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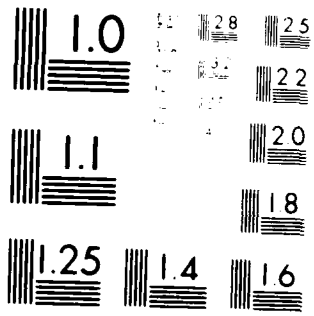
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A RAND NOTE

THE IMPACT OF TANKER SUPPORT ON SELECTION OF LONG-RANGE COMBAT AIRCRAFT SIZE

R. D. Shaver, H. G. Massey,
A. A. Barbour, J. L. Birkler

September 1982

N-1861-AF

Prepared for The United States Air Force

Rand
SANTA MONICA, CA. 90406

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This note addresses the problem of long-range combat aircraft (LRCA) size selection and the impact of tanker support. It examines two possible LRCA missions (the canonical SIOP requirement and the use of LRCAs for world wide force employment (WWFE) with nonnuclear ordnance) and airframe designs. Section II discusses the range/payload equations (with and without tankers) appropriate for SIOP-like missions. Section III describes the range shortfalls for the SIOP mission given specific airframe designs and mission-specific payload weights. Section IV translates these designs into total life-cycle costs, still concentrating on the SIOP-like mission requirements. That section presents the observations about preferred sizes for LRCA if the SIOP were the only mission to be considered. Finally, Section V discusses the impact of the WWFE mission on the above observations. The appendix presents details of the cost estimates upon which the cost estimating relationships used for the analysis were based.

A RAND NOTE

THE IMPACT OF TANKER SUPPORT ON SELECTION OF LONG-RANGE COMBAT AIRCRAFT SIZE

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PREFACE

During the 1980 Air Force Scientific Advisory Board (SAB) summer study on long-range combat aircraft (LRCA). the issue of sizing a new LRCA was raised and answered. That answer did not attempt, however, to account for the possible impact of employing tanker support. This Note, started in support of the SAB at the time of the study, treats this issue, dealing first with missions whose requirements are derived from the Single Integrated Operational Plan (SIOP), and then expanding the analysis to incorporate missions characterized by the use of LRCAs in worldwide nonnuclear conflicts. Although the analysis was completed in the summer of 1981, it is being published at this time because the issue of tanker support for future LRCA fleets remains.

The results of this preliminary analysis should be of interest to those in the Air Force directly concerned with assessing future strategic aircraft designs and options. It was prepared under the Project AIR FORCE research project, "Assessment of Mixed Strategic Force Concepts for Flexible Requirements and Scenarios."

SUMMARY

One of the issues raised in the 1980 Air Force Scientific Advisory Board (SAB) summer study of long-range combat aircraft (LRCA) was size selection and the impact of tanker support. This Note addresses this issue, examining two possible LRCA missions (the canonical SIOP requirement and the use of LRCAs for worldwide force employment (WWFE) with nonnuclear ordnance) and airframe designs specified in the SAB study. The principal measure of merit used throughout is the LRCA total fleet cost (development, acquisition, and 20 years of operation, expressed in FY 1980 dollars), to include the LRCA and its tankers, if any.

This Note takes as given the mission requirements stated in the SAB summer study:

- Total SIOP unrefueled range equivalent to 8500 n mi maximum cruise range at high altitude. (This range requirement is identical with the B-1B program requirement.)
- Total WWFE mission ranges not to exceed 5000 n mi. This range was derived from an examination of likely theaters of employment and base availability for roundtrip missions.
- Total SIOP payload requirements at the design range of 2.5 million pounds, approximately equivalent to the B-52 fleet's delivery capacity.
- Total WWFE payload requirements at the design range of 12.5 million pounds, again equivalent to the B-52 fleet's capacity.
- Installed mission-specific avionics weights varying between 5000 and 15,000 lb for combat capable aircraft; tankers are assumed not to carry mission-specific avionics.

Given these requirements, the following conclusions pertain.

<u>Assuming the SIOP mission requirements and a fixed maximum payload per aircraft, LRCA life-cycle costs are essentially invariant for aircraft gross takeoff weights in excess of 250,000 lb.</u> Smaller aircraft are less expensive to build and operate, but require greater tanker support. In most circumstances, this added support counterbalances any cost savings associated with smaller aircraft (see Figs. 3-6). Although larger aircraft can carry more payload for a given design range, this additional capability is assumed not to be exploited because of SIOP constraints on effective payload sizing. Therefore, considerations other than fleet costs should determine LRCA sizing, such as operational flexibility and the impact of tanker dependency, total fleet sizing, basing considerations, cost per airframe, and the use of the fleet in non-SIOP roles.

<u>With SIOP requirements, it is not clear whether LRCA aircraft should be sized to require tanker support.</u> Tankers cannot be ruled out on the basis of life-cycle costs, nor can they be readily rejected because of other factors. No-tanker LRCA solutions lead to large aircraft designs, i.e., aircraft with gross takeoff weights in excess of 500,000 lb, and thus to large costs per airframe, small fleet sizes that would be more sensitive to attrition losses in non-SIOP uses, and so forth. Arguments against tankers--operational considerations, survivability concerns, the fear that tankers will be diverted to other uses (e.g., support of the tactical air forces) when nuclear war is threatened--can be diminished through tanker fleet sizing, design, and operational tactics. Tankers can be designed to have survivability characteristics identical with those of combat LRCAs; in fact, mainly for costing purposes, we assume in this study that the tankers are derivatives of the combat LRCA. Additional flexibility is possible by designing the combat and tanker LRCA variants to be interchangeable. (This Note briefly considers the advantages of permitting rapid conversion from a combat LRCA to a tanker and vice versa.)

LRCA life-cycle costs are sensitive to the specified maximum SIOP payload assumed. The costs vary from over $40 billion for the case where the maximum payload per LRCA is 10,000 lb, to $18 billion if payload sizing is unconstrained. These costs are also sensitive to the total payload that the fleet must carry (specified here to be 2.5 million pounds), scaling nearly directly with this amount.

Adding the requirement that LRCA aircraft perform WWFE missions can modify the above observations. Three approaches toward including this mission have been considered:

- Assume that the LRCA fleet is sized to meet the SIOP requirements and examine the resulting WWFE capability inherent in that fleet;
- Assume that two separate fleets are purchased using a common aircraft design--one fleet meeting the SIOP requirements and the other the WWFE needs--with total life-cycle cost minimized; and
- Assume that the fleet is sized to meet the greater mission requirement but not both simultaneously, with total life-cycle cost again minimized.

While these three approaches result in very different fleet sizes and resulting capabilities, the consequences for aircraft design are nearly identical.

If the WWFE mission requirements are added to those of the SIOP, the preferred aircraft design (for minimum life-cycle cost or added WWFE capability) shifts toward larger aircraft. How large depends on the maximum useful payload that a WWFE aircraft is expected to carry; for a limit of 100,000 lb, the preferred aircraft size is about 500,000 lb. Adding tankers does not alter this conclusion. Therefore, no-tanker solutions may indeed be preferred on grounds of cost when WWFE missions are considered. Although a case can be made for larger fleet sizes, particularly if the fleet size is not sufficient to support both missions simultaneously, their costs are also higher.

The utility of tankers in support of LRCAs on WWFE missions is inconsequential. Given the designated WWFE range (a maximum of 5000 n mi), only the smallest LRCA designs require any tanker support, and they were not cost effective options.

Increasing the fleet size to meet WWFE mission requirements can add tens of billions of dollars to the total LRCA fleet cost. Nevertheless, the total fleet size would still be about the same as the existing B-52 fleet. Thus, arms control considerations may be small.

The above conclusions imply the following results:

- If large aircraft designs are included, the need for tankers can be eliminated at little or no life-cycle cost or performance degradation.
- On the other hand, if smaller aircraft are desired, or a minimum fleet size is an important consideration, such designs can be almost as cost-effective as no-tanker designs.
- Therefore, total cost is not very sensitive to the selection of aircraft size, assuming that tanker support is part of the overall fleet design.

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TABLES

I. INTRODUCTION

One of the issues only partially addressed by the Air Force Scientific Advisory Board (SAB) summer 1981 study on the next-generation long-range combat aircraft (LRCA) was the optimum size of that aircraft, given the diverse mission requirements and performance attributes specified during the study.* The designs discussed tended to favor sizes in excess of 500,000 lb gross takeoff weight. These sizes were mainly driven by the difficult mission requirements imposed on the LRCA, e.g., a short field takeoff and landing ability, takeoff acceleration at least equal to the B-1, the ability to perform all missions without tanker support, and the ability to fly at high altitude over 8500 n mi without refueling. Nevertheless, the consensus among study participants was that smaller sizes would be preferable were they feasible. Although recognized as relevant, the important issues of total life-cycle costs, optimum payload sizes, and the impact of tanker support were not covered (tankers were ruled out because of their perceived operational disadvantages). This Note expands on some Rand work generated at the time of the summer study as background support for the SAB and treats these issues sufficiently to illuminate first-order effects on aircraft size selection.

This Note concentrates on SIOP-like mission requirements--8500 n mi high altitude <u>equivalent</u> range, with an aircraft fleet sized to carry a total weapon payload of approximately 2.5 million pounds.† Other missions, e.g., World-Wide Force Employment (WWFE), require less range or do not have well-rationalized weapon payload requirements, leaving the SIOP missions as those that determine aircraft design requirements. Nevertheless, these "other" missions can influence the vehicle design and are treated in some detail.

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*Time and study manpower forced many relevant questions to remain only partially answered.

†In this Note we use the expressions "SIOP" and "SIOP-like" to describe generic missions requiring equivalent high altitude flight ranges in excess of 8500 n mi and weapon payloads that in general are carried internally, thereby limiting the maximum payload that any aircraft can effectively deliver.

Some caveats are in order. First, the depth of analysis contained here does not warrant firm conclusions. These results should be viewed as illustrative, a guide for future work. Second, the results apply only to conventional aircraft; that is, aircraft with lift-to-drag ratios, structural weight fractions, and flight envelopes that are characteristic of current aircraft. No novel designs were considered. And, finally, the results are believed to be sensitive to some of the mission requirements that we have taken as given. Longer ranges or greater payload requirements might have altered our conclusions.

The principal measure of merit used throughout this Note is the LRCA fleet life-cycle cost (development, acquisition, and 20 years operation, expressed in FY 1980 dollars). The mission of prime concern is the SIOP, defined in terms of equivalent high altitude range (in excess of 8500 n mi) and total mission payload (2.5 million pounds). The principal results relate to this mission, but the implications of other missions (termed "WWFE" and characterized by range requirements of 5000 n mi) are included.

This Note is organized in the following way. Section II discusses the range/payload equations (with and without tankers) appropriate for SIOP-like missions. Section III describes the range shortfalls for the SIOP mission given specific airframe designs and mission-specific payload weights. Section IV translates these designs into total life-cycle costs, still concentrating on the SIOP-like mission requirements. That section presents our observations about preferred sizes for LRCA if the SIOP were the only mission to be considered. Finally, Sec. V discusses the impact of the WWFE mission on the above observations.

The appendix presents details of the cost estimates upon which the cost estimating relationships used for the analysis were based.

II. RANGE/PAYLOAD EQUATIONS WITH AND WITHOUT REFUELING

In this section we develop some of the equations needed for calculations of the range/payload capabilities of alternative LRCA designs, different avionic system weights, and gross aircraft weights. We examine both the unrefueled ranges and the ranges obtainable with inflight refueling. In subsequent sections of this Note we apply these equations to the problem of selecting the appropriate size and payload-carrying capacity of the next-generation LRCA.

BREGUET RANGE EQUATION

The widely used Breguet range equation closely approximates precise performance estimates of real aircraft. The following is one form for that equation:

$$R = K \log_e \left[\frac{W_G}{W_e + W_a + W_p} \right] \qquad (1)$$

where R is the aircraft maximum unrefueled range (n mi), K is the Breguet range factor (n mi), W_G represents the aircraft gross takeoff weight, W_e represents the aircraft empty weight (less mission-specific avionics), W_a is the aircraft mission-specific avionics weight, and W_p is the payload weight. A slightly more detailed expression for this equation is obtained by substituting the product v(L/D)/c for K, where v is the aircraft cruise velocity, L/D is the lift-to-drag ratio for the aircraft at cruise conditions, and c is the engine-specific fuel consumption. Figure 1 contains estimates of K and the ratio W_e/W_G as a function of W_G. Two different estimates of the empty weight fraction are shown. One is based on inputs from John Cunningham, a contributor to the SAB summer study. The other is based on detailed aircraft design calculations provided to the SAB summer study by AFSC/ASD.* We will display our principal results using both estimates,

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*The ASD calculations were based on computer designs of aircraft having the desired mission characteristics. Because of the sensitivity of the designs to these characteristics and the lack of time to explore

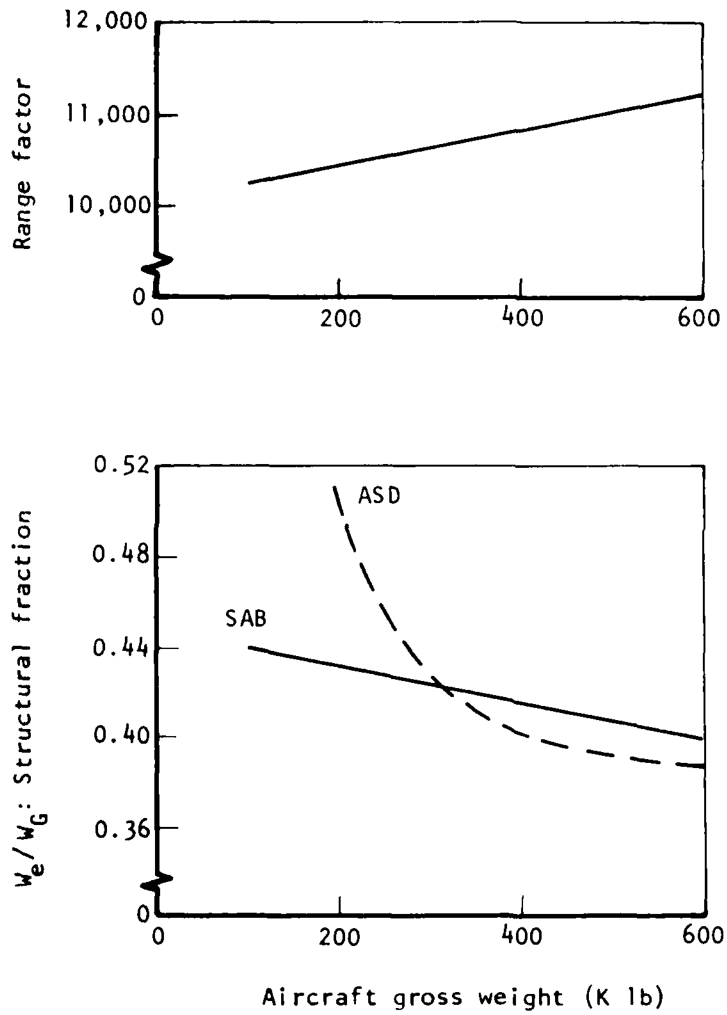

Fig. 1--LRCA design curves

because we believe that they tend to bound the likely outcomes of detailed aircraft design studies.*

Because K and W_e are functions of W_G, only three independent factors dictate the maximum unrefueled range--gross weight, mission-specific avionics weight, and payload size. In the following we will generally fix the avionics weight, and vary widely both the gross weight and the payload size.

