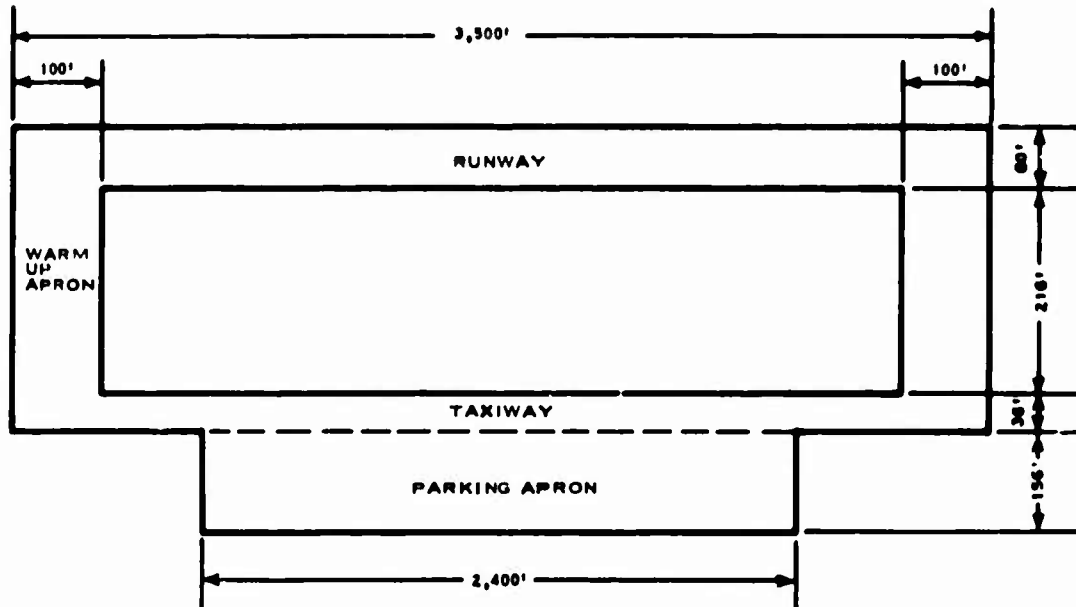
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	600,000 SQ. FT.
TAXIWAY	389,000 SQ. FT.
PARKING APRON	403,000 SQ. FT.
WARM-UP APRON	29,000 SQ. FT.
TOTAL	1,421,000 SQ. FT.

EXHIBIT C-5
Medium Lift Rear Area Airfield



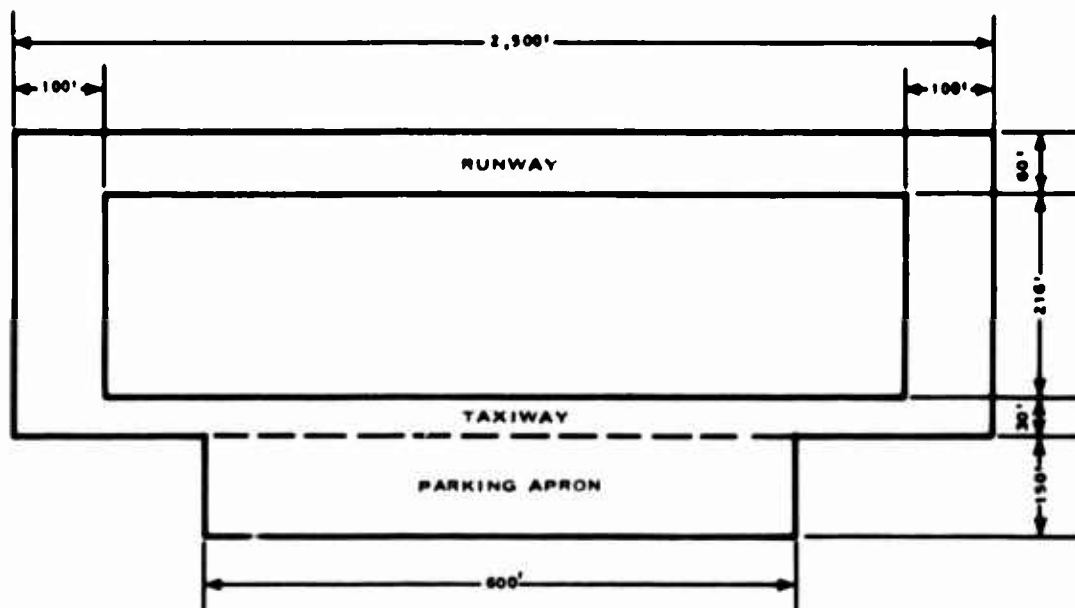
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	432,000 SQ. FT.
TAXIWAY	232,000 SQ. FT.
PARKING APRONS	1,670,000 SQ. FT.
WARM-UP APRONS	27,500 SQ. FT.
TOTAL	2,361,500 SQ. FT.

EXHIBIT C-6
Medium Lift Support Area Airfield



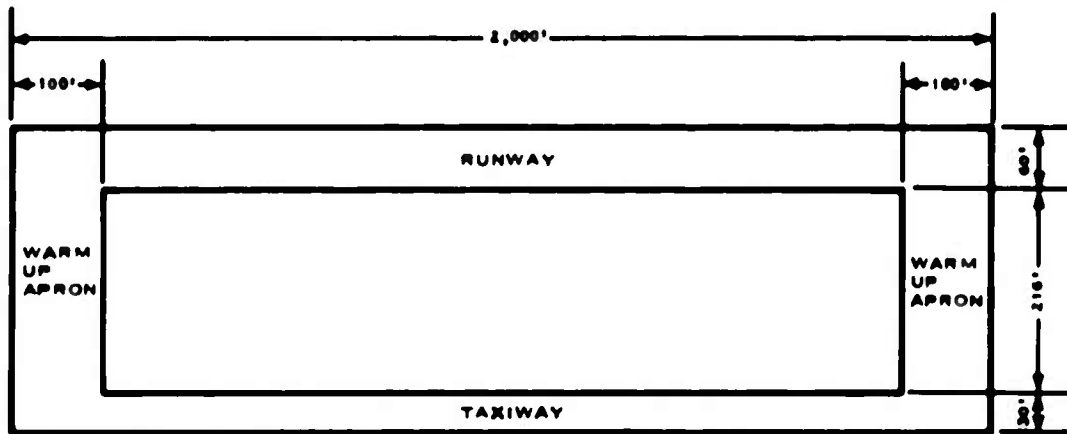
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	210,000 SQ. FT.
TAXIWAY	142,000 SQ. FT.
PARKING APRON	374,400 SQ. FT.
WARM-UP APRON	27,500 SQ. FT.
TOTAL	753,900 SQ. FT.

EXHIBIT C-7
Medium Lift Forward Area Airfield



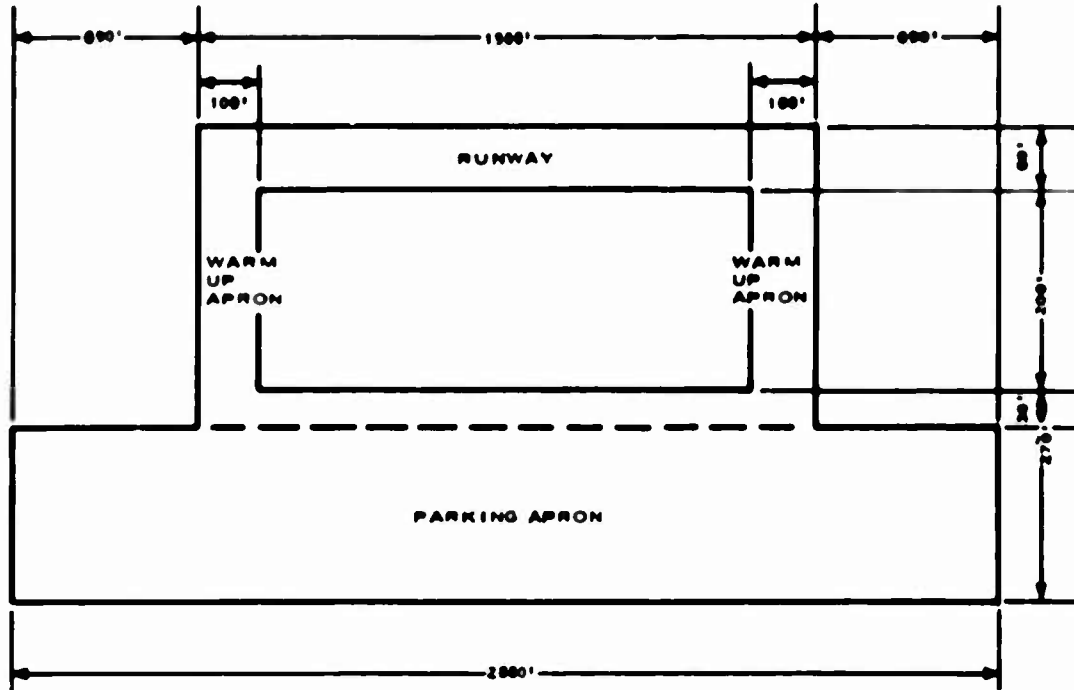
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	150,000 SQ. FT.
TAXIWAY	88,000 SQ. FT.
PARKING APRON	90,000 SQ. FT.
WARM-UP APRON	30,000 SQ. FT.
TOTAL	358,000 SQ. FT.

EXHIBIT C-8
Medium Lift Battle Area Airfield



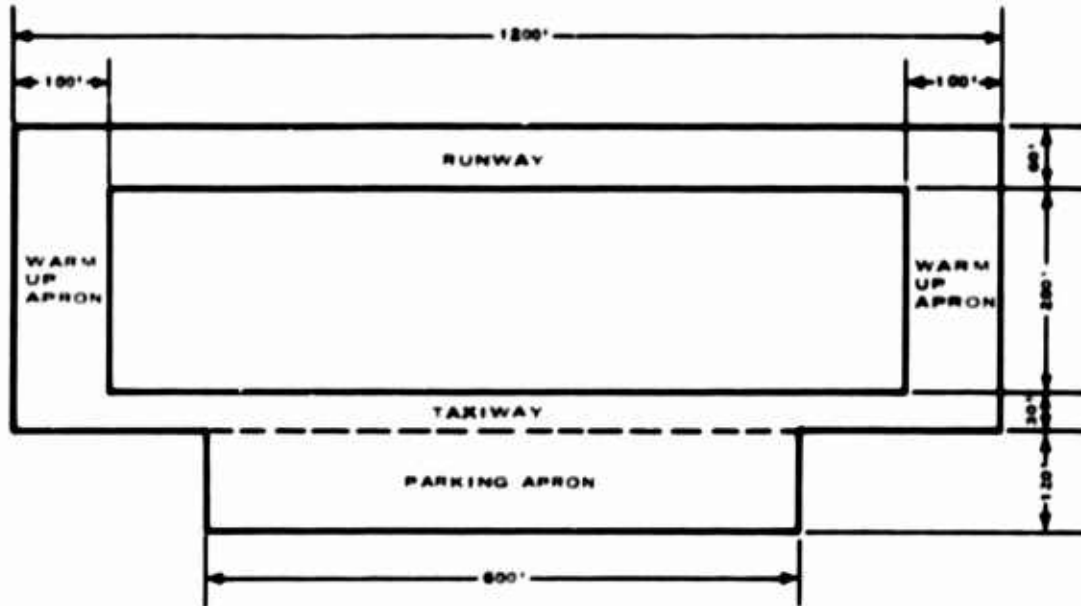
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	120,000 SQ. FT.
TAXIWAY	73,000 SQ. FT.
WARM-UP APRON	30,000 SQ. FT.
TOTAL	223,000 SQ. FT.

EXHIBIT C-9
Light Lift Support Area Airfield



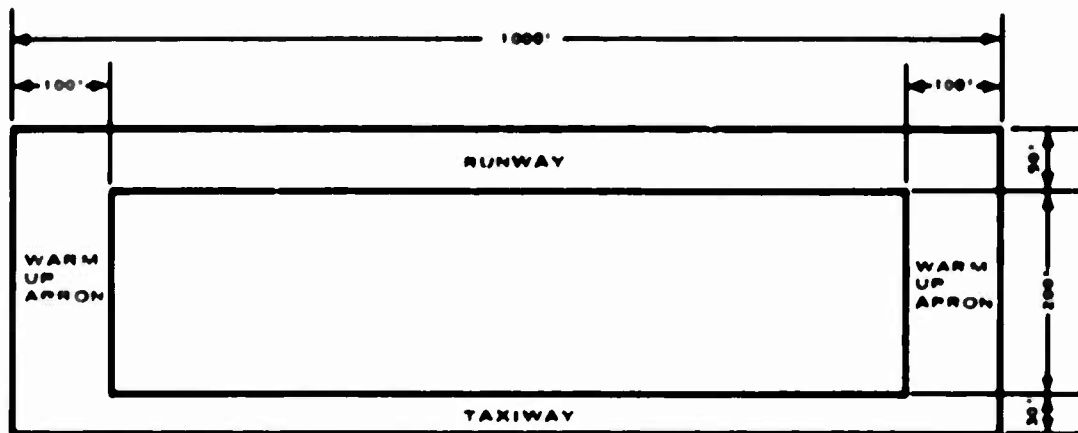
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	90,000 SQ. FT.
TAXIWAY	87,000 SQ. FT.
PARKING APRON	778,000 SQ. FT.
WARM-UP APRON	28,000 SQ. FT.
TOTAL	983,000 SQ. FT.

EXHIBIT C-10
Light Lift Forward Area Airfield



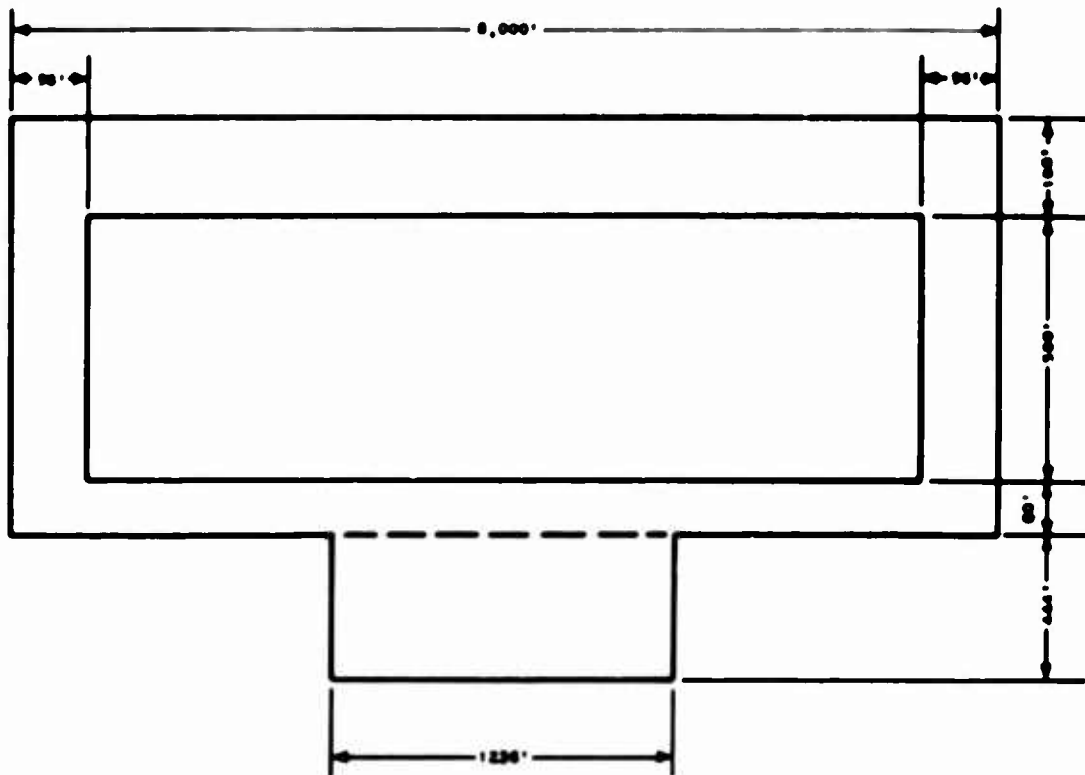
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	72,000 SQ. FT.
TAXIWAY	48,000 SQ. FT.
PARKING APRON	72,000 SQ. FT.
WARM-UP APRON	28,000 SQ. FT.
TOTAL	220,000 SQ. FT.

