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CARGO COMPARTMENT OPTIMIZATION STUDY, ARMY TRANSPORT AIRCRAFT

By

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September 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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Final Report

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SUMMARY

The purposes of this task were to formulate an appropriate study framework for investigating the effects of cargo-compartment size on the utility of Army transport aircraft and to collect the necessary basic data to support such a study. The ultimate objective was the development of a methodology that would enable the judicious design selection of optimal compartment dimensions.

A workable methodology was derived following a thorough review of previous cargo-compartment sizing analyses for transport aircraft. This parametric-type analysis includes a fit-compatibility phase for deriving a set of minimum desirable compartment dimensions, a transport-efficiency phase for modifying these minimum dimensions if warranted from efficiency considerations, and a historical-comparison phase for comparing the design dimensions with those of previously built aircraft.

Since an efficient compatibility between the aircraft and the transportable cargo is necessary to realize proper utilization of the aircraft capabilities, it is essential to conduct a thorough, detailed selection of the cargo-compartment dimensions early in the design phases for future Army transport aircraft.

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INTRODUCTION

Continual efforts have been and are being made by those concerned with air-transport operations to increase the effectiveness and the efficiency of air-transportability. Past efforts to achieve these gains have concentrated primarily on improvement of the aircraft performance capabilities. It is becoming increasingly apparent, however, that the realization of such gains, made possible by improved performance capabilities, is contingent upon the assurance of an efficient compatibility between the aircraft and the transportable cargo.

To this end, AR 705-35[7] has been prepared as a guideline for insuring an air-portable and an airdrop capability for materiel developed and procured by the U. S. Army. This regulation is indicative of those efforts which would strive to achieve compatibility by regulating the dimensions and weights of air-portable items in their design and developmental phases. A second approach is to size the cargo compartments of transport aircraft for optimal compatibility with the air cargo. Suitable implementation and coordination of these two approaches can do much toward achieving greater efficiency and effectiveness in air-transport operations.

In recognition of the necessity for developing a program to enable the efficient sizing of the internal cargo compartments of future Army transport aircraft, initiation of a house task was requested on 16 November 1964 and, following approval, assignment for its execution was made to the Aircraft Systems and Equipment Division on 15 January 1965. The purposes of this task were to collect necessary basic data and to formulate an appropriate study framework for investigating the effects of cargo-compartment size on the utility of Army transport aircraft.

TECHNIQUES OF SIZING ANALYSES

In this section are presented some of the basic ideas and techniques underlying efforts to size the cargo compartments of transport aircraft. Emphasis is placed on those Army aircraft which provide retail transportation support for Army units.

First, it is necessary to look in a general way at how Army transport aircraft are utilized in the performance of their transport missions in order to gain some understanding of the nature of the cargo to be transported. This is followed by a discussion of several supplementary factors, such as clearances between loaded vehicles, which are essential inputs to a sizing investigation.

Then a discussion is presented relative to criteria that may be used for selecting an optimally sized cargo compartment. Various techniques for computing the number of aircraft sorties for transporting a given cargo set are next mentioned. Finally, several other related matters are enumerated, the consideration of which is necessary to realize the benefits of optimally sizing the cargo compartments of transport aircraft.

UTILIZATION OF ARMY TRANSPORT AIRCRAFT

Perhaps the most significant factor in a sizing investigation relates to the nature of the cargo to be transported. This, in turn, is a function of the mission utilization of the aircraft. It is anticipated that Army aircraft are to be employed primarily in four general roles as they relate to the transport function. These include unit deployment and tactical mobility, resupply, casualty evacuation, and retrograde movements. Additional employment of transport aircraft in other than transport roles must not be influential in the selection of cargo-compartment dimensions.

The Deployment Role

One of the primary missions assigned to Army aircraft is the deployment of combat units (including men, equipment, and supplies) into forward areas and subsequent redeployment (tactical mobility) in response to a changing tactical situation. It is unnecessary to treat these two related missions as other than a single transport role since, in either case, the cargo configuration is predicated upon anticipated delivery in a combat environment.

Company-sized and battalion-sized combat units of the airmobile, infantry, and airborne divisions are likely to be the most prevalent to participate habitually in deployments by Army aircraft. In addition to the predominant air-landed delivery, airdrop delivery is used with fixed-wing aircraft as required.

For the purposes of a study such as the one proposed herein, the following guidelines may be assumed to govern the conduct of air-landed deployment operations:

1. Within each serial, the tactical integrity of the transported unit is maintained to promote mission effectiveness at the delivery site.

2. Key personnel and critical items of equipment are distributed among the aircraft so that a loss of any one aircraft does not critically impair the functioning of the unit.

3. At the same time, each aircraft load should be at least temporarily self-sufficient in the event that the aircraft lands in an isolated location.

4. There may be some priority in the sequence of delivery, particularly when several serials are required to transport the unit.

5. Each aircraft load should contain those personnel (1) required to operate the accompanied equipment, (2) necessary to off-load the accompanied equipment and supplies, and (3) to be transported by the accompanied equipment in a tactical situation.

6. All personnel should be provided adequate seating and restraining devices.

7. Vehicles are transported in a combat configuration. This requires that (1) they are fueled to approximately three-fourths capacity, (2) they are loaded to a maximum, cross-country payload of accompanying cargo, (3) integrally mounted equipment is not removed for transport, (4) substantial modifications are not made in an effort to reduce the shipping dimensions, and (5) towed vehicles are loaded with their prime movers in a hitched configuration.

8. Ammunition accompanies each crew-served weapon.

9. As far as practical, full utilization is made of both payload and space capacities of each aircraft.

The Resupply Role

Another primary mission assigned to Army transport aircraft is that of resupply of Army units, either on a scheduled or on an as-required basis. Both air-landed and airdrop modes of delivery are employed. The primary commodities delivered are those consumed on a daily basis; in particular, ammunition, fuel, and rations. Much of the resupply cargo may be delivered on 40-by-48-inch expendable pallets with the 500-gallon, collapsible fuel drum playing a significant role in the delivery of fuel. Future requirements for the air transport of resupply cargo may introduce significantly different cargo configurations, for example, 463L-type loaded platforms.

The Casualty-Evacuation Role

A third primary mission of Army transport aircraft is that of casualty evacuation. Typical loads consist of litter patients, ambulatory patients, and attendant equipment and personnel. This mission is of sufficient importance that typical casualty-evacuation loads must be considered in a sizing investigation, not only to preclude gross inconsistencies but also to provide efficient compatibilities.

The Retrograde Role

Secondary to these primary roles, Army transport aircraft can be expected to be utilized in the return phase of the resupply cycle for retrograde cargo transport. A large gamut of cargo types is transported during retrograde movements, including collapsed 500-gallon fuel drums, repairable equipment, supplies being redistributed to meet changing requirements, refugees, prisoners of war, casualties, and many others. Since this type of movement is considered to be of secondary importance and since the cargo types are, by and large, represented in the three primary roles, the compartment dimensions may be appropriately selected without separate consideration of the use of the aircraft in the retrograde role.

SUPPLEMENTARY INPUT FACTORS FOR SIZING INVESTIGATIONS

In addition to a prior knowledge of the characteristics and quantities of the various types of cargo to be transported and the rules or guidelines governing their transport, certain other input data are required for use in a sizing investigation.

Consider first the necessity for providing adequate clearances between the sides, ends, and top of the cargo compartment and the transported cargo, as well as clearances between adjacent items of cargo in the loaded aircraft. Such clearances are required for maneuvering the loads during the loading and unloading operations, for restraining the loads, and for providing walkways within the aircraft.

AR 705-35 specifies a minimum lateral clearance of 5 inches on each side of the aircraft during and after loading. The efficiency and safety of the loading and unloading operations, for loads which must be maneuvered into final position (not guided), are drastically reduced if this minimum lateral clearance is not strictly adhered to; hence, the minimum clearance must never be compromised. This regulation also specifies a 6-inch vertical clearance after loading.

Longitudinal and transverse clearances between loaded items are necessary, primarily for providing walkways and space for load restraint. Intervehicular space of 8 inches is perhaps the minimum acceptable for these purposes. More is desirable, however, particularly in the longitudinal direction. For adjacent, loaded pallets, additional clearance is required, both to provide working space for personnel and to provide clear access to appropriate tie-down fittings. A detailed analysis which considers the method of restraint and the location of tie-down fittings is necessary to yield accurate estimates of required interpallet clearances.

Now the primary factors that should govern the selection of compartment dimensions are those of effectiveness and efficiency. However, other factors restrict the designer's freedom to perform this selection. The following exemplify this set of input factors:

1. Managerial or political decisions, based on jurisdictional or historical considerations rather than more technical ones, may limit the range of acceptable compartment dimensions.

2. In the event that pressurization of the compartment is required, the external aircraft shape must be structurally amenable to such pressurization. This may influence the internal compartment dimensions.

3. In a similar manner, the external shape may be influenced by aerodynamic considerations.

Finally, the designer must be aware that the dimensions derived from the efficiency and effectiveness analyses are clear or usable dimensions. They must be modified as necessary to account for unusable space, such as that caused by impediments within the compartment (for example, wheel wells) and either integral or removable equipment which is used to assist the cargo-handling operations.

CRITERIA FOR OPTIMAL SIZING

One of the historically significant techniques for selecting the cargo-compartment dimensions of transport-type aircraft is that based primarily on estimates of average cargo density. The design compartment volume (or floor area) is calculated directly from the aircraft allowable cargo load and the estimated average cargo density (or average cargo floor loading) with due allowances made for such factors as average packing efficiency, average weight-loading efficiency, density variations, and unusable space such as aisle space and clearances.

This approach may be satisfactory if the cargo can be treated as an amorphous mass (such as small parcels) and if the various modifying factors (such as packing efficiency) are relatively independent of aircraft size and cargo configuration. However, in sizing small Army transport aircraft which carry relatively large, whole units of cargo, both the weight fit and the space fit become critically important and highly dependent upon the exact compartment dimensions. At the same time, additional guidance is necessary concerning the optimal relationships among compartment length, width, and height. Therefore, the density method of sizing is not sufficiently responsive to Army requirements.

Alternative methods of size determination are available which differ significantly in philosophy from the density method. These methods are characterized by a parametric-type analysis in which the cargo-compartment dimensions are varied over wide ranges and in which the efficiency and capability of each set of dimensions are determined. The primary question then becomes: which of the several alternative compartments is optimal?

The critical element of such a design becomes the criterion used to select the optimal set of dimensions among all the alternatives considered. It is the intent, herein, to examine possible criteria for use in sizing analyses.

Fit Compatibility - Essential Items

In virtually every sizing determination, it is not only possible but also necessary to identify certain cargo items essential for proper mission performance of the supported units which must be portable in the design aircraft. An analysis of the dimensions of these items provides the foundation for establishment of minimum acceptable compartment dimensions.

The criterion for comparison of alternative compartment sizes in such a situation becomes a fit-compatibility or go/no-go check. Compartment sizes not amenable to the transport of all essential items must be immediately rejected as not responsive to the aircraft requirements. This criterior, then, provides a first procedure for distinguishing the set of acceptable compartment dimensions from those unacceptable under all circumstances. Another criterion is necessary to identify the optimal size from among the set of acceptable compartments.

Fit Compatibility - Other Items

In addition to the limited number of absolutely essential cargo items, there are significant quantities of other items having weights less than the design allowable cargo load which, if portable in the design aircraft, would greatly enhance its utility and capability for providing responsive air-transport support.

For those circumstances in which it is unnecessary to identify these items by nomenclature, a simple measure can be used to compare alternative designs. First, an appropriate pool of cargo items must be identified. This pool may consist of all items (having weights less than the aircraft allowable cargo load) in the Army inventory or in the TOE's of particular Army units, such as a ROAD infantry division, or it may consist of any other pertinent set of cargo items. An appropriate criterion is the percentage of items (by weight, by volume, or by number of items) in the pool which are portable in the proposed aircraft.

That alternative compartment size which maximizes the portable percentage of the item pool becomes the optimal compartment. Unfortunately, this criterion never decreases with increasing compartment size. Because of this, its primary utility is realized in identifying break points at which significant gains can be achieved with small dimensional increases.

Transport Efficiency

The above two criteria, based on fit compatibility, may be adequate by themselves for aircraft having small allowable cargo loads, particularly when the typical aircraft load consists of one or two cargo items. However, for larger allowable cargo loads, it is important to size the compartment for an efficient fit of several items in each aircraft load. In such situations, other more responsive criteria for comparison must be sought.

Common to all comparisons of this nature is the necessity for establishing one or more typical transport missions which define, in large measure, the nature of the cargo to be transported. The basis for comparison, then, is how well each of the alternative aircraft performs the stated missions. However, before valid comparisons can be made, it is important to assure that the alternative aircraft designs have equivalent capabilities in terms of the specific items that can be transported. For example, these techniques would not be valid for comparing directly the efficiencies of two aircraft in deploying an infantry battalion if the compartment dimensions are such that one of the two aircraft can carry the 3/4-ton cargo truck while the second cannot.

Maximum Average Payload Utilization

The cargo-carrying capability of transport aircraft is contingent upon the provision of both weight-lifting capacity (payload) and space-carrying capacity. Payload is often considered to be the more critical of these two capacities, since it is one of the most important of the aircraft design parameters and one that materially affects the performance capabilities. It may be reasoned, therefore, that to utilize the aircraft effectively, its payload must be utilized to the maximum possible extent.

On the basis of this rationale, the compartment dimensions may be selected to yield a maximum average payload utilization for the performance of a particular mission or set of missions. By calculating the average payload utilization for each of several sets of compartment dimensions, a series of curves may be developed as illustrated in Figure 1. The shapes of the curves shown in this figure (and those immediately following) are hypothetical and are for illustrative purposes only. While discontinuities are present in actual curves, these hypothetical curves are shown as continuous functions for simplicity and clarity.

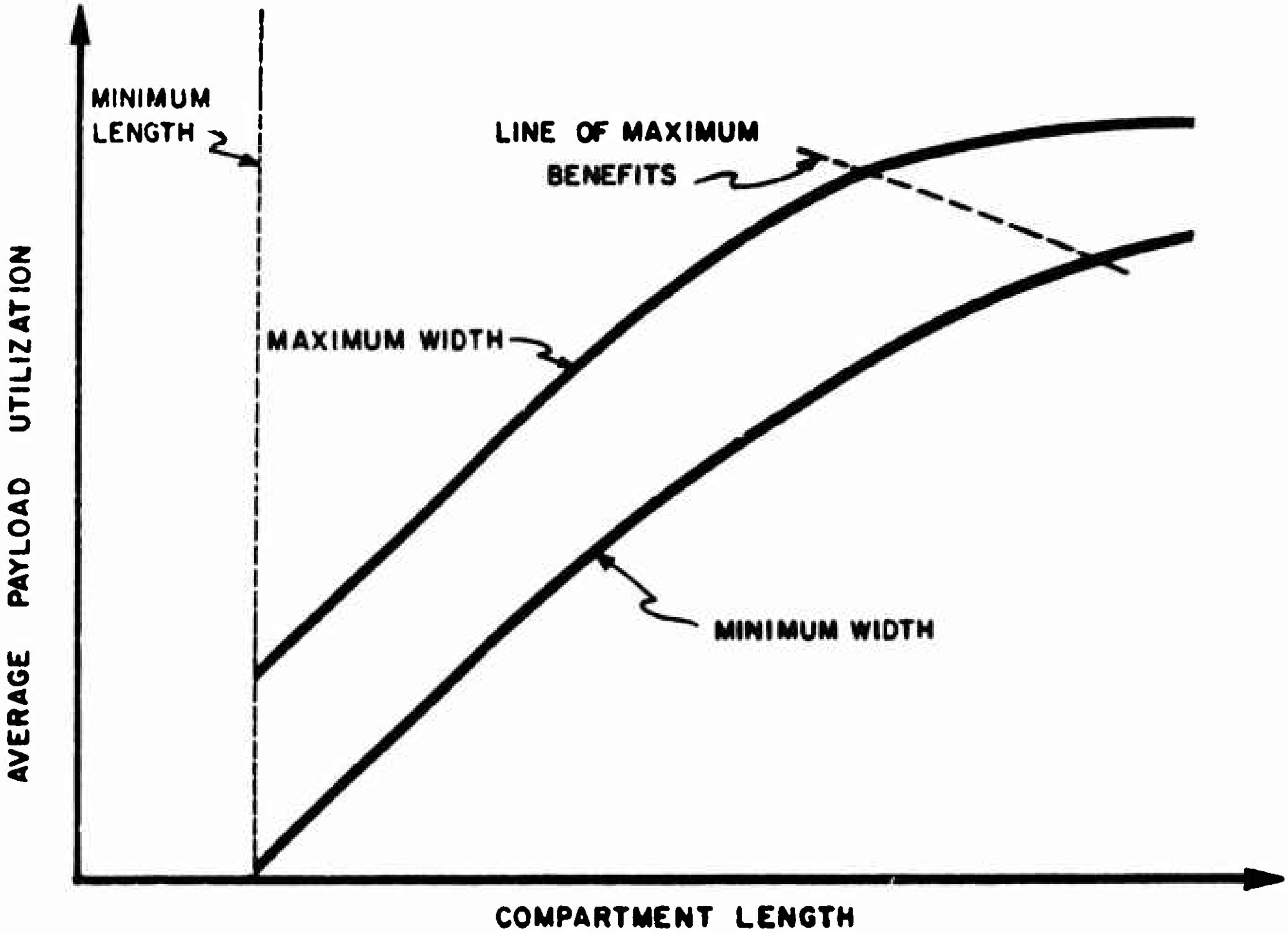

Figure 1. Hypothetical Example - Criterion of Maximum Average Payload Utilization.