RANGE ENHANCEMENT: A SINGLE DEDICATED TANKER

Equation (1) is a specific solution to a more general equation:

$$W(r) = W_G \exp\left(-\frac{r}{K}\right) \tag{2}$$

where r is the range flown and W(r) is the aircraft gross weight at range r. The total weight of the fuel burned at range r is simply the initial gross weight minus the weight at range r. If we designate ΔF_b as the weight of fuel burned, then

$$\Delta F_b = W_G \left[1 - \exp\left(-\frac{r}{K}\right)\right] \tag{3}$$

Assuming that the aircraft at takeoff is fully loaded, ΔF_b is also the maximum fuel that can be loaded into the LRCA at any range r.† We state without proof that optimum refueling is obtained by fully loading the bomber during air refueling, assuming sufficient tanker fuel is available. Thus ΔF_b also represents the amount of fuel that

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the many possible variations in aircraft designs that would affect the weights, ASD's results were not used by the SAB for tradeoff considerations.

*We have taken these design curves as given. Substantial changes in their magnitude or slope could yield different results. In general, these curves tend to favor larger aircraft.

†Under some reasonable conditions, LRCAs might leave their bases not fully loaded (e.g., if insufficient runway length was available for a fully fueled LRCA to take off). In such circumstances the

the LRCA would receive from the tanker at range r if the tanker had that amount of fuel to offload. We also note that if refueling occurred at range r, and the LRCA was fully loaded, then r would also represent the total range enhancement from that refueling.

In this Note we assume that the LRCA will be configured as a tanker as well as a combat aircraft. By assumption, the mission payload and mission-specific avionics are removed from the tanker variant, and extra fuel is added.* Furthermore, we assume that the tanker and the combat aircraft to be refueled fly the "buddy" system, i.e., they depart from the same base at the same time and fly in formation until the refueling point is reached. We assume that after refueling the tanker proceeds to a forward recovery base located within s miles from the refueling point (s is a parameter to be specified later). The amount of fuel available for offloading into the combat aircraft, defined as ΔF_a, is simply

$$\Delta F_a(r) = W(r) - W_e \exp\left(\frac{S}{K}\right) \tag{4}$$

where the last term in the equation represents the minimum tanker gross weight required at range r for the tanker to be able to fly s miles to the recovery base.

We state without proof that the optimum increase in range for the LRCA is obtained if the refueling occurs when $\Delta F_a(r) = \Delta F_b(r)$.†

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initial unrefueled range R would become

$$R = K \log_e \left[\frac{W_G - \Delta F_o}{W_e + W_a + W_p}\right]$$

where ΔF_o is the weight of the fuel offloaded at takeoff. All the remaining equations are unaltered.

*The total performance would be slightly worse if the avionics were not removed, but the trends of the results would remain unaltered.

†The proof is straightforward and is presented in Ref. 1.

If Δr_1 denotes this range,

$$1 - \exp\left(-\frac{\Delta r_1}{K}\right) = \exp\left(-\frac{\Delta r_1}{K}\right) - \left(\frac{W_e}{W_G}\right) \exp\left(\frac{s}{K}\right)$$

or

$$\Delta r_1 = K \log_e \left[\frac{2}{1 + \left(\frac{W_e}{W_G}\right) \exp\left(\frac{s}{K}\right)}\right] \tag{5}$$

Since the LRCA is completely refueled at Δr_1, Δr_1 represents the maximum increase in range obtained with the aid of a single tanker.*

RANGE ENHANCEMENT: MULTIPLE TANKERS PER BOMBER

An added increase in the LRCA range can be obtained by using two or more tankers. Assuming the same buddy tactics as above, we can rewrite Eq. (3) for the LRCA to account for a prior refueling. Assume a single prior complete refueling at Δr_1. Then

$$\Delta F_b(r > \Delta r_1) = W_G \left[1 - \exp\left(-\frac{r - \Delta r_1}{K}\right)\right] \tag{6}$$

Equation (4) still applies to the second tanker. Furthermore, the optimum refueling point still occurs when the fuel available to be offloaded exactly equals the fuel needed to fill the LRCA. Thus

$$1 - \exp\left(-\frac{\Delta r_2}{K}\right) \exp\left(\frac{\Delta r_1}{K}\right) = \exp\left(-\frac{\Delta r_2}{K}\right) - \left(\frac{W_e}{W_G}\right) \exp\left(\frac{s}{K}\right)$$

where Δr_2 is the new total range augmentation obtained by two refuelings. Solving for Δr_2,

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*It is worth noting that the range augmentations are entirely independent of the LRCA payload or mission avionics weights. The reason for this nonintuitive result is that the tanker does not carry either the payload or mission-specific avionics.

$$\Delta r_2 = K \log_e \left[\frac{1 + \exp\left(\frac{\Delta r_1}{K}\right)}{1 + \left(\frac{W_e}{W_G}\right) \exp\left(\frac{s}{K}\right)} \right] \quad (7)$$

Equation (7) can be rewritten to portray Δr_2 solely as a function of Δr_1, i.e.,

$$\Delta r_2 = K \log_e \left\{ \frac{\exp\left(\frac{\Delta r_1}{K}\right)\left[1 + \exp\left(\frac{\Delta r_1}{K}\right)\right]}{2} \right\} \quad (8)$$

By a similar procedure we can derive expressions for range enhancements from three or more tankers. If we specify that Δr_n is the total range obtained by using n tankers and the buddy system,

$$\Delta r_n = K \log_e \left[\frac{1 + \exp\left(\frac{\Delta r_{n-1}}{K}\right)}{1 + \left(\frac{W_e}{W_G}\right) \exp\left(\frac{s}{K}\right)} \right] \quad (9)$$

Tactics other than the buddy system could further increase the total range obtained from refueling. In particular, basing tankers at forward locations and not requiring them to fly as far as the combat aircraft before the optimum refueling point would make additional fuel available to the LRCA and increase its total range potential. Operationally, such tactics add problems (e.g., in mating aircraft) not existing in the buddy system, thereby increasing the probability of less than perfect use of the tanker inventory. It is beyond the scope of this Note to explore such factors or to specify which set of tactics would be preferred.

RANGE ENHANCEMENT: TWO LRCAS PER TANKER

It frequently occurs that the desired total mission range is greater than the maximum unrefueled range of the aircraft, but substantially less than the range obtainable with a single optimum refueling from a dedicated tanker. Under such circumstances, one tanker might be capable of supporting two or more LRCAs, refueling first one, then the next, and so forth. Since multiple refuelings cannot occur simultaneously, the tanker must fly some distance between refueling points. The variable t is defined to be the total range flown by the tanker from the termination of one refueling to the termination of the next. If we assume that two combat aircraft and one tanker fly the buddy system, and that the refueling is accomplished so that both combat aircraft obtain the same range augmentation, then the following formula pertains:

$$\Delta r_{1/2} = K \log_e \left[\frac{3}{2 + \left(\frac{W_e}{W_G}\right) \exp\left(\frac{s + t}{K}\right)} \right] \tag{10}$$

where $\Delta r_{1/2}$ is the range augmentation each aircraft receives. $\Delta r_{1/2}$ is obviously the range at which the first aircraft is refueled, $\Delta r_{1/2} + t$ is the range at which the second aircraft is refueled.

Other assumptions about refueling, e.g., the second refueling exactly fills the second combat aircraft or the fuel loaded into each aircraft is the same, produce slightly different range augmentations and refueling distances. In general, the equal range augmentation assumption used to derive Eq. (10) leads to the smallest estimate of average augmentation, but the largest range enhancement for the first aircraft.

OVERALL TANKER REQUIREMENTS

We will now combine the above equations and Fig. 1 to determine the number of tankers per combat aircraft required to support the assumed SIOP mission. Table 1 shows the various maximum range augmentations obtainable with tanker support as a function of the aircraft gross weight.* Figure 2 plots maximum range vs. gross weight

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*In the calculations in Table 1, we assume that all recovery distances are the same, regardless of where the last refueling occurs.

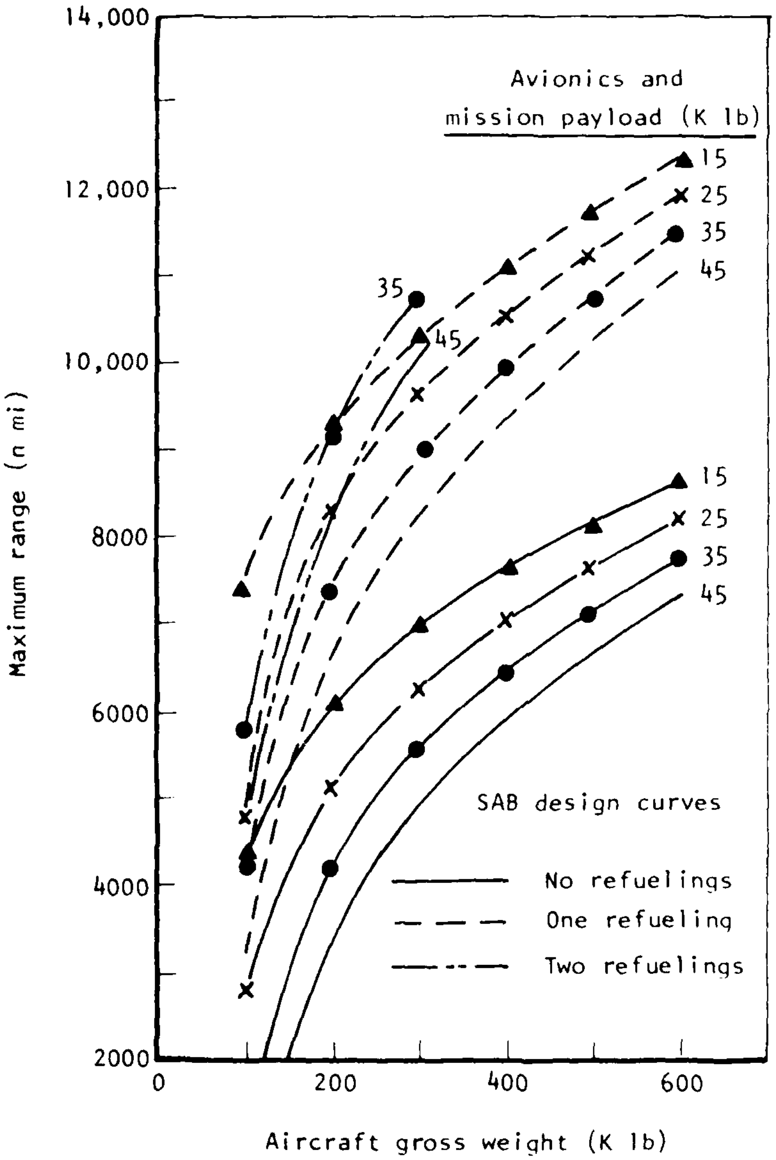

Fig. 2--Maximum range vs gross weight

Table 1

MAXIMUM RANGE ENHANCEMENT (n mi)[a]

(SAB Curves)

Range Enhancement	Aircraft Gross Weight (K lb)				
	200	300	400	500	600
$\Delta r_{1/2}$	1808	1902	1985	2063	2149
Δr_1	3178	3325	3454	3578	3717
Δr_2	4888	5117	5319	5512	5729

[a]Range between refuelings (t) = 1000 n mi; tanker recovery range (s) = 1000 n mi.

where zero, one, and two refuelings are included for comparison, as well as the total weight devoted to mission-specific items (avionics and payload). Obviously, refueling can significantly enhance the range/payload performance for aircraft of all sizes.

Still at issue is how many tankers are needed overall to support the SIOP mission profile. Because the required range is an expected

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Obviously, this assumption is overly simplistic, even if analytically convenient. If we imposed the more general condition that tanker recovery distances are a function, f(r), of LRCA range at last refueling, then Δr satisfies (for a single refueling) the following equation:

$$2 \exp\left(-\frac{\Delta r}{K}\right) - \left(\frac{W_e}{W_G}\right) \exp\left(\frac{f(\Delta r)}{K}\right) - 1 = 0$$

This equation requires numerical solution except for simple expressions for $f(\Delta r)$. Estimates of f(r) are heavily dependent on planning assumptions, available recovery bases, initial bomber/tanker alert bases, the routes flown, etc., and are beyond the scope of this study.

average, with a substantial variation about that average for individual bomber routes, we will define our tanker requirements to meet an _average_ requirement. The derivation of the real requirement rests on detailed mission plans, clearly beyond the scope of this Note. Therefore, we approximate this requirement by the following relation. If α equals the ratio of tankers to bombers,

$$\alpha = \begin{cases} 0.5\ (\Delta R/\Delta r_{1/2}) & 0 \leq \Delta R \leq \Delta r_{1/2} \\ 0.5 \left[1 + \dfrac{\Delta R - \Delta r_{1/2}}{\Delta r_1 - \Delta r_{1/2}} \right] & \Delta r_{1/2} \leq \Delta R \leq \Delta r_1 \\ (n - 1) + \left[\dfrac{\Delta R - \Delta r_{n-1}}{\Delta r_n - \Delta r_{n-1}} \right] & \Delta r_{n-1} \leq \Delta r \leq \Delta r_n, \text{ and } n \geq 1 \end{cases} \tag{11}$$

where ΔR is the difference (shortfall) between the desired mission range and the maximum unrefueled range of the combat aircraft, and Δr_1, Δr_2, and $\Delta r_{1/2}$ are given in Eqs. (5), (9), and (10).

III. MISSION RANGE SHORTFALLS VS. AIRCRAFT GROSS WEIGHT

In this and the next section we examine the intercontinental nuclear strike missions--the SIOP and SIOP-derivatives--since these missions appear to have the strongest influence on aircraft sizing and tanker requirements. WWFE mission requirements will be introduced in a later section where we discuss the impact of diverse mission requirements on a single aircraft buy.

Table 2 displays the maximum unrefueled range as a function of aircraft gross weight, using the SAB designs. As already indicated in Fig. 2, large (i.e., heavy) aircraft carrying small payloads can fly 8500 n mi and beyond without refueling; smaller aircraft or aircraft with very large payloads cannot. Range shortfalls are the differences between these values and 8500 n mi. Using these shortfall data, the range enhancement values in Table 1, and Eq. (11), we can calculate the number of tankers per combat aircraft needed for SIOP mission

Table 2

MAXIMUM UNREFUELED RANGE

(n mi) (SAB Design Data)

Total Avionics and Payload Weight (K lb)	Aircraft Gross Weight (K lb)				
	200	300	400	500	600
15	7105	8003	8624	9131	9627
25	6123	7277	8040	8638	9195
35	5226	6597	7486	8166	8779
45	4400	5958	6959	7712	8377
55	3635	5356	6457	7278	7990
65	2923[a]	4786	5977	6860	7615

NOTE: Shading indicates cases where refueling is unnecessary.

[a]Must be refueled before the optimum refueling point (3178 n mi).

achievement. Table 3 displays the resulting tanker requirements, assuming the SAB curves (henceforth we shall use the SAB curves unless indicated otherwise). From Table 3 we observe that generally less than one tanker per bomber is required for the range and parameters shown.

