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TECHNICAL REPORT

Expendable Missiles vs. Reusable Platform Costs and Historical Data

Thomas Hamilton

Prepared for the United States Air Force
Approved for public release; distribution unlimited



RAND PROJECT AIR FORCE

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Preface

This RAND Project AIR FORCE report documents research performed in fiscal year 2010, in support of the Vice Chief of Staff, U.S. Air Force, that analyzed the historical use of air-to-ground attack. This work was intended to support decisionmaking concerning the need for the United States to have a substantial capability to conduct air-to-ground attack in the future. In particular, this report investigates why it is cost-prohibitive to rely exclusively on cruise missiles or similar expendable weapon systems in the event that the United States faces the possibility of conflicts comparable in duration and intensity to those of the past. The intended audience is policymakers at all levels of government. The issues addressed in this report are also outlined in RAND publication WR-778-AF (Hamilton, 2010).

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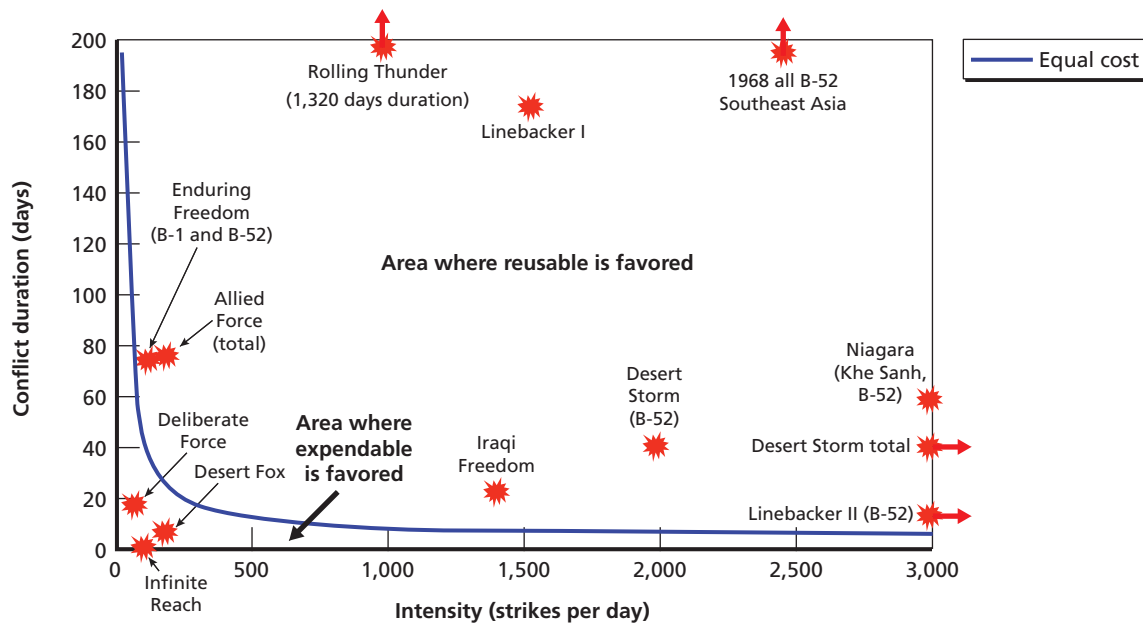
Summary

The purpose of this report is to evaluate the economic wisdom of the United States adopting policies that rely primarily on expendable weapons, such as cruise missiles, to conduct air-to-ground strike missions. We examine the historical use of air-to-ground attack by the U.S. military during and since the Vietnam War and examine when exclusive use of expendable methods would be cost-prohibitive compared to using reusable weapon platforms. This analysis focuses solely on cost and does not explore the range of capabilities of the different weapon systems. Thus, conclusions do not address strategies involving a mix of reusable penetrating aircraft and expendable munitions.

We analyzed campaigns in terms of two parameters: the average intensity of the conflict in average weapons delivered per day and the duration of the conflict in days.