For small compartment lengths and widths, the average payload utilization is small because a large number of the required sorties are space limited. As the length increases to that point at which it is sufficiently large to accommodate all combinations of cargo having total weights less than the aircraft payload, the average payload utilization likewise increases. As the width increases above the minimum, average payload utilization is increased if side-by-side packing of cargo within the aircraft can be more fully exploited.

A set of large compartment dimensions would be selected if the criterion of maximum average payload utilization were strictly adhered to. Intuitively, it is felt that somewhat smaller dimensions can be tolerated that will result in more economical operation without extreme sacrifices in payload utilization. The line of maximum benefits, shown in Figure 1, illustrates this intuitive compromise. Unfortunately, the location of this line is a matter of individual judgment.

This particular criterion of transport efficiency has the very serious disadvantage of failure to economize objectively in the transport operation. The excessive compartment dimensions that may be provided heavily weight the balance between weight-limited and space-limited sorties toward the weight-limited side. The primary utility of the maximum-payload-utilization criterion is that it enables the identification of points at which significant benefits can be achieved with minor increases in compartment dimensions.

Maximum Average Space Utilization

In addition to the desirability of fully utilizing payload capacity, it is likewise desirable to make full use of the space-carrying capacity. Therefore, it is wise to examine a second possible criterion of transport efficiency, namely, maximum average space utilization.

Curves similar to those of Figure 1, but germane to the criterion of space utilization, are illustrated in Figure 2. The general trend

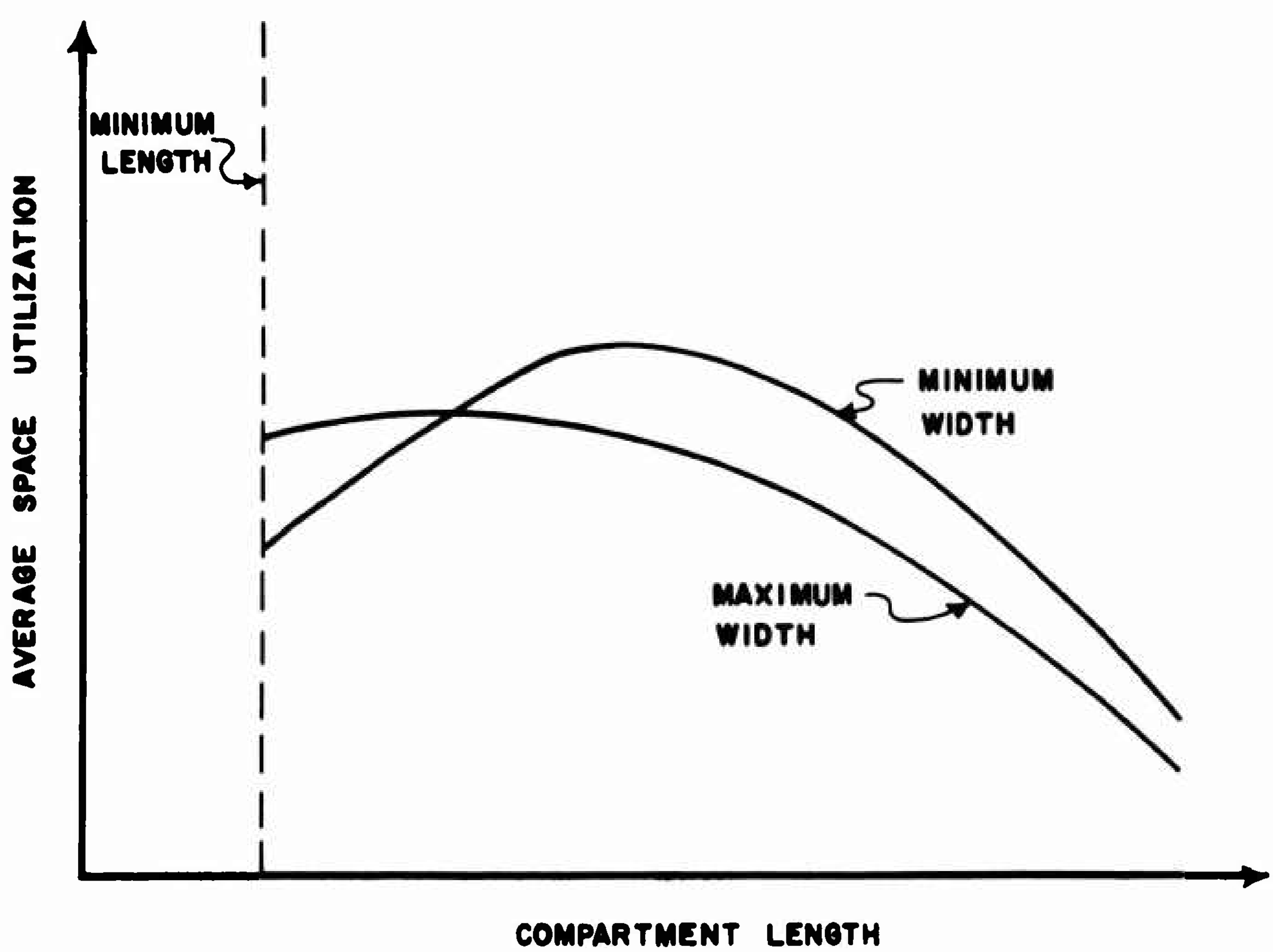

Figure 2. Hypothetical Example - Criterion of Maximum Average Space Utilization.

evidenced by these curves is for average space utilization to reach a maximum at an intermediate compartment length. This maximum is reached at a length sufficiently large to allow efficient length utilization because of a variety of potential end-to-end packing arrangements but, at the same time, sufficiently small so that a limited number of flights are weight limited.

At smaller compartment lengths, efficient side-by-side packing may increase the space utilization for the large widths. However, if such efficiencies are impossible to achieve, excess width will only decrease the space utilization. At very large lengths, the available payload can be reached simply by end-to-end packing. For such a condition, the space utilization will reach its maximum at the smallest compartment width.

If the maximum-average-space-utilization criterion were strictly applied, the tendency would be to select small compartment dimensions. This would result in a large number of space-limited flights in proportion to the number of weight-limited flights. The available payload could not then be well utilized, and the cost for providing this payload would be sacrificed.

Maximum Average Composite Utilization

Neither the criterion of maximum average payload utilization nor that of maximum average space utilization seems sufficient in itself, since neither assures an efficient balance between the number of weight-limited and space-limited sorties. Clearly a compromise between the payload-utilization and space-utilization criteria is indicated to achieve an efficient aircraft design. A third possible criterion, maximum average composite utilization, represents a first attempt to achieve this compromise.

The composite-utilization factor may be defined in a number of ways to reflect the joint effect of both payload and space utilizations. At the same time, subsequent discussion can be clarified without loss in generality by defining composite utilization as the sum of the space utilization and the payload utilization. The attempt, then, is to select a set of compartment dimensions which maximizes the average composite utilization.

Curves that might be applicable to such an attempt are illustrated in Figure 3. It is likely to expect that, for a given width, the average composite utilization will reach a maximum at some moderate length

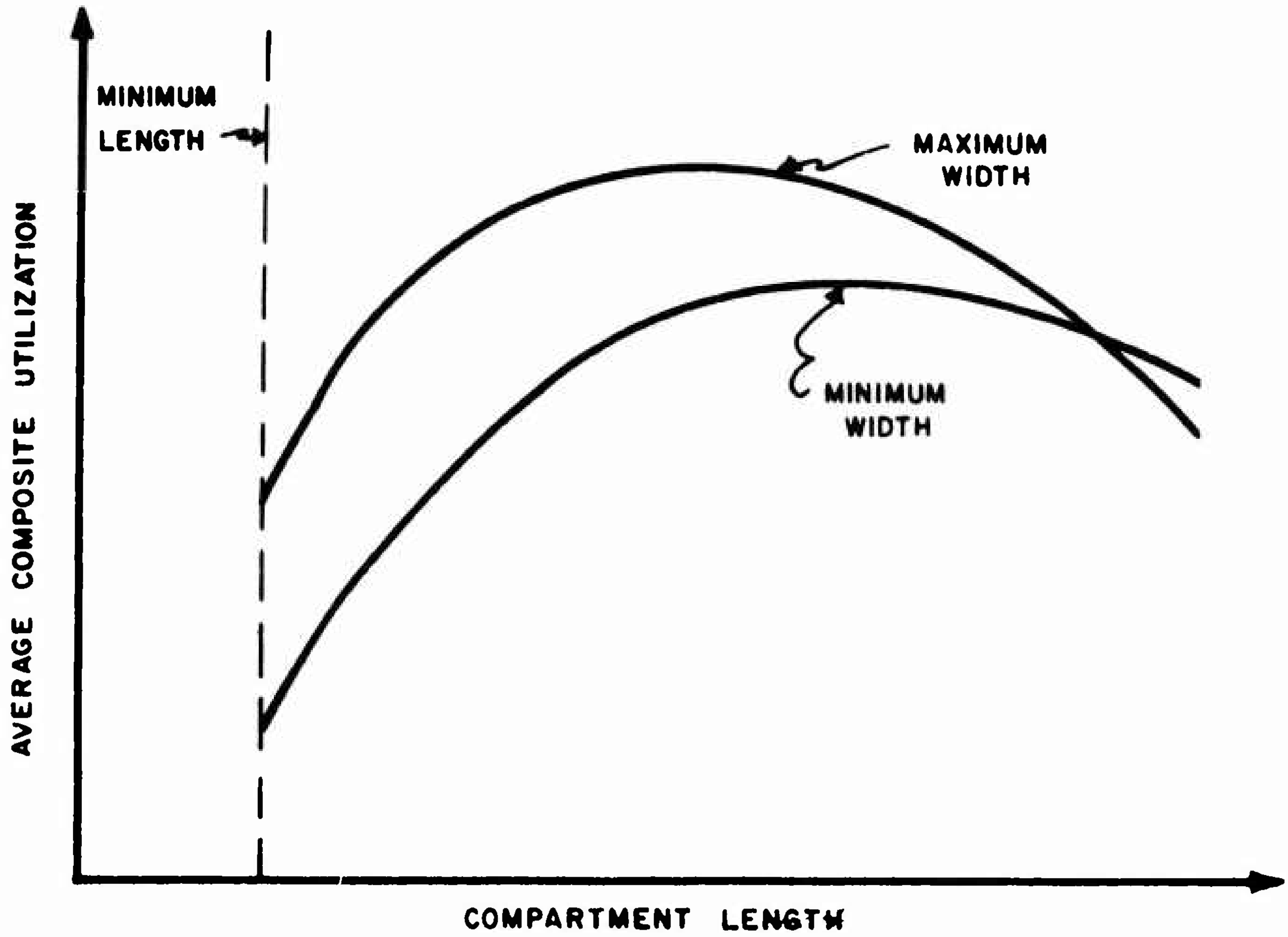

Figure 3. Hypothetical Example - Criterion of Maximum Average Composite Utilization.

rather than at either extreme. At minimum compartment length, the maximum-width compartment will probably exhibit the largest average composite utilization, since this width yields the largest average payload utilization and perhaps the largest average space utilization. At very large lengths, the minimum width will probably yield the largest average composite utilization, since the average space utilization is largest for the minimum width and the average payload utilization is relatively unaffected by compartment width.

Application of this third possible criterion of transport efficiency would yield that set of compartment dimensions corresponding to the maximum point on the curves of Figure 3. This criterion of maximum average composite utilization represents an attempt to achieve a full compromise between space-utilization and payload-utilization criteria. Unfortunately, the compromise is arbitrary and intuitive and furnishes no real assurance of an optimal and efficient design. At the same time, it does furnish a method which avoids the pitfalls of grossly oversizing or undersizing the cargo compartment. These are pitfalls that cannot be avoided in the respective application of payload-utilization and space-utilization criteria.

Minimum Number of Sorties

The previous three criteria were derived in response to the question: to what extent are the capacities of alternative aircraft configurations utilized in the performance of stated missions? The underlying philosophy here is that the best configuration is that which maximizes utilization of the cargo-carrying capacities.

Since deficiencies were noted with each of these criteria, a second question may be posed: which of the alternative configurations requires the fewest aircraft or sorties to accomplish the stated missions? The fourth criterion under consideration, then, is the minimum number of sorties. That set of compartment dimensions which minimizes the sortie requirements becomes the optimal set.

Hypothetical curves illustrating the application of this criterion are shown in Figure 4. For a given width, the number of sorties decreases as the length increases. Likewise, for a given length, the number of sorties generally decreases as the width increases. These trends reflect the fact that the required number of sorties cannot increase as the compartment dimensions are increased. In the lower range of dimensions, the penalties associated with inadequate available space are reflected in increased number of sorties. After the manner shown in Figure 1, a line of maximum benefits has been constructed in Figure 4 to isolate that region where significant dimensional changes cause only minor decreases in the number of sorties.

Unfortunately, the success of this criterion lies in the location of this line of maximum benefits; without it, excessively large dimensions would be required. Unfortunately, too, the proper location of this line is subject to individual judgments into which it is difficult to inject considerations of economy.

Minimum Mission Cost

The basic purpose of a sizing investigation is to achieve greater efficiency and effectiveness in air-transport operations by proper compartment design. The factors of efficiency and effectiveness imply increased capability, increased productivity, and reduced cost. The fit-compatibility criteria furnish some indications as to the

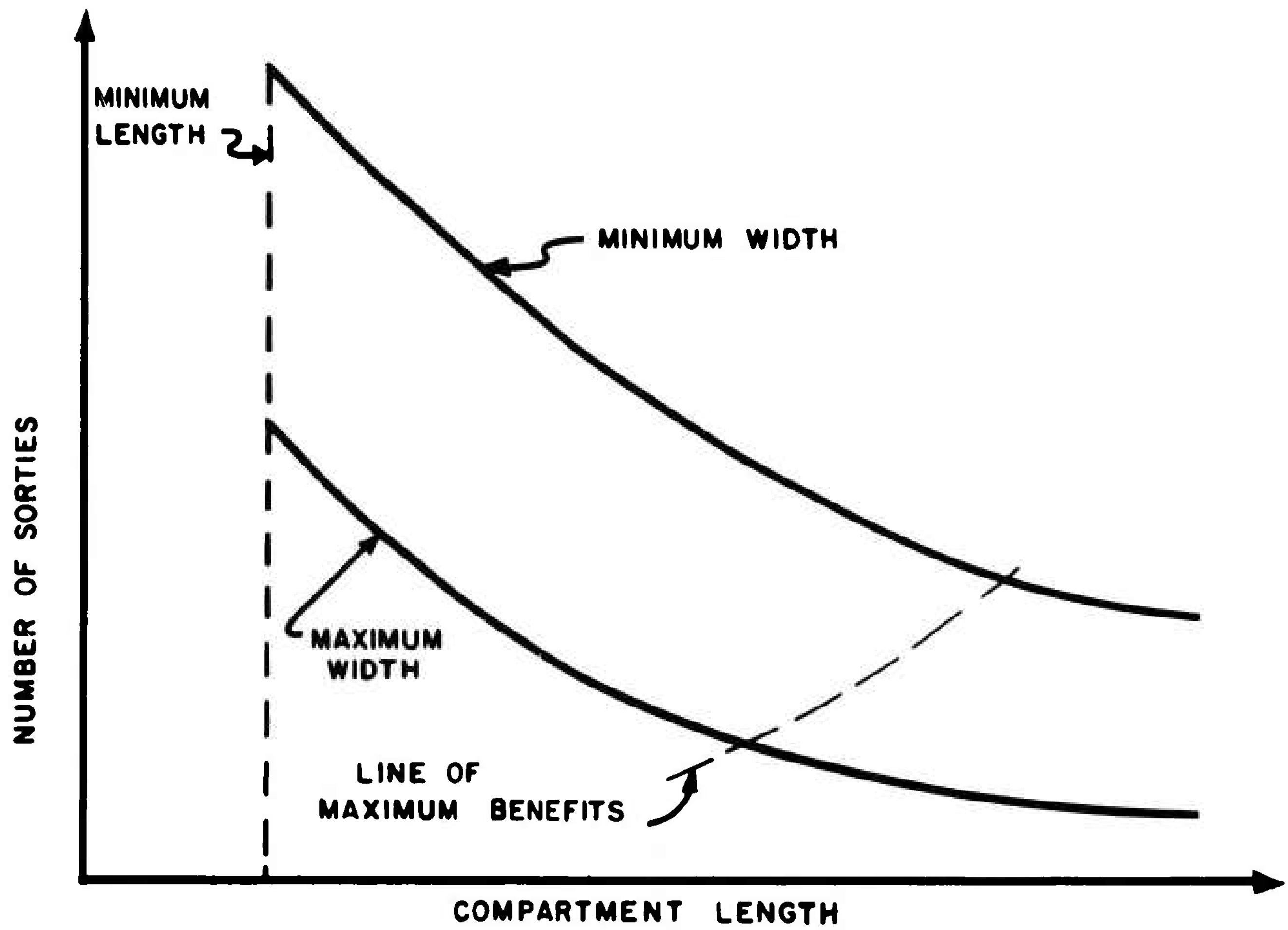

Figure 4. Hypothetical Example - Criterion of Minimum Number of Sorties.

capabilities of alternative designs. The transport-efficiency criterion of minimum number of sorties is a measure of productivity, since the most productive design yields the smallest number of sorties required. The remaining element of cost is essential to the fifth possible criterion of transport efficiency, namely, minimum mission cost.