EXHIBIT C-11
Light Lift Battle Area Airfield



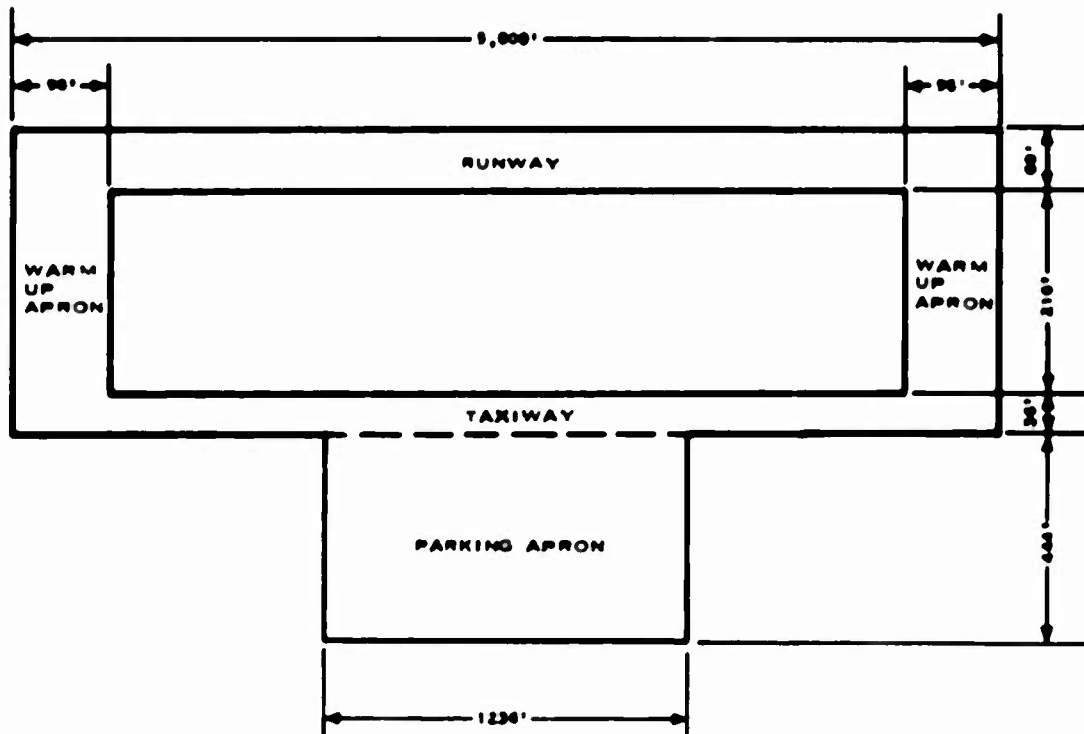
AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	50,000 SQ. FT.
TAXIWAY	42,000 SQ. FT.
WARM-UP-APRON	28,000 SQ. FT.
TOTAL	120,000 SQ. FT.

EXHIBIT C-12
Tactical Rear Area Airfield



AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	881,000 SQ. FT.
TAXIWAY	340,000 SQ. FT.
PARKING APRON	349,000 SQ. FT.
WARM-UP APRONS	16,000 SQ. FT.
TOTAL	1,686,000 SQ. FT.

EXHIBIT C-13
Tactical Support Area Airfield



AIRFIELD TRAFFIC AREA REQUIREMENTS	
RUNWAY	300,000 SQ. FT.
TAXIWAY	196,000 SQ. FT.
PARKING APRON	549,000 SQ. FT.
WARM-UP APRON	20,000 SQ. FT.
TOTAL	1,071,000 SQ. FT.

field-type designation is the amount of surfacing required, which is determined by runway length and parking area requirements. Runway lengths are governed by the performance characteristics of the various aircraft and their takeoff and landing weights.

Airfields of a specific type designation, such as medium lift, have different configurations depending upon where they may be located in the TO. For example, a medium lift field in the battle or forward area requires less surfacing than medium lift fields in areas to the rear since there is a lesser requirement for parking space and taxiways in the forward areas and the aircraft normally operate with lighter takeoff loads. Reduced requirements for surfacing in forward fields also reduces the construction time required to prepare an operational field.

It is important to note that the surfacing material required on a field of a given type designation (e. g. , medium lift type) will be the same regardless of the field's location within the theater. Only the quantity of surfacing required varies with location of the field in the theater.

3.2.1 Heavy Lift Airfield

The primary mission of the heavy lift airfield is to support the largest U.S. Air Force transport aircraft involved in the strategic lift mission from CONUS to the theater of operations. Included are such

aircraft as the C-5A, the C-141, and the C-135, as well as commercial-type aircraft in support of the Military Airlift Command (MAC). It is assumed, however, that the heavy lift airfield will also support intra-theater support aircraft such as the C-130, the C-123, and the C-7 in their distribution mission.

3.2.2 Medium Lift Airfield

The mission of the medium lift field is essentially restricted to intratheater logistics support. It is expected to support such aircraft as the C-130, the C-123, and the C-7, and will be constructed in all operational areas to perform that mission.

3.2.3 Light Lift Airfield

The light lift field augments the medium lift field in the intra-theater support mission. It is constructed to meet the operational requirements of aircraft such as the C-7.

3.2.4 Tactical Airfield

Tactical airfields are constructed to meet the operational characteristics of fighter and fighter-bomber aircraft such as the F-4C, the F-111B, and the F-15. Although these aircraft may land on other fields in an emergency, for purposes of this study they are restricted to

tactical fields because of the critical performance and physical characteristics of the aircraft, and the resultant high performance required of the surfacing materials.

4. Aircraft Traffic in the Theater of Operations

The landing mat systems that are the subject of this study may, in the 1975 time frame, be required to support the operation of a broad spectrum of U. S. and Allied military and commercial aircraft types. The cost-effectiveness analysis of this study required that the operational load imposed by these aircraft on the expedient surfaces airfields of a typical theater of operations be characterized quantitatively. In developing this characterization, it was necessary to:

- . Identify a set of aircraft types whose characteristics (i. e., single wheel load, tire pressure, and tire contact area) are representative of the full spectrum of 1975 time frame aircraft characteristics
- . Estimate the number of sorties (i. e., landings and takeoffs) that will be performed by each of the selected aircraft types, at each expedient surface airfield, each month.

The 1975 time frame aircraft that will use expedient surfaces airfields were categorized as either tactical or cargo (i. e., logistics support) aircraft. Representative aircraft were selected from both categories

as described below. It will be noted in the discussion that no Army aircraft are included in the list of representative 1975 time frame aircraft. This results from the fact (shown in Exhibit C-14) that their landing gear characteristics are such that they impose negligible wear on landing mats. This fact has also been confirmed by WES tests.

4.1 Tactical Aircraft Traffic

As viewed by the landing mat designer, tactical aircraft of two classes are of interest:

- . Fighter aircraft such as the F-105, the F-106, the F-4C, and the F-15. As indicated in Exhibit C-14, following this page, the single wheel loadings of this group fall at or below 25,000 pounds. Of this group, the F-4C with its 250 psi tire pressure imposes the most severe stresses on landing mats. For this reason, the WES has selected it as representative of 1975 time frame fighter aircraft and has conducted extensive tests of medium duty mats under simulated F-4C loading characteristics. For these reasons, the F-4C was used in this study to represent all 1975 time frame fighter class aircraft.
- . Fighter-bomber aircraft such as the F-111B. The single wheel loading of fighter bombers is significantly greater than that of the fighters. To characterize fighter-bomber characteristics in tests of heavy duty landing mats, WES has made extensive use of a test rig that simulates F-111B characteristics. Thus, the F-111B was used in this study to represent all 1975 time frame fighter-bomber aircraft.

EXHIBIT C-14
Aircraft Landing Gear Characteristics

Aircraft	Gear Type & Wheel Spacing	Equivalent Single Wheel Load	Inflation Pressure	Contact Area
F-105	Single	15,000	193	125
F-111B	Single	53,000	215	241
F-15 (est.)	Single	20,000	250	100
F-4C	Single	25,000	250	100
F-106	Single	15,200	214	80
F-111A	Single	37,000	150	241
C-130	Single Tandem	30,000	100	300
C-119	Twin Tricycle	32,300	82	203
C-123J	Single	24,180	88	272
C-133	Twin	34,000	98	400
C-7A	Twin	12,300	39	150
C-141	Twin Tandem	50,050	185	208
C-135	Twin Tandem	44,700	142	261
C-5A	Multiple	47,400	110	260
C-124	Twin Tricycle	49,000	64	630
OV-1	Single Tricycle	6,900	89	70

Aircraft	Gear Type & Wheel Spacing	Equivalent Single Wheel Load	Inflation Pressure	Contact Area
UA-1	Single	3,000	28	102
O-1E	Single	1,150	21	52
B-707	Twin Tandem	40,000	160	250
B-747 (est.)	Multiple	45,000	204	200
DC-8	Multiple	50,000	131	250

The QMR for prefabricated airplane landing mats estimates that the level of activity at each expedient surface airfield will be 1,000 sorties per month. For tactical airfields considered in the study, this means that the total of 1,000 sorties per month will be comprised of some number of fighter aircraft (i.e., F-4C) sorties plus some number of fighter-bomber (i.e., F-111B) sorties.

It is not now possible to estimate precisely the ratio of fighter-to-fighter-bomber aircraft that will be deployed in any theater of operations in the 1975 time frame. However, current planning suggests that the ratio of fighters-to-fighter-bombers in the U.S. inventory in 1975 could fall between 10- and 20-to-1. A mix of aircraft at the 10-to-1 end of this spectrum (because of the heavier concentration of fighter bombers) would impose the most severe stress on the expedient surfaces airfield system. Thus, the assumption was made in the study that the 1,000 sorties flown at each tactical airfield each month would be made up of 900 fighter (F-4C) sorties and 100 fighter-bomber (F-111B) sorties.

4.2 Cargo Aircraft Traffic

Cargo aircraft used for logistics support of the theater of operations are categorized by mission lift capability and aircraft characteristics as follows:

- . Heavy lift aircraft are primarily used in the strategic lift missions and in this study it is assumed that they will normally operate only from heavy lift airfields in the TO. Included in this category are aircraft such as C-5A, C-141, C-135, C-124, DC-8, B-707, and B-747. The C-5A and the C-141 were selected as the study aircraft to represent the heavy lift category because they are relatively modern aircraft and are representative of the entire group in terms of wheel loading and tire pressure characteristics. Additionally, WES was able to supply valid test data on each aircraft.
- . Medium lift aircraft are required for intratheater logistics support. The medium lift aircraft are restricted to the heavy and medium lift fields in this study. They include such aircraft as C-130, C-133, C-123, and C-119. For study purposes, the C-130 and the C-123 were selected as representative of the group for the same reasons indicated above for the heavy lift aircraft.
- . Light lift aircraft are also used in the intratheater logistics role. The C-7 is considered to be representative of this class of aircraft and, in fact, is the heaviest of a group which would include the Army's utility and cargo fixed- and rotary-wing aircraft.

The numbers of aircraft in the TO are based upon classified data incorporated in the LOG ALOC II Study which identified the programmed aircraft fleet for the time frame concerned. An analysis of this data which considered cargo aircraft of all types, and the study aircraft specifically, provided the basis for potential aircraft deployment to a theater of operations. This data was converted to percentages of aircraft rather than actual numbers, which are presented below. These percentages attempt to present not only the actual aircraft shown in the

table, but also similar types in terms of wheel loading impact upon the theater airfields. The purpose of using the percentages rather than actual numbers was to maintain the unclassified nature of the report while still reflecting a realistic aircraft deployment.

<u>Aircraft</u>	<u>Percentage by Type in Theater</u>
C-5A	11%
C-141	31%
C-130	33%
C-123	12%
C-7	13%

In order to determine expected traffic rates by the above aircraft, it was necessary to consider the missions of each and determine monthly sortie rates.

Data derived from the LOG ALOC II Study indicate that strategic lift aircraft, such as a C-5A or C-141, flying a sortie from CONUS to the TO and return of 16,000 miles would make six (6) such trips monthly.

The same study indicated that for 200-mile round trip, intra-theater sorties, the medium lift aircraft used in this study would be capable of the following sortie rates:

C-130 2.9 per day (86.5 per month^o)

C-123 .9 per day (26.5 per month)

^o 30 day mont..

The C-7, as a light lift aircraft, flying 100 miles round trip sorties is capable of averaging 1.6 sorties daily or 48.7 sorties monthly.

4.3 Aircraft Traffic by Type Airfield

As indicated above, aircraft have been assigned to specified airfield types for study purposes. Based upon the above density and sortie data, the 1,000 monthly sorties or round trips are distributed by type aircraft and type field as shown below.

The figures shown below were derived as follows:

- . Columns 1, 2, and 3 from paragraph 4.2 above
- . Column 4, round trip ratio, resulted from multiplying column 2 by column 3
- . Column 5 was derived by dividing each of the aircraft's round trip ratios by the total round trip
- . Column 6 converts the percent of sorties per month to actual sorties, based upon a total of 1,000 per month for the particular field concerned.

Heavy Lift Field

<u>Aircraft</u>	<u>% of Total A/C</u>	<u>Round Trip per Mo.</u>	<u>Round Trip Ratio</u>	<u>% Sorties per Mo.</u>	<u>Sorties per Mo.</u>
C-5A	. 11	6	. 66	. 020	20
C-141	. 31	6	1. 86	. 045	45
C-130	. 33	86. 5	28. 40	. 700	700
C-123	. 12	26. 5	3. 20	. 075	75
C-7	. 13	48. 7	6. 32	. 160	160
Total	1. 00	173. 7	40. 44	1. 000	1000

Medium Lift Field

<u>Aircraft</u>	<u>% of Total A/C</u>	<u>Round Trip per Mo.</u>	<u>Round Trip Ratio</u>	<u>% Sorties per Mo.</u>	<u>Sorties per Mo.</u>
C-130	. 57	86. 5	49. 25	. 750	750
C-123	. 20	26. 5	5. 30	. 080	80
C-7	. 23	48. 7	11. 20	. 170	170
Total	1. 00	161. 7	65. 75	1. 000	1000

Light Lift Field

<u>Aircraft</u>	<u>% of Total A/C</u>	<u>Round Trip per Mo.</u>	<u>Round Trip Ratio</u>	<u>% Sorties per Mo.</u>	<u>Sorties per Mo.</u>
C-7	1. 00	48. 7	48. 7	1. 000	1000

Tactical Field

<u>Aircraft</u>	<u>% of Total A/C</u>	<u>Round Trip per Mo.</u>	<u>Round Trip Ratio</u>	<u>% Sorties per Mo.</u>	<u>Sorties per Mo.</u>
F-4	. 90	30	27. 00	. 900	900
F-111B	. 10	30	30. 00	. 100	100
Total	1. 00	60	57. 00	1. 000	1000

For purposes of this study, it was assumed that the aircraft sortie mix shown above will apply to each like airfield in the TO and that each airfield will support 1,000 sorties per month as required by the QMR.

4.4 Development of Coverage

In order to relate the traffic mix developed above to the candidate mat systems considered in the study, it was necessary to express the sortie or traffic rates above as equivalent test coverages. WES has performed exhaustive tests on existing mats simulating actual aircraft loads with a test mechanism. The tests are performed under controlled conditions on the ground at the test agency. For example, an F-4C wheel and tire are mounted upon a test rig which imposes a 25,000 pound (F-4C) load on a tire with the appropriate (250 psi) pressure and contact area. Test mats are laid on a subsurface of known soil strength (usually 4 CBR) to form a test section. The test section is normally 40 feet long and 24 feet wide, with a 10-foot wide traffic test lane in the longitudinal center of the section. The test rig is moved longitudinally along the test lane simulating the F-4C or any other aircraft for which the test rig is prepared. One application of the test wheel of the test rig over the entire test lane is called a coverage.