Table 3

TANKER/BOMBER RATIO REQUIRED FOR 8500 N MI MISSION RANGES

(SAB Design Data)

Total Avionics and Payload Weight (K lb)	Aircraft Gross Weight (K lb)				
	200	300	400	500	600
15	.39	.13	--	--	--
25	.71	.32	.12	--	--
35	1.06	.51	.26	.08	--
45	1.54	.73	.39	.19	.03
55	1.99	.94	.52	.30	.12
65	2.68	1.22	.68	.39	.21

Avionics weights are expected to be between 5000 and 15,000 lb, depending on assumptions about electronic countermeasures (ECM) requirements, the need for active defense onboard the ERCA, etc. By specifying the avionics weight (which would presumably apply for all aircraft sizes),* we can obtain the payload weight per ERCA vs. tanker requirement. These relationships are used in Sec. IV, where we calculate total life-cycle costs as a function of aircraft and payload weight.

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*The total mission-specific avionics weights may scale slightly with size, depending on the nature of the ECM employed and the scaling of radar cross-section (and other observables) with size.

IV. LIFE-CYCLE COSTS FOR SIOP-LIKE MISSIONS

The principal remaining unspecified variable needed to calculate the required aircraft buy is the total payload necessary for mission accomplishment. Unfortunately, no definite mission requirement exists that would permit specifying this variable. Therefore, as in the SAB study, we will specify a value that has at least a reasonable rationale: the total payload must be sufficient to replace the aging B-52 fleet--namely, 2.5 million pounds. The total aircraft buy is scaled to exceed this requirement by 20 percent, to account for replacement spares, training, and other odds and ends. If Q is the total aircraft buy,

$$Q = 1.2(1 + \alpha)\left(\frac{2.5 \times 10^6}{W_p}\right) \qquad (12)$$

Table 4 shows Q for the assumptions listed. For a fixed aircraft gross weight, Q decreases with increasing aircraft payload. Thus larger payloads lead to smaller aircraft buys and, at fixed gross weights, lower total costs. Similarly, at constant payloads per LRCA, increasing aircraft gross weight again reduces the total buy. However, the least-cost solution cannot be determined until the relative costs between aircraft sizes are specified.

Table 4

TOTAL AIRCRAFT BUY: SIOP-LIKE MISSIONS
(Avionics Weight = 15 K lb)
(SAB Weight Fraction Curve)

Payload (K lb)	Aircraft Gross Weight (K lb) 200	300	400	500	600	Minimum Buy (no tankers)
10	512	397	335	**300**	**300**	300
20	308	225	188	162	**150**	150
30	254	173	139	119	103	100
40	224	145	114	97	84	75
50	221	133	101	84	72	60

NOTE: Shading indicates cases without tankers.

The appendix describes in some detail the aircraft cost relationships, including development, acquisition, and total support cost for major aircraft parts. Despite the numerous relationships involved in this detail, very good agreement with overall aircraft life-cycle costs can be obtained by using the following simple formula

$$\text{Cost } (\$M) = 37.43(\text{AFWT})^{0.5664}(Q)^{0.7278} \qquad (13)$$

where AFWT is the aircraft empty weight (in thousands of pounds) less the engine and avionics weight. This equation excludes payload costs and includes only 5000 lb of avionic "black boxes." Table 5 displays the life-cycle costs for the entire force for the conditions pertaining to Table 4.

Table 5

LRCA LIFE-CYCLE COSTS VS. GROSS WEIGHT AND DESIGN PAYLOAD
(Costs in $B 1980)

Design Payload (K lb)	Aircraft Gross Weight (K lb)				
	200	300	400	500	600
10	41.85	43.15	44.38	46.02	50.43
20	28.91	28.54	29.15	29.39	30.45
30	25.13	23.57	23.40	23.48	23.16
40	22.93	20.73	20.25	20.23	19.97
50	22.71	19.47	18.55	18.22	17.85

Figures 3 through 6 graph these life-cycle costs under different assumptions about the aircraft design curves (SAB vs. ASD) and mission-specific avionics weight (5 vs. 15 K lb). Several observations are worth noting.

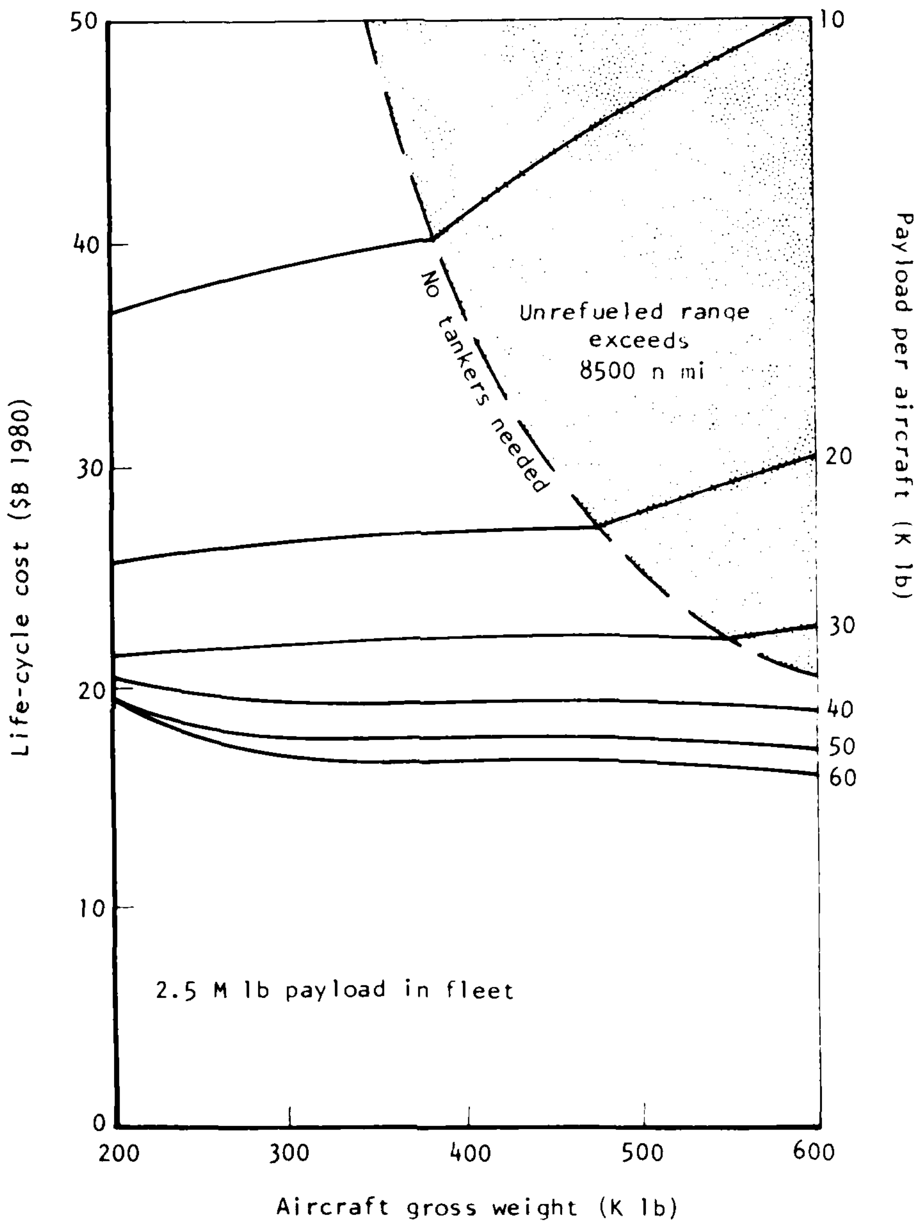

Fig. 3--LRCA life-cycle costs vs gross weight and design payload: SIOP-like missions with avionics weight = 5 K lb (SAB structural weight fractions)

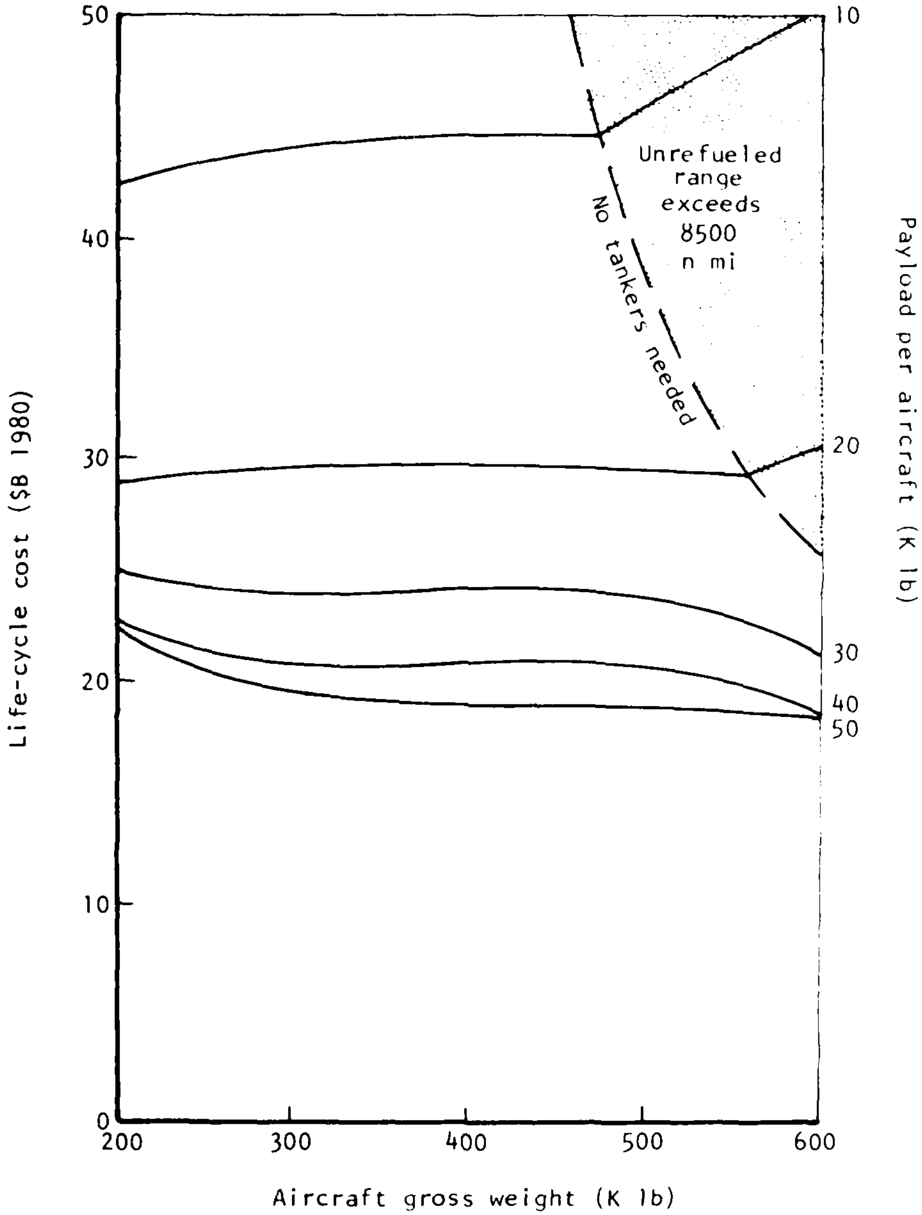

Fig. 4--LRCA life-cycle costs vs gross weight and design payload: SIOP-like missions with avionics weight = 15 K lb (SAB structural weight fractions)

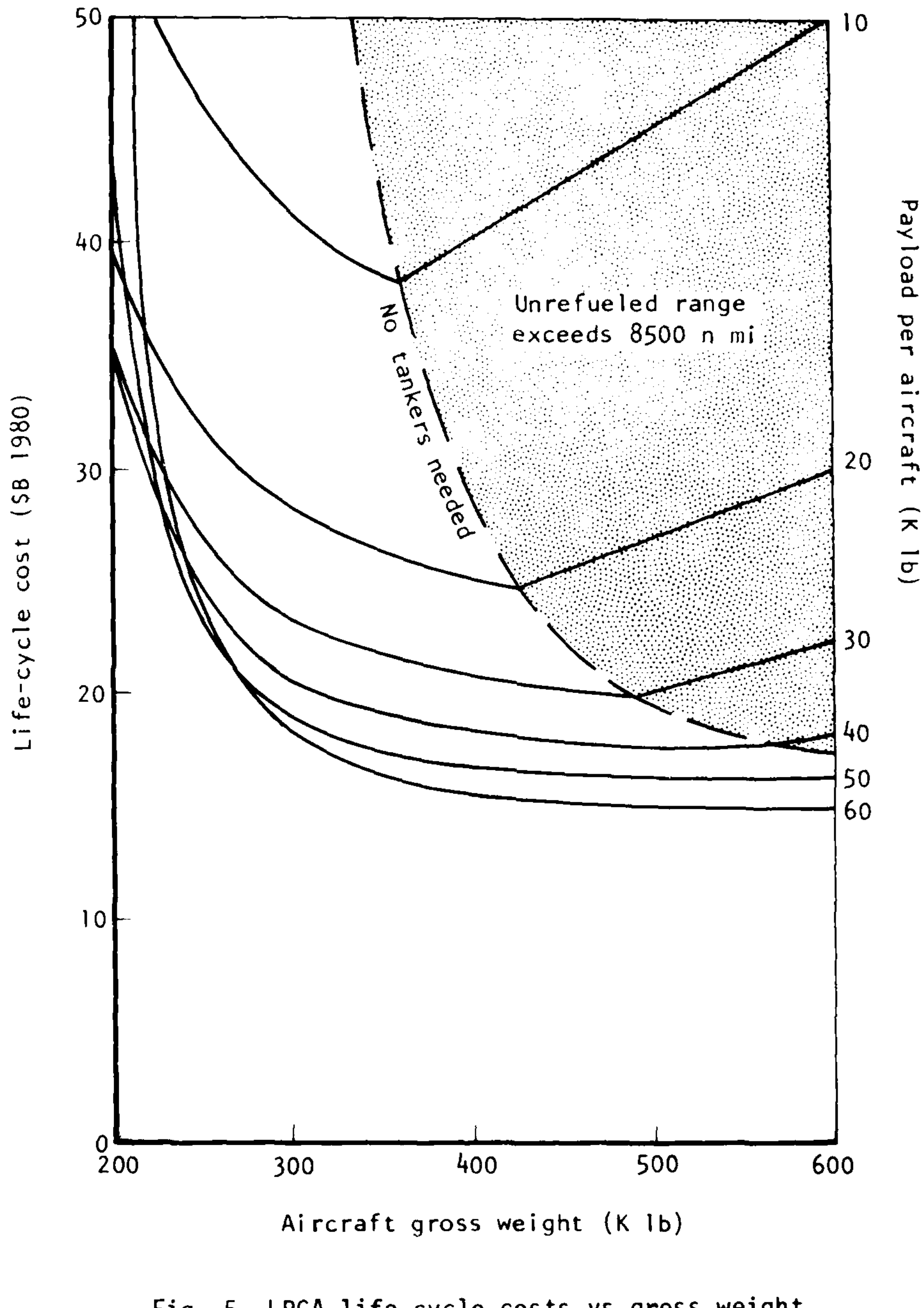

Fig. 5--LRCA life-cycle costs vs gross weight and design payload: SIOP-like missions with avionics weight = 5 K lb (ASD structural weight fractions)