The minimum-mission-cost approach strikes directly at the heart of the matter. It stipulates that the best among alternative designs of equivalent capabilities is that which enables proper mission performance at a minimum cost level. The underlying philosophy is to provide first the minimum dimensions to assure the required capabilities but to increase these dimensions only if the corresponding mission cost is thereby decreased.

Hypothetical data based on the minimum-mission-cost approach are illustrated in Figure 5. The positions of these curves are purely arbitrary and will vary depending on the situation under investigation. The mission cost is a function of the number of sorties and the cost

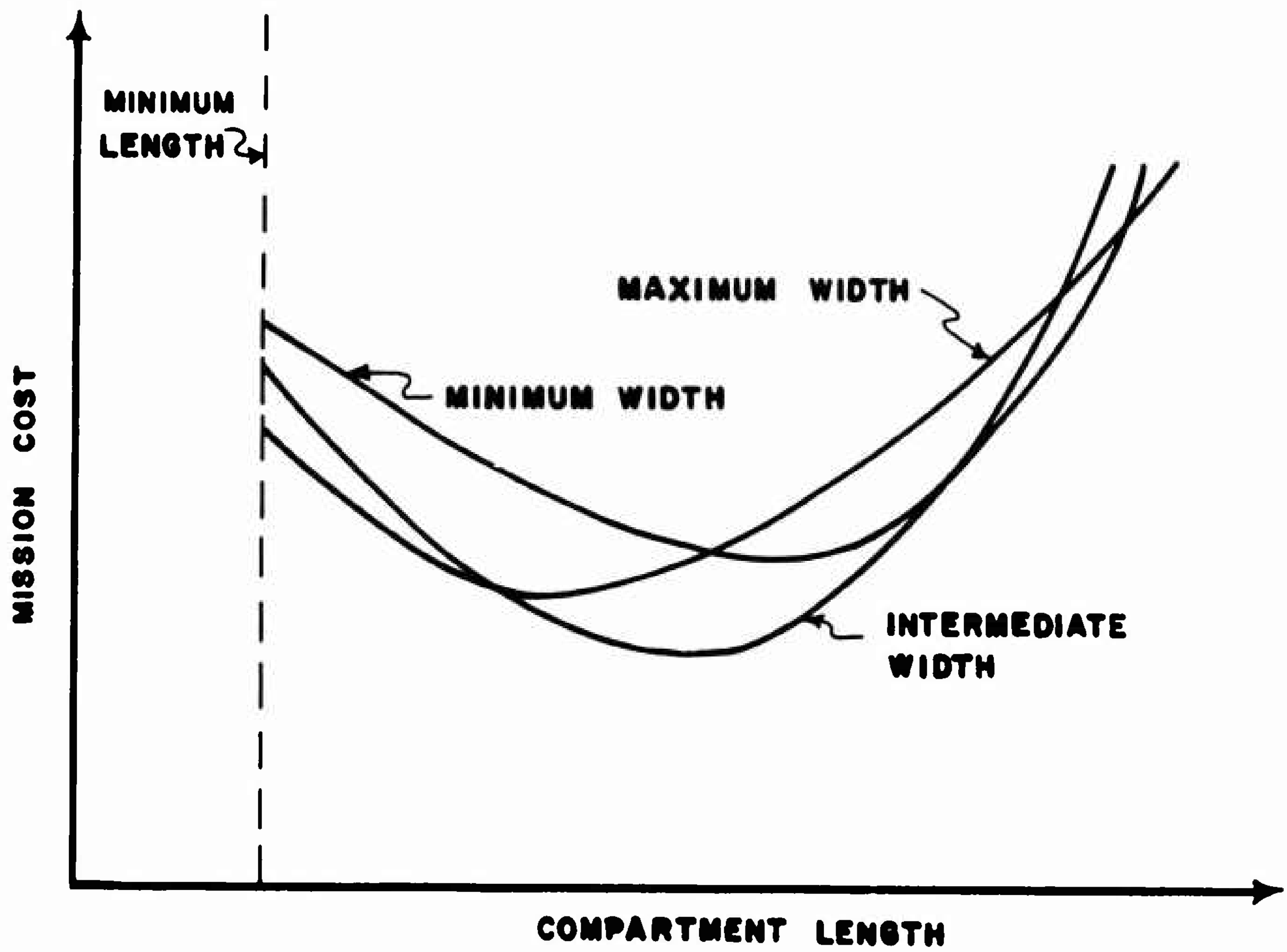

Figure 5. Hypothetical Example - Criterion of Minimum Mission Cost.

per sortie. Generally, the cost per sortie may be assumed to increase as the compartment size increases.

At small compartment dimensions, the cost per sortie is low, but the number of sorties is large; the resulting mission cost is similarly large. At large compartment dimensions, the number of sorties is small, but the cost per sortie is large. Therefore, the mission cost becomes increasingly large as the compartment dimensions increase beyond a certain point. The minimum-mission-cost point can be expected to correspond to intermediate compartment dimensions. Therefore, these are the dimensions that would be selected on the basis of the minimum-mission-cost criterion.

In theory, the best criterion of transport efficiency would seem to be that of minimum mission cost. However, in practice, serious difficulties are encountered in the development of a cost model responsive to the effects of dimensional variations. While it is obvious that increases in dimensions generally result in increases in both operating and investment costs, the magnitude of the increases is normally unidentified. There simply does not exist at this time a mission-cost model adaptable to the requirements of this particular problem.

Maximum Merit Factor

A final possible criterion for selecting the optimal compartment among possible alternatives is that of a maximum merit factor. Both space and payload merit factors may be used, but, to avoid unnecessary repetition, subsequent discussion is limited to the payload merit factor.

The payload merit factor is the product of the average payload utilization and the percentage by weight of the total cargo which is portable. Since both of these factors tend to increase as the compartment dimensions increase, the payload merit factor never decreases with increasing compartment size. The shapes of payload-merit-factor curves are similar to those of average payload utilization (as shown in Figure 1). Similar difficulties are encountered in locating the line of maximum benefits.

The payload-merit-factor approach represents an attempt to combine into a single measure a fit-compatibility criterion and a transport-efficiency criterion. While a single such measure has considerable merit in reducing the number of decisions to be made, it does tend to mask the independent effects of what the aircraft can transport and how well it accomplishes the transport function. Since the payload merit factor is monotonically increasing, the approach tends to yield excessively large dimensions. This fact imposes the necessity for establishing a line of maximum benefits with its attendant ambiguities. The primary utility of the maximum-payload-merit-factor criterion is that it enables the identification of points at which significant benefits can be achieved with minor increases in compartment dimensions. This is likewise true for the maximum-payload-utilization, maximum-space-utilization, and minimum-number-of-sorties criteria.

COMPUTATION OF SORTIE REQUIREMENTS

The preceding discussion on the criteria for optimal sizing has emphasized the necessity for computing at some point in most sizing investigations the minimum number of aircraft loads or sorties necessary to transport a given cargo set. While several techniques are available for computing these sortie requirements, the most desirable is one which (1) is accurate, (2) is simple, (3) is readily adaptable to computer usage, (4) yields the minimum requirements, (5) reflects appropriate loading rules, (6) allows the precise fit of whole items in the proposed aircraft, and (7) considers all pertinent fit considerations such as clearances, space, weight, and center of gravity.

If a technique were available that possessed all of these desirable characteristics, it would also be invaluable for detailed and accurate air-movement planning in noncompetitive situations in which a sole aircraft type is available.

There are three generally recognized types of techniques that are used to compute sortie requirements: weight methods, space methods, and type-load methods. A fourth possible type involves the application of linear programming techniques. The application of these techniques remains largely unexplored to date. However, if they were found to be adaptable to the problem at hand, minimum sortie requirements would be virtually assured. This assurance is impossible with most other techniques.

Weight Methods

A gross measure of the sortie requirement is obtained using weight methods. The sortie requirement is computed by dividing the total weight of the cargo by the allowable cargo load of the aircraft. A factor may be applied to correct for less than full payload utilization. This method obviously yields no information about the individual sorties such as space and payload utilizations. It is totally unsatisfactory for use in a sizing analysis, since the basic assumption is that total weight is always the most critical factor.

Accurate sortie requirements are computed only if all flights are payload limited and there are no step-function* and cube-out** losses.[26] For deployment missions, the weight method may seriously underestimate the sortie requirement.

The space method described in TM 57-210[25] is in actuality a weight method. The cargo weights are converted into weight increments (or

*The step-function loss is that portion of the allowable cargo load that cannot be utilized because there exists no cargo item having a weight equal to or less than the potential step-function loss which can be added to the aircraft load.

**The cube-out loss is that portion of the allowable cargo load that cannot be utilized because there exists no cargo item capable of fitting within the remaining available space in the aircraft load.

spaces) by dividing by the weight of a combat-equipped soldier, 240 pounds. The same conversion is applied to the allowable cargo load of the aircraft. The number of sorties is determined by dividing the number of spaces to be transported by the number of spaces provided per sortie. The limitations of this method are similar to those previously enumerated.

Space Methods

The space methods of sortie determination are particularly suitable for deployment missions. Properly augmented, they yield much more accurate estimates of sortie requirements than the weight methods while retaining the basic features of simplicity and speed of computation.

As a starting point in the analysis, a graph similar to that shown in Figure 6 is constructed. To produce this graph, the list of vehicles is first ordered by decreasing width, and the total vehicle length (assuming end-to-end packing) within each width category is calculated. The clearances that will occur between vehicles in a loaded configuration may be added to these totals to reflect aircraft requirements more accurately. These width-category subtotals are in turn summed to produce the graph shown in Figure 6. The value of "l_2" is the total length of all vehicles, including intervehicular clearances.

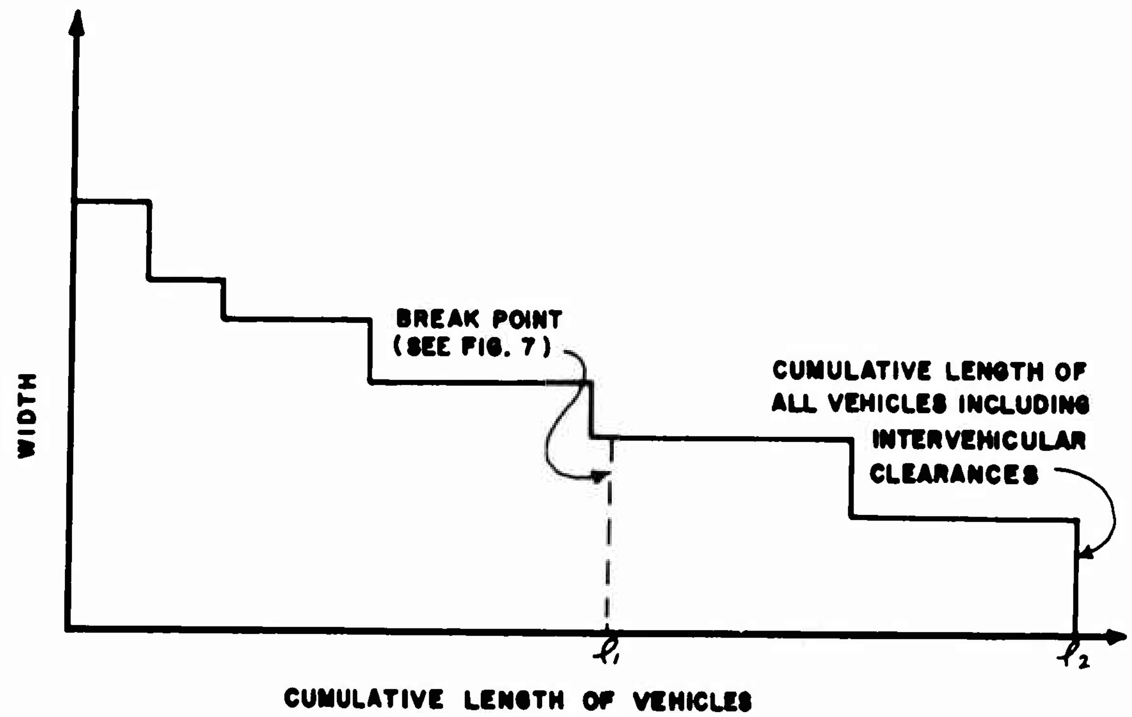

Figure 6. Illustration of Space Method for Sortie Computation - End-to-End Packing.

To account for side-by-side packing (two rows), a graph similar to Figure 7 is produced. Using Figure 6 as a basis, vehicles in the smallest-width category are placed adjacent to the widest group for which the sum of the two widths does not exceed the aircraft width less the necessary clearances. This procedure is repeated until the lengths of the two rows are equal, in this case "l_1".

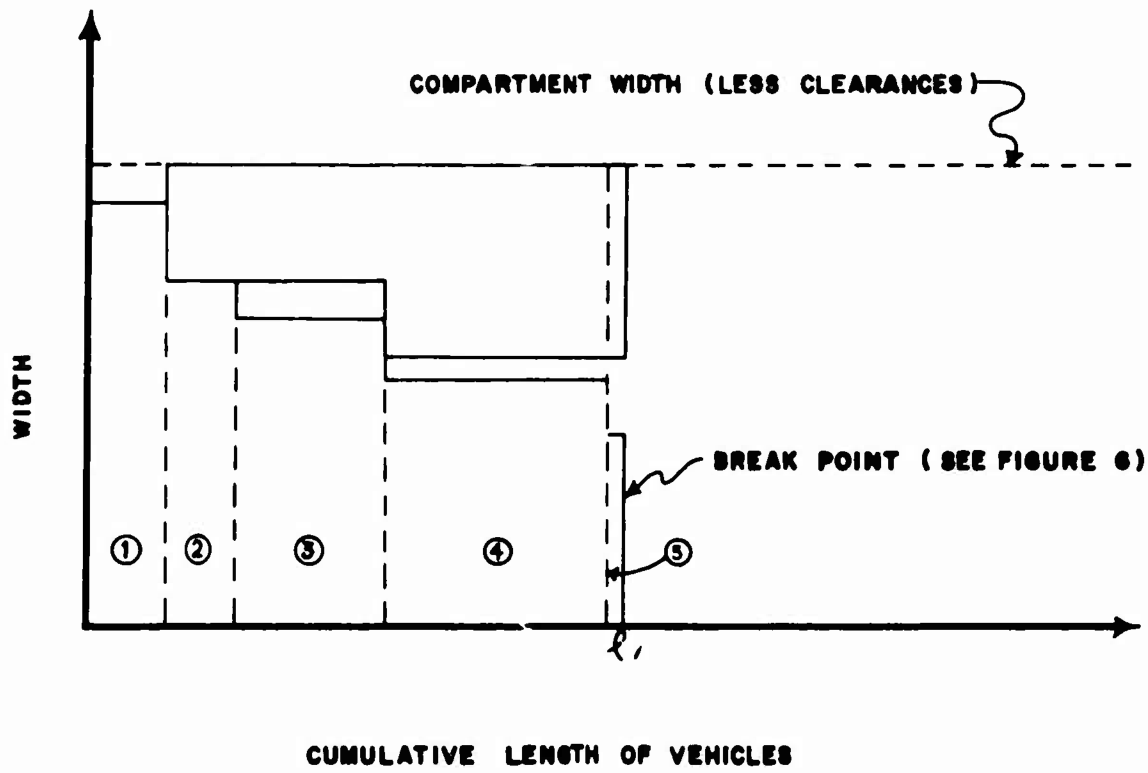

Figure 7. Illustration of Space Method for Sortie Computation - End-to-End and Side-by-Side Packing.