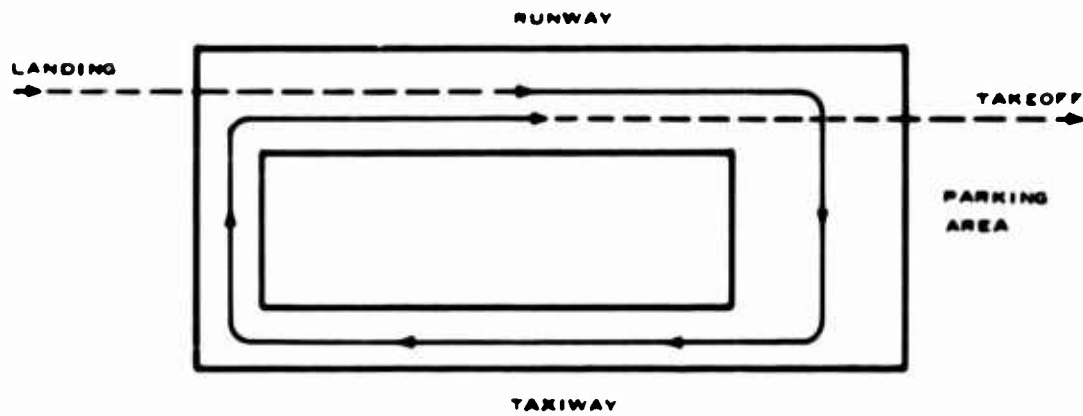
To determine the number of coverages applied to an airfield surface during one sortie, it is necessary to know the shape of the airfield and the pattern of the aircraft's ground maneuvers on the airfield. All the airfields considered in this study are "D" shaped, as pictured in Exhibit C-15, following this page. On this type field, an aircraft sortie involves:

- . Touchdown and landing roll
- . Taxi to parking area
- . Taxi to runway
- . Takeoff roll and lift off.

If it is recognized that low speed (low lift, heavy load) portions of the landing and takeoff rolls occur at opposite ends of the runway, then it is approximately correct to state that each point along the aircraft's path bears the full weight of the aircraft once during each sortie on a "D" shaped airfield.

Once it has been determined that each sortie by an aircraft results in one (full load) pass over each point on the ground maneuver track, it is possible to express the wear imposed on the surface during each sortie by using WES supplied "Coverage per Sortie Factors." These factors are presented in Annex F.

EXHIBIT C-15
"D" Type Airfield
(One Cycle of Operation
Equals One Sortie)



ANNEX D
CHARACTERISTICS OF CANDIDATE
LANDING MAT SYSTEMS

1. Purpose

This annex describes the candidate landing mat systems whose cost-effectiveness was evaluated in the study; discusses the factors that were considered in selecting the candidate systems; and catalogs certain design and performance characteristics of the landing mats.

2. Landing Mat System Definition

The term "landing mat system" is not defined by the QMR (Annex A), nor is it defined by the contract Work Statement (Annex B). However, to avoid possible conflicts in the event that the term is in use for military applications which are not currently apparent, definition of the term, as used in this study, is in order.

A landing mat system for surfacing of airfields in a theater of operations is defined as one or more types of landing mats, by duty class, with subgrade waterproofing either integral to the mats or provided by a membrane underlay.

The QMR for Prefabricated Airfield Surfacing contemplates three duty classes of landing mats, i. e., heavy-duty, medium-duty, and light-duty. As the above landing mat system definition indicates, however, this study explores the possibility that the expedient surfaces mission could be accomplished with greater cost-effectiveness with fewer than three duty classes.

3. Candidate Landing Mat Systems

To assure that the cost-effectiveness and tradeoff analyses would produce meaningful results (in the context of the study objectives), it was necessary to define a set of alternative candidate landing mat systems whose characteristics span the range of interest of critical systems design variables. This required consideration of the following factors:

- . Quantitative cost-effectiveness comparisons of systems comprised of different mixes of mat duty classes (i. e., heavy duty, medium duty, and light duty classes). The list of candidate systems, therefore, includes systems that are representative of each possible mix of duty classes. Thus, seven families of systems were synthesized for analysis:

- Heavy duty mats only
- Medium duty mats only
- Light duty mats only
- Heavy and medium duty mats only
- Medium and light duty mats only
- Heavy, medium, and light duty mats
- Heavy and light duty mats only.

These seven general families of landing mat systems were combined with the four basic types of airfields in the theater of operations to produce a total of 18 distinct landing mat systems. These are further divided into two groups of nine systems each, according to whether membrane underlay or integral waterproofing is included. Exhibit D-1, following this page, lists the constituent elements of the 18 landing mat systems analyzed in the study.

- . Comparisons of the cost effectiveness of landing mats now in development, production, or operational inventory with hypothetical mats that meet the requirements of the QMR. The mat systems of Exhibit D-1 were structured to facilitate these comparisons.

The same membrane, i. e., the Army's T-16 membrane, was used for all nine landing mat systems utilizing this type of waterproofing.

Since this study evaluates the performance of landing mats and not the performance of membranes, the use of membrane underlay affects only the cost of landing mat systems, in terms of the initial cost, shipping cost, and placement cost of the membrane. The T-16 membrane was selected for use in this study because it has demonstrated long life and reasonable cost. Any other acceptable (to the Army) membrane could have been used, and the landing mat system costs would vary in direct proportion to the costs associated with the membrane type. Thus, each landing mat system with membrane underlay would realize the same advantages, or suffer the same penalties, which would be attributable to membrane costs.

Each of the landing mat systems defined in Exhibit D-1 was evaluated using the models described in Annex F of this report. The results of the evaluation are presented in Annex G.

Exhibit D-1 indicates only the identification of the mats and water-proofing types included in the candidate systems whose cost effectiveness was analyzed. Pertinent design and performance characteristics of the various landing mat types are presented in Exhibit D-2, at the end of this annex.

EXHIBIT D-1
Candidate Landing Mat
Systems Analyzed

Landing Mat System No.	W/MEM, #	Airfield Type			
		Tactical	Heavy Lift	Medium Lift	Light Lift
1	10	HDM	HDM	HDM	HDM
2	11	MDM	MDM	MDM	MDM
3	12	LDM	LDM	LDM	LDM
4	13	HDM	HDM	MDM	MDM
5	14	HDM	HDM	LDM	LDM
6	15	HDM	MDM	MDM	MDM
7	16	HDM	LDM	LDM	LDM
8	17	HDM	MDM	MDM	LDM
9	18	MDM	MDM	LDM	LDM

Systems Nos. 1 through 9 include T-16 type membrane for waterproofing.

Systems Nos. 10 through 18 are the same as Systems Nos. 1 through 9 except that they are integrally waterproofed.

Notes:

- The 18 basic candidate systems described at left are comprised of:
 - Heavy duty mats (HDM)
 - Medium duty mats (MDM)
 - Light duty mats (LDM)
 as indicated in the table.
- In conducting the cost effectiveness evaluation of candidate systems, five sets of systems (drawn from the 18 basic systems described at left) were evaluated. The five sets of systems were synthesized as follows:
 - In Set No. 1, all mats were assumed to be hypothetical mats meeting the requirements of the QMR and the set includes all 18 basic systems.
 - Set No. 2 includes only System No. 2 and the mat type evaluated is the AM-2.
 - Set No. 3 includes all 18 basic systems and the mat types evaluated were:
 - HDM, Dow Trus Web
 - MDM, Dow AM-18
 - LDM, Hypothetical mat
 - Set No. 4 includes all 18 basic systems and the mat types evaluated were:
 - HDM, Dow Trus Web
 - MDM, Kaiser XM-19
 - LDM, Hypothetical mat
 - Set No. 5 includes all 18 basic systems and the mat types evaluated were:
 - HDM, Dow XM-20
 - MDM, Dow AM-18
 - LDM, MSAI

Exhibit D-2 has been structured according to the three duty classes of landing mats, beginning with heavy duty in the first column at the left. On the first line in each duty class, the hypothetical (QMR) mat requirements are given. Then, in the same duty class, specific existing landing mats are listed. These existing mats have been assigned to the duty classes based on the experience of the Waterways Experiment Station in testing and evaluation of those mats.

3.1 Mat Placement Rate Derivation

Placement rates for landing mats are important in system cost estimating since they represent a major labor cost item. These rates can vary considerably, however, depending on whether the data is taken from engineering tests conducted at the Waterways Experiment Station, where the mats are placed on flat surfaces, or from field tests where the mats are placed on a crowned surface. Higher rates are achieved on flat surfaces than on crowned surfaces. While it is more desirable to use field placement rates for cost estimating, appropriate data are not available for all of the existing mats considered in the study, and certain rates had to be derived.

The placement rates used for system cost purposes in this study, and shown by Exhibit D-2, were obtained in the following manner:

- . The QMR "Essential" rate was used for the hypothetical mats with membrane underlay
- . The placement rates for existing heavy duty mats with membrane underlay are taken as one-half the WES engineering test rates, in accordance with general Army experience
- . The placement rates, for medium duty mats with membrane underlay are taken as 60 percent of the WES engineering test rates, in accordance with general Army experience
- . The placement rates for light duty mats with membrane underlay are Army field test rates except for the Harvey light duty mats which are estimated.
- . For all mats with integral waterproofing, the placement rates are taken as 50 percent of the rates for the same mats with membrane underlay. WES experience with integrally waterproofed mats, while limited to date, indicates that these reduced placement rates are expected.

Finally, it is noted (and shown by Exhibit D-2) that the placement rates for existing mats with membrane underlay generally exceed the "Essential" rates given by the QMR.

A

MAT TYPE	Design Conditions				Coverag Level
	Single Wheel Load (x1000 lb.)	Tire Pressure (lb. / in. ²)	Tire Contact Area (in. ²)	Soil CBR	
Heavy Duty (QMR)	50	250	200	4	1000
Dow Truss Web	"	"	"	"	1602
NM20	"	"	"	"	620
Medium Duty (QMR)	25	250	100	4	1000
NM1 ⁹ (Kaiser)	"	"	"	"	1785
NM18	"	"	"	"	1100
AM-2	"	"	"	"	950
Goodyear All-Bonded	"	"	"	"	900
Light Duty (QMR)	30	100	300	4	1000
Harvey LD	"	"	"	"	367
M8A1	"	"	"	"	750

Values listed for existing mats are current actual values. The terms

Placement rates shown are for mats using membrane underlay. Rate

B

c	Unit Weight (lb. /ft. ²)		Placement Rate ^a (ft. ² /man-hour)		Material	Fabrication Method	Mat Panel Dimensions (Nominal)		
	Essential	Desirable	Essential	Desirable			Width (Ft.)	Length (Ft.)	1
	6.5	5.0	150	400	-	-	-	-	
	6.34	-	390	-	Aluminum	Extrusion	2	9	
	6.05	-	310	-	Aluminum	Extrusion	2	12	
	4.5	4.0	250	400	-	-	-	-	
	4.1	-	350	-	Aluminum	Sandwich	4.2	4	
	4.8	-	350	-	Aluminum	Extrusion	2	12	
	5.89	-	390	-	Aluminum	Extrusion	2	12	
	4.07	-	275	-	Aluminum	Sandwich	4	4	
	3.0	2.5	400	600	-	-	-	-	
	3.07	-	225	-	Aluminum	Extrusion	1	12	
	7.5	-	243	-	Steel	Roll	1.6	11	

^aEssential" and "Desirable" refer only to the QMR (hypothetical) mats.

^b for integrally waterproofed mats are one-half the rates shown.

C

Mat Panel Dimensions (Nominal)			Panel Placing Area (Ft. ²)	Panel Weight (Lbs.)	Panel Bundle Dimensions (Ft.)			Bundle Weight (Lbs.)	Bundle Volume (Ft. ³)	P
	Length (Ft.)	Depth (In.)			Width	Length	Depth			
	-	-	-	-	-	-	-	-	-	
	9	1.5	18	113.0	2.37	9.20	2.14	2,177	46.60	
	12	1.5	24	146.15	2.37	12.20	2.14	2,830	61.88	
	-	-	-	-	-	-	-	-	-	
	4	1.5	16.73	68.0	4.13	4.00	4.19	2,484	69.21	
	12	1.5	24	116.8	2.37	12.20	2.14	2,330	61.88	
	12	1.5	24	148.40	2.33	12.12	2.72	2,690	61.88	
	4	1.5	16.73	67.5	4.13	4.00	4.19	2,475	69.21	
	-	-	-	-	-	-	-	-	-	
	12	1.5	12	37.0	2.37	12.20	2.14	1,427	61.88	
	11	1.14	19.2	144	1.9	12.02	1.08	2,036	24.7	

Exhibit D-2
Landing Mat Characteristics

D

Panel Placing Area (Ft. ²)	Panel Weight (Lbs.)	Panel Bundle Dimensions (Ft.)			Bundle Weight (Lbs.)	Bundle Volume (Ft. ³)	Placing Area per Bundle (Ft. ²)
		Width	Length	Depth			
-	-	-	-	-	-	-	-
18	113.0	2.37	9.20	2.14	2,177	46.60	324
24	146.15	2.37	12.20	2.14	2,830	61.88	432
-	-	-	-	-	-	-	-
16.73	68.0	4.13	4.00	4.19	2,484	69.21	536.55
24	116.8	2.37	12.20	2.14	2,330	61.88	432
24	148.40	2.33	12.12	2.72	2,690	61.88	432
16.73	67.5	4.13	4.00	4.19	2,475	69.21	536.55
-	-	-	-	-	-	-	-
12	37.0	2.37	12.20	2.14	1,427	61.88	432
19.2	144	1.9	12.02	1.08	2,036	24.7	268.8

ANNEX E
COST ANALYSIS DATA

1. Purpose

The purpose of this annex is to describe the elements that comprise the life-cycle cost of a landing mat system, to present the cost estimates that were used in the study, and to describe the manner in which the estimates were developed.

2. Elements of Life-Cycle Cost

As used in this study, the term "life-cycle cost of a landing mat system" is understood to mean the sum of all costs to develop, test, procure, transport, deploy, and operate the mat system for a specified life duration; minus the value remaining in the deployed mat system at the end of the specified life.

Thus, the major life-cycle cost elements are:

- . Research, Development, Test, and Evaluation (RDT&E) Costs
- . Investment (Procurement) Costs

- . Operating Costs
 - Transportation
 - . Producer to CONUS port, CONUS port to overseas theater
 - . Intratheater
 - Mat/Membrane Placement
 - Maintenance
- . Value Remaining.

The rationale supporting estimates of these cost elements is described below.

2.1 Research, Development, Test, and Evaluation (RDT&E) Costs

The development history of most dynamic weapons systems begins with the perception of a new mission or functional requirement. The new requirement engenders the formulation of a system concept that will satisfy the requirement. Normally, the system concept contemplates some new blend of technically feasible features.

In this type of development situation, the major challenge to the developer's ingenuity is in the assembling, blending, and packaging of a broad array of technical features. Indeed, it is the new blend of features that is the essence of the new system itself. Implementation

of the new blend of features is then the principal objective and the major focus of effort in most weapons system development programs. In these programs, the major share of the RDT&E efforts toward implementation of the new blend of features are clearly visible and easily recognized as elements of the system development program.

Not so for landing mats. In landing mat development programs, RDT&E efforts and costs are difficult to isolate and identify. The continuing improvement of mats has been an evolutionary process. Frequently, an improved landing mat emerged as a by-product of advances in metallurgy (e. g., development of new, harder, and stronger alloys of light, soft metals like aluminum or magnesium) or in metal processing techniques (e. g., new extrusion presses). In these instances, the mat development program may not have been precipitated by a clearly perceived and explicitly defined new military requirement. Thus, it is extremely difficult to state when the development program actually began, who conducted it, who paid for it, and how much it cost.

Nevertheless, it is generally agreed that both the mat producer and the Government incur research, development, test, and evaluation costs in bringing a new landing mat into being. Therefore, an effort was made in this study to obtain knowledgeable estimates of these costs.

2.1.1 R&D Costs to Industry

A survey of major producers indicates that a certain level of mat R&D costs have been borne by industry which has, of course, been amortized through production orders. However, these costs must be included in the overall RDT&E costs to the Government. These are the elusive costs referred to earlier, but a reasonable estimate for a new mat process is considered to be \$1,000,000.

2.1.2 Government RDT&E Costs

In deriving Government RDT&E costs, the development, testing, and evaluation costs of a specific mat system incurred by WES were used. These costs were considered to be typical and were used as a constant for all mats. The following costs are estimated to be representative Government RDT&E costs for landing mat development:

. Research and Development Contracts	\$140,000
. Test mat procurement and modifications	\$ 75,000
. Testing and Evaluation costs	\$110,000
. Project management including personnel	<u>\$ 40,000</u>
<u>Total</u>	<u>\$365,000</u>

2.1.3 Total RDT&E Costs

The standard or constant RDT&E cost used in this study for all mat development is:

\$1,365,000

2.2 Investment (Procurement) Costs

The Work Statement for this study includes a requirement that procurement costs for landing mat systems be developed for five different procurement levels: 10, 25, 50, 75, and 100 million square feet. This requirement resulted from the assumption that unit cost of mats would decrease with increasing procurement quantities.