Figure S.1 summarizes both the historical data and our simple model for the sum of development and procurement costs. The blue line is the cost indifference curve between conducting the campaign with long-range cruise missiles and conducting it with a new, 20,000-lb-payload reusable aircraft. The line goes up sharply on the left side of the table, which corresponds to relatively small campaigns. If the United States only has to prepare for small campaigns, the

Figure S.1
Reusable Versus Expendable Costs and Historical Conflicts



RAND TR1230-S.1

development cost of a reusable platform is an unnecessary expense. A few missiles will suffice. On the right side of the chart, the indifference curve becomes flat. Whether exclusive reliance on expendable platforms is cost-prohibitive depends entirely on the length of the conflict. This reflects the fundamental fact that there is no point in buying a reusable platform if you are not going to reuse it. The conflict duration at which exclusive reliance on expendable platforms becomes prohibitive depends on a number of assumptions about the cost, availability, and utilization rates of weapon systems, but for any realistic possibilities, expendable platforms become costly for conflicts persisting on the order of ten days. Appendix A describes our baseline cost assumptions. Appendix C describes several alternative cost assumptions.

Note that each of the major conflicts in recent history depicted in Figure S.1 has lasted longer than ten days. This analysis assumes that a reusable platform will be designed, purchased, and used in only one conflict. In reality, U.S. planning should be based on the total number of days of conflict for which the United States needs to be prepared over the lifetime of a proposed reusable platform. Only if the United States is confident that all possible conflicts over the system lifetime can be ended in a total of less than about ten days is exclusive reliance on expendable assets prudent.

This conclusion does not imply that expendable assets are not an important part of a well-designed force mix. There are important operational advantages to having at least some expendable weapons that this report does not address.

However, if the United States wishes to maintain the capability to wage air war efficiently for more than a few days, reusable platforms are an important part of an efficient force mix. This implies that, if the United States has a requirement for a substantial long-range strike capability and if the existing bomber fleet will for some reason, such as age or survivability, not be able to meet that requirement in the future, the nation should take steps to have appropriate weapon systems available when needed. Defining appropriate weapon systems requires analysis of alternative strategies relying on mixes of currently available expendable and reusable platforms and/or new weapon systems.

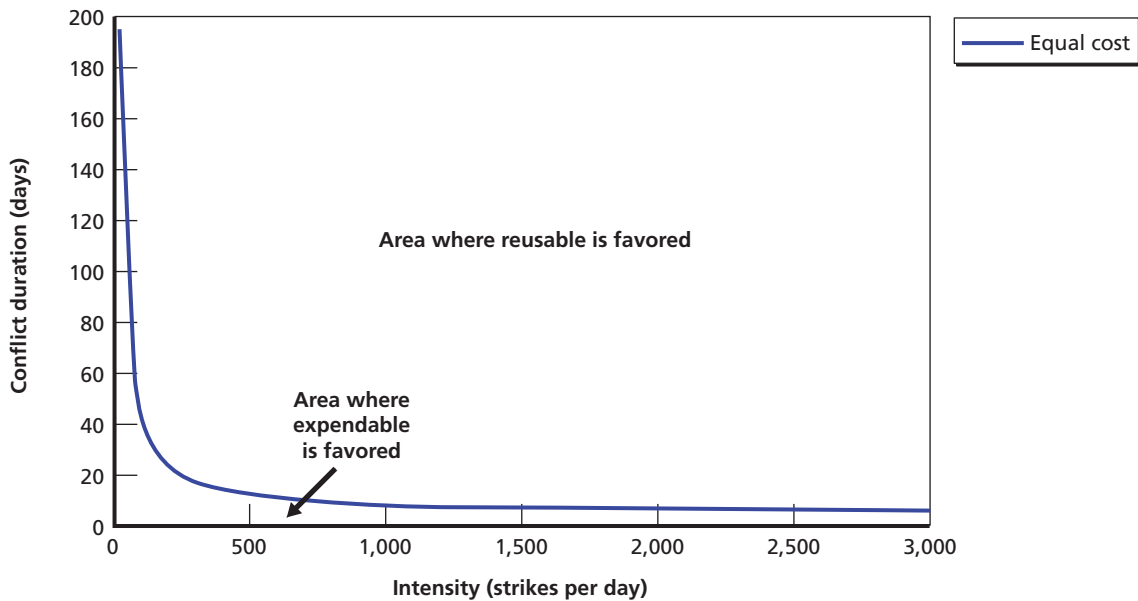
Expendable Missiles Versus Reusable Platform Costs and Historical Data

The purpose of this report is to evaluate the economic wisdom of the United States adopting policies that rely primarily on expensive expendable weapons, such as cruise missiles, to conduct air-to-ground strike missions. We examine the historical use of air-to-ground attack by the U.S. military during and since the Vietnam War and examine when exclusive use of expendable methods would be cost-prohibitive compared to using reusable weapons platforms. This analysis focuses solely on cost and does not explore the range of capabilities different weapon systems offer. Thus, our conclusions do not address strategies involving a mix of reusable penetrating aircraft and expendable munitions.