If all the flights are space limited, the sortie requirement equals the quotient of "l_1" and the aircraft length (less clearances). This procedure assumes that the aircraft length is fully utilized for every flight. However, it is possible to divide this quotient by an arbitrary factor, say, 0.95, to account for less than full utilization of the aircraft length. This procedure is extremely tenuous in a study such as this, particularly when relatively small aircraft are involved, since the length utilization factor may be highly dependent on the actual compartment length.

If all of the flights are not space limited, another requirement is evident. First, regions are identified in Figure 7 in which the vehicle types are constant. These are numbered 1 through 5 in this figure. Within each region the sortie requirements are calculated, assuming all flights to be space limited.

$$x_i = \frac{\Delta l_i}{L_m (F_1)} \quad (1)$$

where

x_i = number of sorties required to transport the vehicles in region i, assuming all sorties to be space limited.

Δl_i = the length of vehicles in region i with side-by-side packing.

L_m = the aircraft length less end clearances.

F_1 = a length utilization factor having a value less than one.

Then the sortie requirements are calculated, assuming all flights to be weight limited.

$$y_i = \frac{\Delta w_i}{P (F_2)} \quad (2)$$

where

y_i = number of sorties required to transport the vehicles in region i, assuming all sorties to be weight limited.

Δw_i = the total weight of vehicles in region i.

P = the aircraft allowable cargo load.

F_2 = a factor having a value less than one which accounts for the step-function loss.

The number of sorties required to transport the vehicles in region i is the maximum of "x_i" and "y_i". The total number of sorties becomes

$$S = \sum_i \max (x_i, y_i) \quad (3)$$

where

S = sortie requirement.

The space method, appropriately modified to consider allowable-cargo-load limitations, is simple, quick, and more accurate than weight methods. It is useful for the general planning of deployment missions, particularly when large aircraft are used. However, it lacks the precision necessary for use in a sizing analysis, primarily because the factors "F_1" and "F_2" of equations 1 and 2, respectively, must be made independent of compartment size. Also, the procedure does not allow the proper vehicle mix to utilize the available compartment length most fully.

Type-Load Methods

The basic characteristic of all type-load methods is that each item of cargo is treated as a separate entity in the loading process. Individual sorties are composed by separately fitting each item into the proposed aircraft. A basic requirement for all type-load methods is that the generation of each aircraft load must be terminated only if there is no additional item that can be added without exceeding the payload capacity, the space capacity, or the center-of-gravity limitations. Complete knowledge of each sortie is generated, including the space and payload utilizations and the specific cargo items within the load. All pertinent loading rules and fit considerations may be appropriately considered.

Use of Templates

The first of the type-load methods to be mentioned here is that requiring the use of templates. Scaled templates of the cargo compartment and of each type of cargo are constructed. A trial-and-error procedure is used to fit the cargo items into the aircraft. An effort is made to utilize to as large an extent as possible the available capacities of the aircraft.

This method is fairly accurate and allows all of the pertinent loading rules to be considered. However, it is time-consuming and not adaptable to computer usage. There is no real assurance of optimality in terms of the generation of minimum sortie requirements. However, an experienced technician can produce results superior to either the weight or the space method while, at the same time, generating useful data concerning not only the composite sortie requirement but also each load.

Sequential Sortie Composition

Because of the arduous nature of the template method and the experience required for proper determinations, other more appropriate type-load methods must be sought. Methods involving the sequential composition of individual sorties from an ordered list of cargo items offer some promise of improvement over the template method.

First, the list of cargo items is ordered in some prescribed way. The ordering scheme is intuitively selected to yield type loads which utilize the aircraft capacities. For example, high- and low-density items may be intermixed in alternate positions within the ordered list. The composed type loads will then consist of a mix of both high- and low-density items. Other ordering schemes that may be used are ordering by decreasing item length, ordering by alternating long and short items, ordering by decreasing width, and ordering by alternating wide and narrow items. The items may be ordered by a random selection procedure to promote the mixing of different cargo types within each aircraft load. A priority scheme may also be devised which orders the items with respect to their desired arrival at the off-loading site.

After the ordered list has been developed, the generation of sorties proceeds. The first item is placed in the first aircraft load. If the second item will fit, it, too, is placed in the first load. This procedure is repeated until an item is reached which will not fit in the developing load. This item is skipped and the next item is considered in the same manner. The generation of the first load is terminated only when there is no additional item on the list that will fit in the first type load.

The ordered list is, of course, updated to reflect the items transported in the first load. Second and subsequent sorties are generated in much the same manner until the complete cargo list has been depleted.

The overriding disadvantage of the sequential-sortie-composition methods is the lack of assurance that the minimum number of sorties has been generated and that aircraft capacities are well utilized for each sortie. The degree of optimality is a direct function of the manner in which the cargo items are ordered. An optimal ordering scheme for one set of cargo and one aircraft type may not be optimal for other, different situations.

Optimization Procedures

Because the sequential-sortie-composition methods yield no assurance that the minimum sortie requirements have been generated, it is necessary to look at additional type-load methods involving optimization procedures. The optimization procedures may generally be categorized into two classes: the first is the collective, simultaneous examination of all sorties, and the second is the independent examination of each individual sortie.

The objective of the first class is the examination of alternative sets of type loads, each set of which is capable of transporting the entire assemblage of cargo items, and the selection of that set yielding the minimum sortie requirement. The objective of the second class is the examination of alternative type loads for each sortie and the selection of that type load which best utilizes the aircraft weight and space capacities.

The collective, simultaneous examination of all sorties requires the generation of alternative sets of type loads. One way in which these sets can theoretically be generated is to examine all combinations of cargo items capable of fitting within the proposed aircraft and all combinations of the type loads so generated that are capable of transporting the complete set of cargo.

Unfortunately, this method of generating sortie requirements is not practical, even with very high speed computers, because of the extensive computations that are required.

A second way in which the sets of type loads can be generated involves the application of Monte Carlo techniques. Each set of type loads is generated by using the sequential-sortie-composition methods in which the items are ordered in a random fashion. Repeated application of this procedure yields a number of such sets from which the optimum can be selected. The degree to which an optimal arrangement is reached naturally increases as the number of sets increases.

The independent examination of each sortie requires the generation of alternative type loads for each sortie. Once again, the possibility of selecting the best type load for each sortie from the set of all possible combinations is rejected from the realm of practicality because of the extensive computations. The most satisfactory technique currently available is probably to generate a number of alternative type loads by the random selection of cargo items. The best of these alternative type loads on the basis of a composite of payload and space utilizations is selected for a particular sortie, the list of cargo items is updated, and the entire procedure is repeated until the original set of cargo items is depleted.

Either the collective examination of all sorties or the independent examination of individual sorties will yield results commensurate with the problem requirements. Minimum sortie requirements can probably be best assured by the application of the former technique. However, the latter is probably the more efficient of the two. Perhaps a combination of the two techniques may provide a best solution to the problem.

OTHER RELATED MATTERS

To realize the benefits of optimally sizing the cargo compartments of transport aircraft, a number of related matters demand detailed attention. While it is not the intent to examine these in depth, the more important are mentioned below for emphasis:

1. The main cargo door must be of a size sufficient to allow the passage of all cargo capable of fitting within the cargo compartment.

2. The height of the compartment floor above the ground should be sufficiently low so as not to impair loading and unloading efficiencies, particularly in tactical situations.

3. An unobstructed loading envelope is necessary to permit the loading of all items at aircraft floor height or from the ground.

4. Straight-in loading, preferably through an aft door, is necessary to permit "drive-on/drive-off" capabilities for vehicles and to facilitate performance of the airdrop function.

5. An integral ramp capable of handling vehicles as well as other types of cargo must be provided.

6. The compartment floor should be of sufficient strength to make shoring unnecessary for the more predominant cargo items.

7. Tie-down fitting of sufficient strength, number, and location must be provided.

8. A large allowable center-of-gravity range is necessary to utilize weight and space capacities fully while retaining a minimum loading time.

9. An integral weight-and-balance calculator may increase the aircraft effectiveness and safety while, at the same time, reducing mission cost.

10. An integral cargo-handling system may greatly improve the efficiency of the transport function.

CARGO-COMPARTMENT CHARACTERISTICS

Designers of transport aircraft have, in the past, relied extensively on the compartment dimensions of previously built aircraft in selecting the dimensions of new aircraft. Sole reliance on this means of sizing analysis is unnecessarily precarious, since the existing aircraft may have been improperly sized and since the nature of the cargo to be transported and the design missions may be considerably different. Nevertheless, this rather unfortunate circumstance is readily explained: (1) adequate procedures for proper sizing analysis have not, in the past, been formalized to any real extent; (2) those procedures that have been formalized remain tedious and time-consuming; (3) the necessary input data are difficult to accumulate; and (4) informed judgments are required which the designer is often not qualified to make and about which he is seldom given the necessary guidance by those who are properly informed.

One of the purposes of this study is to emphasize the necessity for a proper sizing analysis. However, much can still be gained and possible gross inconsistencies avoided by examining the compartment dimensions of previously built transport-type aircraft.

Table I summarizes the allowable cargo loads and cargo-compartment dimensions of selected transport-type aircraft. The list is necessarily restricted to those aircraft having a single cargo compartment. Although not all of the aircraft represented in Table I are properly classified in the transport category, all may be expected to transport typical Army cargo regularly.

The capacities of some of the aircraft, while outside the current realm of interest for Army aircraft, serve to establish trend lines between the compartment dimensions and allowable cargo loads.

Figure 8 shows how the compartment length has been related to the allowable cargo load. Data points include those for both rotary- and fixed-wing aircraft, since no apparent differences could be found between these two aircraft types. Subsequent data plots likewise reflect the similarity between rotary- and fixed-wing aircraft.

Logically, the compartment length continually increases as the allowable cargo load increases. This increase is approximately linear beyond an allowable cargo load of 5,000 pounds. The length provided at this allowable

TABLE I

ALLOWABLE CARGO LOADS AND CARGO-COMPARTMENT DIMENSIONS OF TRANSPORT-TYPE AIRCRAFT*

Aircraft Nomenclature	Allowable Cargo Load** (lb)	Compartment Length (in.)	Compartment Width (in.)	Compartment Height (in.)
U-1A	2,522	156	60	52
CV-2B	7,500	345	73.5	75
CV-7	10,600	377	93	78
Hypothetical				
10-Ton STOL***	20,000	345	147	98
C-119G	17,500	443	118	92
C-123B	20,000	345	110	98
C-130B	36,000	492	123	108
C-141A	68,500	840	123.25	109
UH-1D	2,582	92	97.5	49
CH-21	4,749	240	46	60
CH-34	4,283	163.5	59	48
CH-37	6,110	364	80	66
CH-47A	13,000	366	90	78

*Data sources include references 3, 14, and 25.

**Approximate radii of 50 nm for rotary-wing aircraft and 100 nm for fixed-wing aircraft serve as bases for the determination of allowable cargo loads.

***See reference 3.

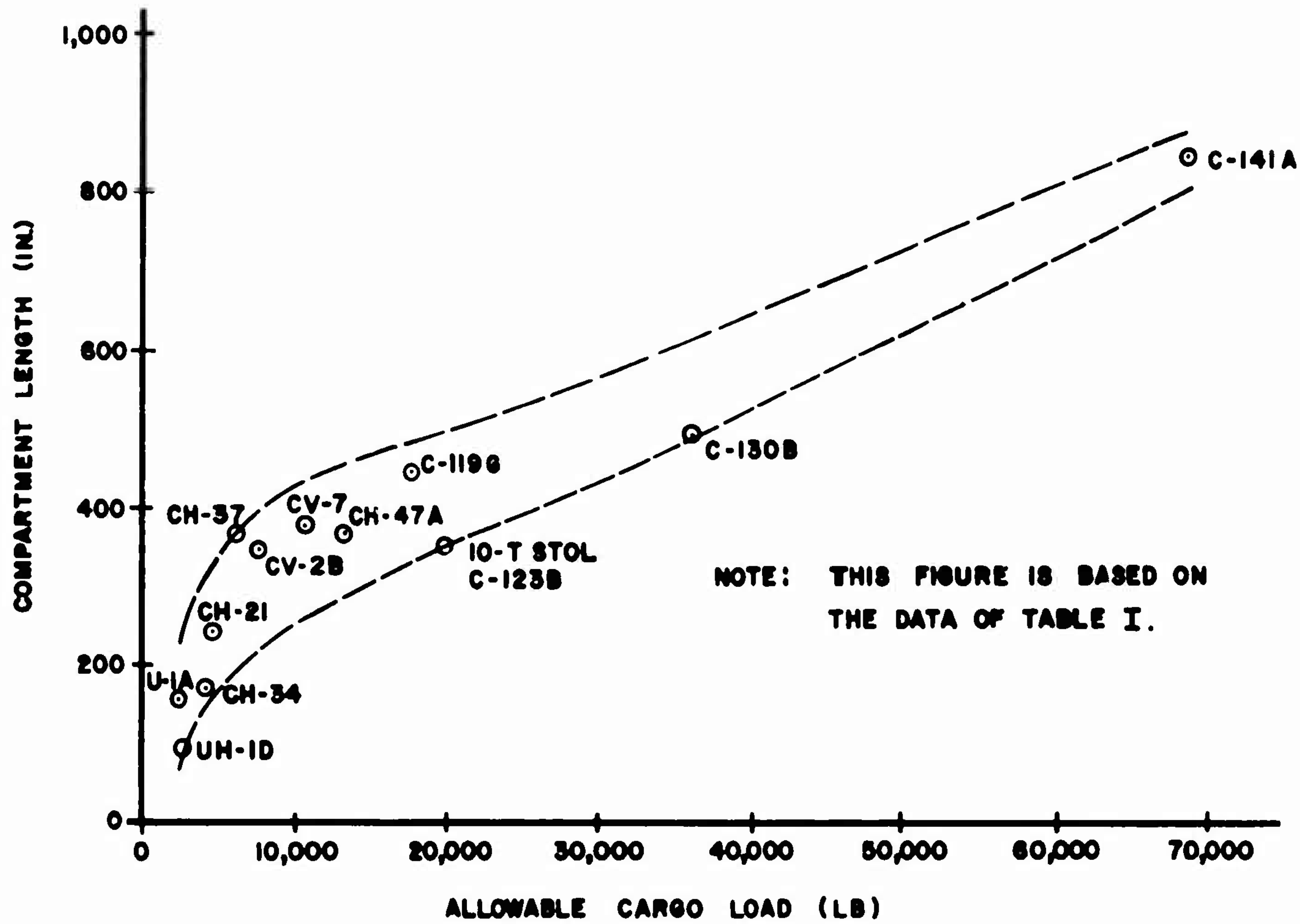

Figure 8. Cargo-Compartment Lengths of Transport-Type Aircraft.

cargo load is adequate to allow proper fit of virtually all of the critical items having weights of 5,000 pounds or less. Beyond this point, however, end-to-end packing is required to enable most aircraft loads to approach the allowable cargo load. The extent of this end-to-end packing is limited primarily by the allowable cargo load and, of course, the extent of side-by-side packing that is possible.

Figure 9 depicts the relationship between compartment width and allowable cargo load. Notice particularly the wide range of variation in compartment widths for a specific allowable cargo load. One of the primary reasons for this variability is the possibility for side-by-side packing and the increased flexibility afforded thereby.