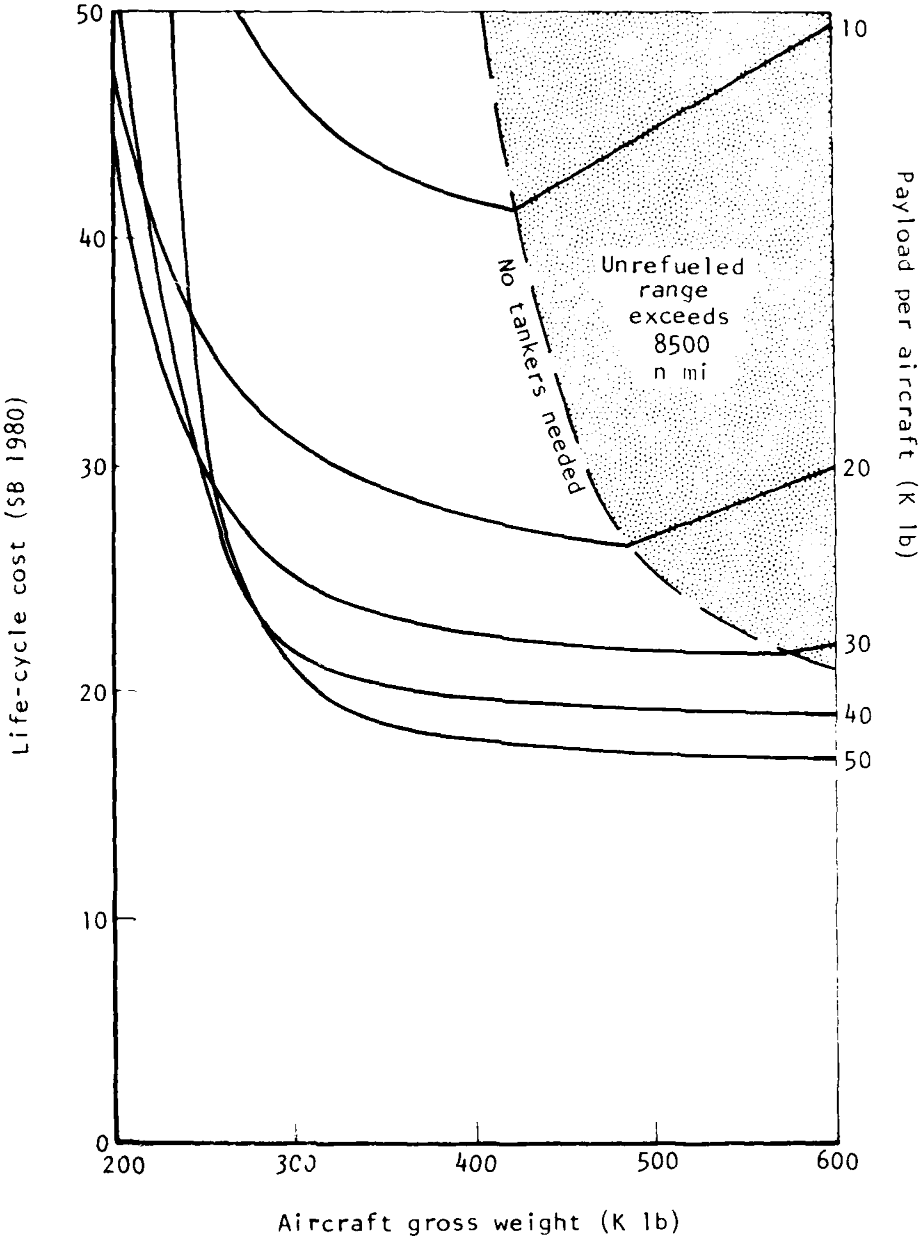

Fig. 6--LRCA life-cycle costs vs gross weight and design payload: SIOP-like missions with avionics weight = 15 K lb (ASD structural weight fractions)

First, if the aircraft must operate without tanker support, larger aircraft are the most cost-effective, so long as there is no upper limit on total payload size. For a given aircraft payload, the optimum (unrefueled) size falls along the dashed curves in the figures. Obviously, these sizes are the smallest possible consistent with the capability to fly 8500 n mi. Other considerations, e.g., basing, can influence the choice of sizing, but in general aircraft with gross weights greater than 500,000 lb will be preferred. This observation agrees closely with the SAB summer study.

Second, tanker support permits smaller aircraft designs that are nearly equal in cost to larger designs. If the cost and tanker requirement estimates are accurate, aircraft as small as 300,000 lb may be considered cost-effective. This is particularly true if the weapon payload is constrained to 30,000 lb or less--a reasonable constraint when weapon delivery mission planning is considered.

Finally, assuming the SAB design curve, using tankers is frequently the cost-effective solution, although the difference between cases with and without tankers is generally not very large, and the result is sensitive to maximum aircraft payload. Obviously, this last observation ignores operational considerations that might increase both the number of tankers needed or the cost of tanker support.

V. IMPACT OF OTHER LRCA MISSIONS ON SIZING

The previous sections examined SIOP-like mission requirements. However, LRCA are expected to perform other missions, in particular, a WWFE mission where the aircraft must be able to fly 5000 n mi round trip.*

Multimission requirements can be treated in several ways, with potentially different implications for LRCA sizing. First, it can be assumed that the fleet of SIOP-specified aircraft will also carry out the WWFE missions. In this case, we need to determine the capacity of the SIOP fleet to perform WWFE missions, and then to judge the implications of that performance level on aircraft size selection. Second, it can be assumed that additional aircraft must be acquired to perform the WWFE role. Two variants are worth considering: one where the entire WWFE mission must be accomplished by tne additional aircraft, i.e., no SIOP aircraft can be used; the other where only enough aircraft are added to make the SIOP fleet capable of performing the WWFE mission. For these two variants it is reasonable to specify a total WWFE payload to be delivered, calculate the joint costs of the two aircraft acquisitions, and seek to minimize the total life-cycle costs. In all cases we need to address the question of maximum usable payload per aircraft in the WWFE mission and the implications of tanker support.

IMPACT OF UNREFUELED WWFE MISSIONS ON LRCA SIZING

We start with the assumption of no refueling on WWFE missions. Breguet's equations can be applied to 5000 n mi missions as well as 8500 n mi missions. Using the SAB weight fractions and 15,000 lb of (installed) avionics, Table 6 presents the maximum range obtainable for a specified payload size and aircraft gross weight. The shaded area points out all payload-gross weight combinations that can perform

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*We will require that the full payload be carried the entire 5000 n mi, since sometimes the munitions might not be delivered and (for cost reasons) should be recovered. Dropping the payload halfway would add about 200 n mi to the mission radius.

Table 6

MAXIMUM UNREFUELED RANGE
(n mi) (SAB Aircraft Designs)

Payload Weight (K lb)	Aircraft Gross Weight (K lb)				
	200	300	400	500	600
20	5226	6597	7486	8166	8779
40	3635	5356	6457	7278	7990
60	2256	4245	5517	6457	7257
80	1038	3240	4652	5693	6561
100	0	2321	3852	4978	5909

NOTE: Shading indicates cases where tankers are not needed.

5000 n mi missions without refueling. Figure 7 replots these data, showing the maximum payload weight that can be carried 5000 n mi as a function of aircraft gross takeoff weight. Clearly, large aircraft can transport very large payloads.

Case 1: Total Fleet Sized for SIOP Mission Only

Under the assumption that the LRCA acquisition derived in Sec. IV is fixed, we may indicate the impact of WWFE missions on LRCA size selection in two ways. First, we can rule out all aircraft incapable of carrying a minimum-sized payload 5000 n mi without refueling. From the prior section and Fig. 7 it is clear that small WWFE mission payloads (e.g., 20,000 lb or less) will have little effect on LRCA size selection, because cost-effective gross takeoff weights permit payloads larger than the maximum. On the other hand, large payloads (e.g., more than 50,000 lb) could influence that selection. Figures 8 and 9 are copies of Figs. 3 and 4, where we have added as a minimum WWFE payload restriction the requirement that these payloads not be less than those selected for the SIOP mission. The consequence of this assumed limit is to remove very small aircraft carrying large payloads as LRCA options.

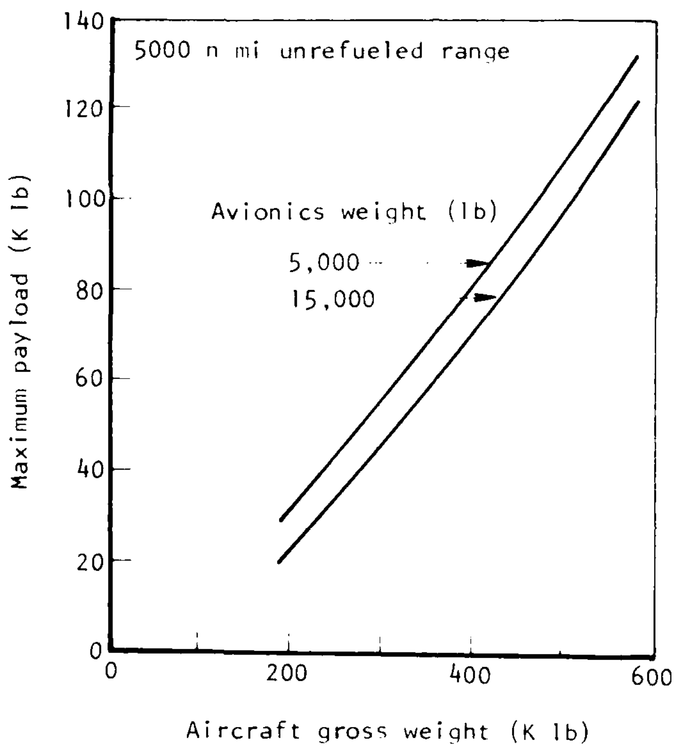

Fig. 7--Maximum payload vs gross weight: WWFE mission (SAB weight curves)

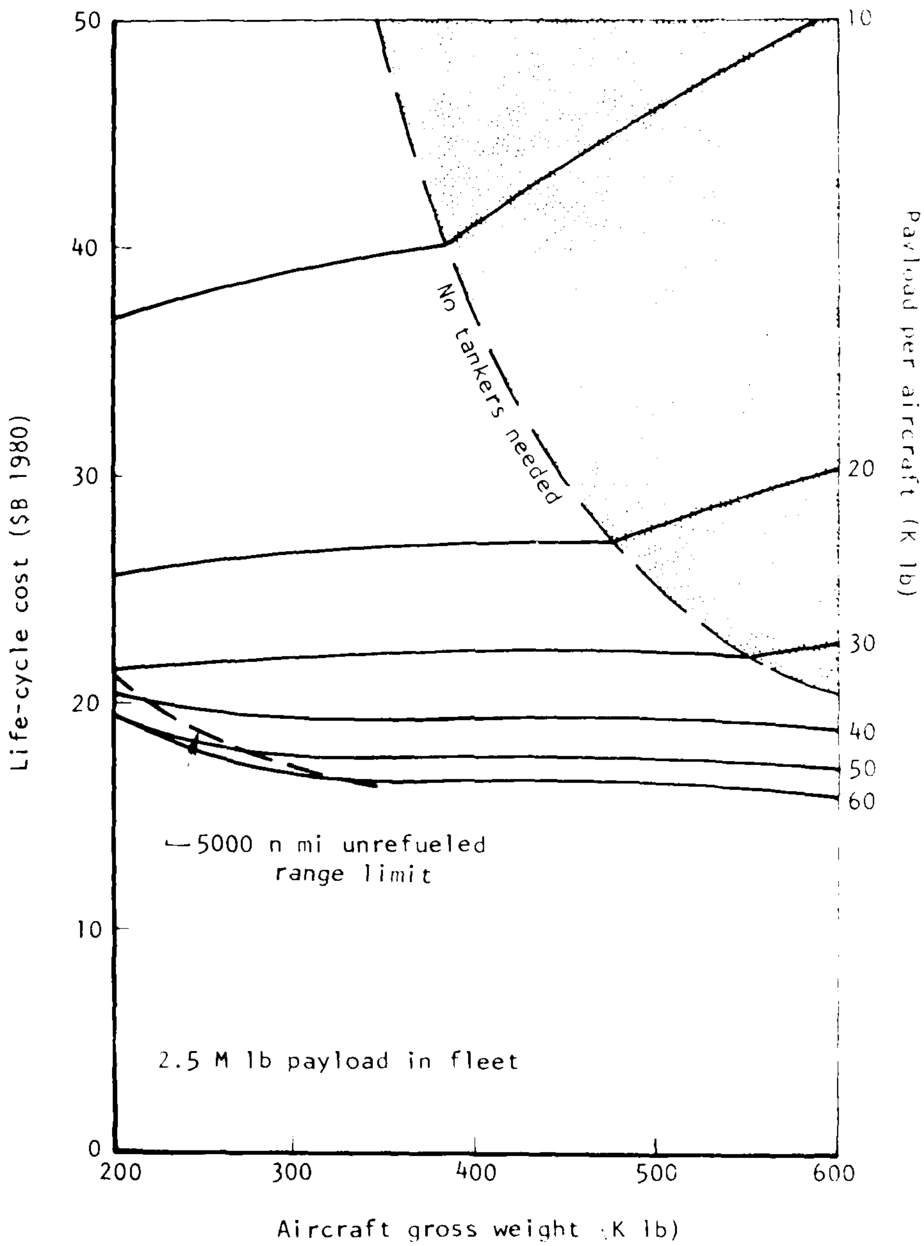

Fig. 8--LRCA life-cycle costs vs gross weight and design payload: SIOP missions only with avionics weight = 5 K lb (SAB structural weight fractions)