The survey of major landing mat producers, made during the study, resulted in two significant findings:

- . Unit cost of landing mats will probably be a minimum for a procurement quantity of 10 million square feet. That is, increases in procurement quantity above 10 million square feet will result in no further reduction of unit cost.
- . Unit cost of landing mats is critically dependent upon the fabrication process employed.

These findings are further discussed below.

2.2.1 Procurement Levels and Unit Costs

As noted above, it was the consensus of major mat producers contacted during the study that unit costs would bottom out at a procurement level of 10 million square feet. This conclusion results from the following facts:

- . Limited production capacity of the various producers operating under delivery time limitations would restrict the volume produced
- . The cost of raw materials and processing are such that the minimum profitable unit cost is reached at approximately 10 million square feet.
- . Should the Government desire volumes in excess of 10 million square feet, e. g. 50 million square feet under a time constraint, it would be necessary to contract with multiple producers. Each of the producers would thus be constrained to approximately the same minimum unit cost.

Thus, in the cost-effectiveness evaluation, procurement cost estimates were based on landing mat unit costs for procurement quantities of 10 million square feet.

2.2.2 Impact of Fabrication Process Upon Unit Costs

The survey of major mat producers identified several significant facts concerning the impact of fabrication process on landing mat unit costs:

- . Unit costs of aluminum mats produced through extrusion presses increase as the weight per square foot of the mat decreases. This results from the fact that the cost of the extruded product is measured in terms of the tonnage processed through the extrusion presses. Presses of this size and type are limited in number and are leased at a high cost; thus, the efficiency of usage is measured in the amount of metal processed. Also, as the extruded item becomes more refined, and precisely tooled such as a light weight mat may require, the quality control problem is increased.
- . Unit costs of honeycomb or sandwich type mats decrease as the weight per square foot of the mat decreases. This results from the fact that a standard multistep process is involved in the fabrication of the mats with the major variable being the metal content of the mat which is controlled by skin and edge thickness and density of the honeycombed material. Thus, a decrease in metal content will result in a lower unit cost.

Exhibit E-1, following this page, displays the unit costs of both extruded and sandwich type landing mats. For mats requiring membrane underlay for waterproofing, the unit costs of membrane are shown also. These latter costs assume the use of type T-16 membranes. Unit costs of mats with integral waterproofing include the costs of water seals. All of the unit costs displayed assume a procurement quantity of 10 million square feet.

Since ancillary items required for the installation of landing mats are essentially common to all mat types and duty classes, the costs of these items have no significance in a comparison of costs among various

EXHIBIT E-1
Unit Costs of Landing
Mat Systems

<u>Cost (\$ per Square Foot)</u>			
<u>Mat</u>	<u>Extruded</u>	<u>Sandwich</u>	<u>Average</u>
Heavy duty mat	3.00	3.85	3.43
Membrane	<u>.21</u>	<u>.21</u>	<u>.21</u>
Total	<u>3.21</u>	<u>4.06</u>	<u>3.64</u>
Heavy duty mat w/waterproofing	3.21	4.06	3.64
Medium duty mat	3.30	3.50	3.40
Membrane	<u>.21</u>	<u>.21</u>	<u>.21</u>
Total	<u>3.51</u>	<u>3.71</u>	<u>3.61</u>
Medium duty mat w/waterproofing	3.51	3.71	3.61
Light duty mat	3.63	3.15	3.39
Membrane	<u>.21</u>	<u>.21</u>	<u>.21</u>
Total	<u>3.84</u>	<u>3.36</u>	<u>3.60</u>
Light duty mat w/waterproofing	3.84	3.36	3.60

types and classes of mats and are not included in the figures of Exhibit E-1.

In exercising the Life-Cycle Cost portion of the Landing Mat Evaluation model (described in Annex F), the following ground rules were employed:

- . Sandwich mat unit costs were used to determine procurement costs of the XM-19 and the Goodyear bonded mats
- . Extruded mat unit costs were used to determine procurement costs of the Truss Web, XM-20, XM-18, AM-2, and Harvey light weight mats.

Owing to the fact that the fabrication process that will be employed to produce a new series of mats to meet the QMR requirements is not now known, procurement costs of the hypothetical QMR mats of this study were developed using the average unit costs shown in Exhibit E-1.

2.3 Operating Costs

Operating costs as defined for this study are those costs incurred in the construction of specified airfields in a theater of operations including the transportation, handling, deployment and maintenance of landing mat systems in the foreign theater of operations.

2.3.1 Transportation Costs

Transportation costs of interest in the study included the cost of:

- Transport of mat system material from a CONUS port to an overseas theater
- Intratheater transport of mat system material to the points of use.

Costs for shipment, within CONUS, from the producer's plant to the CONUS port are assumed to be included in the unit procurement cost figures.

2.3.1.1 Transportation Cost From CONUS Ports to Overseas Theaters

For costing purposes, it has been assumed that all mat and membrane shipments from CONUS to overseas theaters will be accomplished by surface transportation means. Data received from Headquarters, Military Traffic Management and Terminal Service (MTMTS) indicates that handling charges for metal products at CONUS ports will amount to \$22.50 per measurement ton. The Military Sea Transport Service (MSTS) costs similar cargo at \$32.30 per measurement ton from the West Coast of CONUS to Southeast Asia. Since the study has postulated a theater of operations which is 8,000 miles from CONUS, these figures were used to determine the overseas shipping costs.

The total overseas shipping costs for mat systems was determined to be \$54.80 per measurement ton (handling cost, \$22.50 plus shipping costs, \$32.30).

For study purposes, it was considered desirable to convert the cost per measurement ton to cost per short ton (2,000 lbs.). The average cubic footage and weight per bundle of the various mats currently in production is 64.3 cubic feet at 2,548 pounds. To determine the weight of a measurement ton of 40 cubic feet of mat material:

$$X = \frac{40 \text{ ft.}^3 / \text{meas. ton} \times 2548 \text{ lbs. / bundle}}{64.3 \text{ ft.}^3 / \text{bundle}} = 1585 \text{ lbs. / meas. ton}$$

Since \$54.80 has been determined as the cost for a measurement ton or 1585 pounds of mat material, the cost for 2000 pounds was developed.

$$Y = \frac{\$54.80 / \text{meas. ton} \times 2000 \text{ lbs. / short ton}}{1585 \text{ lbs. / meas. ton}} = \$69.15 \text{ per short ton}$$

Thus, the cost to ship a short ton from CONUS to the overseas theater (CONUS to SEA) by surface transportation is \$69.15 per ton.

2.3.1.2 Intratheater Transportation Cost

The transportation means used to transfer surfacing materials (mats and membranes) to construction sites within the theater of

operations will depend upon the geographical environment, the urgency of the requirement, transportation means available, and the enemy situation. The study assumes the availability of surface transportation in the form of 5-ton cargo trucks and air transportation using Army CH-47 helicopters or USAF C-130 cargo aircraft.

It is also assumed that the theater of operations is located in a relatively underdeveloped geographic area in which few, if any, permanently surfaced airfields exist and surface lines of communication are limited. Potential enemy interdiction of the road network would require the deployment of major combat units to insure reliable traffic flow.

Consequently, it is assumed that air lines of communications will be used to transfer mats within the theater and the cost of such transportation will be used in the study.

The cost of moving cargo by three modes of transportation; 5-ton cargo trucks, C-130 aircraft, and CH-47 aircraft; is shown below. In each case, a 200 mile round trip from pickup point to construction site is assumed. The per ton cost of intratheater transport was determined for the three methods of transport using the formulae of Exhibit E-2, following this page.

EXHIBIT E-2
Formula and Data for Calculation
of Intratheater Transport Costs

Formula:

$$C_{IT} = \left(\frac{D}{S} + \frac{T_{OL}}{60} \right) \times \frac{C_{VO}}{P_V}$$

Where:

C_{IT} = Intratheater transport cost (\$/ton)
D = Average intratheater round trip transport distance (miles)
S = Vehicle speed (miles/hour)
T_{OL} = Off loading time (minutes)
C_{VO} = Vehicle hourly operating cost (\$/hour)
P_V = Vehicle payload in tons

Data:

	<u>D</u>	<u>S</u>	<u>T_{OL}</u>	<u>C_{VO}</u> ¹	<u>P_V</u>	<u>C_{IT}</u>
5-ton truck	200	20	30	1.8	5	\$ 18
CH-47	200	75	30	606	5	\$384
C-130	200	200	30	790	15	\$ 79

¹ For the CH-47 and C-130 aircraft, these data were taken from COMUSARV Study "Cost-Effectiveness Analysis of the XM-19 Landing Mat for C-130 Airfields in RVN." For the 5-ton truck, the data were derived from the Cost Analysis Office, HQ, AMC, based on data from the REVAL Wheels Study.

From the formula and data of Exhibit E-2, it is apparent that the per ton cost of intratheater transport by the various modes of transportation are:

. 5-ton truck	\$18/ton
. C-130 aircraft	\$79/ton
. CH-47 aircraft	\$384/ton.

To provide a valid basis for comparison of the various candidate landing mat systems in the cost-effectiveness analysis of this study, the C-130 intratheater transport cost was used throughout the analysis.

2.3.2 Mat/Membrane Placement Costs

In the life-cycle cost calculations of this study, mat/membrane placement cost of each airfield is determined from the equation:

$$\text{Placement Cost} = \frac{A_F}{R_P} \times C_L$$

Where:

R_P = mat (or membrane) placement rate (square feet/
man hour)

C_L = labor cost of placement crew (\$/man hour)

A_F = area of the airfield (square feet).

Hourly labor costs used in the study were derived from the Army Cost Handbook (Comptroller of the Army) for TOE 5-118G, Engineer Company, Construction, which is organic to TOE 5-115G, Engineer Battalion, Construction. The battalion annual cost in the Republic of Vietnam is estimated at \$10,364,000. This includes Procurement of Equipment and Missile, Army (PEMA), Operations and Maintenance, Army (O&MA)) and Military Personnel, Army (MPA) appropriated funds.

Based upon a strength of 935 officers and men, a 12-hour working day and a 30-day working month, the following computations were made.

$$\cdot \quad \frac{\text{Total Annual Cost}}{\text{Strength}} = \text{Annual cost per person}$$

$$\cdot \quad \frac{\$10,364,000}{935} = \underline{\$11,085}$$

$$\cdot \quad \frac{\text{Annual cost per person}}{\text{Annual hours per person}} = \text{Hourly cost per person}$$

$$\cdot \quad \frac{\$11,085}{4320} = \underline{\$2.57}$$

As a result of the above data, costs for an engineer construction battalion laying, maintaining, or picking up mats and membranes were estimated at \$2.57 per man hour.

The mat and membrane placement rates that were used in these calculations were presented in Annex D.

2.3.3 Cost for the Maintenance of Airfield Surfaces

In developing the maintenance cost estimates of the study, it is assumed that 10% of the mats on an airfield will be replaced during the airfield's operational life. As used here, the term operational life describes the time from initial placement of the airfield to failure. Failure is presumed to occur when the aggregate of coverages applied equals the coverage capability of the surface. (The calculation of airfield life is further described in Annex F.)

During the airfield's operational life, the monthly maintenance cost (C_{MM}) is calculated from the equation:

$$C_{MM} = \frac{10(C_{Pi} + C_{Ti}) + C_{PU} + C_{RE}}{L}$$

Where:

- C_{Pi} = initial procurement cost of the mats on the airfield
- C_{Ti} = initial transportation cost of the mats on the airfield
- C_{PU} = labor cost to pick up 10% of the airfield surface
- C_{RE} = labor cost to relay 10% of the airfield surface
- L = airfield's operational life in months.

2.3.4 Value Remaining

Elsewhere in this report, it is explained that the cost-effectiveness of various candidate landing mat systems was evaluated against an expedient surfacing mission requirement of specified duration. Some candidate landing mat systems failed before reaching the end of the mission duration, while others survived beyond it.

To provide a means for discriminating between short-lived and long-lived systems in the life-cycle cost calculations, the concept of "value remaining" was introduced.

"Value remaining" was defined as the cost of the unconsumed operational life of an airfield at the end of the specified mission duration. It was calculated as:

$$\text{Value Remaining} = \left[C_{PO} - C_{PUO} \right] + \left[C_{PI} \times \frac{(L - D_M)}{L} - C_{PUI} \right]$$

Where:

C_{PO} = procurement cost of outer 2/3 of airfield's mats

C_{PUO} = labor cost to pick up outer 2/3 of airfield's mats

C_{PI} = procurement cost of inner 1/3 of airfield's mats

C_{PUI} = labor cost to pick up inner 1/3 of airfield's mats

D_M = mission duration

L = airfield life.

In making the value remaining calculation, the salvage value of the metal in dissipated mats (which is small relative to other terms in the above equation) was taken as negligible.

ANNEX F

THE LANDING MAT EVALUATION MODEL

1. Purpose

The purpose of this annex is to describe the Landing Mat Evaluation Model developed for this study. The description proceeds from an overview of the model to a detailed presentation of the elements of each of the major submodels. To ease the burden of calculation, the equations which make up the Landing Mat Evaluation Model were translated into a simple computer program. In the interests of clarity, the details of the computer program are not included here, but a complete listing of the computer program is included as Annex H.

2. Overview

The Landing Mat Evaluation Model is really two models which may be used independently. The first, a Performance submodel, is a tool which accepts data describing mat design characteristics and details of operational environment and from these computes mat life. The second, a Life-Cycle Cost submodel, is a tool which accepts data describing a given landing mat system, details of operational environment, and the life of an individual mat in its operational environment;

and from these computes total life-cycle cost of the given landing mat system. Exhibit F-1, following this page, is a pictorial representation of the Landing Mat Evaluation Model.

Although the submodels may be operated independently, it is more convenient to discuss the Landing Mat Evaluation Model as a single entity which accepts input information, processes it, and produces life-cycle cost of candidate mixes as output. Exhibit F-2, following this page, presents a complete list of the input information required by the Landing Mat Evaluation Model. The description of the two major submodels in the next two sections presents the details of how the input information is processed to produce the life-cycle costs for each candidate landing mat system.

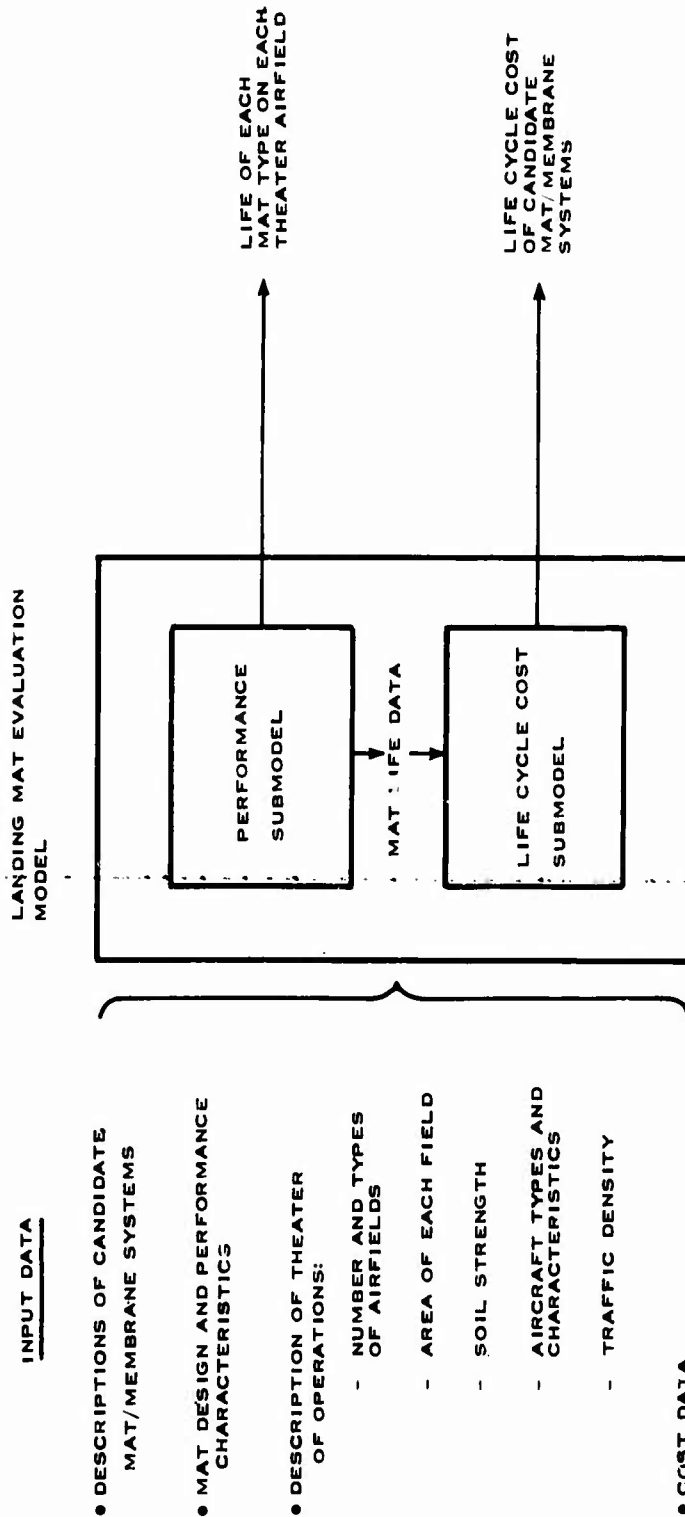
3. Performance Submodel

The Performance submodel can calculate the operational life of landing mat systems under varying specifications of:

- . Traffic loads
- . Soil strength (CBR)
- . Mat types.