The large increases in widths at the lower allowable cargo loads reflect the greatly increased capabilities for transporting wider items as allowable cargo load is slightly increased. For the intermediate range in allowable cargo loads, the compartment width increases reflect, in addition, the effects of side-by-side packing. The compartment width tends to

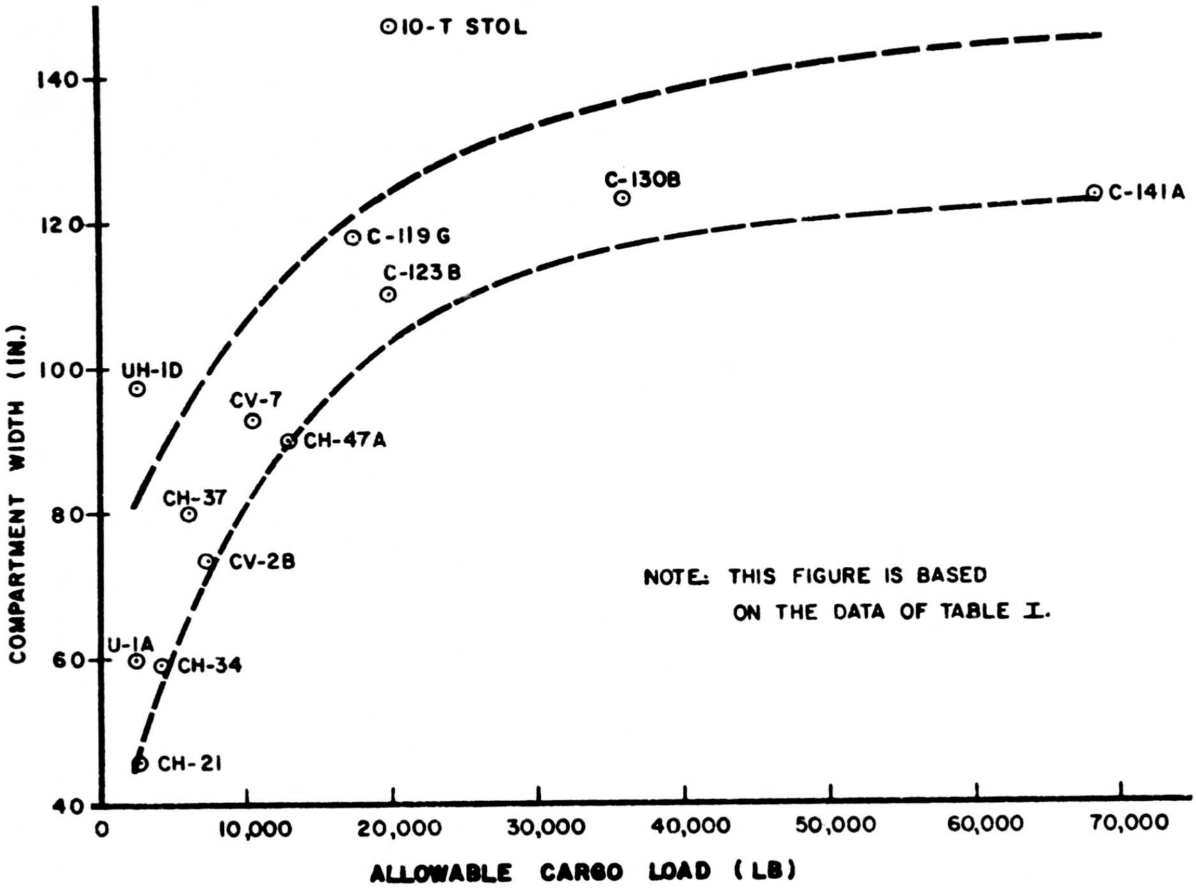

Figure 9. Cargo-Compartment Widths of Transport-Type Aircraft.

reach a maximum at the larger allowable cargo loads as the width of the largest item that can be transported is exceeded and maximum side-by-side packing efficiencies are achieved.

Compartment height is shown as a function of allowable cargo load in Figure 10. The variability of heights is much less than that of widths (Figure 9), since fit considerations rather than packing considerations are paramount in the compartment-height selection. The maximum height, which is reached over a wide range in the larger allowable cargo loads, is indicative of a height exceeded by few of the otherwise transportable items.

An indication of the available aircraft floor loading is shown in Figure 11. The loading factor, plotted as an ordinate in Figure 11, has no real relationship to the average cargo floor loading because of clearances, packing inefficiencies, and so forth. The increase in available floor loading with allowable cargo load reflects more efficient packing (larger actual floor

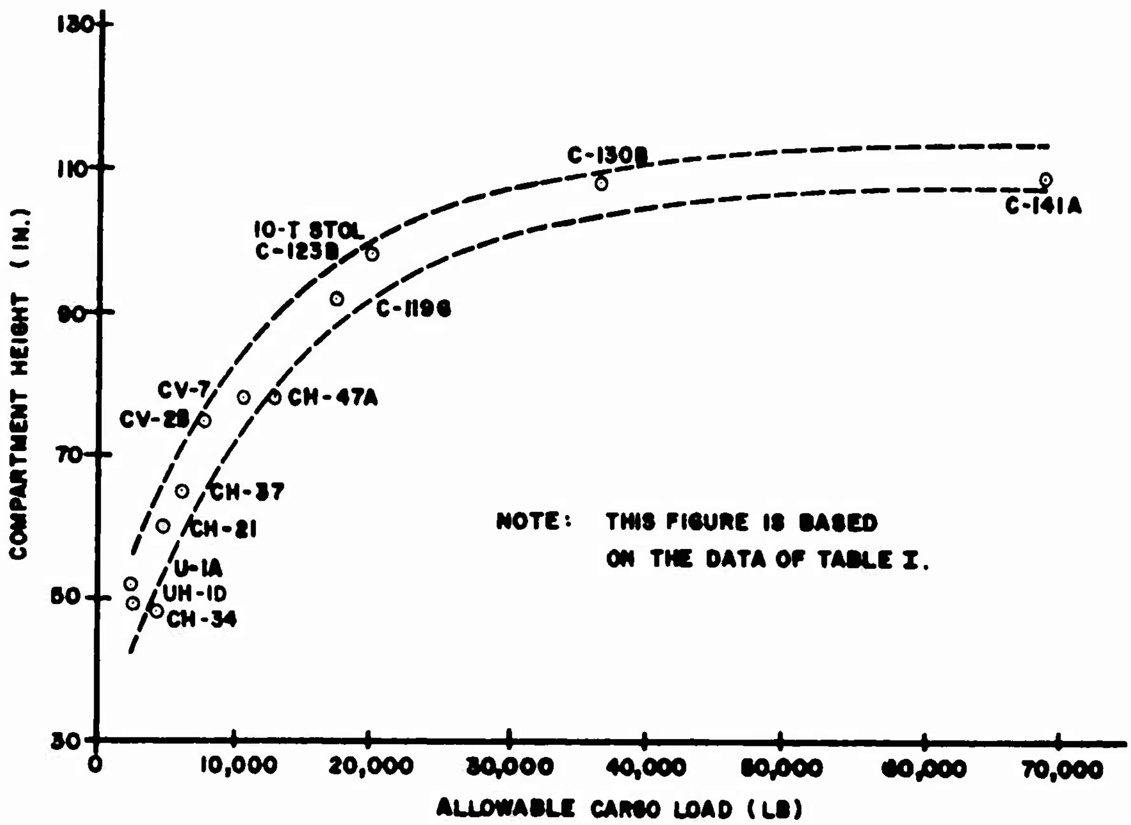

Figure 10. Cargo-Compartment Heights of Transport-Type Aircraft.

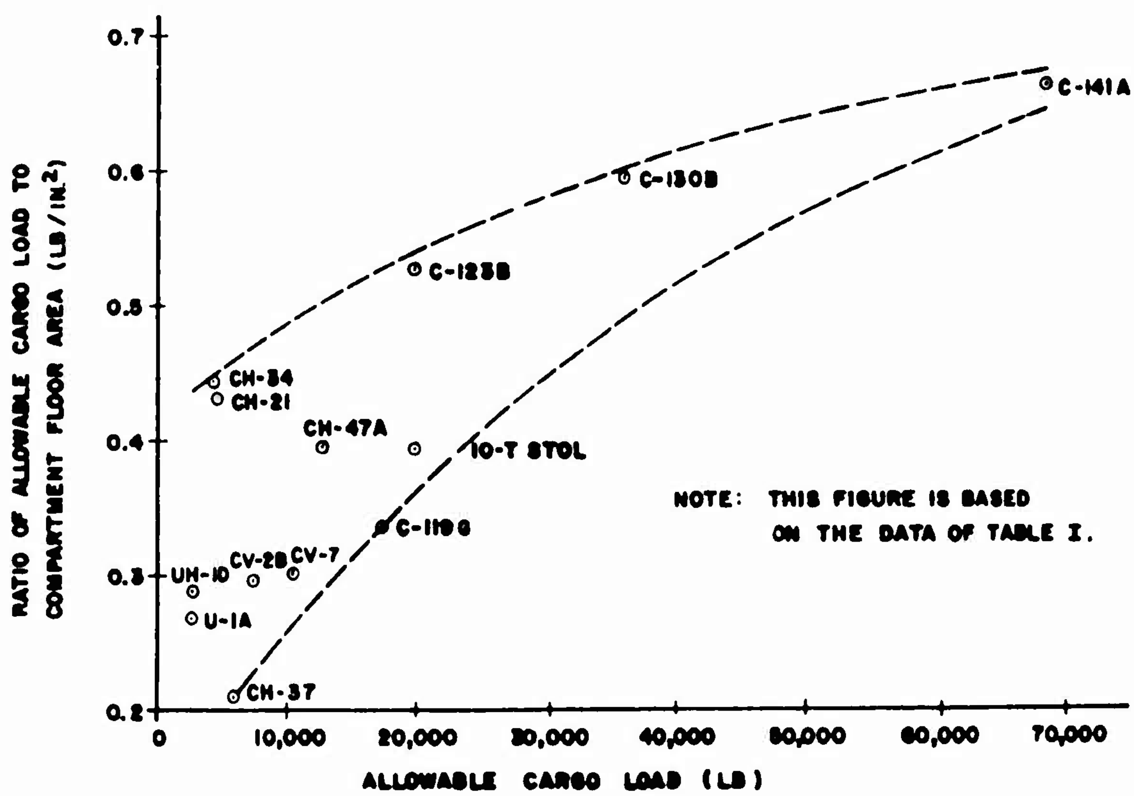

Figure 11. Ratios of Allowable Cargo Load to Cargo-Compartment Floor Area for Transport-Type Aircraft.

area utili·ation) in the larger aircraft sizes and perhaps a change in the characteristics of the portable cargo.

Figure 12 shows that no particular relationship has existed between allowable cargo load and the ratio of compartment length to compartment width. A length-to-width ratio of approximately four seems representative of tactical transports, but much variation is evident.

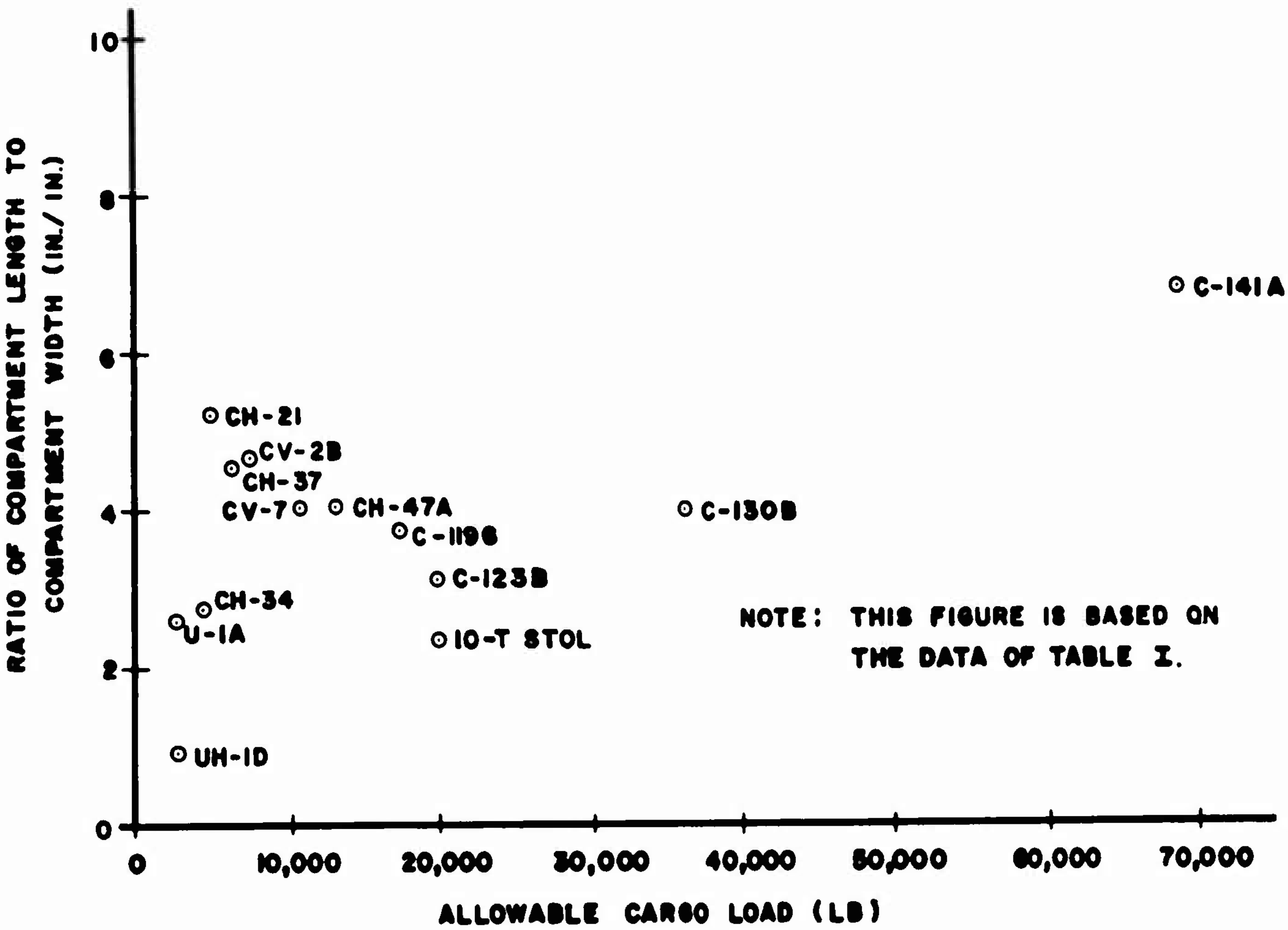

Figure 12. Ratios of Cargo-Compartment Length to Cargo-Compartment Width for Transport-Type Aircraft.

SELECTED METHODOLOGY

On the basis of the background information previously presented, it is possible to select a workable methodology for performing the sizing analysis. The methodology presented herein represents a compromise between theoretically optional techniques and practical considerations. The following postulates are instrumental in the analysis:

1. The sole cargo-compartment configuration of interest is that of a rectangular prism. There are no impediments within the cargo compartment, the loading envelope is not restrictive, and straight-in loading from an aft door is permitted.

2. There are a number of constraints and factors that should theoretically be considered in the dimensional design of the cargo compartment. However, certain of these are omitted from this methodology primarily for the sake of simplicity and convenience. These include (1) the constraints imposed by center-of-gravity limitations; (2) the dimensional relationships imposed by aerodynamic considerations; (3) the economic costs, including those of procurement, operation, and maintenance, engendered by increasing the size of the cargo compartment; and (4) the nontechnical constraints restricting cargo-compartment size.

3. A relatively austere compartment is assumed in which there is no integral, mechanized cargo-handling equipment for normal operations. If, on the other hand, such equipment is provided, its physical characteristics must be considered in the analysis.

4. The primary input for the analysis is the aircraft allowable cargo load. To restrict the compartment dimensions within reasonable limits, the allowable cargo load should not be taken as the maximum permissible load, but rather that which is allowed for a typical mission radius. The allowable cargo load excludes the weight of cargo-handling equipment and necessary restraint mechanisms.

5. No special provision is made to accommodate troops in the same aircraft load as the vehicle to which they are assigned. A partial justification for this assumption is that, in many cases, the

step-function or cube-out loss may be sufficiently large and adequate space may be available to accommodate these troops without special consideration.

6. The recommended internal clearances for vehicular loads are shown in Table II.

7. The cargo items are configured for delivery into a combat environment.

TABLE II

RECOMMENDED INTERNAL CLEARANCES FOR VEHICULAR LOADS

Location	Direction	Clearance (in.)	Primary Requirement
Compartment Side to Item	Transverse	5	AR 705-35
Item to Item (Side-by-Side Packing)	Transverse	8	Walkway and Vehicle Maneuverability
Item to Item (End-to-End Packing)	Longitudinal	12	Restraint
Compartment Bulkhead to Item	Longitudinal	18	Restraint
Compartment Rear to Item	Longitudinal	0	Access From Ramp
Compartment Top to Item	Vertical	6	AR 705-35

The selected methodology encompasses three distinct phases: fit-compatibility considerations, transport-efficiency considerations, and a historical comparison.

FIT COMPATIBILITY

The purpose of the fit-compatibility phase is to select a set of minimum desirable compartment dimensions. The compartment length and width so selected (but not normally the height) may be subsequently modified in the transport-efficiency phase. The classes of cargo that are independently evaluated in the fit-compatibility phase include essential items of equipment, supplies, litters, airdrop items, personnel, and other items of equipment.

Each independent evaluation (with the exception of that pertaining to "other items of equipment") will yield a set of minimum acceptable dimensions. These several sets are examined to select the largest of each dimension. The set of largest dimensions may be increased somewhat by an examination of the list of "other items of equipment", if significant gains in the number of portable items can be achieved with small dimensional increases. The final set of dimensions becomes the minimum desirable compartment dimensions.

Essential Items of Equipment

The first portion of the fit-compatibility phase should be an identification and examination of items of equipment that are essential to proper mission performance and which must be portable in the design aircraft. The item list need not be restricted to vehicles, since other equipment, for example, generator sets not mounted on vehicles, may be equally as essential. Items that must be transported in combination to realize proper mission effectiveness, such as prime mover-trailer combinations, should be treated not only individually but also as combinations.

To develop such a list, a proper point of beginning is an evaluation of the TOE's of combat battalions. To this evaluation must be added essential items under development or testing, essential items in divisional support units which will regularly engage in air movements, and nondivisional equipment where quick deployment may be essential. In developing the item list, equipment should be included without considering weights or dimensions so that the list may be valid for aircraft having any allowable cargo load.