This report does not examine many important aspects of this issue, such as range and survivability. It is narrowly focused on how scenario properties affect the cost-effectiveness of alternative approaches to strike.

We chose to examine scenarios in the context of two variables. The horizontal axis in Figure 1.1 represents intensity, defined as the average number of air-to-ground weapons deliv-

Figure 1.1
Reusable Versus Expendable Cost Indifference Curve



RAND TR1230-1.1

ered per day over the period of the conflict. The vertical axis represents the duration of the conflict in days. The blue line is the cost indifference curve.

The specific value of the cost indifference curve is determined by the set of cost assumptions detailed in Appendix A. This particular indifference curve was generated by comparing the costs of a new, 20,000-lb-payload strike aircraft with the costs of cruise missiles fired from a converted commercial airliner. We focused on the general shape and approximate position of the curve, not on any particular case. Appendix C shows explicitly that the important conclusions of this report are robust over a substantial range of specific cost assumptions. The curve has the character shown whenever a strike system with a high cost per strike, such as an expendable missile, is compared with a system with a high fixed cost but lower cost per use, such as a reusable aircraft.¹

The particular parameters—intensity and duration—were chosen partly because they are well defined and readily available for historical events and partly because fairly simple mathematical analysis with them produces results that, we hope, provide useful insights.

In particular, the two asymptotes of the blue line have clear meanings. The close to vertical part of the indifference curve on the far left side of the graph represents the case in which very few total munitions are being used in the conflict. If only a few strikes are required, the requisite munitions can be purchased for less than the development cost of a new aircraft.

The increasingly flat part of the line on the right side of the graph represents the case in which the aircraft buy is sufficiently large that the total program cost is not dominated by development costs. In this case, whether exclusive reliance on expendable platforms is cost-prohibitive depends entirely on the length of the conflict. One way to look at this issue is to reflect that there is little value in buying reusables if one is not going to reuse them. Reusable systems will rarely be justified if one is confident that one does not need the capability to wage war for more than a few days.

It is also important to note that looking at scenarios in this way undervalues the utility of reusable platforms. An important quality of reusables is that they can be used in more than one scenario. Indeed, if a modern aircraft has a lifetime of 30 or more years, it is likely to be used in more than one conflict.

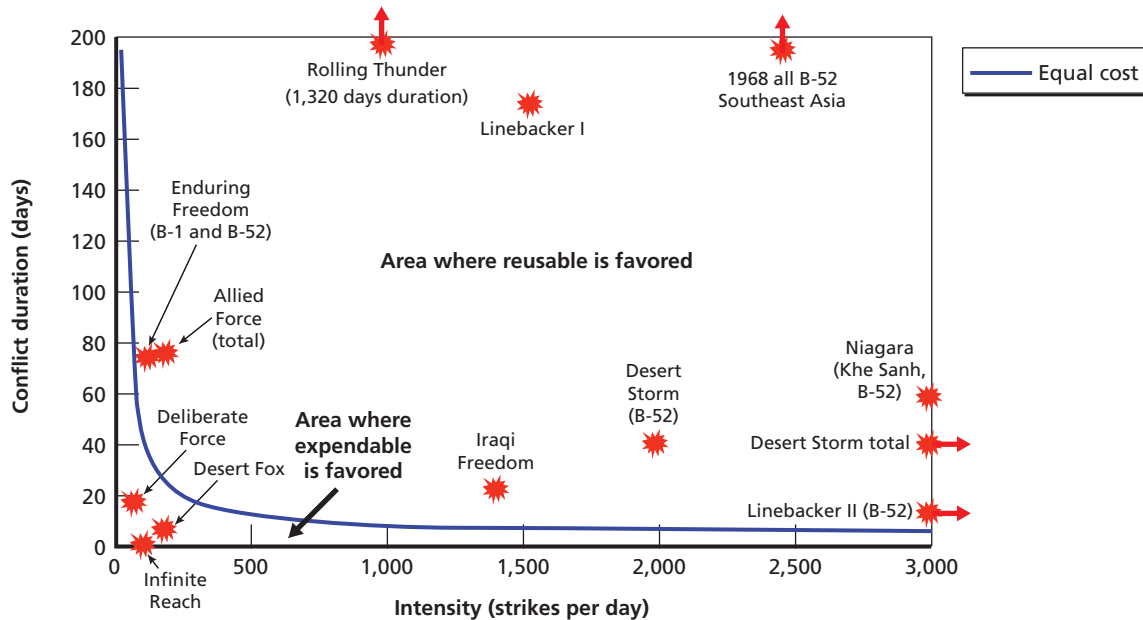
Conversely, if a conflict will last a long time, relying primarily on expendable munitions becomes cost-prohibitive. The conflict duration for which exclusive reliance on expendable platforms becomes prohibitive depends on a number of assumptions about the cost, availability, and utilization rates of weapon systems, but for any realistic possibilities, expendable platforms become costly for conflicts persisting on the order of ten days.