The Performance submodel uses traffic data, aircraft characteristics, mat characteristics, theater definition, and mat system description to calculate the life of an airfield surfaced with a given type mat.

EXHIBIT F-1
The Landing Mat
Evaluation Model



DEFINITION OF INPUTS TO THE MODELTHEATER OF OPERATION INPUTSField Characteristics

TYPES	Total types of fields
TYP [F]	Type of field (TACF, HLF, MLF, LLF)
AREA [F]	Area of field type F in ft. ²
DIST [F]	Intratheater shipping distance in miles to field type F
NUM [F]	Number field of each type
CBR [F]	CBR on field type F

Craft Characteristics

CNO	Number of craft in inventory to be considered
ESWL [C]	Equivalent single wheel load in lb. for craft C
TP [C]	Tire pressure in psi
TCA [C]	Tire contact area in sq. in.
CPS [C]	Coverages per sortie by craft C

Traffic Data

SPM [C, F]	Expected number of sorties per month of craft type C on field type F.
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MAT SYSTEM DESCRIPTION

MATYPE	Number of the types of mats
MAT [TYP [F] S]	Identification of the type of mat to be laid on field type F for mix identified as S
MF SYS	Required life of T. O. surface with the given mix in month.

MAT & MEMBRANE CHARACTERISTICSTechnical Characteristics

WT [M]	Mat weight in lb. /sq. ft.
MEMW [M]	Membrane weight in lb. /sq. ft.
PLR [M]	Mat placement rate in sq. ft. /man-hour
MEMP [M]	Membrane placement rate in sq. ft. /man-hour
PACS [M]	Bundle size of the mat in cu. ft.
PACN [M]	Number of mats in a bundle
PACW [M]	Weight of one bundle of mats in lb.

Cost Characteristics

COST [M]	Unit purchase price of the mat in \$/sq. ft.
RDC [M]	R&D cost assigned to unit mat in \$/sq. ft.
ACC [M]	Cost of accessories with a mat bundle in \$/pack

MEMC [M]	Unit purchase price of the membrane in \$/sq. ft.
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Support System Inputs

SCPT	Overseas shipping cost in \$/ton
MHRC	Man-hour cost in \$/man-hour
SPEED	Speed of intratheater shipping vehicle (Helicopter, truck, etc.) in mph.
ITHSR	Intratheater shipping vehicle hourly rates in \$/hour
PAY	Intratheater vehicle payload in lb.

A flow diagram showing the calculation steps of the model is presented as Exhibit F-3, following this page. Calculation steps are:

- . Traffic data conversion
- . Coverage capability calculation
- . Mat life calculation.

These calculations are described in detail in the paragraphs below.

3.1 Traffic Data Conversion

The first function of the Performance submodel is to convert traffic load data from monthly sortie rate for each aircraft type on each airfield to coverages per month. One landing and one takeoff cycle is called a sortie. Coverages per month are computed as the product of sorties per month times a coverage per sortie factor.

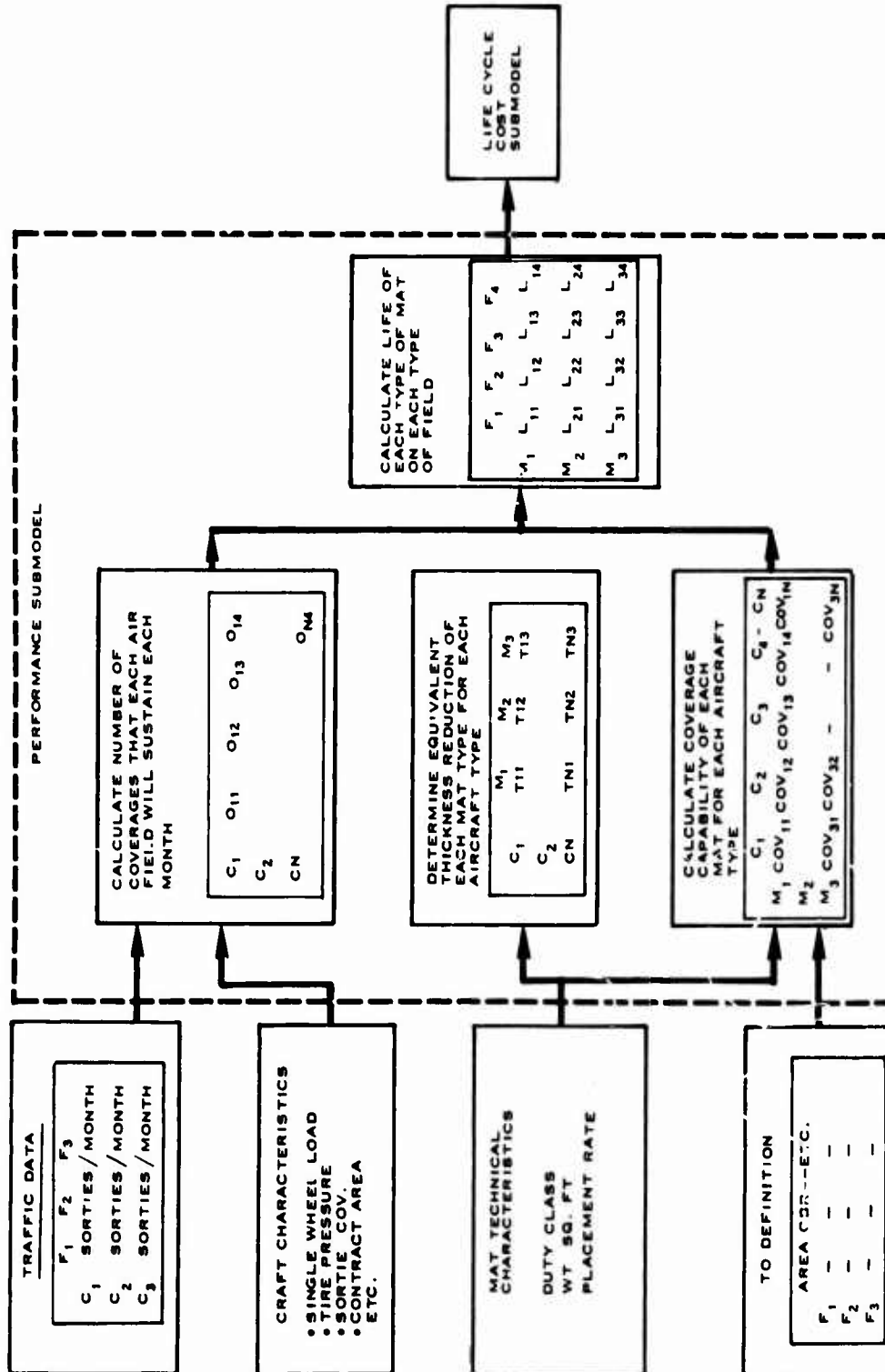
Coverages factors for some selected aircraft types are given below:*

<u>Aircraft</u>	<u>Coverage per Sortie Factor</u>
F-111B	0.190
F-4C	0.140
C-130	0.454
F-111A	0.190
C-123	0.192
C-7A	0.224
C-141	0.458
C-5A	0.722

* These factors were derived from the following WES formula:

$$\text{Operations/Coverage} = \frac{40 \text{ wander} + \text{tire width} + \text{wheel spacing}}{.75 \times \text{tire width} \times \text{number of tires}}$$

EXHIBIT F-3
Performance Submodel
Flowchart



Coverages per month define the operational loading the mat sustains.

3.2 Coverage Capability Calculation

The calculation of how many coverages (by an aircraft with given loading characteristics) a mat can sustain is approached by first noting that there exists an empirically derived formula which relates thickness of flexible pavement to capacity to sustain coverages (i. e. coverage capability). This formula and the concept of equivalent thickness make possible the desired calculation. The equivalent thickness concept assumes that a landing mat is equivalent in load carrying capability to some thickness of flexible pavement structure. To calculate coverage capability, this equivalent thickness is substituted in the flexible pavement formula.

3.2.1 Equivalent Thickness

Equivalent thickness of each mat for a given aircraft is determined by using a set of empirical curves. Exhibits F-4, F-5, and F-6 show the equivalent thickness curves for heavy, medium, and light duty mats respectively.