After the list has been generated, the items are ordered in terms of increasing net weights, and their normal dimensions (not reduced for shipment) are tabulated. All items having net weights less than the allowable cargo load must be transported. The compartment dimensions necessary to accomplish this are readily selected by examination.

Supplies

Supplies will be delivered in a variety of configurations. It is anticipated, however, that most of the liquid POL will be transported in 500-gallon, collapsible fuel drums, and most of the other supplies will be palletized.

The remaining bulk cargo is of such a variety as to preclude its consideration in a sizing analysis. Therefore, it is sufficient to look only at the transport of loaded fuel drums and palletized supplies.

The loaded fuel drum is 80 inches wide, 54 inches high, and 54 inches long. It weighs approximately 3,550 pounds and is designed to be rolled into the aircraft with the 80-inch dimension in the transverse direction. Sufficient space should be provided to allow full payload utilization when transporting a load of fuel drums. The minimum acceptable compartment width is 90 inches. The required length will depend on the number of drums to be carried and restraint requirements.

There are two primary types of pallets that currently are envisioned for transport in the air line of communication. These are the loaded, standard 40-by-48-inch Quartermaster pallets and the loaded 463-L platforms.

When loaded, the standard Quartermaster pallet may be assumed to have the following dimensions: 44-inch width, 52-inch length, and 54-inch height. The loaded weight will vary over a considerable range, depending primarily on the class of supplies. A minimum weight of approximately 1,000 to 1,500 pounds and a maximum weight of approximately 3,000 to 3,500 pounds may be anticipated.

There are two 463-L platforms of interest. The larger platform has a 10,000-pound rated capacity and may be expected to exhibit an average loaded weight of about 8,000 pounds. When loaded, it may be assumed to have the following dimensions: 88-inch width, 108-inch length, and 75-inch height. The smaller platform has a 5,000-pound rated capacity and may be expected to exhibit an average loaded weight of about 4,000 pounds. When loaded, it may be assumed to have the following dimensions: 88-inch width, 54-inch length, and 75-inch height.

All Army transport aircraft must have the capability to transport the standard Quartermaster pallets. Furthermore, it is desirable to provide that amount of space capacity sufficient to insure the capability for full payload utilization. If conventional restraint devices are used, this may result in excessive compartment dimensions because of the clearances required for pallet restraint.

In any case, a detailed analysis is required which considers average pallet weight, appropriate restraint criteria, and characteristics of the restraint devices and fittings. The average pallet weight should be taken as 2,000 pounds. A target payload utilization of at least 70 percent should be employed.

There remains the question as to how far forward in the air line of communication the loaded 463-L platforms are to be carried. The arguments concerning the possible extent of involvement of Army aircraft with the transport of 463-L platforms are as yet unresolved, and no purpose would be served by repeating them here. In the interim until these arguments are resolved, compartments of Army transport aircraft should be made compatible with the platforms, if the aircraft allowable cargo load is at least 8,000 pounds and if the compartment dimensions so required are not greatly in excess of those warranted on the basis of other considerations.

Friction-reducing devices may be employed in handling the Quartermaster pallets and will definitely be used with the 463-L platforms. Their height must be considered when determining the compartment height required for transporting pallets.

Litters and Attendants

The necessary space to transport a full load of litter patients and attendant personnel and supplies must be provided. Accommodations for at least one attendant for each six litter patients must be provided. The weight of a patient, plus litter, may be taken as 250 pounds and that of an attendant as 200 pounds. The allowable cargo load must be reduced by the weight of the necessary litter kits. Two types of litters may be used: the standard pole-type litters or the NATO cot-type litters. The normal configuration is in tiers of four.

Airdrop Items

The dimensions of items rigged for airdrop must also be considered in the selection of a set of minimum desirable compartment dimensions. These items will include both equipment and supplies.

It is first necessary to identify a list of items that must be air-dropped from the proposed aircraft. The list of essential items of equipment should be useful in this regard. For each of these items the rigged dimensions and weights must be determined. The "10-500" series of technical manuals contains much pertinent information that is useful in this regard.

Personnel

In addition to the dimensional requirements imposed by those cargo types previously mentioned, adequate provisions are required to accommodate both combat-equipped soldiers and parachutists. This requires that the compartment be sized to allow full payload utilization with adequate seating for all troops. The weight of a combat-equipped soldier is taken to be 240 pounds and that of a parachutist to be 260 pounds.

To estimate the required space, use of side-facing, variable-width, standard interchangeable troop seats may be assumed. Either two or four rows may be used, depending on the compartment width. The seat width may be varied to accommodate the different types of passengers. A door should be provided on each side of the aircraft to serve as an emergency exit and a jump door. This may require an increase in the compartment length.

Other Items of Equipment

The purpose of examining other items of equipment is to ascertain if significant gains in the number of portable items can be achieved with small dimensional increases above those previously recommended.

To perform the required analysis, it is necessary to identify an appropriate list of items for consideration. A recommended list includes all those items for which dimensional and weight data are given in TB 55-46[22] and which weigh less than the design allowable cargo load. To this list should be added any appropriate items that are still in the development or testing phases. An appropriate analysis of this list will identify break points at which significant gains can be achieved with small dimensional increases. A decision as to whether the minimum desirable compartment dimensions are to be increased to provide this expanded capability must, unfortunately, be based on informed judgments.

TRANSPORT EFFICIENCY - DEPLOYMENT MISSIONS

At this point in the sizing analysis, a set of minimum desirable compartment dimensions will have been established solely on the basis of fit-compatibility considerations. It now becomes necessary to ascertain if improved transport efficiencies may be achieved by increasing the length and width dimensions. The height dimension is not normally altered by this process. However, if increases in length and/or width are recommended, it is desirable to recheck the fit-compatibility considerations so that the originally recommended height does not preclude the transport of important items of equipment otherwise transportable with the increased length and width.

In general, increases in width will be justified only if side-by-side packing of some items is possible and if such packing results in a more complete utilization of the aircraft capacities. The length which has been established by the fit-compatibility considerations is somewhat less firmly established than the width. The transport-efficiency consideration is quite helpful in justifying a length selection or in modifying that previously recommended.

The transport-efficiency consideration is limited to deployment missions. Appropriate Army organizations to consider are the infantry battalions of the airmobile and infantry divisions. These are combat units which will typically be involved in tactical-mobility deployments. In addition, each possesses a reasonable variety of equipment in sufficient quantities to make the comparisons meaningful.

Subsequent discussion of the transport-efficiency evaluation is presented in four parts: data accumulation, go/no-go check, loading program, and analysis or results.

Data Accumulation

The purpose of the data-accumulation phase is to develop an item list for the deployment mission which contains all the items that must be transported exclusive of personnel. The basis for development of this list is the TOE of the transported unit.

The TOE is examined to identify all equipment that is normally integrally mounted on other equipment. For the remaining analyses, these items are considered to be inseparable. For these inseparable combinations and all other TOE items, the dimensions (not reduced for shipment), the net weights, the gross cross-country weights, and the quantities are identified. Finally, trailers are combined with their associated prime movers, the dimensions and weights of these prime mover-trailer combinations are derived, and the item quantities are adjusted to reflect these combinations.

All mobile equipment (excluding aircraft) in the TOE is included in the item list. Other equipment is included only if the net weight exceeds 1,000 pounds. This is in recognition of the fact that much of the lighter equipment will be either hand-carried or preloaded on vehicles.

Go/No-Go Check

Before the computation of sortie requirements can be initiated, the cargo lists for the deployment missions must be examined to ascertain which items will not fit in the proposed aircraft and which must be modified to allow such a fit. This is the primary function of the go/no-go check which precedes the loading program.

The required aircraft inputs include an allowable cargo load and the usable dimensions of the cargo compartment: its length, width, and height. For each cargo item, the following information is required: (1) the quantity, (2) the item nomenclature, (3) the normal outside dimensions not reduced for shipment, (4) the net weight (operating weight exclusive of crew and/or payload), (5) the gross cross-country weight for vehicles (the total operating weight for other items), and (6) a code identifying prime mover-trailer combinations. Internal clearances are also specified.

The prime mover-trailer combinations are first checked to see if they can be loaded intact at their gross cross-country weights. If they cannot be so loaded, the prime movers and the trailers are separated, and the appropriate item quantities are adjusted to reflect these separations. A rejection table is constructed which indicates the nomenclature of the combinations rejected and the reason for rejection, either excess weight or excess size.

The modified item list is then examined to identify each item type whose net weight exceeds the allowable cargo load or whose size is excessive. Another rejection table is constructed for these item types which indicates their nomenclature and the reason for rejection, either excess weight or excess size. The item list is again modified to reflect these deletions. The total net and gross weights and the total projected area of these rejected items are calculated.

A final examination is made of the modified item list to identify each of those item types whose gross weight exceeds the allowable cargo load but whose net weight is not excessive. Cargo is off-loaded from these items to that point at which the item weight equals the allowable cargo load. The item list is again modified to reflect these changes, and a rejection table is constructed which identifies these item types by nomenclature and which gives the total weight of the off-loaded supplies.

The final output from this preliminary check is the modified item list which includes only those item types portable in the proposed aircraft. It serves as input for the loading program which is subsequently described.

Loading Program

The primary function of the loading program is the computation of the minimum sortie requirements for transporting a given cargo set. The technique chosen for this derivation entails a type-load optimization procedure for the independent examination and optimization of each individual sortie. This loading program has been adapted for use with the IBM 1620 and 7090 computers.

The required aircraft inputs include an allowable cargo load and the usable dimensions of the cargo compartment: its length, width, and height. The go/no-go check furnishes the following information for each item that can be carried in the aircraft: (1) the quantity, (2) the item number (an identification number), (3) the normal outside dimensions not reduced for shipment, and (4) the net and gross weights. Other input data include a three-digit random number starter, which is used in the internal operations; the total number of different item types; and the allowable internal clearances.

The primary output of the program is the required number of sorties, the average payload utilization, the average floor area utilization, and the average composite utilization.* In addition, the total net weight, the total gross weight, and the total area for all items transported are furnished. The following information is produced for each sortie: the payload utilization, the floor area utilization, the composite utilization, and the item numbers of all items in the sortie.

The basic procedure is to generate randomly 20 possible type loads for each sortie and to select the best of the 20 on the basis of maximum payload and space utilizations. After the best load has been selected for a particular sortie, the item list is modified, and the entire procedure is repeated until the item list has been depleted.

To generate randomly 1 of the 20 possible type loads for a particular sortie, the following procedure is used. An item is selected at random from the item list** and is placed in the possible type load. The quantity of this item is temporarily reduced by one to reflect its placement in this possible load. Another item is selected at random, and a determination is made as to whether the second item will fit in the proposed aircraft with the first item. If it will, the appropriate accumulators are updated to reflect the addition of this second item, and its quantity is temporarily reduced by one. If it will not, its quantity is temporarily reduced to zero to preclude its subsequent reselection. The process is continually repeated until all items in the item list have been loaded or until there exists no additional item which can be added to the developing type load without exceeding the aircraft

*The composite utilization has been defined as the algebraic sum of the payload and floor area utilizations.

**The probability of selecting any particular item equals the proportion of the quantity of that item to the quantity of all items.

capacities. Once an item has been found to fit in a developing type load and subsequently added to that load, it is never removed or replaced by another item.

After such a possible type load has been generated, the original quantities in the item list are reestablished and the entire process is repeated until 20 similar type loads have been developed.

Since these 20 loads will differ in their abilities to utilize the aircraft capacities, it is necessary to select the best of the 20 to represent the particular sortie being evaluated. To accomplish this selection, the 20 loads are ordered with respect to both payload and space utilizations, and order numbers from 1 to 20 are assigned to each load for each type of utilization. Order number 1 represents the best of the type loads. For each type load, the two order numbers are then summed to obtain a composite order rating. The best of the 20 loads is that load having the smallest composite rating. This load is then selected to represent the sortie under consideration. While it is recognized that better loads might be developed if the number of type loads exceeded 20, the gains would likely be small and the extent of the computations prohibitive.

The item quantities are next permanently updated to reflect the generation of a useful sortie. The entire process is repeated until that point is reached at which the item list is depleted. The output data for the entire movement are then printed or punched to terminate the operation.

One procedure in the above discussion warrants special explanation; this is the procedure for determining whether a set of items will fit in the proposed aircraft. In accomplishing this determination, a simple weight check is first made to ascertain if the aircraft allowable cargo load is exceeded. It it is not, a space check is made. To perform the space check, the items are arranged in order of decreasing width. A maximum of two columns of items are permitted within the cargo compartment. The widest item is placed in the forward end of column one. Subsequent items, selected in order, are checked first to see if they will fit in column one. If they will not, an attempt is made to place them in column two, beginning at the aft end of the cargo compartment. The process is repeated until an item is found which will not fit in either column - at which point a determination is made of the unsuitability of this type load - or until all items have been loaded.

Analysis of Results

The go/no-go check and the loading program provide the tools with which to evaluate the transport-efficiency criterion. To enable the judicious selection of an optimal compartment, a number of compartment sizes must be evaluated. The smallest of these is represented by the minimum desirable dimensions derived from the fit-compatibility considerations. This set of minimum dimensions is then incremented to cover a wide range of possible dimensions.

For each set of compartment dimensions, application of the go/no-go check and the loading program provides the sortie requirement; the average payload utilization; the average space utilization; the average composite utilization; and go/no-go information, including the items that cannot be carried, the weight of off-loaded supplies, and so forth. These output data are used to construct figures similar to those of Figures 1, 2, 3, and 4.

These figures are analyzed to ascertain if significant gains in transport efficiency can be achieved by selecting dimensions in excess of the minimum desirable set. In analyzing these figures, care must be exercised to assure that comparisons are made among sets of dimensions which have equivalent capabilities in terms of the items that can be transported.

HISTORICAL COMPARISON

Before the sizing analysis is terminated, the design compartment dimensions should be briefly compared with those dimensions of previously built aircraft. Figures 8 through 12 should be useful in this regard. The purpose of this comparison is simply to assure that gross inadequacies in the design dimensions are avoided. If major inconsistencies are observed, the design procedure should be reviewed to assure its accuracy and completeness.

EXAMPLE PROBLEM

Now that a suitable methodology has been selected for performing the sizing analysis, it is desirable to demonstrate its feasibility and to illustrate its application by means of an example problem.

It will be recalled that the selected methodology consists of three distinct phases: the fit-compatibility phase, the transport-efficiency phase, and the historical-comparison phase. Unfortunately, all the necessary data have not been accumulated at this time to enable the fit-compatibility phase to be properly demonstrated. However, once the data are assembled, it becomes a simple, albeit important, matter to select by comparison the set of minimum desirable compartment dimensions. At the same time, application of the historical-comparison phase is such a simple matter that it need not be demonstrated herein.

Therefore, the example problem of this section is devoted to demonstrating the application of the transport-efficiency phase only. This example is also used to demonstrate the feasibility of the primary tool developed for the analysis, namely, the computer loading program.

The unit to be deployed in this example is the infantry battalion of the ROAD infantry division. This unit is of sufficient size to encompass a reasonable variety and quantity of equipment and may be expected to participate regularly in deployments by Army aircraft.

The hypothetical aircraft has an allowable cargo load of 14,000 pounds for its typical mission radius. The compartment is therefore sized around this allowable cargo load. Six compartment lengths are investigated; namely, 240, 300, 340, 380, 420, and 480 inches. For each of these lengths, six widths are investigated; namely, 84, 96, 108, 120, 132, and 144 inches. Thus, 36 compartment sizes are treated in the parametric analysis.

The compartment height is normally determined solely from the fit-compatibility phase and does not directly affect the transport-efficiency considerations. For this example, it is necessary only to assume that the height is sufficient to enable the transport of all items otherwise transportable in the proposed aircraft.

An additional required input to the analysis is a set of internal clearances. That set recommended in Table II has been chosen for use in this demonstration.

DATA ACCUMULATION

The first necessary step is to develop an appropriate data list describing the items to be transported and summarizing their quantities, dimensions, and weights. The data list must reflect the desired transport configurations. This means that mounted equipment, such as radios, must be an integral part of the vehicles on which they are mounted, that prime movers and their associated trailers must be carried together in a hitched configuration if possible, that all items must be carried at their gross cross-country weights if possible, and that normal dimensions (not reduced for shipment) must be used.

The data list that was developed for this example is shown as Table III. The item nomenclatures and quantities were derived from TOE 7-15E, dated 15 July 1963. The item dimensions and weights were derived primarily from references 16 and 24. The item numbers shown in Table III are arbitrary numbers serving for purposes of identification only. The quantities reflect the desired transport configuration. Where quantities of zero are shown, the associated item is integrally mounted on another item or is configured for transport in a prime mover-trailer combination.

Note especially that personnel have been excluded from the data list for reasons previously described. In addition to all mounted equipment and all vehicles in the referenced TOE, other items of equipment having net weights in excess of 1,000 pounds were also included in the data list.

GO/NO-GO CHECK

It is next necessary to ascertain which of the items of Table III will not fit in the various compartments and which must be modified from the desired transport configuration to allow such a fit.