Furthermore, if a conflict is fought using primarily expendables, it is possible that, even if the United States wins the conflict, the U.S. arsenal of expendable munitions at the conflict's conclusion would be significantly depleted, requiring additional procurement and possibly creating temporary risk to U.S. security. This analysis does not look at that effect.

Figure 1.2 is the same as the preceding figure, except that data from a range of historical cases are added. The position of each mark on the horizontal axis represents the historical average number of weapons delivered per day, while the vertical position represents the number of days the conflict lasted. Details and sources of the data are described in Appendix B.

¹ Strictly speaking, we are comparing a system with a relatively expensive penetrating platform and relatively cheap munitions, such as glide bombs, against a system with a relatively cheap nonpenetrating aircraft, such as a commercial derivative, carrying relatively expensive munitions, such as long-range cruise missiles.

Figure 1.2
Reusable Versus Expendable Costs and Historical Conflicts



RAND TR1230-1.2

As shown in Figure 1.2, some of the data points represent only munitions delivered by bombers (B-52s in Vietnam and Desert Storm, and both B-52s and B-1s in Afghanistan). The others represent all munitions delivered by air.

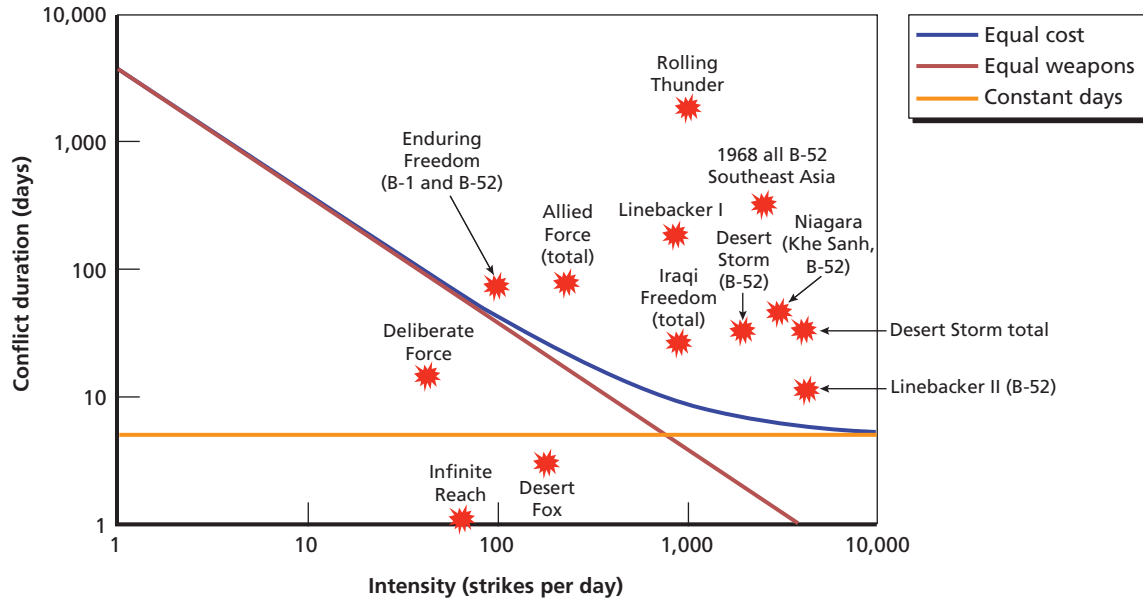
Figure 1.3 contains exactly the same data as the previous chart. Both axes have been changed from linear to logarithmic. This form makes it easy to see that the indifference curve is the sum of two simple lines. One line is proportional to the inverse of intensity. It reflects the fact that, if the war can be won with a small number of weapons, a development program for a reusable aircraft is an unnecessary expense. The other line is flat and simply reflects the number of days of war necessary for a reusable platform to justify its procurement.