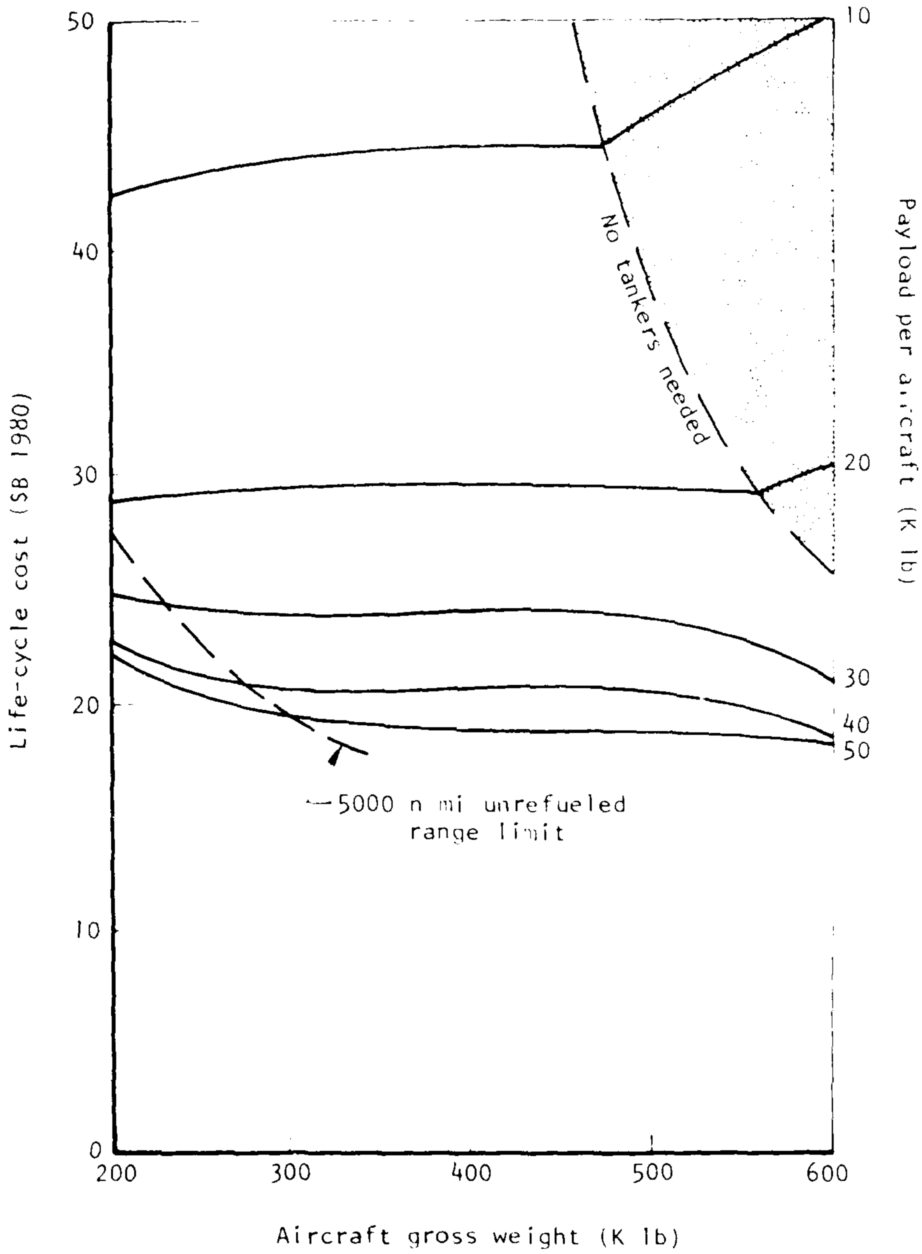

Fig. 9--LRCA life-cycle costs vs gross weight and design payload: SIOP missions only with avionics weight = 15 K lb (SAB structural weight fractions)

Second, we can calculate the total payload that can be carried by the SIOP fleet to 5000 n mi. If we place no limit on the payload that a single LRCA carries on a WWFE mission, allowing it to carry the maximum possible, then we can multiply the fleet size in Table 4 (scaled down to account for maintenance, training, etc.) by the maximum payload per aircraft in Fig. 7 to obtain total maximum payload capacity. Figure 10 crossplots that total with the life-cycle costs of the acquisition. Larger aircraft designs produce greater WWFE payload capacity, with greater or lesser life-cycle force costs depending on the size of the SIOP payload. Certain observations follow: (1) If minimum cost is the prime driver, select the biggest SIOP payload that can usefully be employed, and take whatever WWFE payload capacity this implies. This leads to the selection of large aircraft if large SIOP payloads are permitted and smaller aircraft if only small payloads are permitted. (2) For fixed LRCA gross weights, the total WWFE payload grows almost linearly with total life-cycle force costs. (3) If the resulting WWFE payload is judged inadequate, then additional payload can be obtained only by adding more aircraft. Since total WWFE payload scales directly with aircraft acquisition so long as aircraft gross takeoff weight is held fixed, the added costs of more payload can be read directly off Fig. 10.

The above assumes no constraints on WWFE aircraft usable payload weight. For a variety of reasons this assumption can be challenged. Figure 11 plots total life-cycle cost versus WWFE total payload, where no LRCA is permitted to carry more than 100,000 lb of payload. For large LRCA SIOP payloads, total life-cycle costs are still minimized by selection of large aircraft designs, but beyond the limit implied by the 100,000 lb payload restriction, total WWFE payload capability is reduced rather than enhanced. Therefore, the motivation for selecting the larger aircraft is diminished beyond this limit.

Case 2: Total Fleet Sized To Satisfy Both SIOP and WWFE Missions

To size the fleet requirements for the WWFE mission, we need to specify a total payload capacity requirement. Lacking a firm mission-

All options carry 2.5 M lb payload on SIOP missions
Avionics weight = 15 K lb

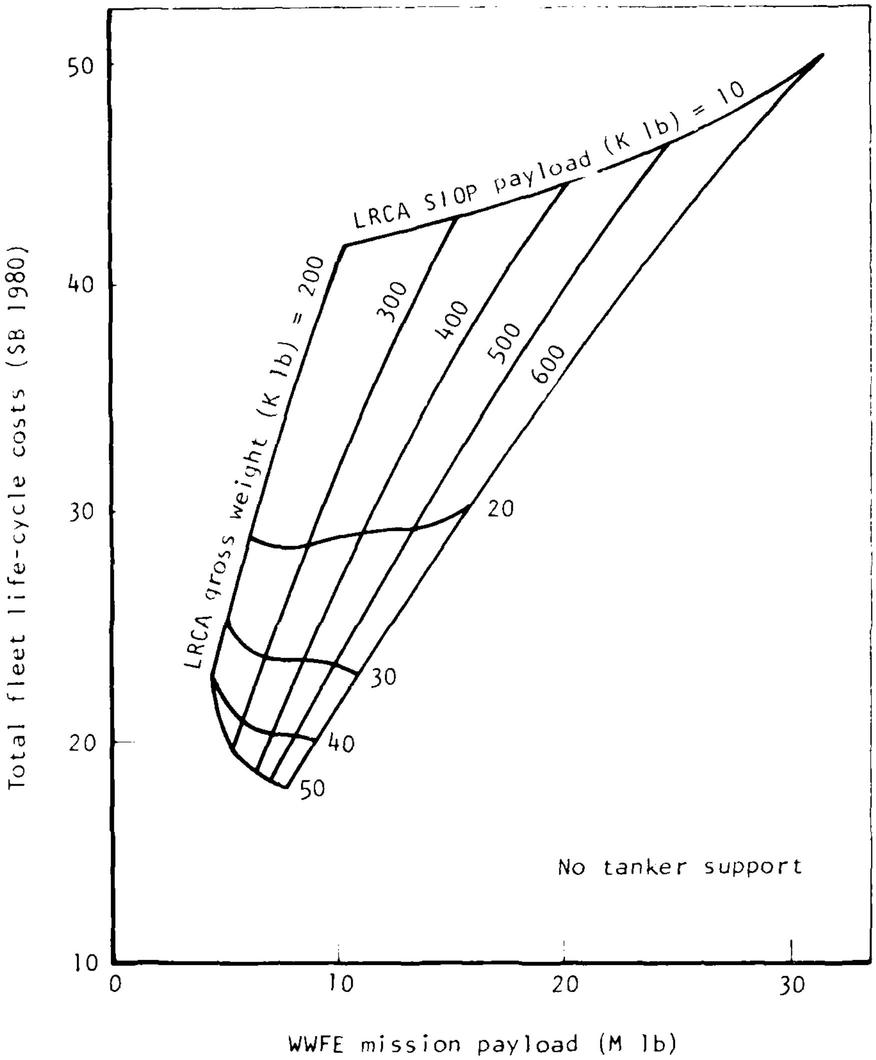

Fig. 10--LRCA life-cycle costs vs total WWFE mission payload and gross weight: SIOP missions only

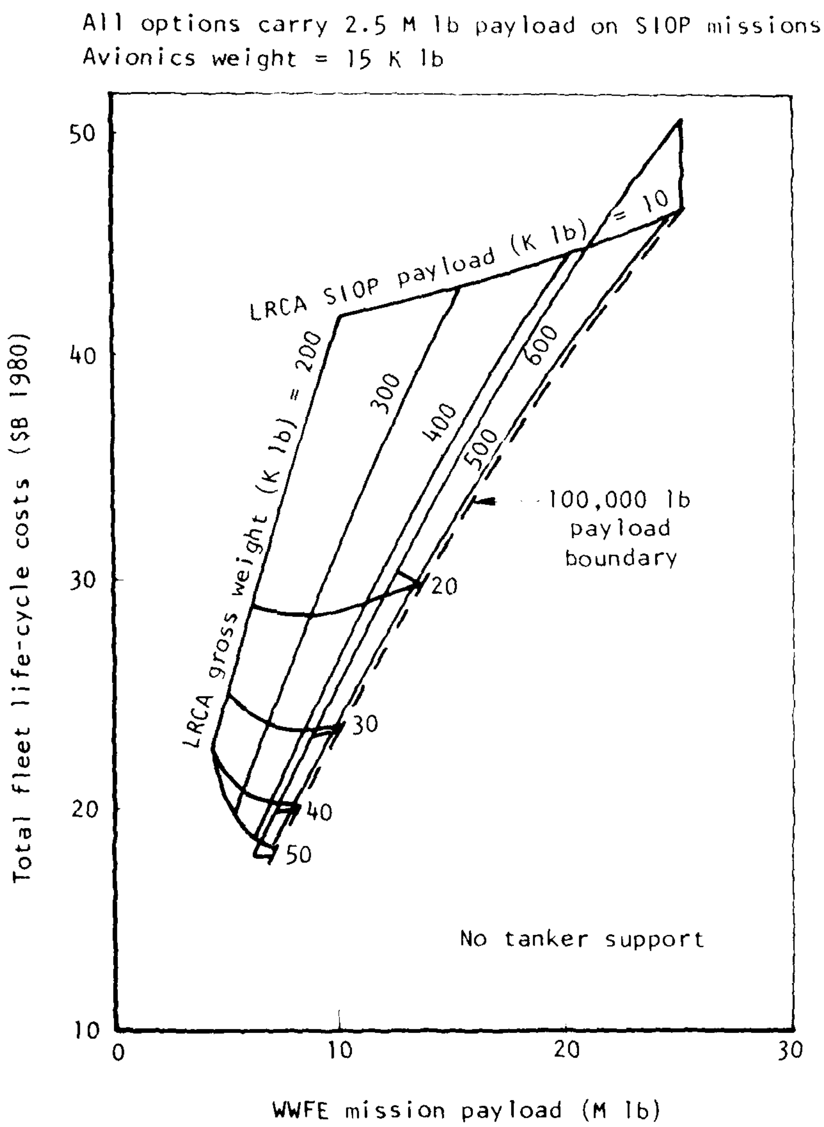

Fig. 11--LRCA life-cycle costs vs total WWFE mission payload and gross weight: SIOP missions only and LRCA payload limit set at 100,000 lb

derived requirement, we assume that the LRCA fleet must be able to carry 12.5 million pounds on 5000 n mi high altitude missions, a number used in the SAB study.*

There are two conditions where the LRCA fleet can satisfy both the SIOP and WWFE missions. It can satisfy both simultaneously, thereby requiring a fleet sized by the sum of the requirements for both missions. Or it can satisfy each mission separately but not simultaneously, requiring the fleet to be sized by the larger mission requirement. Table 7 portrays the total LRCA acquisition needed if the fleet must perform both missions simultaneously--the first condition. Figure 12 displays the resulting fleet life-cycle costs. Two observations are worth noting. First, adding the WWFE mission as a simultaneous requirement sharply increases the total life-cycle costs beyond those of the SIOP mission alone. Second, the preferred aircraft size definitely moves toward aircraft sizes larger than would have been selected for SIOP missions alone. This latter point needs a caveat, however: maximum usable payload restrictions can place an upper limit on the desired size.

Table 7

LRCA ACQUISITION SIZE: JOINT SIOP/WWFE BUY

LRCA SIOP Payload (K lb)	LRCA Gross Takeoff Weight (K lb)				
	200	300	400	500	600
10	1174	722	543	451	415 (450)
20	970	550	396	313	265 (300)
30	916	498	347	270	218 (253)
40	886	470	322	248	199 (234)
50	883	458	309	235	(222)

NOTES: Avionics Weight = 15 K lb; ( ) = Limit of 100,000 lb for WWFE payload.

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*Like the SIOP mission payload requirement, these numbers reflect current B-52 capabilities.

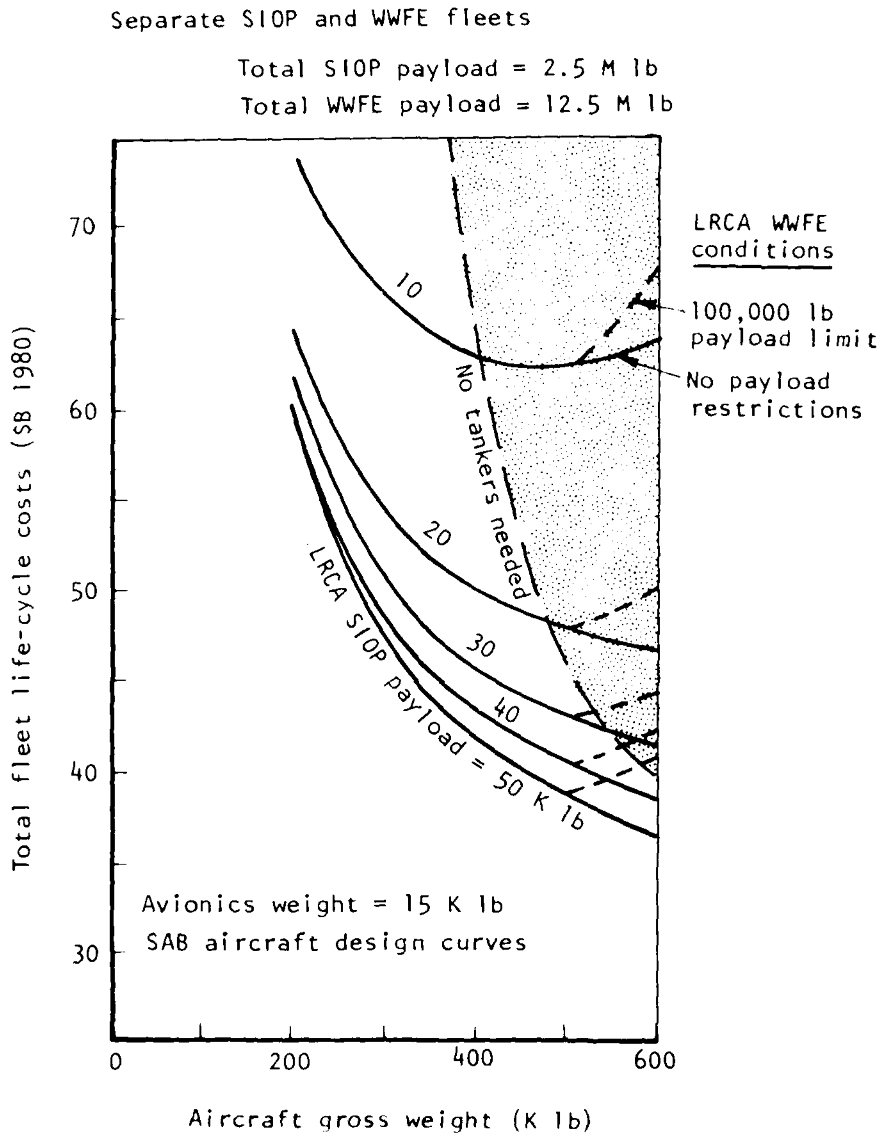

Fig. 12--LRCA life-cycle costs vs gross weight: Joint SIOP/WWFE buy

The second condition--each mission requirement must be satisfied separately but not simultaneously--calls for a comparison of the fleet sizes for the separate missions, with the largest requirement sizing the fleet. Figure 13 plots the resulting life-cycle cost. The SIOP mission requirements dominate if the maximum SIOP payload is small. Otherwise, and for most vehicle sizes and payloads of interest, the WWFE mission requirements dominate. As above, adding the WWFE mission increases the motivation for selecting larger aircraft.