EXHIBIT F-4
QMR Requirement For
Heavy Duty Mat

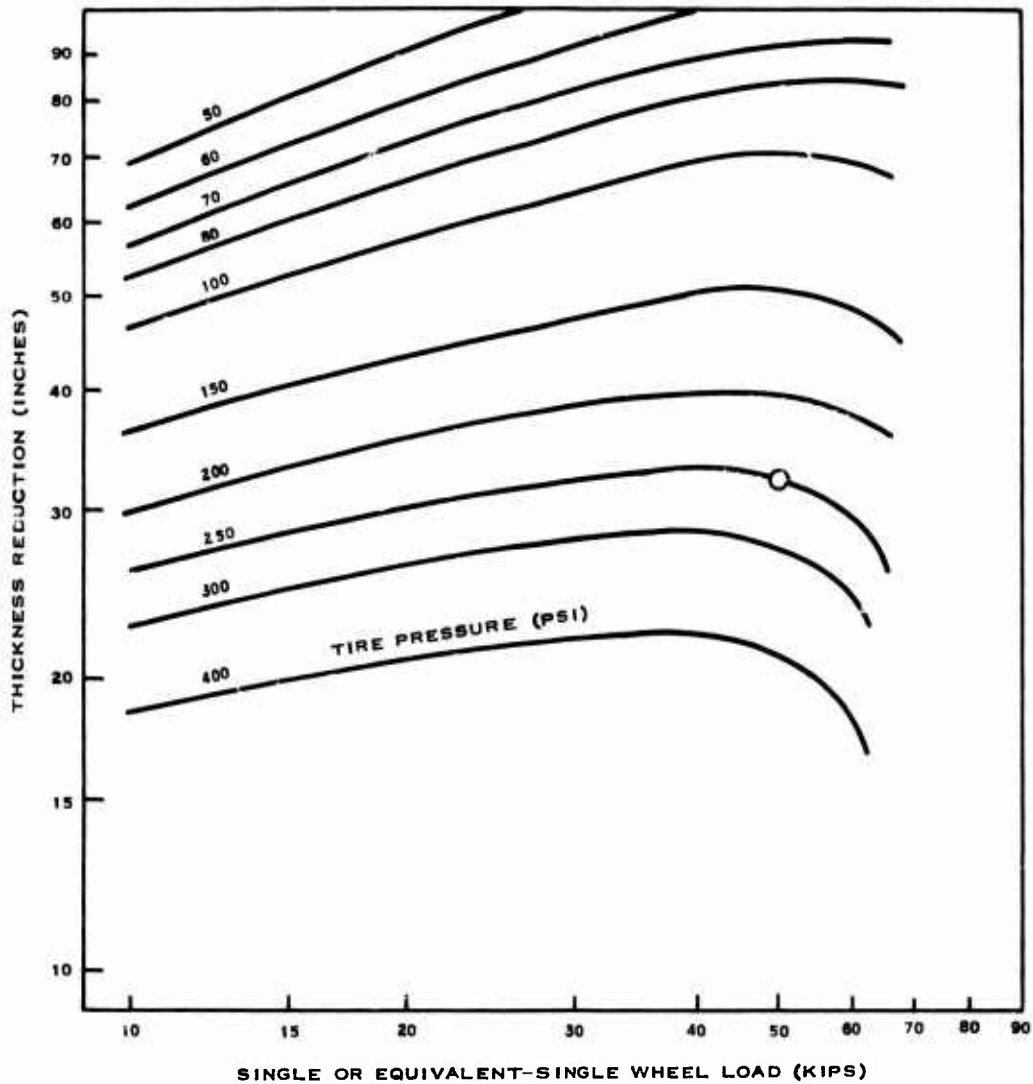


EXHIBIT F-5
QMR Requirement For
Medium Duty Mat

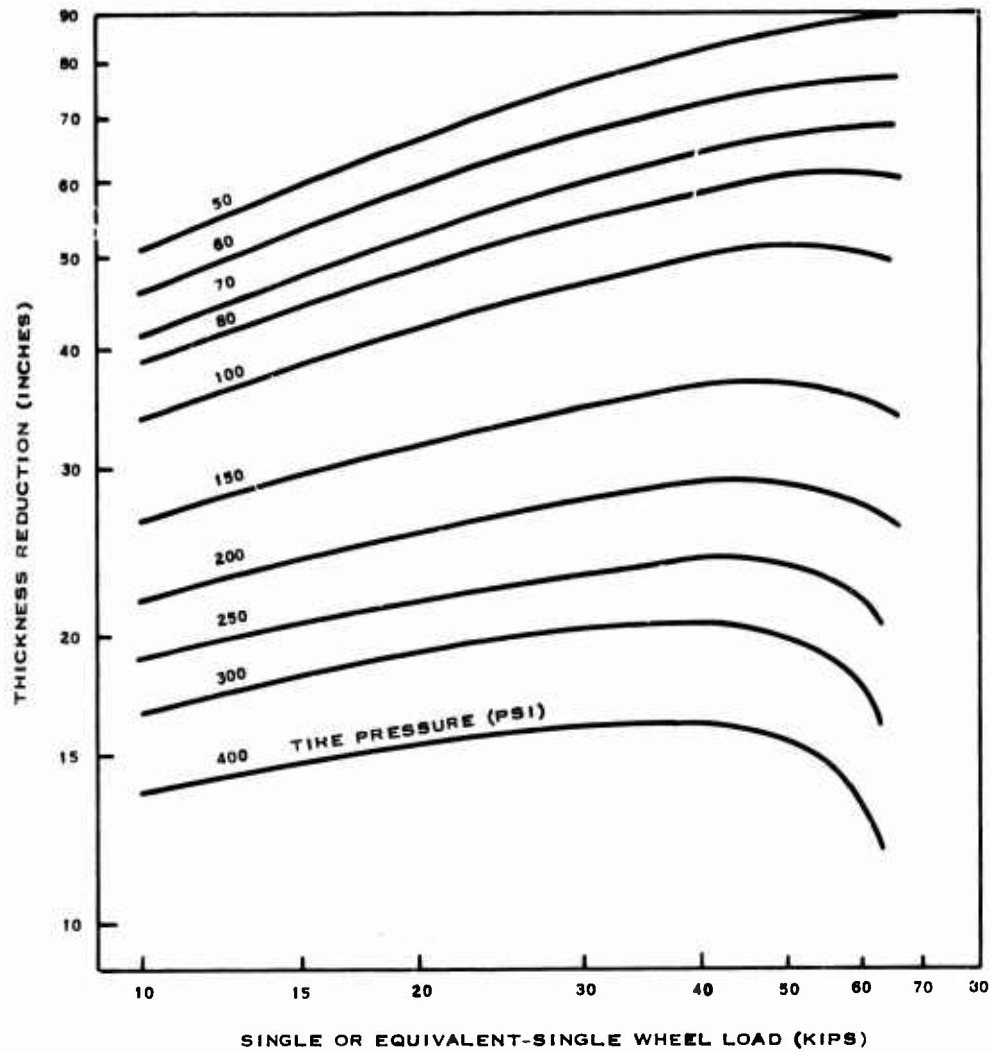
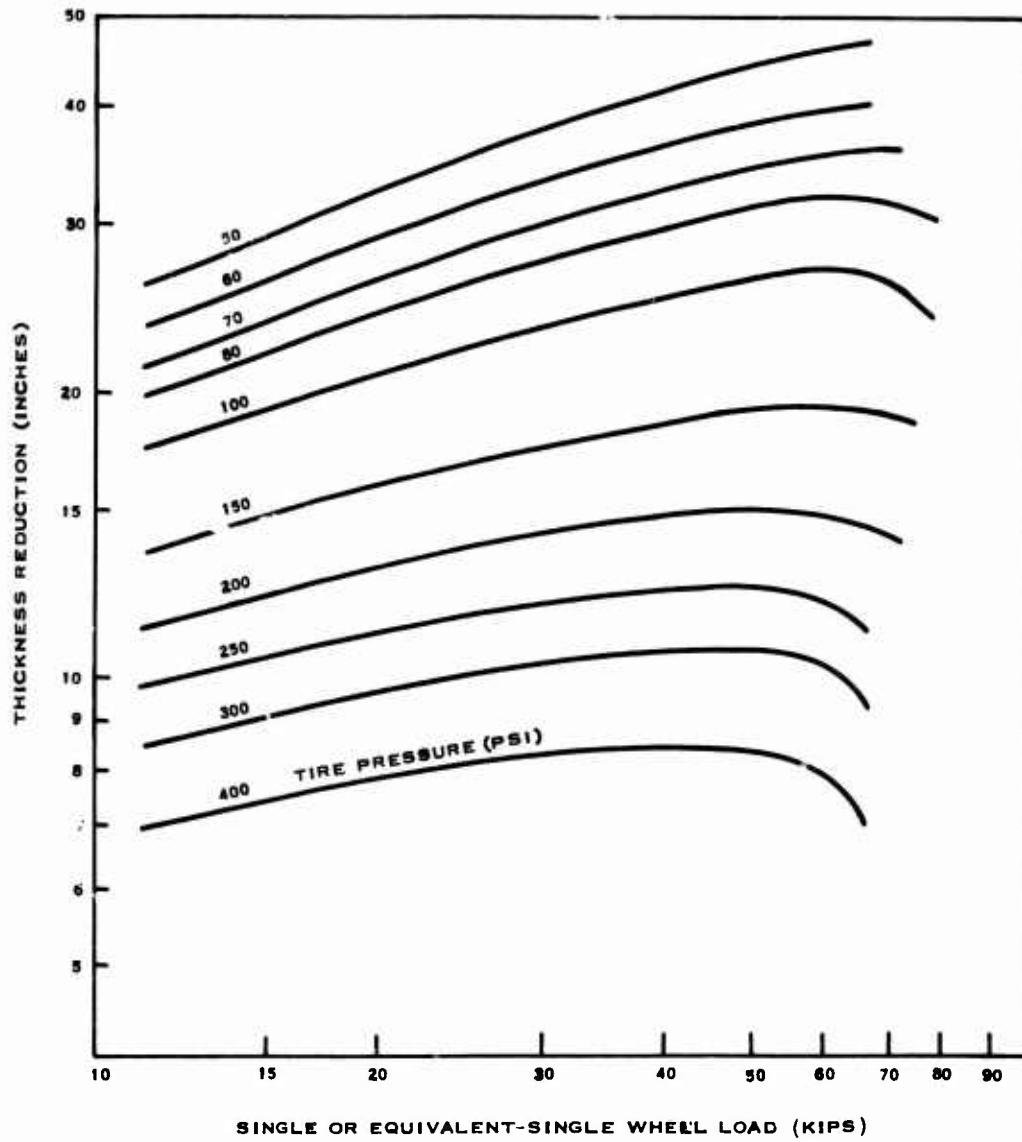


EXHIBIT F-6
QMR Requirement For
Light Duty Mat



The computer program uses an extrapolation and interpolation subroutine to determine equivalent thickness for an aircraft of a given equivalent single wheel load and tire pressure. The equivalent single wheel load is the load on a single tire with characteristics equivalent to one tire of the assembly, which will produce the same effect on a mat as the total assembly.

3.2.2 Coverage Capability

Equivalent thickness determined previously for each aircraft and mat combination is substituted in the flexible pavement formula to compute the number of coverages that could be sustained by each mat. The flexible pavement formula* is:

$$C = 10 \text{ Exp } \left[\frac{4.348t}{\sqrt{\frac{P}{8.1 \text{ CBR}} - \frac{A}{11}}} - 0.653 \right]$$

Where:

- C = Coverages that the mat can sustain
- t = Equivalent thickness (inches)
- P = Equivalent single wheel load (pounds)
- CBR = Soil strength (California Bearing Ratio)
- A = Tire contact area (square inches).

* This formula was taken from a memorandum dated 8 January 1970, issued by the Acting Chief, Flexible Pavement Branch, WES.

3.3 Mat Life Calculation

The airfield mission requirements (stated in terms of the number of coverages that will be applied to the field by the aircraft that will land and take off from the field each month) and coverage capability are used to calculate mat life on the field. The equation used is:

$$\text{LIFE}_{MF} = 1 / \sum_C (\text{CPM}_{CF} / \text{CC}_{MC})$$

Where:

LIFE_{MF} = Life of the mat M on field type F (months)

CPM_{CF} = Number of coverages applied to airfield F each month by aircraft type C

CC_{MC} = Number of coverages by aircraft type C that can be sustained by mat type M.

The term $(\text{CPM}_{CF} / \text{CC}_{MC})$ is the wear sustained by the expedient surface during one month, which is summed over the total number of aircraft to give aggregate wear in a month. The reciprocal of aggregate wear gives the life of the expedient surface on a given field in months.

The major assumptions of the performance submodel are:

- . Maximum wheel braking or locked wheel braking imposes impact loading throughout the length of the runway and damages the runway surfacing two to three times more severely than normal touchdown and roll out. It has been assumed that the number of landings with locked-wheel will be so small that their overall effect will be insignificant during the life of the system.
- . Since the wear factor of some aircraft on mats is insignificant and the mat will last indefinitely, a maximum figure of 25,000 coverages was established to permit quantification of results.

4. Life-Cycle Cost Submodel

The Life-Cycle Cost submodel computes the life-cycle cost of surfacing a theater of operation for a given mission life and theater air traffic loading. Life-cycle cost of the landing mat system is composed of the following basic cost elements:

- . Research and Development Cost
- . Procurement Cost
- . Transportation Cost
- . Placement Cost
- . Maintenance Cost
- . Replacement Cost
- . Salvage Value.

The life-cycle cost of a candidate system is the algebraic sum of its cost in the seven categories above. In the following sections, the estimating procedures which comprise the Life-Cycle Cost submodel

are presented. Exhibit F-7, following this page, is a pictorial representation of this submodel.

4.1 Research and Development Cost

The Research and Development Cost reflects production engineering and production costs of the test mats, as well as costs incurred at WES and TECOM for functions such as WES engineering support, testing by Army and contractual agencies, evaluation, publication, and training.

The R&D cost input to the model is considered to be a constant as discussed in Annex E. The R&D cost for each hypothetical landing mat system is 1.35 million. In evaluating the existing mats, the R&D cost is assumed to be a sunk cost.

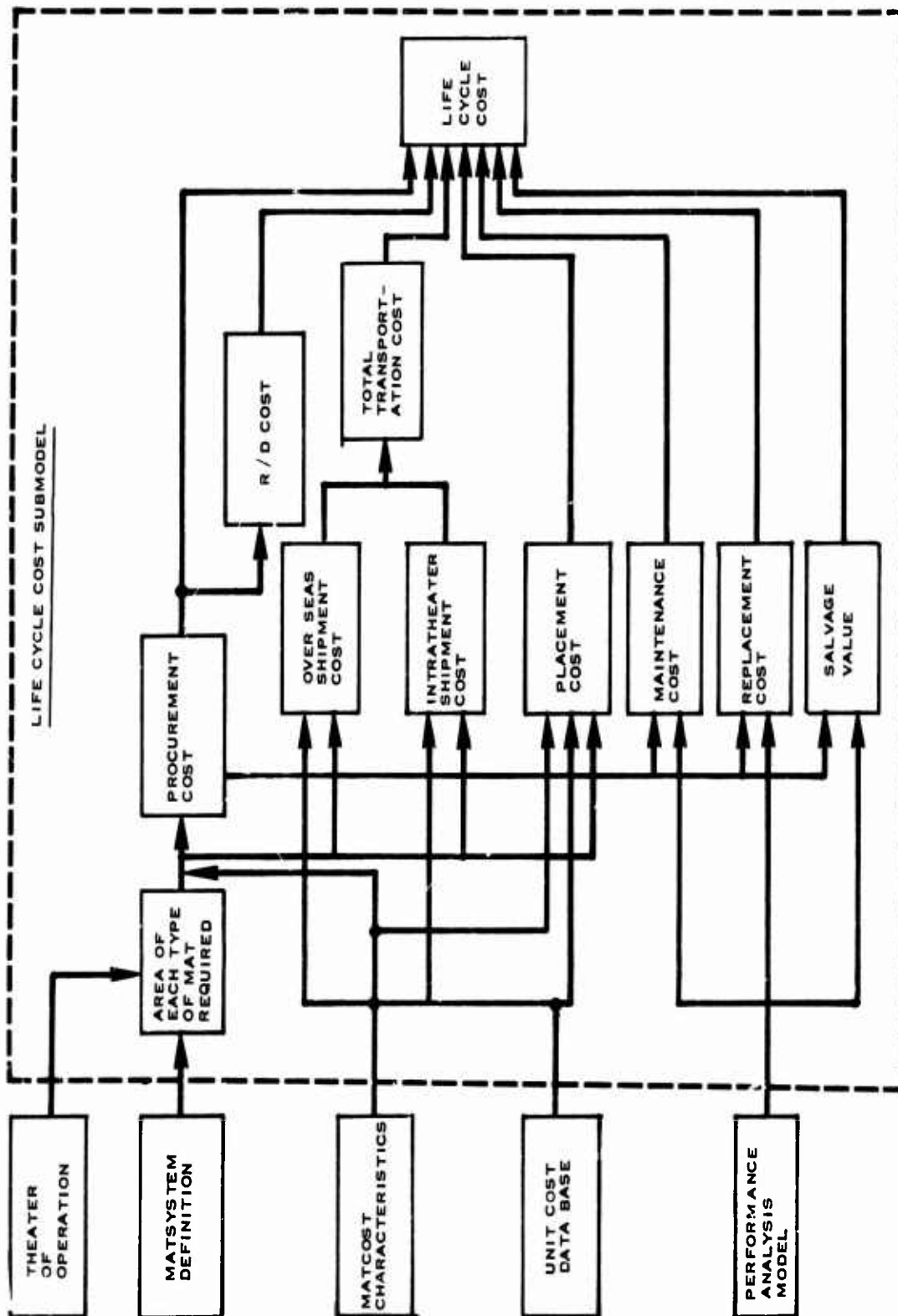
4.2 Procurement Cost

Procurement Cost, as described in Annex E, is input to the model as unit procurement cost in dollars per square foot.

Procurement Cost = Unit purchase price x area of the field.

Quantity purchase discounts, price reductions due to learning and inventory handling costs are reflected in the unit purchase price of the mats.

EXHIBIT F-7
Life Cycle Cost Submodel
Flowchart



4.3 Transportation Cost

Transportation Cost includes shipping cost to theater (from continental United States to communication zone) and shipping cost within the theater. The first step in the transportation cost computation is the calculation of weight of mats and membrane required by each field.

Where:

$$\begin{array}{lcl} \text{Total weight of mat and} & = & \text{Area of the field x (weight per} \\ \text{membrane for a field} & & \text{square foot of mat + weight per} \\ & & \text{square foot of membrane)} \end{array}$$

The overseas shipment cost is calculated by multiplying total weight of mat and membrane by overseas shipment cost per ton as explained in Annex E.

Intratheater shipping costs are determined by multiplying the number of intratheater vehicle trips by total time required for each trip and cost per hour for the vehicle.

$$\begin{array}{lcl} \text{Number of trips required} & = & \frac{\text{mat and membrane wt. (lbs.)}}{\text{vehicle capacity (lbs. per trip)}} \\ \text{to deliver} & & \end{array}$$

$$\begin{array}{lcl} \text{Trip time} & = & (\text{Distance to theater/speed}) + \\ & & \text{loading and unloading time} \end{array}$$

$$\text{Intratheater shipping cost} = \text{Trip time} \times \text{number of trips to deliver} \times \text{vehicle cost per hour.}$$

The delivery vehicle used for intratheater shipment may be a helicopter, truck, or aircraft (C-130).

4.4 Placement Cost

Total Placement Cost is composed of labor cost and construction equipment cost. Labor and equipment costs are determined by dividing the airfield area by the placement rate (i. e. , sq. ft. /man-hour) and multiplying by cost per man-hour. The cost of an engineer construction company (TOE 5-118), as described in Annex E, was used as input data.

The total placement cost can be expressed as the sum of labor and equipment cost for placing mat and membrane.

$$\text{PLC (F)} = (\text{MHRC} + \text{EHRC}) \times \frac{\text{AREA (F)}}{\text{PLR (M)}} + \frac{\text{AREA (F)}}{\text{MEMP (M)}}$$

Where:

MHRC = Average labor cost per man-hour

EHRC = Average construction equipment cost per hour

AREA (F) = Area of the field in sq. ft.

PLR (M) = Mat placement rate in sq. ft. /man-hour

MEMP (M) = Membrane placement rate in sq. ft. /man-hour.

Construction crew security force, clearing, grading, and soil preparations are essential to all fields; therefore, costs of these are common to all mat systems and are not included in the cost model.

4.5 Maintenance Cost

Maintenance cost is the maintenance labor cost plus the cost of supplies. For this model, a uniform maintenance policy providing corrective actions only at the time of breakdown has been used.

Therefore:

$$\text{Total Maintenance Cost} = \frac{\text{LIF SYS}}{\text{MTBF}} \times (\text{ALCPF} + \text{ASCPF})$$

Where:

LIF SYS	System life in months
MTBF	Mean time between failure
ALCPF	Average labor cost per failure
ASCPF	Average supply cost per failure.

To meet the QMR requirement, a mat should be capable of withstanding required coverages and load with a maximum of 10% replacement. Therefore, maintenance cost during full life of an expedient surface airfield is the cost of replacing 10% of the surface. This cost of replacement is assumed to be distributed uniformly over the lifetime

of the airfield. Therefore, for the purpose of evaluation of hypothetical mats, the maintenance cost for an airfield of a given life is:

$$\text{Maintenance Cost} = \text{Cost of replacing 10\% of the mats} \\ \times \frac{\text{Required life of the field}}{\text{Life expectancy of the mat}}$$

If corrective maintenance data for the existing mats are available, they can be used instead of the procedure described above.

4.6 Replacement Cost

If a mat on a field does not last as long as the required life of the field, the mat is replaced by a new mat. The study assumes the airfield to have failed when one-third of the surfacing has failed. The number of times a particular mat must be replaced in the course of required airfield life was established by taking a ratio of the required airfield life to the life of the mat. Three cost factors were estimated for each replacement:

- . Procurement cost
- . Transportation cost
- . Placement cost.

The computations for replacement cost are the same as those for original placement except the membranes used under mats do not usually fail; therefore, replacement cost for membrane has not been included in the replacement costs.

4.7 Value Remaining

When an expedient surface airfield fails, approximately 67% of the emplaced mat can be recovered in reusable condition. In addition to the 67% value, the salvage value of the other 33% is considered. When the life expectancy of a mat exceeds the required life of the field, a salvage value of the center one-third of the mat is computed. The procurement cost of one-third of the mat is computed. The procurement cost of one-third of the field is amortized by multiplying it by the ratio of the mat life remaining to the total life expectancy. From this amortized cost, the cost of picking up the mats is subtracted to give salvage value.

$$\text{Value Remaining} = \text{Procurement Cost} \times \left[.67 + \frac{.33 \times \text{Life Remaining}}{\text{Total Life Expectancy}} \right] - \text{Pickup Cost}$$

The sum of placement cost and intratheater shipment cost is adopted as an average figure for pickup cost. Salvage value of the membrane is assumed negligible.