The algebra underlying these two straight lines is described in detail in Appendix A.

Figure 1.4 is the same graph as in Figure 1.3 with added lines illustrating the bomb capacity of the existing B-2 force and a possible standoff missile buy. The chart shows that, if the existing B-2 force were aggressively employed with theater basing, it would be able to support the intensity of munitions delivery historically seen in Enduring Freedom and Allied Force. This is not the same thing as saying it would have all the same capabilities as the forces historically employed, just that it could deliver sufficient munitions at a sufficient rate, the one capability we are studying. However, the existing fleet is much too small to support the intensity of operations of air delivery in Iraqi Freedom or B-52 operations in Desert Storm.

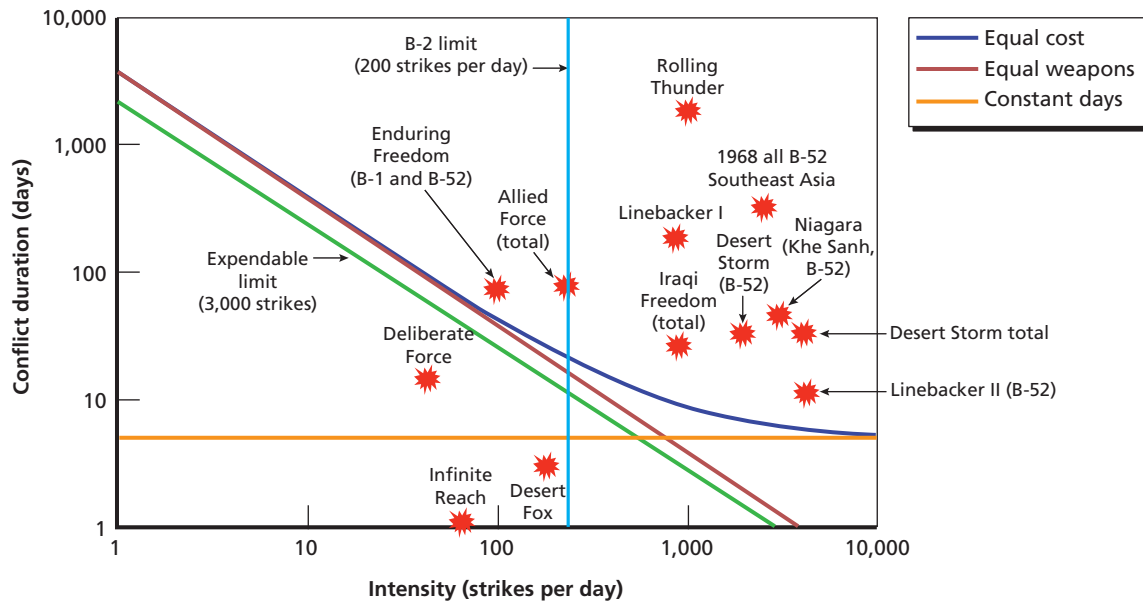
The green line shows the capability of a force able to successfully carry out 3,000 cruise missile strikes. (Of course, this is not the same thing as possessing only 3,000 cruise missiles; some targets would require more than physical weapons as a result of operational mistakes, mishaps, etc., as well as the need to keep a reserve.) Such a force would not have enough munitions to support either Enduring Freedom or Allied Force, although it would be more than adequate for Desert Fox and the other smaller operations in the lower left corner.

Figure 1.3
Reusable Versus Expendable (log scale)



RAND TR1230-1.3

Figure 1.4
Reusable Versus Expendable, with B-2 Bomb Capacity and Standoff Missile Buy (log scale)



RAND TR1230-1.4

The point here is not to compare B-2s and cruise missiles but to make the observation that, while both systems can efficiently handle a range of important conflicts, many historical conflicts have simply been too large for either our current B-2 fleet or the hypothetical 3,000-strike cruise missile force.