The first checks involve weight-fit considerations, since these checks retain their validity for all compartment sizes. To begin with, all the prime mover-trailer combinations of Table III are examined to ascertain which of these have gross weights in excess of the allowable cargo load. Table IV summarizes the results of this analysis.

TABLE III

EQUIPMENT ORGANIC TO INFANTRY BATTALION,

ROAD INFANTRY DIVISION

Nomenclature	Item Number	Quan-tity	Length (in.)	Width (in.)	Height (in.)	Net Weight (lb)	Gross Weight (lb)
RIFLE 106MM ON MOUNT M40A1	M*	0	134	32	44	484	484
TOOL KIT ORG MAINT NR2 COMMON	1	1	48	24	51	4376	4376
TLR AMPHIB CGO 1/4T 2WH M100	2	0	109	58	43	565	1065
TLR CGO 3/4T 2WH M101	3	0	147	74	83	1340	2840
TLR CGO 1-1/2T 2WH M105A2	4	0	166	83	98	2650	5650
TLR CGO 1-1/2T W/ TANK UNIT	5	0	166	83	98	3147	5650
TLR TANK WATER 1-1/2T 2WH M149	6	0	162	81	80	2840	6040
TRK AMB FRONT LINE 1/4T 4X4 M170	7	4	155	61	80	2963	3763
TRK AMB 1/4T W/ AN/VRC-47	8	2	155	61	80	3095	3763
TRK CGO 3/4T 4X4 M37	9	1	186	74	92	5700	7200
TRK CGO 3/4T W/ AN/GRC-19	10	0	186	74	92	5939	7200
TRK CGO 3/4T W/ AN/GRC-19 W/ TLR CGO 3/4T	11(C)*	1	327	74	92	7279	10040
TRK CGO 3/4T W/ AN/GRR-5	12	0	186	74	92	5775	7200
TRK CGO 3/4T W/ AN/GRR-5 W/ TLR CGO 3/4T	13(C)	1	327	74	92	7115	10040
TRK CGO 3/4T W/ AN/VRC-24	14	0	186	74	92	5788	7200
TRK CGO 3/4T W/ AN/VRC-24 W/ TLR CGO 3/4T	15(C)	1	327	74	92	7128	10040
TRK CGO 3/4T W/ AN/VRC-46	16	0	186	74	92	5815	7200
TRK CGO 3/4T W/ AN/VRC-46 W/ TLR CGO 3/4T	17(C)	5	327	74	92	7155	10040
TRK CGO 3/4T W/ AN/VRC-47	18	0	186	74	92	5832	7200
TRK CGO 3/4T W/ AN/VRC-47 W/ TLR CGO 3/4T	19(C)	3	327	74	92	7172	10040
TRK CGO 3/4T W/ RADIO TT SET AN/GRC-46	20	1	186	74	92	6750	7200
TRK CGO 3/4T W/ TLR CGO 3/4T	21(C)	24	327	74	92	7040	10040
TRK CGO 3/4T 4X4 W/ WN M37	22	2	191	74	92	5950	7450
TRK CGO 2-1/2T 6X6 LWB M35	23	0	263	96	112	12465	17815
TRK CGO 2-1/2T M35 W/ TANK + PUMP UNIT	RI*	0	263	96	112	14185	17815
TRK 2-1/2T W/ TANK + PUMP W/ TLR 1-1/2T W/ TANK	RC*	2	423	96	112	17332	23465
TRK CGO 2-1/2T M35 W/ TLR CGO 1-1/2T	RC	7	423	96	112	15115	23465
TRK CGO 2-1/2T 6X6 LWB W/ WN M35	24	0	276	96	112	12880	18230
TRK CGO 2-1/2T M35 W/ WN W/ TLR CGO 1-1/2T	RC	7	436	96	112	15530	23880
TRK CGO 2-1/2T M35 W/ WN W/ TLR TANK WATER 1-1/2T	RC	2	432	96	112	15720	24270
TRK CGO 5T 6X6 LWB W/ WN M54	RI	0	313	97	120	19945	29945
TRK CGO 5T M54 W/ WN W/ TLR TANK WATER 1-1/2T	RC	2	469	97	120	22780	35985
TRK UTIL 1/4T 4X4 M151	25	14	132	63	71	2350	3150
TRK UTIL 1/4T W/ AN/VRC-53	26	0	132	63	71	2419	3150
TRK UTIL 1/4T W/ AN/VRC-53 W/ TLR CGO 1/4T	27(C)	2	235	63	71	2984	4215
TRK UTIL 1/4T W/ AN/GRC-125	28	0	132	63	71	2431	3150
TRK UTIL 1/4T W/ AN/GRC-125 W/ TLR CGO 1/4T	29(C)	2	235	63	71	2996	4215
TRK UTIL 1/4T W/ AN/VRC-46	30	0	132	63	71	2465	3150
TRK UTIL 1/4T W/ AN/VRC-46 W/ TLR CGO 1/4T	31(C)	8	235	63	71	3030	4215
TRK UTIL 1/4T W/ AN/VRC-47	32	0	132	63	71	2482	3150
TRK UTIL 1/4T W/ AN/VRC-47 W/ TLR CGO 1/4T	33(C)	9	235	63	71	3047	4215
TRK UTIL 1/4T W/ AN/VRC-49	34	0	132	63	71	2562	3150
TRK UTIL 1/4T W/ AN/VRC-49 W/ TLR CGO 1/4T	35(C)	1	235	63	71	3127	4215
TRK UTIL 1/4T W/ TLR CGO 1/4T	36(C)	5	235	63	71	2915	4215
TRK UTIL 1/4T W/ AN/VRC-47 W/ RIFLE 106MM	37	0	152	68	73	3352	3465
TRK 1/4T W/ AN/VRC-47 W/ RIFLE 106MM W/ TLR 1/4T	38(C)	8	255	68	73	3917	4530
TRK UTIL 1/4T 4X4 CARRIER W/ RIFLE 106MM	39	0	152	68	73	3220	3465
TRK VAN SHOP 2-1/2T 6X6 M220	-	0	267	96	131	15085	20435
TRK VAN SHOP 2-1/2T W/ TWO AN/VRC-46	RI	1	267	96	131	15315	20435
TRK WRECKER MED 5T 6X6 W/ WN M62	RI	1	349	96	110	33325	33325
INTRENCH OUTFIT INF ENG SM 5-4-5180-S11	40	1	-	-	-	4650	4650
TANK AND PUMP UNIT LIQUID DISP TRK MTD	M	0	119	137	111	1720	9400
TANK UNIT TLR MTD	M	0	61	72	56	497	4500
RADIO SET AN/GRC-19 MTD IN TRK 3/4T	M	0	-	-	-	239	239
RADIO SET AN/GRR-5 MTD IN TRK 3/4T	M	0	-	-	-	75	75
RADIO SET AN/VRC-53 MTD IN TRK 1/4T	M	0	-	-	-	69	69
RADIO SET AN/GRC-125 MTD IN TRK 1/4T	M	0	-	-	-	81	81
RADIO SET AN/VRC-24 MTD IN TRK 3/4T	M	0	-	-	-	88	88
RADIO SET AN/VRC-46 MTD IN TRK 1/4T	M	0	-	-	-	115	115
RADIO SET AN/VRC-46 MTD IN TRK 3/4T	M	0	-	-	-	115	115
RADIO SET AN/VRC-46 MTD IN TRK VAN SHOP	M	0	-	-	-	115	115
RADIO SET AN/VRC-47 MTD IN TRK 1/4T	M	0	-	-	-	132	132
RADIO SET AN/VRC-47 MTD IN TRK 3/4T	M	0	-	-	-	132	132
RADIO SET AN/VRC-49 MTD IN TRK 1/4T	M	0	-	-	-	212	212
RADIO TT SET AN/GRC-46	M	0	78	58	61	1050	1050

*Code explanation: M = integrally mounted equipment; C = prime mover-trailer combinations; RC = combinations rejected because gross weight in excess of allowable cargo load; and RI = items rejected because net weight in excess of allowable cargo load.

These combinations are then separated into their prime mover and trailer components by increasing the component quantities of the item list by the combination quantity and decreasing the combination quantity to zero.

TABLE IV

COMBINATIONS REJECTED FOR EXCESSIVE GROSS WEIGHT

Nomenclature	Quantity	Gross Weight (lb)
TRK 2½T W/ TANK + PUMP W/ TLR 1½T W/ TANK	2	23465
TRK CGO 2½T M35 W/ TLR CGO 1½T	7	23465
TRK CGO 2½T M35 W/ WN W/ TLR CGO 1½T	7	23880
TRK CGO 2½T M35 W/ WN W/ TLR TANK WATER 1½T	2	24270
TRK CGO 5T M54 W/ WN W/ TLR TANK WATER 1½T	2	35985

The modified item list is then examined to determine which items have excessive net weights and, hence, cannot be carried under any circumstances. The results of this examination are shown in Table V. The total net weight, total gross weight, and total area of the six items falling within this category are also shown on this table.

The next checks are somewhat more extensive. For each set of compartment dimensions, the prime mover-trailer combinations are examined to ascertain if sufficient space is available. If it is not, the prime movers and trailers are separated, and the appropriate item quantities are adjusted to reflect these separations. Then a space check is performed on the single items to ascertain which will not fit. The items which will not fit are identified, and the total net weight, total gross weight, and total area of these rejected items are computed. Finally, the weight of supplies that must be off-loaded is calculated for each of those items whose gross weight is excessive but whose net weight is less than the allowable cargo load. Table VI summarizes the results of these checks.

TABLE V

ITEMS REJECTED FOR EXCESSIVE NET WEIGHT*

Nomenclature	Quantity	Net Weight (lb)
TRK CGO 2½T M35 W/ TANK + PUMP UNIT	2	14185
TRK CGO 5T 6X6 LWB W/ WN M54	2	19945
TRK VAN SHOP 2½T W/ TWO AN/VRC-46	1	15315
TRK WRECKER MED 5T 6X6 W/ WN M62	1	33325

*Total Number of Items = 6
Total Net Weight = 116,900 lb
Total Gross Weight = 149,280 lb
Total Area = 170,354 sq in.

RESULTS OF LOADING PROGRAM

The quantitative results of the loading program are tabularly summarized as Table VII and are graphically portrayed in Figures 13 through 18.

It is recalled that comparisons among alternative sets of dimensions are meaningful only when those sets have equivalent capabilities. For all practical purposes, such comparisons can be made for those compartments having lengths of 300 inches or more and widths of 108 inches or more. These compartments are marked with asterisks in Table VII and are joined by solid lines in Figures 13 and 18. Table VI lists the various cargo items and item combinations of the infantry battalion which are not portable due to space limitations.

Examination is first made of the effects of compartment width. The 84-inch width excludes the transport of 2-1/2-ton trucks and 1-1/2-ton trailers. Increasing the width to 96 inches provides the additional capability for transporting the 1-1/2-ton trailers. All cargo items in the battalion with acceptable net weights are portable with widths of 108 inches or more. Widths of 120 and 132 inches are less desirable than the 108-inch width from the transport-efficiency consideration, since they exhibit decreased average space (Figure 14) and average composite (Figure 16)

TABLE VI

SPACE REJECTIONS AND OFF-LOADED SUPPLIES

Aircraft Length (in.)	Aircraft Width (in.)	Code for Rejected Combinations*	Code for Rejected Items*	Rejected Single Items: Number of Items	Rejected Single Items: Net Weight (lb)	Rejected Single Items: Gross Weight (lb)	Rejected Single Items: Area (sq in.)	Weight of Off-Loaded Supplies (lb)
240	84	RC1 RC2	RI1 RI2	36	257,929	403,335	688,136	-
240	96	RC1 RC2	RI2	16	203,175	288,775	415,200	-
240	108	RC1 RC2	RI2	16	203,175	288,775	415,200	-
240	120	RC1 RC2	RI2	16	203,175	288,775	415,200	-
240	132	RC1 RC2	RI2	16	203,175	288,775	415,200	-
240	144	RC1 RC2	RI2	16	203,175	288,775	415,200	-
300	84	RC1	RI1 RI2	36	257,929	403,335	688,136	-
300	96	RC1	RI2	16	203,175	288,775	415,200	-
300	108	RC1	-	-	-	-	-	64,775
300	120	RC1	-	-	-	-	-	64,775
300	132	RC1	-	-	-	-	-	64,775
300	144	RC1	-	-	-	-	-	64,775
340	84	RC1	RI1 RI2	36	257,929	403,335	688,136	-
340	96	RC1	RI2	16	203,175	288,775	415,200	-
340	108	RC1	-	-	-	-	-	64,775
340	120	RC1	-	-	-	-	-	64,775
340	132	RC1	-	-	-	-	-	64,775
340	144	RC1	-	-	-	-	-	64,775
380	84	-	RI1 RI2	36	257,929	403,335	688,136	-
380	96	-	RI2	16	203,175	288,775	415,200	-
380	108	-	-	-	-	-	-	64,775
380	120	-	-	-	-	-	-	64,775
380	132	-	-	-	-	-	-	64,775
380	144	-	-	-	-	-	-	64,775
420	84	-	RI1 RI2	36	257,929	403,335	688,136	-
420	96	-	RI2	16	203,175	288,775	415,200	-
420	108	-	-	-	-	-	-	64,775
420	120	-	-	-	-	-	-	64,775
420	132	-	-	-	-	-	-	64,775
420	144	-	-	-	-	-	-	64,775
480	84	-	RI1 RI2	36	257,929	403,335	688,136	-
480	96	-	RI2	16	203,175	288,775	415,200	-
480	108	-	-	-	-	-	-	64,775
480	120	-	-	-	-	-	-	64,775
480	132	-	-	-	-	-	-	64,775
480	144	-	-	-	-	-	-	64,775

*RC1 includes items 11, 13, 15, 17, 19, and 21 of Table III (3/4-ton, truck-trailer combinations).
RC2 includes items 27, 29, 31, 33, 35, 36, and 38 of Table III (1/4-ton, truck-trailer combinations).
RI1 includes items 4, 5, and 6 of Table III (1-1/2-ton trailers).
RI2 includes items 23 and 24 of Table III (2-1/2-ton trucks).

TABLE VII

RESULTS OF LOADING PROGRAM

Aircraft Length (in.)	Aircraft Width (in.)	Average Payload Utilization (pct)	Average Space Utilization (pct)	Average Composite Utilization (pct)	Number of Sorties
240	84	26	49	75	164
240	96	28	45	73	184
240	108	28	40	68	184
240	120	28	36	64	184
240	132	28	32	60	184
240	144	37	39	76	139
300	84	36	53	89	122
300	96	36	47	83	142
300*	108	43	45	88	158
300*	120	43	41	83	158
300*	132	43	37	80	158
300*	144	49	39	88	138
340	84	42	56	98	102
340	96	46	52	97	113
340*	108	52	49	101	129
340*	120	52	44	96	129
340*	132	52	40	92	129
340*	144	58	41	99	116
380	84	53	62	115	82
380	96	56	56	112	92
380*	108	63	52	114	108
380*	120	63	47	109	108
380*	132	63	43	105	108
380*	144	74	46	120	91
420	84	59	62	120	74
420	96	62	56	118	83
420*	108	69	52	121	98
420*	120	68	46	114	99
420*	132	68	42	110	99
420*	144	76	43	119	89
480	84	58	53	111	75
480	96	64	51	116	80
480*	108	70	46	117	96
480*	120	70	42	112	96
480*	132	72	39	110	94
480*	144	82	41	123	82

*Compartment dimensions so marked identify those aircraft having equivalent capabilities and for which direct comparisons can be made.

utilizations while not affecting average payload utilization (Figure 13) and sortie requirements (Figure 18).