ANNEX G

SUMMARY OF MODEL INPUT DATA AND RESULTS OF MODEL EXERCISES

1. Purpose

The purpose of this annex is to present a summary of the input data used in exercising the Landing Mat Evaluation Model, and to present the results of the exercises.

2. Summary of Model Input Data

Development of model input data used in the study was discussed earlier in Annexes C, D, and E. This annex contains a consolidated summary of the input data actually used in the model exercises. It is presented in 9 exhibits as follows:

- . Exhibit G-1 - Aircraft Traffic Load
- . Exhibit G-2 - Aircraft Characteristics
- . Exhibit G-3 - Landing Mat Characteristics -
Hypothetical Extruded Mats
- . Exhibit G-4 - Landing Mat Characteristics -
Hypothetical Sandwich Mats
- . Exhibit G-5 - Landing Mat Characteristics -
Hypothetical Average Mats

- . Exhibit G-6 - Landing Mat Characteristics - Existing Mats
- . Exhibit G-7 - Airfield Data
- . Exhibit G-8 - Coverage Capability of Hypothetical QMR Mats
- . Exhibit G-9 - Coverage Capability of Existing Mats.

3. Results of Landing Mat Life Calculations

As described earlier in Annex F, the Landing Mat Evaluation Model contains a Performance submodel that calculates the life (from deployment to failure) of each type of landing mat under the operational and environmental conditions of each type of airfield in the theater of operations. The results of those calculations are presented in Exhibit G-9, following this page.

4. Results of Landing Mat System Life-Cycle Cost Calculations

The results of life-cycle costs calculations for the candidate landing mat systems are presented in Exhibit G-10, following this page. As described earlier in Annex D, 18 candidate systems (9 basic mixes of mat duty classes considered first with membrane underlay, then alternatively with integral waterproofing) were identified. The 9 basic systems were evaluated with 5 sets of hypothetical and existing mats.

EXHIBIT G-1
Aircraft Traffic Load
(Sorties/Month)

Type of Aircraft	Type of Airfield			
	Tactical Airfield	Heavy Lift Airfield	Medium Lift Airfield	Light Lift Airfield
F-111B	100	0	0	0
F-4C	900	0	0	0
C-130	0	700	750	0
C-123	0	75	80	0
C-7A	0	160	170	1,000
C-141	0	45	0	0
C-5A	0	20	0	0

Note: Development of these data was discussed in Annex C.

EXHIBIT G-2
Aircraft Characteristics

Aircraft	Equivalent Wheel Load in Lb. ESWL (C)	Tire Pressure in Psi TP (C)	Contact Area in Sq. In. TCA (C)	Sortie To Coverage Conversion Factor
1. F-111B	50,000	250	200	. 19
2. F-4C	25,000	250	100	. 14
3. C-130	30,000	100	300	. 454
4. C-123	24,180	88	272	. 192
5. C-7A	12,300	39	150	. 224
6. C-141	50,050	185	208	. 458
7. C-5A	47,400	110	260	. 722

EXHIBIT G-3
Landing Mat Characteristics -
Hypothetical Extruded Mats

Characteristics Mat Type	Mat Cost \$/Sq. Ft. Cost (M)	Mem Cost \$/Sq. Ft. MEMC (M)	Mat Wt. Lb/Sq. Ft. Wt (M)	Mat Place- ment Rate Sq. Ft./Man Hr. PLR (M)	Membrane Weight Lb/Sq. Ft. MEMW (M)	Membrane Placement Rate Sq. Ft./Man Hr. MEMP (M)
Heavy Duty	3.00	.21	6.5	150	.444	300
Medium Duty	3.30	.21	4.5	250	.444	300
Light Duty	3.63	.21	3.0	400	.444	300
Heavy Duty Waterproof	3.21	-	6.5	75	-	-
Medium Duty Waterproof	3.51	-	4.5	125	-	-
Light Duty Waterproof	3.84	-	3.0	200	-	-

EXHIBIT G-4
Landing Mat Characteristics -
Hypothetical Sandwich Mats

Characteristics Mat Type	Mat Cost \$/Sq. Ft. Cost (M)	Mem Cost \$/Sq. Ft. MEMC (M)	Mat Wt. Lb/Sq. Ft. Wt (M)	Mat Place- ment Rate Sq. Ft./Man Hr. PLR (M)	Membrane Weight Lb/Sq. Ft. MEMW (M)	Membrane Placement Rate Sq. Ft./Man Hr. MEMP (M)
Heavy Duty	3.85	.21	6.5	150	.444	300
Medium Duty	3.50	.21	4.5	250	.444	300
Light Duty	3.15	.21	3.0	400	.444	300
Heavy Duty Waterproof	4.06	-	6.5	75	-	-
Medium Duty Waterproof	3.71	-	4.5	125	-	-
Lightduty Waterproof	3.36	-	3.0	200	-	-

EXHIBIT G-5
Landing Mat Characteristics -
Hypothetical Average Mats

Characteristics Mat Type	Mat Cost \$/Sq. Ft. Cost [M]	Mem Cost \$/Sq. Ft. MEMC [M]	Mat Wt. Lb/Sq. Ft. Wt [M]	Mat Place- ment Rate Sq. Ft./Man Hr. PLR [M]	Membrane Weight Lb/Sq. Ft. MEMW [M]	Membrane Placement Rate Sq. Ft./Man Hr. MEMP [M]
Heavy Duty	3.43	.21	6.5	150	.444	300
Medium Duty	3.40	.21	4.5	250	.444	300
Light Duty	3.39	.21	3.0	400	.444	300
Heavy Duty Waterproof	3.64	-	6.5	75	-	-
Medium Duty Waterproof	3.61	-	4.5	125	-	-
Light Duty Waterproof	3.60	-	3.0	200	-	-

EXHIBIT G-6
Landing Mat Characteristics
(Existing Mats)

Character- istics Mats	Cost \$/Sq. Ft.	Weight Lb. /Sq. Ft.	Placement Rate Sq. Ft. /Manhr.
Dow Truss Web	3.00	6.34	390
XM-20	3.00	6.05	310
XM-19	3.50	4.1	350
XM-18	3.30	4.8	350
AM-2	3.30	5.89	390
Goodyear All Bonded	3.30	4.07	275
Harvey Light Duty	3.63	3.07	225
M8A1	0.88	7.5	243

All existing mats were evaluated with membrane and with integral waterproofing.

EXHIBIT G-7
Description of Theater Airfields

Type of Field	Average Area in Sq. Ft. Area (F)	Average Sortie Distance in Miles Dist. (F)	Number of Each Type of Fields Num. (F)	CBR CBR (F)
Tactical Airfield	1,525,000	200	2	4
Heavy Lift Airfield	2,673,500	200	2	4
Medium Lift Airfield	785,700	200	5	4
Light Lift Airfield	275,500	100	6	4

EXHIBIT G-3
Coverage Capability of
Hypothetical QMR Mats

Aircraft	Light-Duty Mat		Medium-Duty Mat		Heavy-Duty Mat	
	Coverage Capability on 4 CBR	Equivalency Factor	Coverage Capability on 4 CBR	Equivalency Factor	Coverage Capability on 4 CBR	Equivalency Factor
C-130	1000	1.0	Unlimited	Insufficient	Unlimited	Insufficient
F-4C	17	.017	1,000	1.0	21,750	21.75
F-111B	8	.008	109	.109	1,000	1.0
F-111A	72	.072	13,990	13.99	Unlimited	Insufficient
C-5A	189	.189	Unlimited	Insufficient	Unlimited	Insufficient
C-141	15	.015	755	.755	14,309	14.31
C-135	62	.062	11,460	11.46	Unlimited	Insufficient
C-123	3140	3.14	Unlimited	Insufficient	Unlimited	Insufficient
C-7A	Unlimited	Insufficient	Unlimited	Insufficient	Unlimited	Insufficient

Notes:

1. An "unlimited" entry in the table was interpreted as a coverage capability of 25,000 coverages.
2. An insignificant equivalency factor indicates that operations of the listed aircraft have an insignificant effect on mat operational life.

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EXHIBIT G-9
Coverage Capability of
Existing Mats

Mat Aircraft	Dow Truss Web	XM-20	XM-19	XM018	AM-2	Goodyear	Harvey Light Duty	M8 A1
F-111B	1602*	620*	195	120	78	98	3	6
F-4C	34,844	13,485	1785*	1100*	714*	900*	6	13
C-130	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	367*	750*
C-123	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	1152	2355
C-7	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
C-141	22,923	8,872	1,348	831	539	680	6	11
C-5	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	69	142

*The astericked coverage figures represent actual test data furnished by WES. The remaining data were derived by using the equivalency factors developed for the coverage data in figure G-9.

EXHIBIT G-10
Landing Mat Performance
(Life in Months)
At CBR 4

Mat Type	Type of Air Field	Tactical	Heavy Lift	Medium Lift	Light Lift
QMR Hypothetical Mats					
Heavy Duty Mat		39.50	59.89	63.46	111.61
Medium Duty Mat		3.15	23.30	63.46	111.61
Light Duty Mat		0.09	0.59	2.78	111.61
Existing Mats					
Truss Web		59.17	61.73	63.46	111.61
XM - 20		25.01	56.75	63.46	111.61
XM - 19		5.95	32.69	63.46	111.61
XM - 18		3.66	24.94	63.46	111.61
AM - 2		2.38	18.68	63.46	111.61
Good Year Bonded		3.00	21.96	63.46	111.61
Harvey Light Duty		0.04	0.22	1.06	111.61
M8 - A1		0.08	0.42	2.16	111.61

EXHIBIT G-1:
Candidate Landing Mail System
Life-Cycle Cost For
6 Month Mission Requirement
On CBR-4

System No. - Item	Set - 1				Set - 2		Set - 3		Set - 4		Set - 5	
	LCC 11-07-20-1 (11-07-20-1)	LCC 11-07-20-2 (11-07-20-2)	LCC Average (11-07-20-1, 2)	Lead Life of the Mail on the System	LCC (11-07-20-1)	Lead Life of the Mail on the System	LCC (11-07-20-2)	Lead Life of the Mail on the System	LCC (11-07-20-1)	Lead Life of the Mail on the System	LCC (11-07-20-2)	Lead Life of the Mail on the System
1	403	416	409	39.5	64.2	2.18 (N)	37.5	39.17	37.5	39.17	37.5	39.17
2	443	416	429	3.15 (N)			41.2	1.66 (N)	28.3	5.91 (N)	41.2	1.66 (N)
3	371.9	371.2	371.5	0.09 (N)			342.6	0.09 (N)	342.6	0.09 (N)	342.6	0.09 (N)
4	377	377	377	39.5			34.6	38.17	33.0	38.17	34.6	38.17
5	403	377	390	2.78 (N)			36.3	2.78 (N)	36.3	2.78 (N)	36.3	2.78 (N)
6	310	314	312	22.7			31.5	24.84	28.7	32.60	31.5	24.84
7	174.6	174.1	174.3	0.39 (N)			164.1	0.39 (N)	164.1	0.39 (N)	164.1	0.39 (N)
8	315	315	315	23.30			31.6	24.84	28.7	32.60	31.6	24.84
9	443	416	429	3.15 (N)			31.6	2.78 (N)	49.6	2.78 (N)	31.6	2.78 (N)
10	443	416	429	3.15 (N)	63.2	2.38 (N)	31.6	2.78 (N)	49.6	2.78 (N)	31.6	2.78 (N)
11	421	410	415	42.5			407.7	3.15 (N)	37.5	39.17	407.7	3.15 (N)
12	367.7	367.0	367.3	0.09 (N)			311.4	0.09 (N)	311.4	0.09 (N)	311.4	0.09 (N)
13	315	315	315	39.5			32.0	39.17	30.6	39.17	32.0	39.17
14	315	315	315	2.78 (N)			33.7	2.41 (N)	33.7	2.78 (N)	33.7	2.78 (N)
15	315	315	315	23.3			29.1	24.84	28.3	32.60	29.1	24.84
16	174.6	174.1	174.3	0.39 (N)			164.1	0.39 (N)	164.1	0.39 (N)	164.1	0.39 (N)
17	315	315	315	2.78 (N)			29.4	24.84	27.1	32.60	29.4	24.84
18	419	443	431	2.78 (N)			31.1	2.78 (N)	49.0	2.78 (N)	31.1	2.78 (N)

NOTE: (N) denotes the system not meeting the 6 month CBR-4 life criterion.

The system life-cycle costs displayed in Exhibit G-12 are based on an airfield life requirement of 6 months on subsurface of CBR 4.

5. Results of Sensitivity Analyses

Exhibits G-10 and G-11 (cited earlier in this annex) presented the results of Performance submodel and Life-Cycle Cost submodel exercises assuming a 6-month airfield life requirement at CBR 4.

As described in Chapter III of the report, sensitivity analysis model exercises were conducted at CBR values of 2, 6, and 8, and for airfield life requirements of 3 and 24 months.

The results of these model exercises are presented in Exhibits G-12, G-13, and G-14 as follows:

- . Exhibit G-12 displays the variations of mat life (for the three duty classes of hypothetical mats) on operational airfields as a function of variations in subsoil strength. These results were obtained from the Performance submodel.
- . Exhibit G-13 displays the variations of candidate system life-cycle costs as a function of variations in subsoil strength with required airfield life held constant at 6 months.
- . Exhibit G-14 displays the variations of candidate system life cycle costs as a function of required airfield life at a CBR of 4.

EXHIBIT G-12
Sensitivity Analysis
Mat Life VS CBR
(Hypothetical Mats)

Field	*Months of Mat Life											
	Heavy Duty Mat						Medium Duty Mat					
	CBR						CBR					
	2	4	6	8	2	4	6	8	2	4	6	8
Taxiway	246	40	334	2008	38	32	17	67	028	09	25	55
Hy. Lift	235	670	9489	95850	27	34	235	1279	099	56	18	47
Med Lift	2968	3.2×10^4	1.1×10^9	2.4×10^{11}	47	7736	5.5×10^3	2.8×10^7	2	29	25	190
Lt Lift	1.9×10^5	2.8×10^{10}	5.3×10^{21}	5.2×10^{36}	5.2×10^6	1.7×10^{11}	1.2×10^{15}	5.7×10^{18}	99	20610	2×10^6	1.5×10^9

*Note For the purposes of this exhibit the coverage capability of the Mats on fields is not limited artificially to 25,000 coverages so that the true impact of CBR on life of the Mat can be shown.

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EXHIBIT G-13
Landing Mat System Life Cycle
Costs for 6 Month Mission
Requirement On Various
CBR Values
(Hypothetical Mats)

System	Life Cycle Cost in Millions of Dollars			
	Sub Soil Strength			
	CBR - 2	CBR - 4	CBR - 6	CBR - 8
1	63.49	40.7	40.17	40.11
2	169.76	44.9	31.28	29.79
3	2095.25	542.0	218.74	110.85
4	60.91	37.9	35.91	37.25
5	280.46	59.0	37.93	34.08
6	88.53	35.2	32.68	33.17
7	877.26	166.3	73.06	44.55
8	89.01	35.7	33.86	33.63
9	390.71	67.4	30.50	28.01
10	61.44	38.7	38.09	38.03
11	165.76	42.5	29.00	27.51
12	2053.71	530.8	213.68	107.29
13	58.78	35.7	35.16	35.10
14	274.48	56.5	32.92	31.88
15	85.99	33.0	31.17	30.94
16	853.25	162.3	70.59	42.04
17	36.45	33.4	31.61	31.39
18	384.91	66.7	30.20	27.73

EXHIBIT G-14
Landing Mat System Life Cycle
Costs for Various Mission
Life Requirements On
CBR-4
(Hypothetical Mats)

System	Life Cycle Cost in Millions of Dollars		
	System Life (Months)		
	3	6	24
1	39.51	40.75	48.22
2	33.97	44.93	99.54
3	293.41	542.01	2005.03
4	36.66	37.89	45.29
5	45.64	59.00	110.63
6	33.29	35.20	54.83
7	103.76	166.37	513.45
8	33.75	35.66	55.28
9	44.35	67.44	166.28
10	37.43	38.67	46.12
11	31.68	42.54	96.61
12	286.97	530.84	1965.76
13	34.51	35.70	43.11
14	43.30	56.52	107.57
15	31.06	32.96	52.41
16	100.76	152.26	502.98
17	31.51	33.41	52.85
18	43.83	66.75	164.94

EXHIBIT G-15
Comparison of Life Cycle Costs
At 6 Month Mission Life, At
Various CBRs for Certain
Medium Duty Landing Mats
(Millions of Dollars)

CBR MATS	2	4	6	8
Hypothetical	169.75	44.9	31.28	29.79
AM2	219.	64.2	40.4	38.4
NM-18	147	43.2	30.2	25.8
NM-19	89.5	26.3	16.7	15.7

EXHIBIT G-16
Existing Medium Duty
Landing Mat Life in Months
on a Heavy Lift Field at Various
CBRs.