In Figure 1.5, we use the methodology described above to make easy cost excursions. Since the height of the sloping line is proportional to the system design and development (SDD) of the strike aircraft, we can readily see the effect of doubling the aircraft SDD. The dotted line above the sloped line shows the movement in that component of the indifference curve.

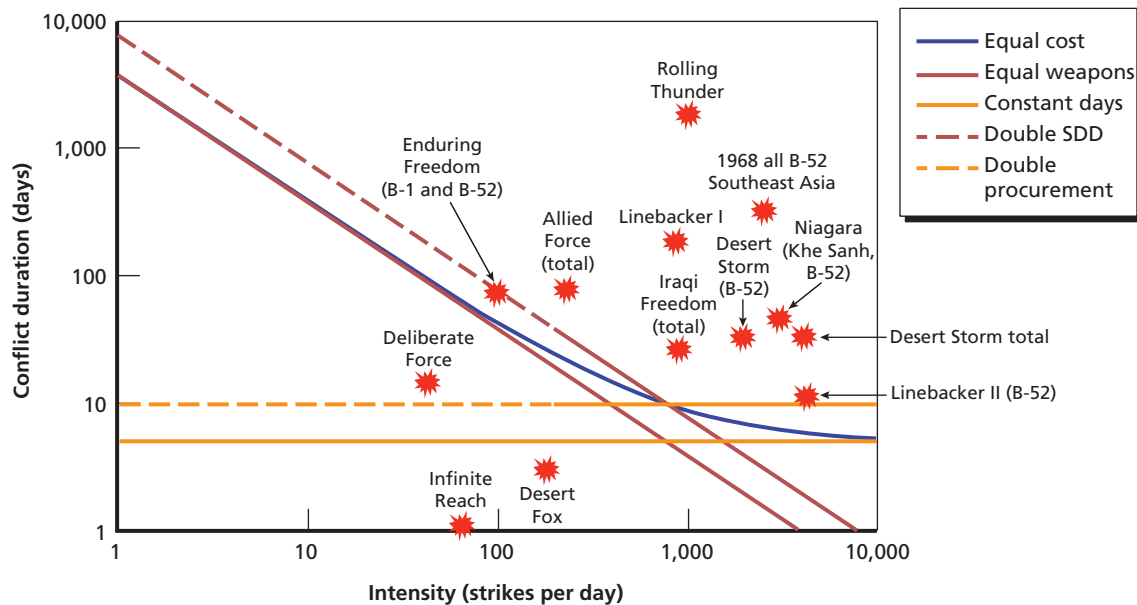
Similarly, movement in the horizontal line reflects the results of doubling the per unit cost for the reusable aircraft. With this chart, it is easy to see that, for expendable weapons to become cost-competitive with reusable aircraft for the Desert Storm B-52 scenario, aircraft-per-unit costs would have to double three times, that is, increase by a factor of eight.

The same effect, cost neutrality in the Desert Storm B-52 case, could also be achieved by reducing weapons procurement costs by a factor of eight. We concluded from this that the fundamental economics of the relative advantage of expendable and reusable platforms in the sort of campaigns in which U.S. airpower has been used historically are not affected by changes in cost of less than an order of magnitude. That is, precise cost data are not necessary to make correct general policy decisions.

It is important to emphasize that this analysis has looked at a very limited set of questions. What are the fundamental economic drivers in deciding between expendable and reusable aircraft? Obviously, important issues of range and survivability have not been considered. The ability of penetrating aircraft to support intelligence, surveillance, and reconnaissance has not been considered. Finally, this sort of analysis is fundamentally biased against reusable aircraft because it only considers reusing them within a particular scenario. The important fact that reusable aircraft can be reused in multiple scenarios is omitted from this formal analysis.

Despite these possible biases against reusable aircraft, we conclude that if the United States wishes to maintain the capability to wage air war efficiently for more than a few days, reusable platforms are an important part of an efficient force mix. This implies that, if the

Figure 1.5
Reusable Cost Excursions



United States has a requirement for a substantial long-range strike capability and if the existing bomber fleet will, for some reason, such as age or survivability, not be able to meet that requirement in the future, the nation should take steps to make appropriate weapon systems available when needed. Defining appropriate weapon systems requires analysis of alternative strategies relying on mixes of currently available expendable and reusable platforms and/or new weapon systems.