IMPACT OF WWFE REFUELING ON LRCA SIZE SELECTION

We now turn briefly to the question of how the use of tankers alters the above observations. As Table 6 makes clear, only small aircraft require any degree of range extension, and then only if they carry large payloads. Nevertheless, all aircraft can increase their payload capacity with refueling, thereby reducing the overall fleet size requirements or, if the fleet size is fixed, increasing the payload delivery potential.

Rather than employ the buddy system (used for the SIOP refueling calculations), we assume a filling-station tactic. (The appropriate range extension equations for this refueling tactic are derived in Ref. 1.) This tactic assumes that the tanker flies forward with the first LRCA, refueling it at a distance r. Then it loiters at this range, refueling subsequent LRCA until the available fuel is exhausted. The tanker then flies r miles back to its original base. We assume that the equivalent (and always equal) distance flown between refuelings is t. Under these conditions, each combat aircraft will be able to enhance its range Δr n mi, where

$$\Delta r = K \log_e \left\{ \frac{\sqrt{\left[1 + \sum_{i=1}^{n-1} (x)^i\right]^2 + 4\left(\frac{W_e}{W_G}\right)\left[1 + (x)^{n-1} + \sum_{i=1}^{n-1} (x)^i\right]} - \left[1 + \sum_{i=1}^{n-1} (x)^i\right]}{2\left(\frac{W_e}{W_G}\right)} \right\} \quad (14)$$

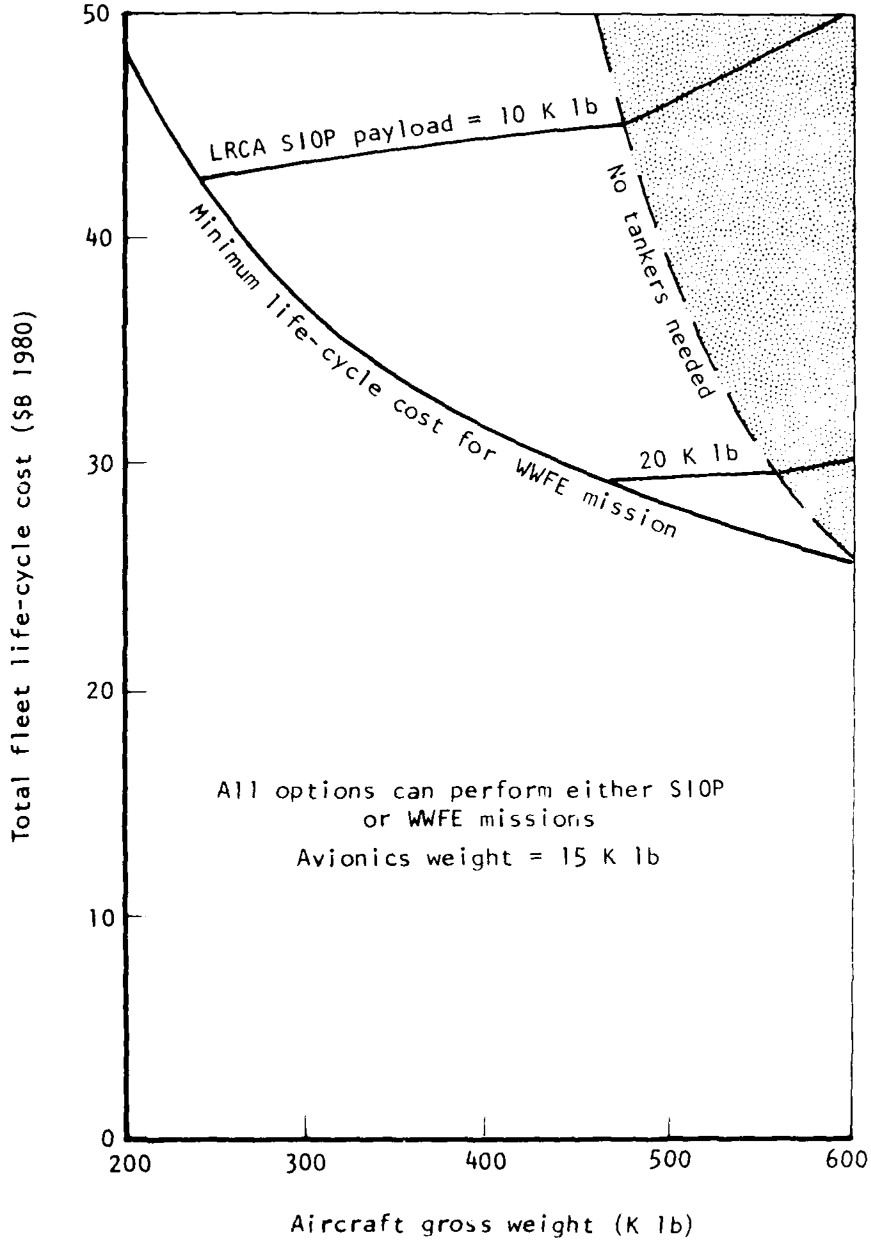

Fig. 13--LRCA life-cycle costs vs gross weight:
Fleet sized for largest requirement

where $x = \exp\left(-\frac{t}{K}\right)$ and n is the number of combat aircraft one tanker supports. Figure 14 shows how Δr varies as a function of n. Curves for two aircraft gross weights--200 K lb and 600 K lb--bound the performance for the sizes considered here. It follows from the figure that, for the range penalty per refueling assumed, a single tanker can provide multiple LRCA with small range enhancements.

From our previous work it is obvious that these small range enhancements can be used to offload fuel from the LRCA, thereby allowing a larger payload. Counterbalancing this is the need to extract aircraft from the LRCA fleet to act as tankers. Figure 15 plots the payload per LRCA obtained by employing tankers in the filling station tactic. Also shown is the average payload over all aircraft (LRCA plus tankers). The increase in average payload means that more total payload can be carried for a given fleet size if some LRCA are reconfigured as tankers than if the LRCA must perform the mission without refueling. For the two aircraft sizes shown, the optimum LRCA/tanker ratio is two. However, it is also important to note that the actual payload carried on a combat mission grows substantially, reintroducing concerns about what constitutes a reasonable limit on its maximum.

Figure 16 plots the maximum average payload with tankers as a function of the LRCA gross takeoff weight. Included in the figure is the impact on that average if the LRCA payload is limited to [illegible] lb. Assuming this limit, aircraft above about [illegible] lb cannot take full advantage of the gains inherent in tanker support, and aircraft above 470,000 lb would not benefit at all.*

Case 1: Total Fleet Sized for SIOP Mission Only

We have repeated the calculations of Figs. 10 and 11 to show how the improved payload capability affects the total WWFE payload capacity. Figures 17 and 18 display the new data. Careful comparison of these figures and the prior ones indicates the smaller vehicles show the

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*Additional calculations indicate that better performance can be obtained by a pre- and poststrike refueling. A 200,000 lb LRCA can deliver (fleet-wide average) 34.7 K lb, an increase of nearly [illegible] K lb above the prestrike refueling only case. Nevertheless, the payload limit effects in Fig. 16 still apply.

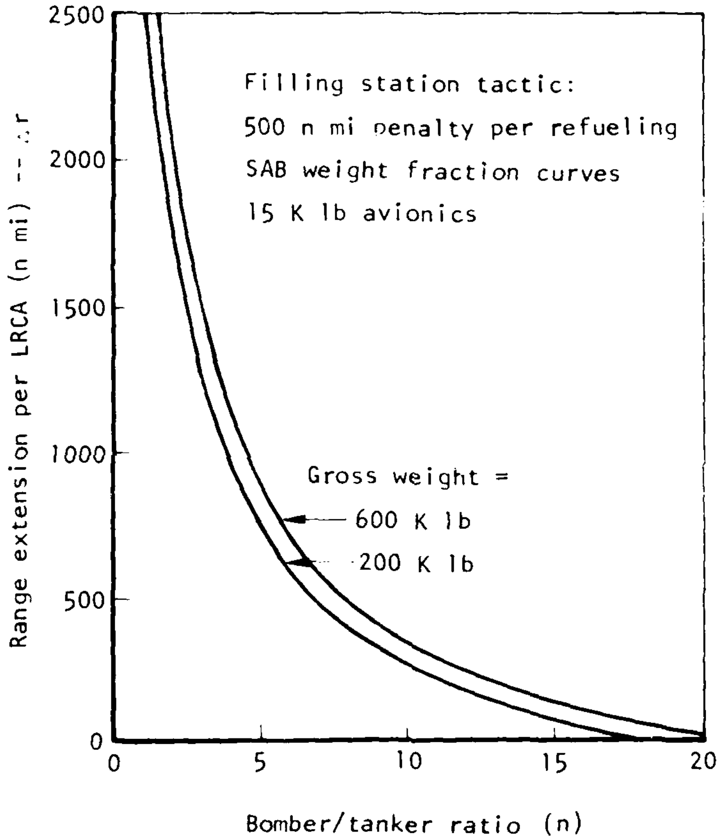

Fig. 14--LRCA range extension (on WWFE missions) from tankers vs bomber/tanker ratio and gross weight

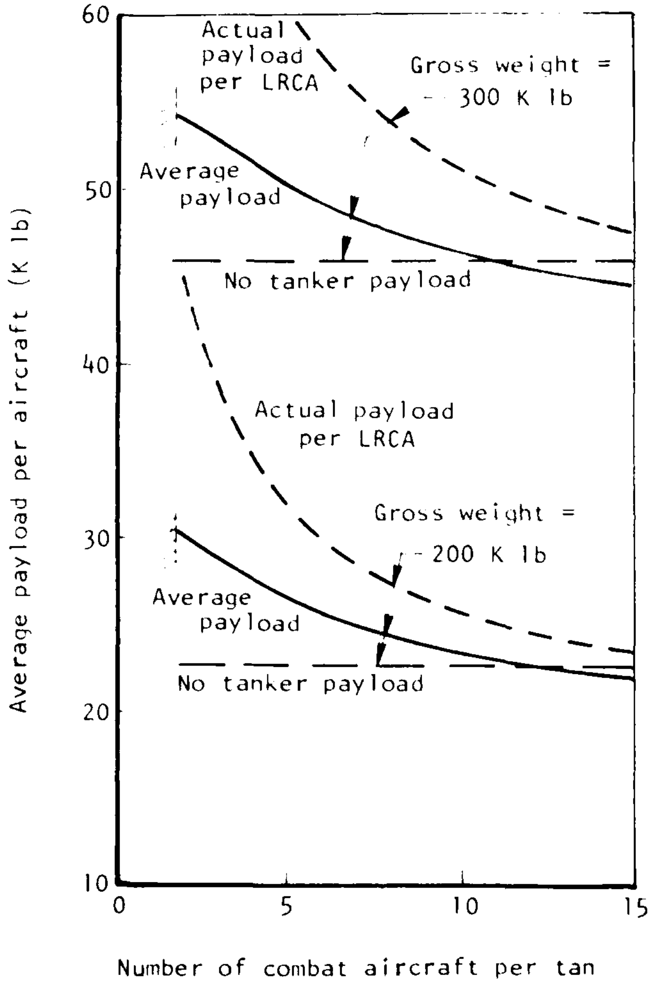

Fig. 15--Impact of prestrike refueling
on WWFE mission payload
(aircraft and fleet average)

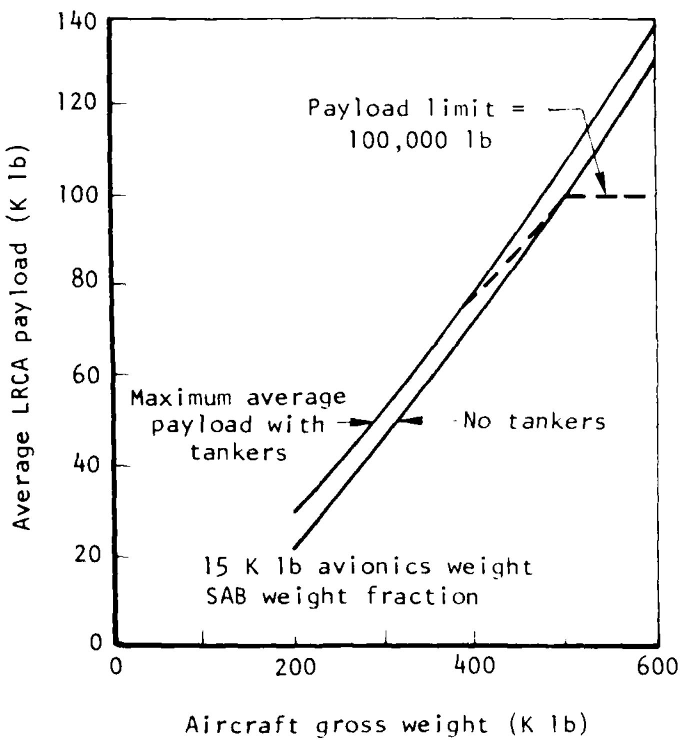

Fig. 16--Maximum average LRCA payload vs gross weight: WWFE mission

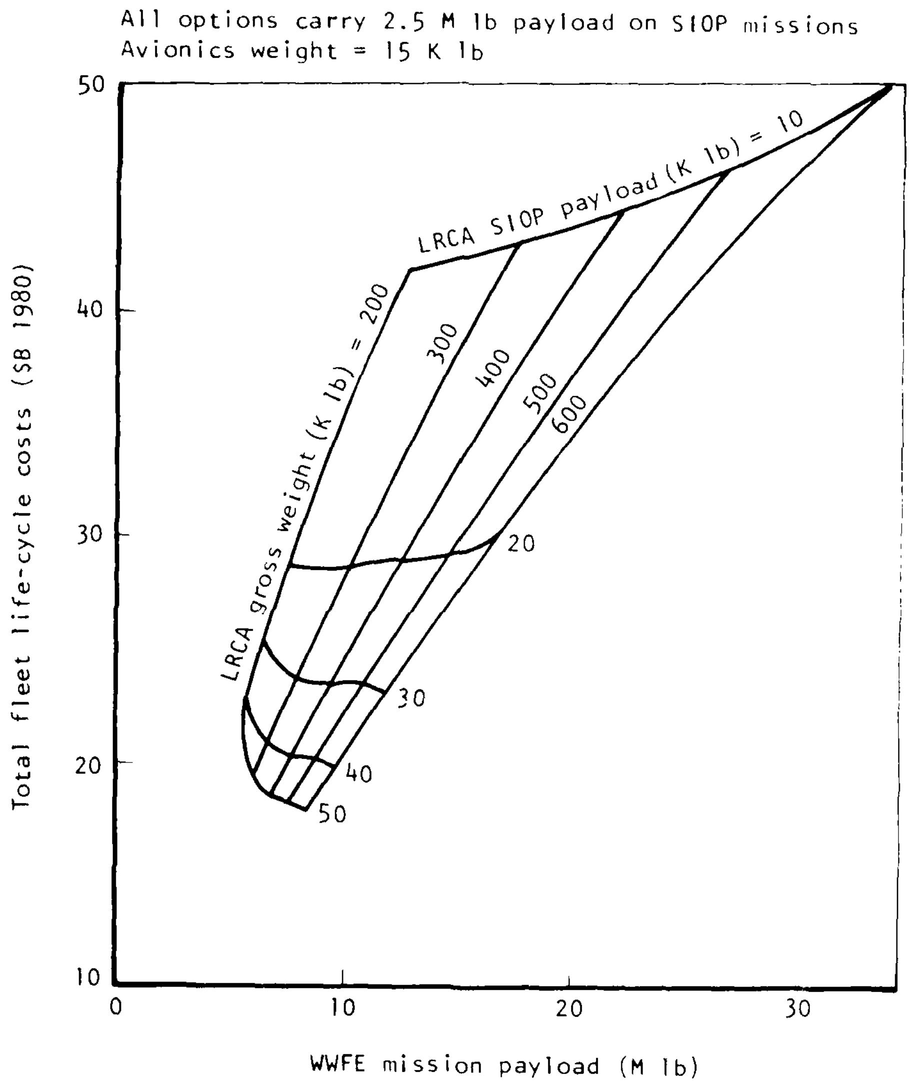

Fig. 17--LRCA life-cycle costs vs total WWFE mission payload (with tanker support) and gross weight: SIOP missions only