MATS \ CBR	2	4	6	8
Hypothetical	1.9	23	160	875
AM2	1.5	19	131	715
XM-18	2.0	25	173	950
XM-19	2.7	33	228	1250

These data are based upon a 25,000 coverage limitation and represent a reasonable estimate of the variation in mat lives under changing CBRs and the expected life of each type mat under such conditions.

The implications of the results presented in this Annex are discussed in Chapter IV and V of the report.

ANNEX H

THE LANDING MAT EVALUATION MODEL COMPUTER PROGRAM

In this annex, the computer program of the Landing Mat Evaluation Model described in Annex F is presented. Exhibits F-1, F-3, and F-7 are the pictorial representation of program logic. As pointed out in Annex F, mat life and life-cycle cost are two outputs of the model. The inputs to the model are defined in Exhibit F-2.

The computer program, shown in Exhibit H-1, is written in basic English language on the Telecomp-II time sharing computer of Bolt Beranek and Newman, Inc. Summaries of the results of the program runs are presented in Exhibits G-12, G-13, and G-14.

EXHIBIT H-1
Computer Program

```

9.006 TYPE FORM 9.006
9.007 DO PART 9.01 FOR L=1:10 FOR M=1:13
9.008 DEMAND ELM,L,1 IN FORM 901 FOR I=1:10
9.009 TYPE #
9.010 DONE
9.018 SET ETR(M,L,1)=ELM,L,1 FOR M=1:13 FOR L=1:10 FOR I=1:10
9.02 SET LOD(L)=10000*L FOR L=1:10
9.03 SET IFR(1)=50, IFR(2)=60, IFR(3)=70, IFR(4)=80, IFR(5)=100, IFR(6)=150
9.031 SET IFR(7)=200, IFR(8)=250, IFR(9)=300, IFR(10)=400
9.035 DO PART 9.04 FOR C=1:1:GNU
9.036 DO PART 9.11
9.04 I=1
9.05 TO STEP 9.08 IF IFR(I)<=IFR(1)
9.06 I=I+1
9.07 TO STEP 9.05
9.08 X1=I
9.081 X1=X1+1 IF I=1
9.09 X2=X1-1
9.10 Y1=IF(ESWL(C)/10000)
9.101 Y1=1 IF Y1=0
9.11 Y2=Y1+1
9.12 DO PART 9.13 FOR M=1:13
9.13 ALF=(ETR(M,Y2,X1)-ETR(M,Y1,X1))*(ESWL(C)-LOD(Y1))/(LOD(Y2)-LOD(Y1))
9.131 ALF=ALF+ETR(M,Y1,X1)
9.14 HE1=(ETR(M,Y2,X2)-ETR(M,Y1,X2))*(ESWL(C)-LOD(Y1))/(LOD(Y2)-LOD(Y1))
9.141 HE1=HE1+ETR(M,Y1,X2)
9.15 INM(M,C)=(ALF-HE1)*(IFR(X1)-IFR(X2))/(IFR(X1)-IFR(X2))
9.151 INM(M,C)=INM(M,C)+HE1
9.16 DONE
9.17 TYPE FORM 917
9.171 TYPE M,C,INM(M,C) FOR M=1:13 FOR C=1:1:GNU IN FORM 9171
9.18 DO PART 9.185 FOR C=1:1:GNU FOR M=1:13
9.185 SOLM(C)=INM(M,C)/(0.23*SQRT((ESWL(C)/(8.1*GRH(F)))-(ICALC(C)/SF1)))
9.19 CC(M,C)=1-(SOLM(C)-.653)
10.01 TYPE "DO YOU WANT TO ADD NEW CHAPTERS IF NO NEW CHAPTERS ARE ADDED"
10.02 TYPE "THAN LOAD FILE      & TYPE 'DO PART 11' TO START "
10.03 DEMAND ANSWER FOR YES=1 , FOR NO=2
10.04 DONE IF ANSWER = NO
10.05 DEMAND GNU IN FORM 1005
10.051 SET F11H=1, F4C=2, C13F=3, F11A=4, C123=5, C7A=6, C141=7, C5A=8
10.052 TYPE FORM 1052
10.053 DEMAND CRIC,ESWL(C),IFR(C),ICALC(C),CFIC(C) IN FORM 105 FOR C=1:1:GNU
10.054 SET CHAP1(C)=CRIC,ESWL(C)=ESWL(C),CPS(C)=CFIC(C) FOR C=1:1:GNU
10.1071 TYPE " DO YOU WANT TO CHANGE TRAFFIC DATA YES OR NO "
10.1072 DEMAND ANSWER
10.1073 TO PART 11.108 IF ANSWER =NO
10.1074 TYPE FORM 1173, FORM 1174
10.1075 DEMAND SFMLC,FJ FOR F=1:1:4 FOR C=1:1:GNU
10.16 TO PART 9
11.101 TYPE " DO YOU WANT TO CHANGE THEATER OF OPERATION "
11.102 DEMAND CHANGE FOR YES = 0 FOR NO = 1
11.1021 TO PART 11.108 IF CHANGE =NO
11.103 TYPE " HOW MANY TYPES OF FIELDS "
11.104 DEMAND TYPES
11.105 TYPE "PLEASE 1.0. DATA "
11.1051 SET HLF=2 , MLF=3 , LLF=4 , IACF=1

```

EXHIBIT H-1 (Continued)

```

11.106 DEMAND IYFL(F),AREAL(F),DIST(F),NUM(F),CHRF(F) FOR F=1:1:1YFES
11.107 AREAL(F) = NUM(F) * AREAL(F) FOR F=1:1:1YFES
11.108 TYPE " ARE THERE ANY CHANGES IN MAI CHAR. ANSWER YES OR NO "
11.109 DEMAND ANSWER
11.110 IF PART 11.118 IF ANSWER = NO
11.112 DEMAND MAYFE
11.113 SET HUM=1, MUM=2, LUM=3, HUMWF=4, MUMWF=5, LUMWF=6
11.114 MA= MAYFE
11.116 DEMAND CUST(M),WIL(M),PLR(M) FOR M=1:1:MA
11.117 DEMAND SCFT, MHRC, SPEED, ITHSK, LIFSYS, PAY
11.118 TYPE "ARE THERE ANY CHANGES IN THE MAI SYSTEMS ANSWER YES/NO "
11.119 DEMAND ANSWER
11.120 IF PART 11.490 IF ANSWER = NO
11.121 DEMAND SYSNO
11.122 DEMAND MAIL(YF(F),S) FOR F=1:1:1YFES FOR S=1:1:SYSNO
11.2005 CC(M,C)=25000 IF CC(M,C)>25000 FOR M=1:1:3 FOR C=1:1:1CNU
11.201 CFMLC(F)=SPMLC(F)*CFS(C) FOR F=1:1:4 FOR C=1:1:1CNU
11.203 LRFL(M,F,C)=CFMLC(F)/CC(M,C) FOR C=1:1:1CNU FOR F=1:1:4 FOR M=1:1:3
11.2031 DO PART 11.204 FOR F=1:1:4 FOR M=1:1:3
11.2033 DO PART 11.20602
11.204 ILRM(M,F)=ILRM(M,F)+LRFL(M,F,C) FOR C=1:1:1CNU FOR ILRM(M,F)=0
11.205 LIFE(M,F)=1/ILRM(M,F)
11.2051 LIFE(M,F,CHR(F))=LIFE(M,F)
11.206 DONE
11.20602 TYPE #, FORM 1129
11.2061 TYPE CBR(1) IN FORM 1126
11.20611 TYPE #, FORM 1127
11.20618 DO STEP 11.2062 FOR M=1:1:3
11.2062 TYPE M, LIFE(M,1),LIFE(M,2),LIFE(M,3),LIFE(M,4) IN FORM 1128
11.2068 DONE
11.207 TYPE LIFE(M,F) FOR M=1:1:3 FOR F=1:1:4
11.48 TYPE FORM 2
11.49 SET LOCTO(S)=0 FOR S=1:1:SYSNO
11.491 TYPE #, #, FORM 2
11.5000 DO PART 11.5002 FOR F=1:1:1YFES FOR S=1:1:SYSNO
11.5002 SET J=F, I=S
11.501 M=MAIL(S,F)
11.5011 SET LIFE(M,F)=LIFE(M,F,CHR) IF M<=3
11.5012 LIFE(M,F)=LIFE(M-3,F,CHR) IF M>3
11.502 PERC(F) = (CUST(M)+MEMCL(M)) * AREAL(F)
11.503 USSC(F) = (WIL(M)+MEMW(M))*AREAL(F)*SCFT/2000
11.504 ITSC(F)=(AREAL(F)*(WIL(M)+MEMW(M))/PAY)*(0.5+DIST(F)/SPEED)*ITHSK
11.505 MFPLC(F)=MHRC*(AREAL(F)/PLR(M))
11.5051 MEMFLC(F)=MHRC*AREAL(F)/MEMF(M) IF MEMF(M)>0
11.5052 MEMFLC(F)=0 IF MEMF(M)=0
11.5053 FLC(F)= MFPLC(F)+MEMFLC(F)
11.506 CUF(F)=PERC(F)+USSC(F)+ITSC(F)+FLC(F)
11.507 MAINC(F)=.1*(CUF(F)+MFPLC(F))+LIFSYS/LIFE(M,F)
11.508 NR(F)=IF(LIFSYS/LIFE(M,F))
11.509 NR(F)=NR(F)-1 IF F P(LIFSYS/LIFE(M,F))=0
11.510 KFLC(F)=0.33*NR(F)*(CUF(F)+MFPLC(F))
11.5105 S(F)=.33*(LIFE(M,F)*(NR(F)+1)-LIFSYS)/LIFE(M,F)
11.511 SVC(F)=PERC(F)*((.67-.33*NR(F))+S(F))-ITSC(F)-FLC(F)
11.512 SVC(F)=0 IF SVC(F)<=0
11.513 LOC(F)=CUF(F)+MAINC(F)+RPLC(F)-SVC(F)
11.514 TYPE LOC(F),PERC(F),CUF(F),RPLC(F),MAINC(F),SVC(F) IN FORM 1

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EXHIBIT H-1 (Continued)

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11.5141 TYPE # 1P P=4
11.515 LCC10(S)=LCC10(S)+LCC1P
11.516 DONE
11.517 TYPE #,0,FORM 517, FORM 518
11.518 TYPE LIPSYS IN FORM 519
11.519 TYPE CRF IN FORM 520
11.520 TYPE #, FORM 521, #
11.5201 TYPE S,LCC10(S) IN FORM 522 FOR S=1111SYSNO
11.522 DONE
1500 1500
FORM      1
#####
FORM      2
LCC      PERC      PLACED&DEL.      REPLAC      MAIN      SALVAGE
FORM      22
#
FORM      517
MAT SYSTEM LIFE CYCLE COST
FORM      518
-----
FORM      519
SYSTEM LIFE= ## MONTH
FORM      520
CRF= #
FORM      521
SYSTEM      LIFECYCLE COST
FORM      522
##      #####
FORM      901
###.#
FORM      917
MAT CRAFT THICKNESS REDUCTION
FORM      1005
NUMBER OF CRAFTS CONSIDERED = ##
FORM      1052
CRAFT ESWL PRESSURE CON AREA COV/SURFIE
FORM      1053
#####
FORM      1126
CRF= ##
FORM      1127
MAT TACT FIELD HEAVY FIELD MED. FIELD LIGHT FIELD
FORM      1128
## #####.## #####.## #####.## #####.##
FORM      1129
MAT LIFE IN MONTHS
FORM      1138
## #.####111 #.####111 #.####111 #.####111
FORM      1173
TRAFFIC DATA
FORM      1174
CRAFT TACT.FIELD HEAVY FIELD MED.FIELD LIGHT FIELD
FORM      1175
#####
FORM      9171
## ## #####.##

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ANNEX I
DATA SOURCES

1. Purpose

This annex lists the principal sources of data used in the study, describes the types of data obtained from those sources, and provides a bibliography of principal reference documents.

2. Data Sources

The data collection efforts focused on three major sources. They were the U. S. Army Engineer Waterways Experiment Station, the U. S. Army Combat Developments Command, and the principal landing mat manufacturers.

The Waterways Experiment Station, as the landing mat development agency, supplied design, test, and cost data from many previous landing mat programs, and was the principal source of data used in the study. The design and test data were supplied in the form of numerous engineering reports generated over many years of landing mat development efforts. The bibliography at the end of this section lists only the principal documents from which reference material was obtained.

The U. S. Army Combat Developments Command served as a major source of operational concept data in the form of documentation of previous studies which included the employment of expedient-surfaced airfields in the theaters of operations. These study documents are also listed in the bibliography.

The third major source of data was composed of a group of private companies which have been heavily involved in landing mat design, development, and production for many years. The firms contacted during the study were:

- . Harvey Aluminum Company, Torrance, California
- . Kaiser Aluminum and Chemical Company, Oakland, California
- . Goodyear Aerospace, Inc., Akron, Ohio
- . Dow Chemical Company, Midland, Michigan.

These four firms have been, in recent years, the principal manufacturers of landing mats, and were particularly helpful in supplying cost projections for landing mat production.

BIBLIOGRAPHY

1. U.S. Army Engineer Waterways Experiment Station, Evaluation of Washington Aluminum Company, Inc. Production AM2 Landing Mat, by C. D. Burns and D. P. Wolf, Miscellaneous Paper S-69-3, Vicksburg, Mississippi, January 1969.
2. U.S. Army Engineer Waterways Experiment Station, Evaluation of May Two-Piece AM2 Landing Mat, by R. W. Grau, Miscellaneous Paper S-68-11, Vicksburg, Mississippi, July 1968.
3. U.S. Army Engineer Waterways Experiment Station, Evaluation of Harvey Two-Piece Landing Mat (AM2), by C. D. Burns and W. R. Barker, Miscellaneous Paper No. 4-852, Vicksburg, Mississippi, November 1966.
4. U.S. Army Engineer Waterways Experiment Station, Evaluation of Dow Chemical Extruded Landing Mat, by H. L. Green and G. L. Carr, Miscellaneous Paper S-68-9, Vicksburg, Mississippi, July 1968.
5. U.S. Army Engineer Waterways Experiment Station, Evaluation of Dow Chemical Extruded Aluminum Landing Mat (XM18E1), by D. W. White and C. J. Gerard, Miscellaneous Paper S-69-51, Vicksburg, Mississippi, December 1969.
6. U.S. Army Engineer Waterways Experiment Station, Evaluation of Dow Chemical Extruded Aluminum Landing Mat (Modified MX18-B), by L. R. Lenzner, Miscellaneous Paper S-69-4, Vicksburg, Mississippi, February 1969.
7. U.S. Army Engineer Waterways Experiment Station, Engineering and Laboratory Tests of M8A1-A Steel Landing Mat, by D. W. White, Jr., Miscellaneous Paper No. 4-967, Vicksburg, Mississippi, February 1968.
8. U.S. Army Engineer Waterways Experiment Station, Evaluation of Kaiser Aluminum Honeycomb Landing Mat, by R. Turner and G. L. Carr, Miscellaneous Paper No. 4-897, Vicksburg, Mississippi, August 1967.

9. U.S. Army Engineer Waterways Experiment Station, Evaluation of Goodyear All-Bonded Aluminum Honeycomb Landing Mat, by C. T. McCormick and G. L. Carr, Miscellaneous Paper S-69-49, Vicksburg, Mississippi, December 1969.
10. U.S. Army Combat Developments Command, Airfield Construction Requirements in the Theater of Operations, 1966-1970 (U), March 1967.
11. U.S. Army Combat Developments Command, Army Logistics Support Concepts, Air Lines of Communications, LOG-ALOC II, (U), 1969.
12. COMUSARV, Cost Effectiveness Analysis of the XM19 Landing Mat for C-130 Airfields in RVN (U), 1966.
13. Department of the Army, Planning and Design for Rapid Airfield Construction in the Theater of Operations, Technical Manual 5-366, November 1965.