This conclusion does not imply that expendable assets are not an important part of a well-designed force mix. They are necessary for some important missions (for reasons not discussed in this report) but are simply too expensive to largely or entirely replace reusable penetrating aircraft in wars of even moderate duration.

Model Assumptions and Methodology

We generated the baseline indifference curve presented in this report with the assumptions detailed below. The model is quite simple and concentrates on the main differences between reusable and expendable systems. Different assumptions will, of course, produce different indifference curves, but the curve's general shape and dependence on key parameters will not change.

Similarly, more sophisticated models including learning curves, discount rates, etc., will show the same general qualitative behavior.

Assumptions

In addition to the numbers in Table A.1, we worked with the following assumptions:

- New reusable is long range, stealthy, with 20,000-lb payload.
- Aircraft launching expendables is modified commercial transport.

Methodology

The algebra we use to generate the indifference curves is simple.

Assume the cost of a system consists of its SDD cost, which is fixed regardless of how many units are procured, its infrastructure cost, such as aircraft purchases, which is determined by the force size which in turn is determined by the intensity of conflict the system

Table A.1
Cost Assumptions

	New Reusable	Expendable Carrier
SDD (\$M)	20,000	5,000
Platform procurement (\$M)	600	100
Weapon procurement (\$M)	0.050	2
Weapons per platform (number)	20	50
Weapons per strike (number)	1	2
Sortie rate	1.3	1

will support, and its expendable costs, such as weapons and fuel, which is determined by the product of the conflict intensity and duration:

$$Cost = SDD + Infrastructure \times Intensity + Expendables \times Intensity \times Duration.$$

If we equate the cost of a penetrating aircraft system with the cost of a standoff missile system, we get

$$SDD_M + Inf_M \times I + Exp_M \times I \times D = SDD_A + Inf_A \times I + Exp_A \times I \times D,$$

where Inf_M is the unit cost of infrastructure for the missile-based system, etc.

Using ΔSDD to represent $(SDD_M - SDD_A)$ and so forth, we subtract the left side from the right, yielding

$$\Delta SDD + \Delta Inf \times I + \Delta Exp \times I \times D = 0.$$

Dividing by $\Delta Exp \times I$ and rearranging terms yields

$$D = -\frac{\Delta SDD}{\Delta Exp} \times \frac{1}{I} - \frac{\Delta Inf}{\Delta Exp}.$$

That is, the indifference curve has one term proportional to $(1/I)$ determined by the ratio of SDD to expendable costs, and one constant term determined by the ratio of infrastructure to expendable costs. This is precisely what we see on the graphs.

To illustrate how this works out numerically in the baseline case we start by computing DSDD. This is \$20 billion – \$5 billion, or \$15 billion. Computing ΔExp is a little more complicated since the expendable requires more weapons per strike:

$$\Delta Exp = 2 \times \$2 \text{ million} - \$50,000, \text{ or } \$3.95 \text{ million.}$$

To compute ΔInf we look at the aircraft cost per strike divided by the sortie rate:

$$\Delta Inf = \frac{\left(\frac{\$600 \text{ million}}{20} \right)}{1.3} - \left(\frac{\$100 \text{ million}}{\frac{50}{2}} \right) = \$23 \text{ million.}$$

We then compute the coefficients and find that the number of days of combat for which expendable and reusable systems are equally efficient is

$$D = -\frac{\$15B}{\$3.95M} \times \frac{1}{I} + \frac{\$23M}{\$3.95M}.$$

Or,

$$D = 3,797 \times \frac{1}{I} + 5.75,$$

where I is the intensity measured in strikes per day.

So if the intensity is higher that a few thousand strikes per day the first term is small and the critical issue is whether the war will last, in this case, more than 5.75 days.

Data Sources

Below is a list of historical sources used for the data presented in this study. All data were taken from readily available unclassified sources. In some cases, particularly in Vietnam, the exact number of weapons dropped was not available, but the total weight delivered was available. In such cases, we estimated the number of weapons by assuming that the average weapon weighed 1,000 lbs. The numbers in parentheses are the weapons per day and duration of the conflict in days. Those are the numbers shown on the figures.