All options carry 2.5 M lb payload on SIOP missions
Avionics weight = 15 K lb

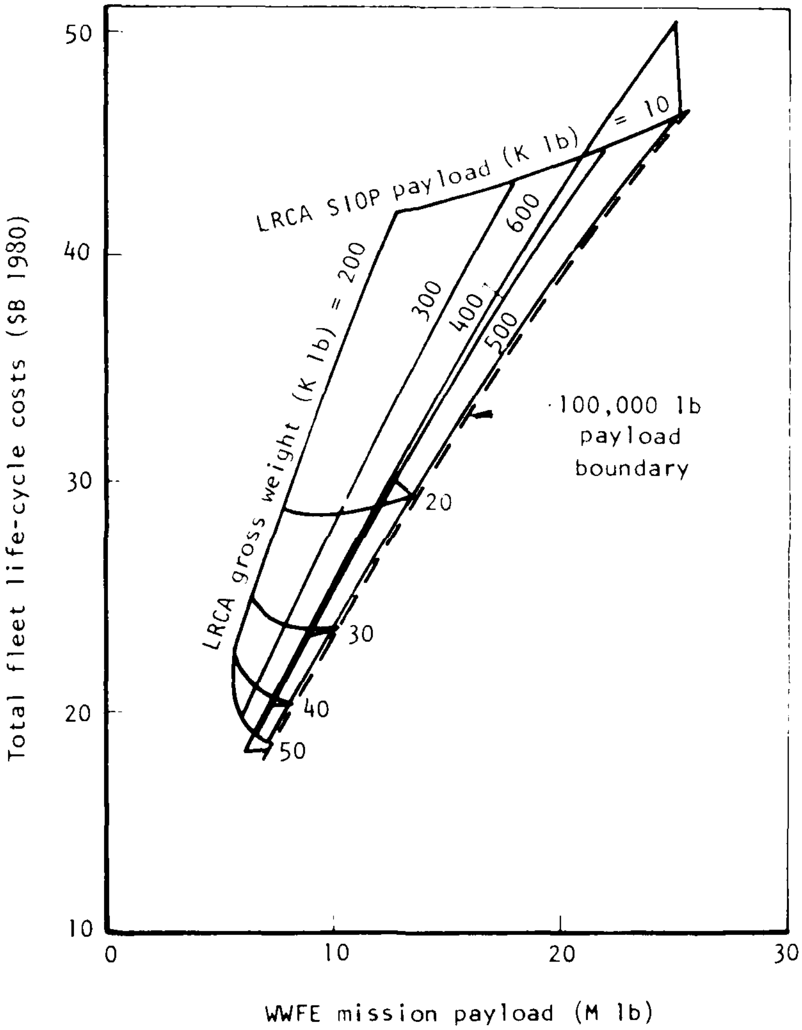

Fig. 18--LRCA life-cycle costs vs total WWFE mission payload (with tanker support) and gross weight: SIOP missions only and LRCA payload limit set at 100,000 lb

biggest gain, not surprising since the payload improvement per vehicle is nearly constant irrespective of aircraft size (see Fig. 16). However, the changes are quite minor, not affecting any of our earlier observations, i.e., there is some benefit from using some of the LRCA as tankers in the KWII mission, but not enough to make a significant difference.

Case 2: Joint LRCA Fleet Sized for Both SIOP and KWII Missions

As before, we can break this case into two parts, one sized to meet the joint mission requirements simultaneously, the other not. [illegible] fleet requirements are lessened somewhat by the use of tankers. Table 8 shows the reduction in the number of LRCAs required as a function of aircraft gross weight. Smaller sized aircraft obviously benefit the most. In addition, limits on usable payload reduce the potential gain. These fewer aircraft lead naturally to a lower required life-cycle cost; Table 8 also contains these estimates, which are derived by calculating the total costs with tanker support and subtracting them from those without (see Fig. [illegible]).

Table 8

REDUCTION IN ACQUISITION BUY IF REFUELING EMPLOYED

(Joint SIOP/KWII Mission Requirements)

Condition	LRCA Gross Takeoff Weight (K lb)				
	200	300	400	500	600
No Payload Limit	162	47	20	11	6
Payload Limit = 100,000 lb	162	47	15	0	0
	Savings in Total Life-Cycle Costs (FY 80 $B)				
No Payload Limit	7.9	3.2	1.7	1.1	0.7
Payload Limit = 100,000 lb	7.9	3.2	1.3	0	0

The previous observations on the needs and benefits of having tankers are in general still not substantively altered. The potential cost savings for small aircraft cannot overcome their initial high cost, and the gains for large aircraft are nil.

Figure 19 plots the life-cycle costs where the two missions are not satisfied simultaneously. Shown for comparison are the curves for no tankers and for the case where useful payload is limited to 100,000 lb. Large airplanes are still the most cost effective--useful payload concerns might limit the size to about [illegible]00,000 lb. And tanker support can be eliminated at small total cost.

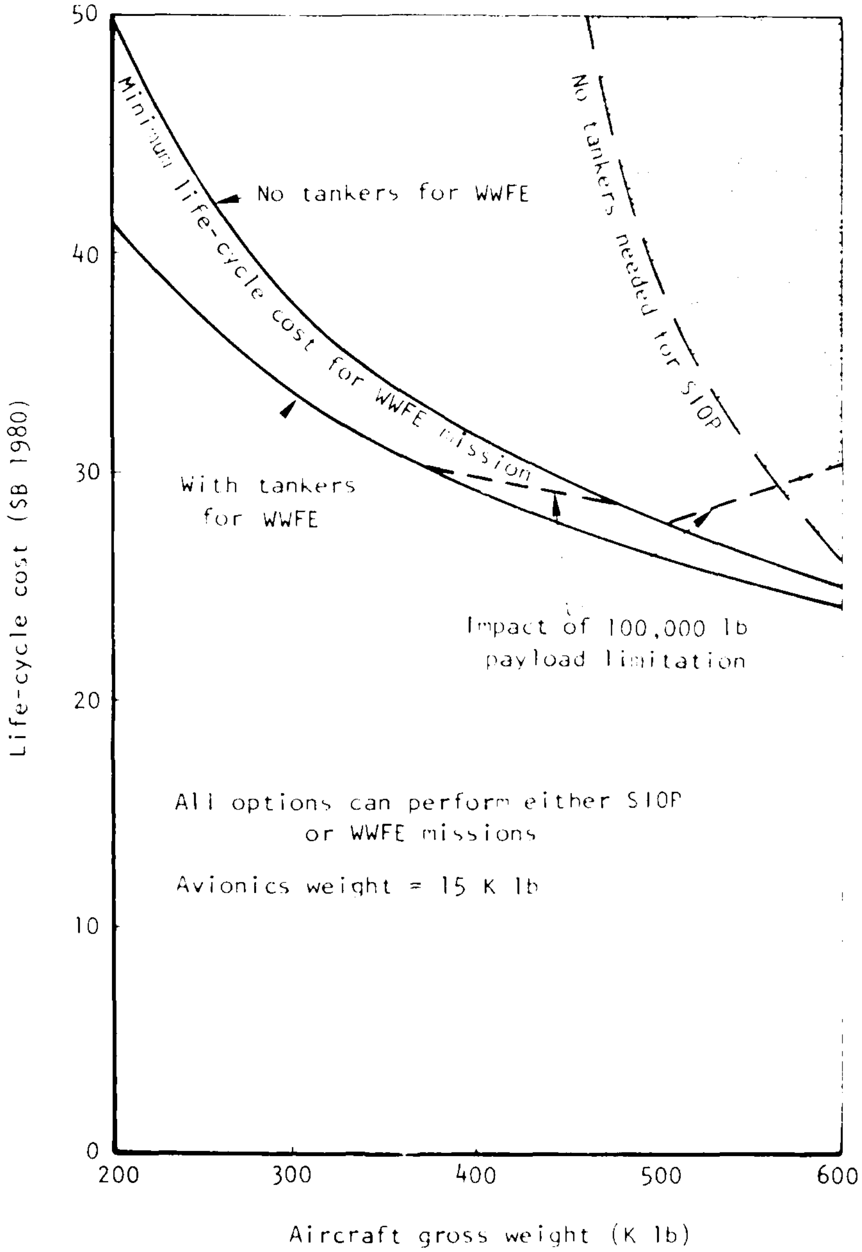

Fig. 19--LRCA life-cycle costs vs gross weight
(with tanker sypport): Fleet sized
for largest requirement

Appendix

COST ESTIMATES

This appendix presents cost estimates for four LRCA designs that were defined early in the course of the SAB study to serve as baselines for examining tradeoffs in size and quantity. Only their weight, speed, and mission characteristics are discussed here. The baseline aircraft cost estimates were used as the basis of the simple cost estimating relationship (CER) used in the study.

BASELINE DESIGNS AND COST ESTIMATES

The characteristics assumed for the four baseline LRCA designs are listed in Table A-1. The performance specifications listed here are not especially demanding, but the aircraft are assumed to incorporate current technology appropriate to a penetrating strategic aircraft. The same avionics suite is assumed to be used in all four designs, and other characteristics, except for aircraft (and engine) size, are also assumed to be the same for all.

Table A-1

LRCA AIRCRAFT DESIGN CHARACTERISTICS

Characteristic	LRCA #1	LRCA #2	LRCA #3	LRCA #4
Gross takeoff weight, lb	200,000	300,000	400,000	500,000
Airframe empty weight (w/o engines or avionics), lb	110,000	150,000	175,000	215,000
No. of R&D aircraft	5	5	5	5
No. of engines	4	4	4	4
Total engine weight (4 engines), lb	6,360	9,500	12,700	15,900
Engine thrust (per engine, w/o afterburners),[a] lb	10,494	15,675	20,955	26,235
Low altitude penetration speed	Mach .7	Mach .7	Mach .7	Mach .7
Max speed at altitude, kt	550	550	550	550
Avionics installed weight,[b] lb	10,000	10,000	10,000	10,000

[a] Engines assumed to use "simple" afterburners for takeoff thrust augmentation only.

[b] Avionics suite weight (uninstalled) is 5,000 lb.

Cost estimates for each design were made by Rand at force levels of 100, 200, and 400 primary authorized aircraft (PAA, the number of aircraft available for the mission). An allowance of 20 percent for training, depot maintenance pipeline, and peacetime attrition reserve aircraft brought total procurement requirements for those force levels to 120, 240, and 480 inventory aircraft. The full cost estimates are presented in Tables A-2 through A-5. Costs show economies of scale both for greater size and greater quantities. The predominant cost-quantity scaling is in procurement costs (and in amortization of development costs over larger quantities), but there are also some cost-quantity efficiencies in operating cost categories, such as replenishment spares. No specific costs for adding tanker capabilities to the aircraft have been added, as we believe such costs to be within the uncertainty level of the estimates. Nor have any costs of mission ordnance (other than for training) or other payload been included. The costs of additional avionics or defensive missiles beyond the baseline 10,000 lb of installed avionics have also been excluded. It is assumed that they would be equal for all designs.

The CER used in the analysis was derived from the total cost "point" estimates by fitting an equation to the points (using least squares and the logarithmic form of the equation):

$$TCOST = 37.43\ AFWT^{.5664}\ Q^{.7278}$$

where TCOST is total development, procurement, and 20-year operating cost in millions of 1980 dollars; AFWT is airframe empty weight, exclusive of engines and avionics;* and Q is total quantity of inventory

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*Airframe empty weight is defined as the weight of the aircraft without fuel, ordnance, or crew. The airframe weight definition we use here (empty weight less engines and avionics) differs from "airframe unit weight" used in contract cost reporting, which also excludes the weight of trapped fuel and oil, armament, instruments, auxiliary power units, and several other items of installed equipment (see AFSCP/AFLCP 800-15). The latter definition is the one used for the weight variable in the airframe cost estimating model we used. We assumed that our AFWT variable was about 10 percent greater than airframe unit weight.

Table A-2

COST ESTIMATES FOR LRCA #1--110,000 LB
AIRFRAME WEIGHT, 200,000 LB GTOW

($M 1980)

Cost Element	120 A/C (100 PAA)	240 A/C (200 PAA)	480 A/C (400 PAA)
DEVELOPMENT			
Airframe	1609		
Engines	415		
Avionics	1078		
Other	248		
Total Development	3350	3350	3350
PROCUREMENT			
Airframe	4499	6932	10754
Engines	657	1145	1993
Avionics	1193	2266	4306
Flyaway (subtotal)	6349	10343	17053
Peculiar support	483	786	1296
Initial spares	381	621	1023
Total Production	7212	11750	19372
Total Acquisition	10563	15100	22722
20-YR O&S ($ million)			
TOTAL 20-YR OPERATIONS	7108	13521	26096
TOTAL 20-YR COST	17671	28620	48819
ANNUAL O&S ($ thousand/PAA)			
Personnel related	1408	1408	1408
Replenishment spares	438	343	286
Base material	186	186	186
POL	421	421	421
Depot maintenance	660	660	660
Class IV modifications	343	280	230
Common support equipment	83	67	55
Training ordnance	15	15	15
Total annual O&S	3554	3380	3262

Table A-3

COST ESTIMATES FOR LRCA #2--150,000 LB
AIRFRAME WEIGHT, 300,000 LB GTOW

($M 1980)

Cost Element	120 A/C (100 PAA)	240 A/C (200 PAA)	480 A/C (400 PAA)
DEVELOPMENT			
Airframe	2004		
Engines	542		
Avionics	1078		
Other	290		
Total Development	3914	3914	3914
PROCUREMENT			
Airframe	5710	8826	13730
Engines	874	1522	2650
Avionics	1193	2266	4306
Flyaway (subtotal)	7777	12614	20686
Peculiar support	591	959	1572
Initial spares	467	757	1241
Total Production	8835	14330	23499
Total Acquisition	12749	18243	27413
20-YR O&S ($ million)			
TOTAL 20-YR OPERATIONS	8034	15276	29470
TOTAL 20-YR COST	20782	33520	56883
ANNUAL O&S ($ thousand/PAA)			
Personnel related	1463	1463	1463
Replenishment spares	438	339	280
Base material	208	208	208
POL	631	631	631
Depot maintenance	740	740	740
Class IV modifications	420	341	280
Common support equipment	101	82	67
Training ordnance	15	15	15
Total annual O&S	4017	3819	3684