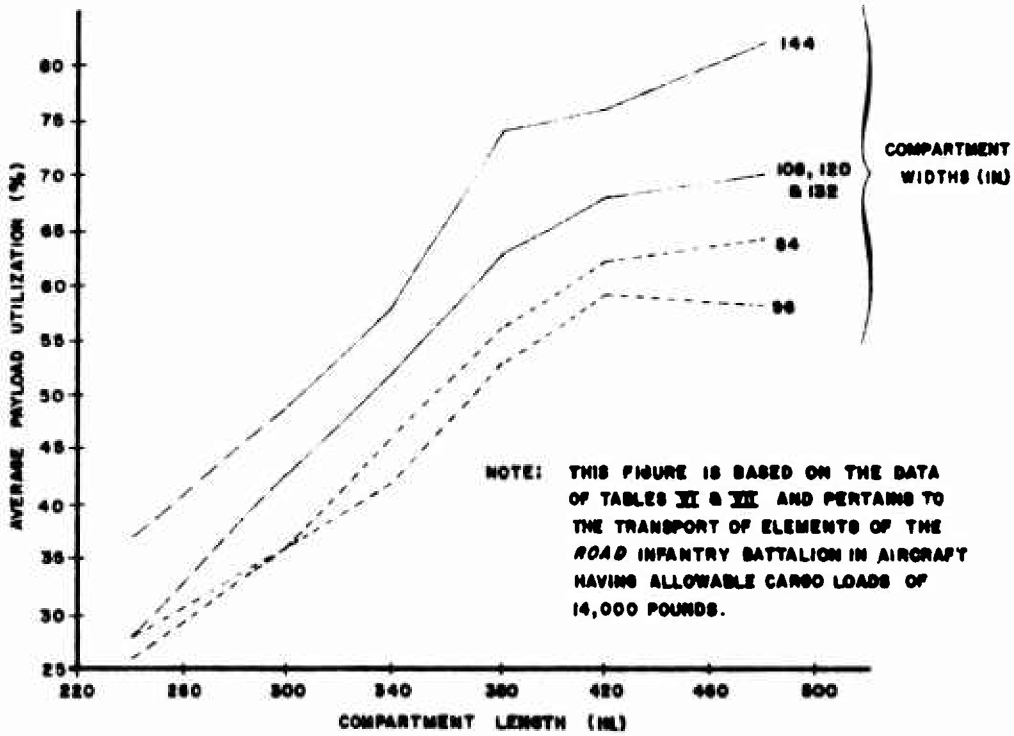

Figure 13. Example Problem - Relation of Average Payload Utilization to Compartment Size.

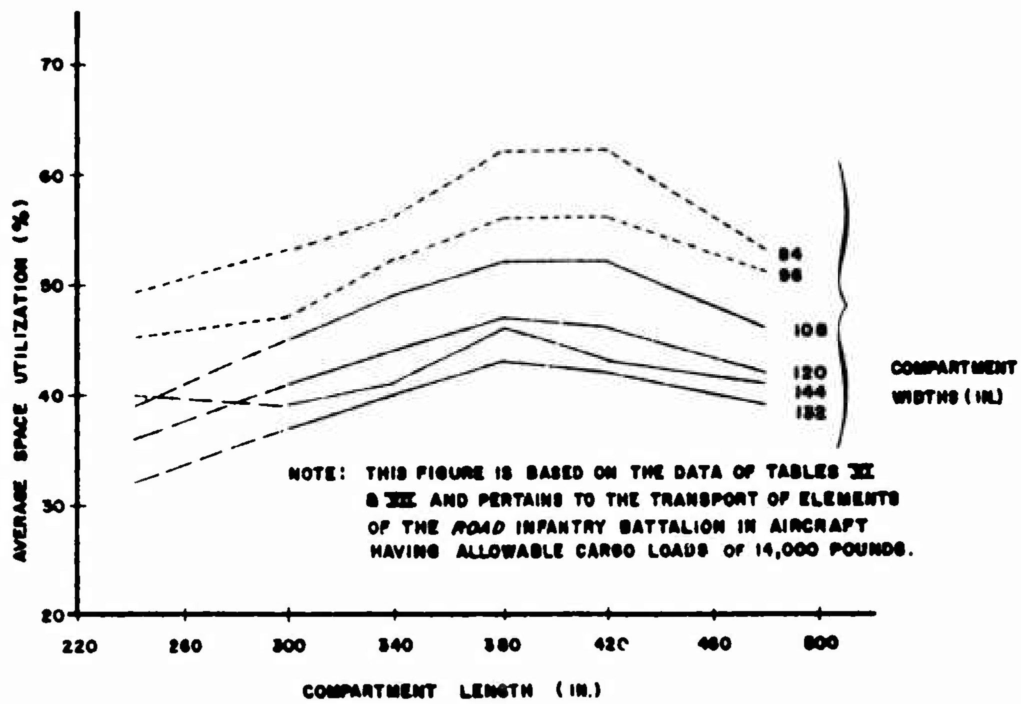

Figure 14. Example Problem - Relation of Average Space Utilization to Compartment Size.

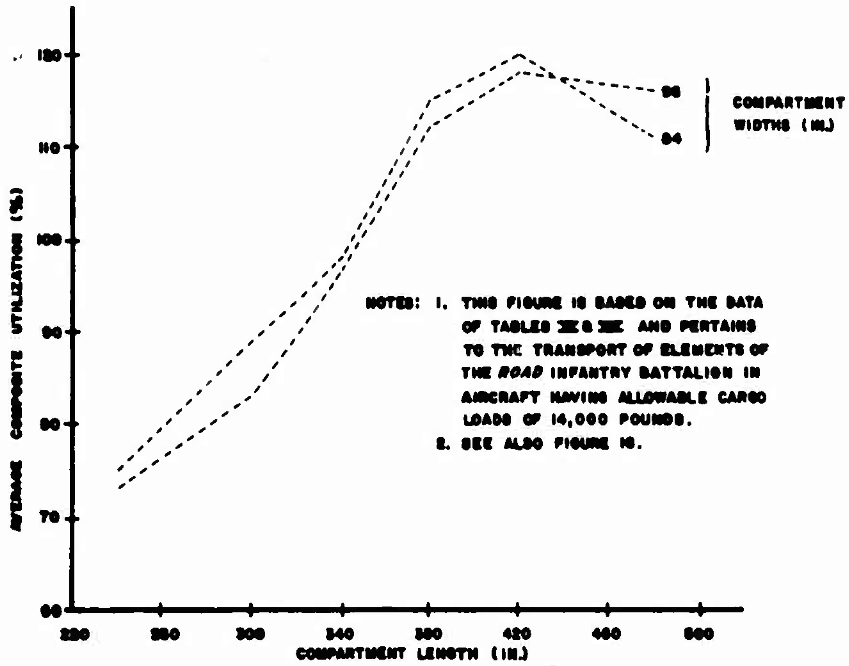

Figure 15. Example Problem - Relation of Average Composite Utilization to Compartment Size (Small Widths).

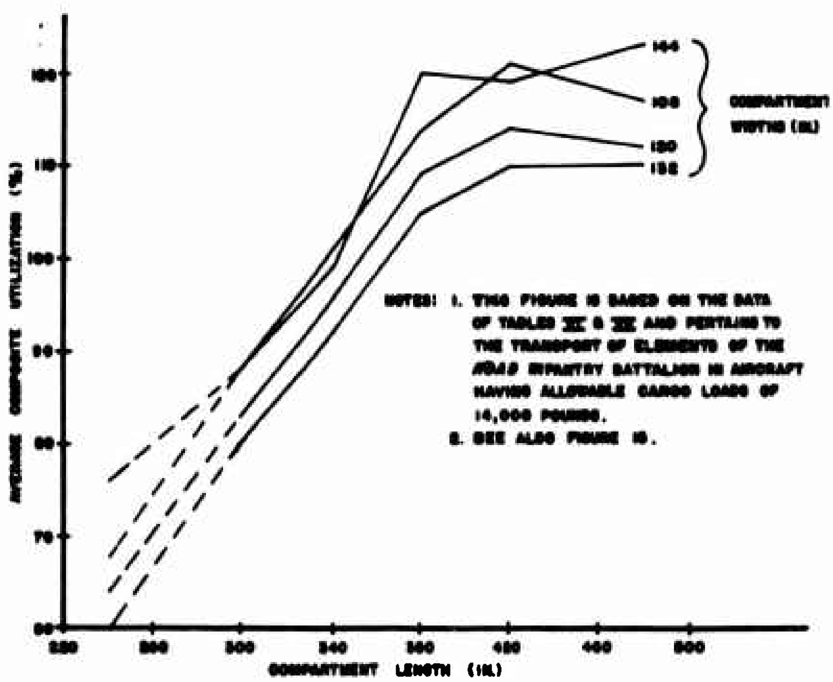

Figure 16. Example Problem - Relation of Average Composite Utilization to Compartment Size (Large Widths).

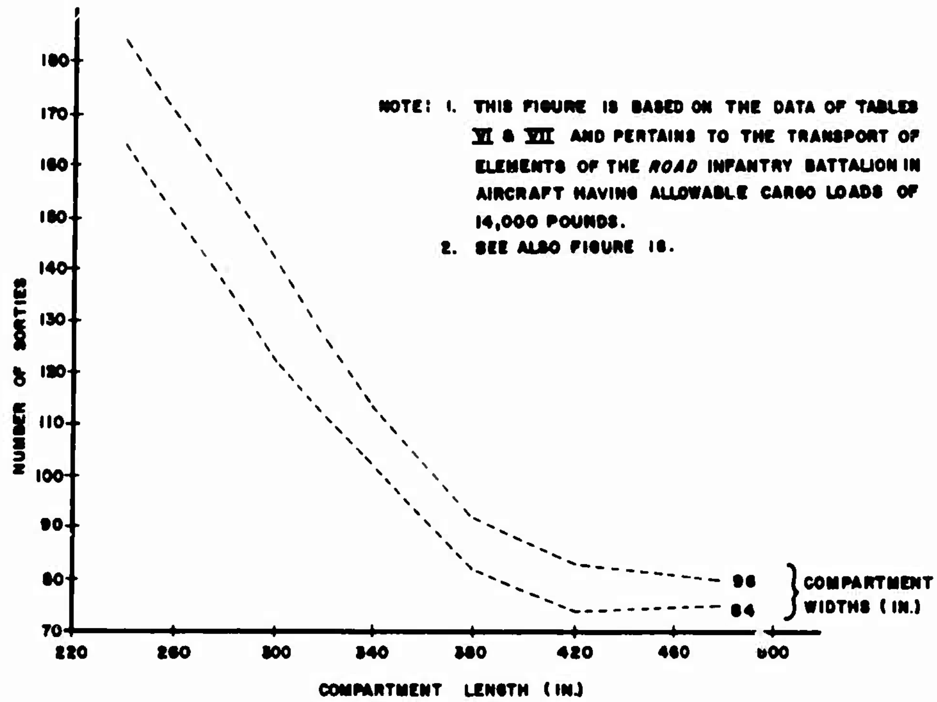

Figure 17. Example Problem - Relation of Number of Sorties to Compartment Size (Small Widths).

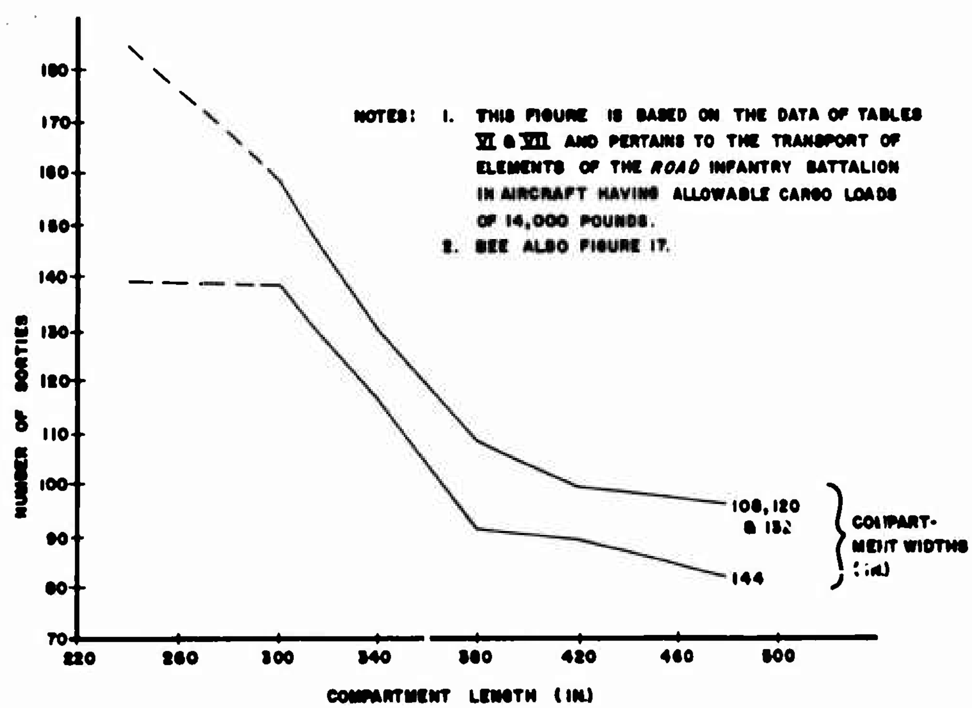

Figure 18. Example Problem - Relation of Number of Sorties to Compartment Size (Large Widths).

The 33-percent increase in width from 108 to 144 inches results in a reduction in sortie requirements of approximately 10 to 15 percent (Figure 18). It also increases the average payload utilization (Figure 13) but decreases the average space utilization (Figure 14). The average composite utilization is virtually unchanged (Figure 16). These effects are associated with the side-by-side packing of 1/4-ton utility trucks made possible with the 144-inch width.

The proper compartment lengths corresponding to widths of 108 and 144 inches lie within the range of 340 to 420 inches, as may be judged from the shapes of the curves shown on Figures 13, 14, 16, and 18. However, definitive conclusions about the proper compartment length for optimum transport efficiency must be withheld. A final selection of recommended lengths would be contingent upon a rerun of the loading program in which the specific range in lengths between 340 and 420 inches would be more fully investigated. However, it does appear that a shorter length is warranted with the 144-inch width as compared with the 108-inch width (see, in particular, Figure 16).

Operating on the premise that the 2-1/2-ton truck must be transported, the transport-efficiency criteria would narrow the choice of compartments to two. One of these would have a width of 108 inches and a length probably within the range of 380 to 420 inches. The other would have a width of 144 inches and a probable length between 340 and 380 inches. Table VIII is presented to compare these two compartment sizes.

TABLE VIII

TRANSPORT-EFFICIENCY COMPARISON OF TWO COMPARTMENT SIZES

	108-by-400-Inch Compartment	144-by-360-Inch Compartment
Floor Area (in.^{2})	43,200	51,840
Average Payload Utilization (percent)	65.5	66.0
Average Space Utilization (percent)	52.0	43.5
Average Composite Utilization (percent)	117.5	109.5
Sortie Requirements	104	104

The results of Table VIII are highly dependent upon the assumed lengths. However, if it is assumed that these lengths have been verified through a rerun of the loading program, the transport-efficiency criterion clearly shows the distinct advantages of the 108-by-400-inch compartment even without consideration of economy.

CONCLUSIONS

It is concluded that:

1. Since an efficient compatibility between the transport aircraft and the portable cargo is necessary in order to realize proper utilization of the aircraft capacities, it is essential to conduct a thorough, detailed selection of the cargo-compartment dimensions early in the design phases for transport aircraft.

2. Past sizing analyses have sometimes been deficient in one or more of the following areas: (1) they often have been predicated on considerations other than those of capability and efficiency; (2) they have been tedious and time-consuming in application; (3) they have been insensitive to the nature of the transported cargo, the pertinent fit considerations, and appropriate loading rules; (4) they have failed to consider all cargo vital to proper mission performance; and (5) they have been based on unsound or incomplete data.

3. An acceptable methodology has been developed for conducting a proper sizing analysis and for assessing the effects of compartment size on the utility of transport aircraft. This parametric-type analysis includes a fit-compatibility phase, a transport-efficiency phase, and a historical-comparison phase.

4. The rather detailed data necessary for the fit-compatibility phase have not been developed to date.

5. The best way to assess the transport-efficiency criterion for deployment missions is through the derivation of mission costs. Since data are generally unavailable to support this assessment, the transport-efficiency criterion must be expressed in other terms. A comparative analysis of average payload utilization, average space utilization, average composite utilization, and sortie requirements may be an adequate substitute for this evaluation.

6. An acceptable way to compute the minimum sortie requirements is a type-load, optimization procedure for the independent examination of each sortie and its optimization in terms of maximum utilization of the payload and space capacities.

RECOMMENDATIONS

It is recommended that:

1. Immediate efforts be undertaken to develop additional data required for proper application of the fit-compatibility phase.

2. Equipment data for battalion-sized units of the airmobile division be assimilated as soon as the appropriate TOE's become available.

3. The go/no-go check be programmed for application with the IBM 7090 computer and subsequently incorporated as an integral part of the loading program.

4. The methodology developed in this study be applied to assist in selecting the cargo-compartment dimensions of future Army transport aircraft as early in the design phases as practical.

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13. ABSTRACT

The purposes of this task were to formulate an appropriate study framework for investigating the effects of cargo-compartment size on the utility of Army transport aircraft and to collect the necessary basic data to support such a study. The ultimate objective was the development of a methodology that would enable the judicious design selection of optimal compartment dimensions.

A workable methodology was derived following a thorough review of previous cargo-compartment sizing analyses for transport aircraft. This parametric-type analysis includes a fit-compatibility phase for deriving a set of minimum desirable compartment dimensions, a transport-efficiency phase for modifying these minimum dimensions if warranted from efficiency considerations, and a historical-comparison phase for comparing the design dimensions with those of previously built aircraft.

Since an efficient compatibility between the aircraft and the transportable cargo is necessary to realize proper utilization of the aircraft capabilities, it is essential to conduct a thorough, detailed selection of the cargo-compartment dimensions early in the design phases for future Army transport aircraft.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Cargo Compartment Size						
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