Table A-4

COST ESTIMATES FOR LRCA #3--175,000 LB AIRFRAME WEIGHT, 400,000 LB GTOW

($M 1980)

Cost Element	120 A/C (100 PAA)	240 A/C (200 PAA)	480 A/C (400 PAA)
DEVELOPMENT			
Airframe	2236		
Engines	650		
Avionics	1078		
Other	317		
Total Development	4281	4281	4281
PROCUREMENT			
Airframe	6429	9953	15505
Engines	1075	1871	3238
Avionics	1193	2266	4306
Flyaway (subtotal)	8697	14090	23049
Peculiar support	661	1071	1752
Initial spares	522	845	1383
Total Production	9880	16006	26184
Total Acquisition	14161	20287	30465
20-YR O&S ($ million)			
TOTAL 20-YR OPERATIONS	8887	16925	32682
TOTAL 20-YR COST	23048	37212	63147
ANNUAL O&S ($ thousand/PAA)			
Personnel related	1516	1516	1516
Replenishment spares	436	335	275
Base material	231	231	231
POL	842	842	842
Depot maintenance	820	820	820
Class IV modifications	470	381	311
Common support equipment	113	92	75
Training ordnance	15	15	15
Total annual O&S	4443	4231	4085

Table A-5

COST ESTIMATES FOR LRCA #4--215,000 LB
AIRFRAME WEIGHT, 500,000 LB GTOW

($M 1980)

Cost Element	120 A/C (100 PAA)	240 A/C (200 PAA)	480 A/C (400 PAA)
DEVELOPMENT			
Airframe	2589		
Engines	743		
Avionics	1078		
Other	353		
Total Development	4763	4763	4763
PROCUREMENT			
Airframe	7534	11690	18242
Engines	1256	2187	3808
Avionics	1193	2266	4306
Flyaway (subtotal)	9983	16143	26356
Peculiar support	759	1227	2003
Initial spares	599	969	1581
Total Production	11341	18338	29940
Total Acquisition	16103	23101	34703
20-YR O&S ($ million)			
TOTAL 20-YR OPERATIONS	9796	18661	36034
TOTAL 20-YR COST	25900	41762	70737
ANNUAL O&S ($ thousand/PAA)			
Personnel related	1575	1575	1575
Replenishment spares	435	330	268
Base material	253	253	253
POL	1052	1052	1052
Depot maintenance	900	900	900
Class IV modifications	540	436	356
Common support equipment	130	105	86
Training ordnance	15	15	15
Total annual O&S	4898	4665	4504

aircraft purchased. The equation generates estimates within 3 percent of the values in Tables A-2 through A-5 and can be used to extrapolate those results to other sizes and quantities of aircraft as long as the extrapolation is not too far outside the range of the baseline points. But the equation is not a general application CER and should only be used in the context to which it was applied here.

The exponent on the quantity variable in the total cost CER is equivalent to an 83 percent "learning" rate in the common log-linear cumulative average cost formulation often used as the model of production cost learning effects.* Because a modest change in that rate can have a dramatic effect on estimated costs at quantities of interest (100 or more), it appears to be a quite sensitive component of the CER. Two points should be noted on this subject: (1) The derivation of the CER does not support a change in one of the coefficients of the equation without changes in the others; and (2) the <u>relative</u> costs of the alternatives compared with one another in this analysis are not very sensitive to the cost-quantity coefficient. The first point arises because the CER is derived from point estimates at production quantities of from 120 to 480 aircraft. One cannot change one of the coefficients in the equation without affecting the others unless the point estimates are disregarded. The "learning" rate in the total cost CER is a composite rate derived from fitting the equation to the points and is conceptually quite different from the production cost learning phenomenon.

The production cost estimates included in the baseline cases were computed using average learning curve slopes for the various components of the aircraft. Different assumptions could result in significant changes in the production cost estimates and some change in the composite slope (and other coefficients) of the total cost CER. However, for the payloads and missions compared in the aircraft size and tanker support analyses, the ratio of fleet sizes for smallest to largest aircraft was never more than 4:1; and in most cases it was nearer 2:1

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*An 83 percent rate (or slope) means that average unit costs are reduced by 17 percent for each doubling in quantity. The exponent, b, is related to the slope, s, by $b = \log s/\log 2$.

(see Tables 4 and 7). Since the learning rate represents the effect of doubling in the production quantity, it is clear that a very sizable change in that rate would be needed to affect the comparative costs of the largest and smallest fleets required to perform any of the missions examined. Hence, the conclusions of the analysis as to aircraft size and tanker support would not be significantly changed by changes in the learning curves.

Airframe weight rather than aircraft gross weight was chosen as the size variable in the CER. The airframe weight to gross weight ratios used in the baseline designs were generally greater than those taken from the curves used in the analysis (see Fig. 1). Airframe weight, however, is a more important variable than gross weight in most of the CERs used to compute the baseline estimates; and a doubling of the gross weight for a given airframe weight would, in fact, add less than 10 percent to our estimated total costs. Hence the total cost CER was formulated, for simplicity, using airframe weight alone as the measure of size.

DEVELOPMENT AND PROCUREMENT COSTS

Airframe Costs

All airframe development and procurement cost estimates were generated by use of the DAPCA model,[2] which incorporates parametric equations developed at Rand in 1975.[3] The equations are based on a sample of aircraft with first flight dates ranging from 1953 to 1970 (the F-14 is the most recent aircraft in the sample). They are widely used in the Air Force and industry cost analysis community, and there is a consensus that they produce somewhat low estimates for new aircraft. To counter this possible bias, we adjusted the model's results for some of the cost elements using a set of factors provided to us by Aeronautical Systems Division.* The factors reflect recent ASD experience--particularly the last B-1 Independent Cost Analysis.

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*Informal correspondence with Mr. John D. S. Gibson, ASD/ACCX, July 1980.

Engines

Engine cost estimates were based on cost data on the General Electric F101-GE-101 engine originally developed for the B-1 aircraft. Both development and production cost estimates were scaled (exponentially) on engine dry thrust.* An additional 7.5 percent was added to production costs and $144 million to development costs for a "simple" afterburner. These figures are half what we would estimate for full afterburners. The learning curve slope for production cost was 87 percent, and 25 percent whole spare engines were added to basic inventory aircraft requirements. Hence, the average unit cost figures shown in Tables 2 through 4 include whole spare engines (i.e., 5 engines per aircraft).

The cost estimates for the engines assume a new engine development program but one that is not too technologically ambitious. An alternative, particularly for engines at the lower end of the range, would be to buy current engines off the shelf. In that case, considerable savings could be gained, depending upon how many engines had already been produced and thus how far down the production cost learning curve the buy for the LRCA program would be. However, engine costs constitute a smaller fraction of total costs for the smaller aircraft than they do for the larger versions. Hence, using off-the-shelf engines has little impact on the question of aircraft size or tanker support preferences.

Avionics

The avionics suite for the LRCA aircraft was defined for purposes of this study only in terms of its overall size--5,000 lb of uninstalled avionics, 10,000 lb installed. The only substantial avionics cost data base available to us at the time of the study consisted of suite and system data for several combat and fighter aircraft (ranging from the A-4M to the FB-111A, the latter being the only strategic aircraft in the data base). A series of suite production cost CERs based on

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*The scaling exponents for development and production costs were taken from engine cost estimating equations in Ref. 4

these data was analyzed,[5] and suite weight (uninstalled) and date of first flight were found to be moderately useful characteristics for deriving cost estimates when details of the avionics systems composing the suites were unknown. Our LRCA suite production cost estimates were based generally on those results. The data showed that larger avionics suites tended to have higher costs per pound than did smaller ones, but the LRCA suite, at 5,000 lb, was almost twice as large as any of those in the data base. It seemed unwise to extrapolate that trend so far outside the range of the data and so instead we used a linear extrapolation (i.e., the cost per pound figure for the LRCA was $2,000 at 120 units, which was about equal to that for the larger suites in the data base). A 95 percent learning curve slope was assumed.

The development cost of an avionics suite consists primarily of the development costs of the individual avionics systems that compose it. The combat aircraft avionics data base was used to derive a development cost CER for avionics systems based on their unit production costs. The LRCA avionics production estimate, however, was for the suite rather than for its components. To estimate the production costs of the systems in the LRCA suite, we allocated the suite cost among a set of 41 systems (based on a mean weight of 122 lb for the systems in the data base) and assumed a weight distribution and cost per pound scaling relationship like those observed in the data base. This provided us with a basis for the LRCA avionics development cost estimate, but it is clear from the number of assumptions that had to be made that the estimate is subject to a good deal of uncertainty. However, since the same suite was assumed for all four aircraft designs, and avionics development costs were a relatively small component of total costs, even large changes in the estimate would not greatly influence the overall conclusions of the study.

Additional development costs, for training and support equipment, were estimated at 8 percent of combined airframe, engine, and avionics development costs. Procurement of support equipment, training equipment and services, and technical data was estimated at 7.6 percent of flyaway cost; and initial spare parts cost was estimated at 6 percent of flyaway.

ANNUAL OPERATING AND SUPPORT COSTS

The LRCA forces were assumed to operate in peacetime like the current force of B-52s, and therefore most of our operating cost estimate is based on cost and manning factors for B-52G/H aircraft in the USAF Planning Factors Guide.(6) The factors were changed to 1980 dollars, where necessary, and adjusted for known (or postulated) differences among the aircraft types. Most of the operating cost elements show economies of scale with aircraft size (e.g., personnel requirements for the largest aircraft were not greatly different from those for the smaller ones). Some of the elements--primarily those based wholly or in part on procurement costs--also show economies of scale with force size (e.g., replenishment spares, modifications, ground support equipment).

Personnel Costs

Table A-6 shows the components of the manpower requirements estimates for the smallest of the LRCA designs and the largest in comparison with average B-52G/H manning. B-52 Primary Program Element strengths were, except for maintenance personnel, considered appropriate for all four LRCA cases. Avionics maintenance personnel requirements were doubled to reflect the assumed greater number and complexity of avionics systems in the LRCA. Field maintenance requirements were scaled up in proportion to differences in the airframe depot maintenance estimates. Support requirements (base operating support, medical, and training) were based on support personnel factors customarily used for SAC activities. The annual cost factors applied to the manpower estimates included pay and allowances, medical support, miscellaneous O&M (BOS non-pay), permanent change of station travel, and annualized acquisition and training costs.

Table A-6

PERSONNEL REQUIREMENTS PER PAA AIRCRAFT

Category	B-52	LRCA #1	LRCA #4
Officers			
Aircrew	6.45	6.45	6.45
Other Direct	3.47	3.47	3.47
Support	.31	.35	.41
Total	10.23	10.27	10.33
Airmen			
Aircrew	1.29	1.29	1.29
Avionics Mtc	7.16	15.00	15.00
Field Mtc	7.64	6.00	15.00
Org. Mtc	9.07	10.00	10.00
Other Direct	16.73	16.73	16.73
Support	6.89	7.84	9.04
Total	48.78	56.86	67.06
Civilians			
Other Direct	.60	.60	.60
Support	1.71	1.95	2.24
Total	2.31	2.55	2.84
Total Personnel	61.32	69.68	80.23

Replenishment Spares

Replenishment spares cost estimates were derived from a set of estimating equations developed at Rand.[7] Separate equations are used for airframes, engines, and avionics, and for total inventory spares (peacetime operating stock) and "true" replenishment. Our total replenishment spares cost estimates include both the cost of true replenishment (replacement of condemned parts) and, in addition, the cost of inventory requirements not covered by initial spares. Initial spares funding covers only the cost of requirements for the first two years of an item's operational life in the inventory; after that time, further inventory buildup as well as true replenishment requirements are funded under the replenishment spares budget category. We used the spares cost CERs to estimate total inventory requirements, deducted the 6 percent (of flyaway) initial spares estimate, and amortized the remaining inventory requirements over the assumed 20-year operational life of the LRCA force. That cost was added to the costs estimated by the true replenishment CERs to obtain our total annual spares cost estimate. An example of the calculation is shown in Table A-7. Note that considerable economies of scale with increasing force size are implied.

Table A-7

REPLENISHMENT SPARES COST COMPUTATION FOR LRCA #4 (500,000 LB)
($M 1980)

Category	100 PAA	200 PAA	400 PAA
Inventory Spares			
Airframe	276	354	457
Engines	64	124	242
Avionics	478	821	1409
Total	818	1299	2108
Less Initial Spares	-599	-969	-1581
Balance	219	330	527
Annual Inventory Cost (20-year amortization)	11	17	26
Annual True Replenishment	33	49	81
Total Replenishment Spares	44	66	107
Annual Cost per PAA	.435	.330	.268

Depot Maintenance

Depot maintenance cost estimates were based on preliminary analysis of USAF depot maintenance cost data for current systems. The analysis was completed subsequent to this study and is published as Ref. 8. Separate estimates were made for airframes, engines, and avionics. The airframe estimates include airframe rework and airframe component repair, and the engine estimates include engine overhaul and engine accessory and component repair.

Airframe rework and component repair costs were estimated at $300,000 annual cost per inventory aircraft for the 500,000 lb aircraft and scaled in proportion to gross weight for the other aircraft. Engine overhaul and component repair costs were estimated at $7,500 annually per installed engine for the largest aircraft and scaled on engine thrust for the others. Avionics component repair costs were estimated at $84 per pound of (uninstalled) avionics, or a total of $420,000 annually per inventory aircraft. Table A-8 summarizes the depot maintenance cost estimates and converts them to cost/PAA figures.

Table A-8

DEPOT MAINTENANCE COST ESTIMATES

($K 1980)

Category	LRCA #1	LRCA #2	LRCA #3	LRCA #4
Cost per inventory aircraft				
Airframe	120	180	240	300
Engines	12	19	25	31
Avionics	420	420	420	420
Total	552	619	685	751
Cost per PAA	660	740	820	900

Base Material and POL

Base material costs were based on B-52G/H factors (System/General Support Material) in Ref. 6. They were scaled for the LRCA estimates in proportion to depot maintenance costs. Average annual B-52G/H depot maintenance costs were $452,000 (at nominal 350 fh/year) per PAA, and base material costs were $127,000 per PAA. The LRCA estimates shown in Table A-2 through A-5 were derived from these values.

POL costs for the 500,000 lb LRCA were estimated on the basis of a fuel consumption rate for that aircraft of about 70 percent of the rate listed in AFP 173-13 for the B-52H (3349 gal/hr). Consumption rates for the other designs were scaled in proportion to gross weight. Actual rate would depend very much upon the amount of low altitude flying training that was done as well as fuel economies achieved through new engine designs and better aerodynamics. The flying hour rated used for the POL cost estimates was 370 fh/PAA (including allowance for some support and training aircraft flying). The fuel cost factor for 1980 was given as $1.18/gal.

Other Operating Costs

Both Class IV modifications cost and common support equipment cost were estimated as a proportion of flyaway cost. The factor for modifications of .0065 (including spares) was taken from AFP 173-13. The common support equipment factor was .0015, plus 4 percent for spares. The factors are multiplied by average flyaway cost per PAA to provide the annual cost/PAA estimates.

The annual cost of training ordnance for B-52 aircraft as shown in AFP 173-13 is approximately $14,000 per PAA. We assumed $15,000 for the LRCA aircraft. This would not include the cost of large missiles, such as Short Range Attack Missile or Air Launched Cruise Missile, expended in training.

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