- 1968 B-52 total (2,500; 366) (Bowman, 2005, p. 74).
- Niagara (2,857; 77) from 110,000 tons (B-52) (Summers, 1995, p. 136).
- Linebacker I (1,515; 165) from 125,000 tons total (Summers, 1995, p. 180).
- Linebacker II (4,000; 10) from 20,000 tons total (Summers, 1995, p. 180).
- Rolling Thunder (974; 1,320) from 643,000 tons total (Summers, 1995, p. 96).
- Desert Storm B-52 (2,000; 40) (Bowman, 2005, p. 146).
- Deliberate Force (60; 17) (Ripley, 1996, p. 111).
- Infinite Reach (75; 1) (Myers, 1998).
- Allied Force (230; 78) (Daalder and O'Hanlon, 2000, pp. 250, 307).
- Desert Fox (173; 4) (Cohen and Zinni, 1998).
- Enduring Freedom (153; 76) (Global Security, 2012).
- Iraqi Freedom (1,343; 22) (Moseley, 2003, p. 11).

Additional Cost Excursions

This appendix repeats the familiar figure from the body of this report with a few different sets of cost assumptions. The point of this section is to demonstrate that our general conclusion (that cruise missiles are not a cost-effective solution for future scenarios resembling historical scenarios) is not dependent on the details of the cost assumptions.

Figure C.1 looks at a case in which the procurement cost of a penetrating strike aircraft carrying 20 weapons is \$1.2 billion instead of the \$600 million assumed in the base case. This causes little change in the position of the left side of the indifference curve but doubles the level of the right side. That is, if the penetrating aircraft is that expensive, we should only buy it if we anticipate the need to prepare for conflicts lasting more than about 12 days.

Figure C.2 presents an indifference curve for a penetrating aircraft with a unit procurement cost of \$3 billion. (That is just the procurement cost. We assumed, as in the baseline, an additional \$20 billion for SDD.) We further assumed that such an aircraft would be able to carry 40 independently targeted weapons. This indifference curve is very similar to the one above.

Figure C.1
Case with Doubled Reusable Aircraft Procurement Cost

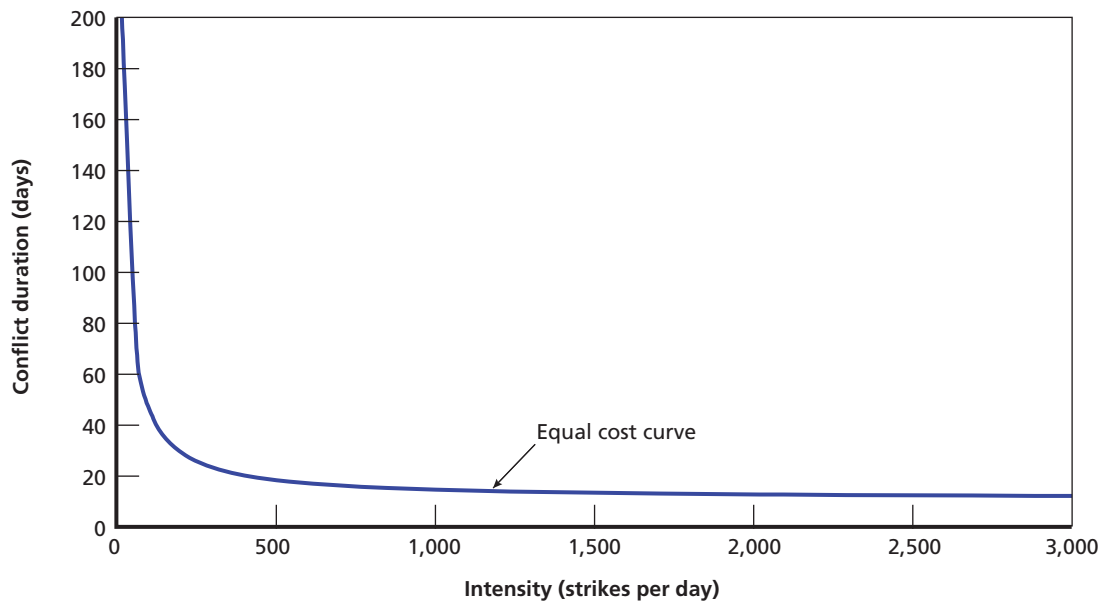
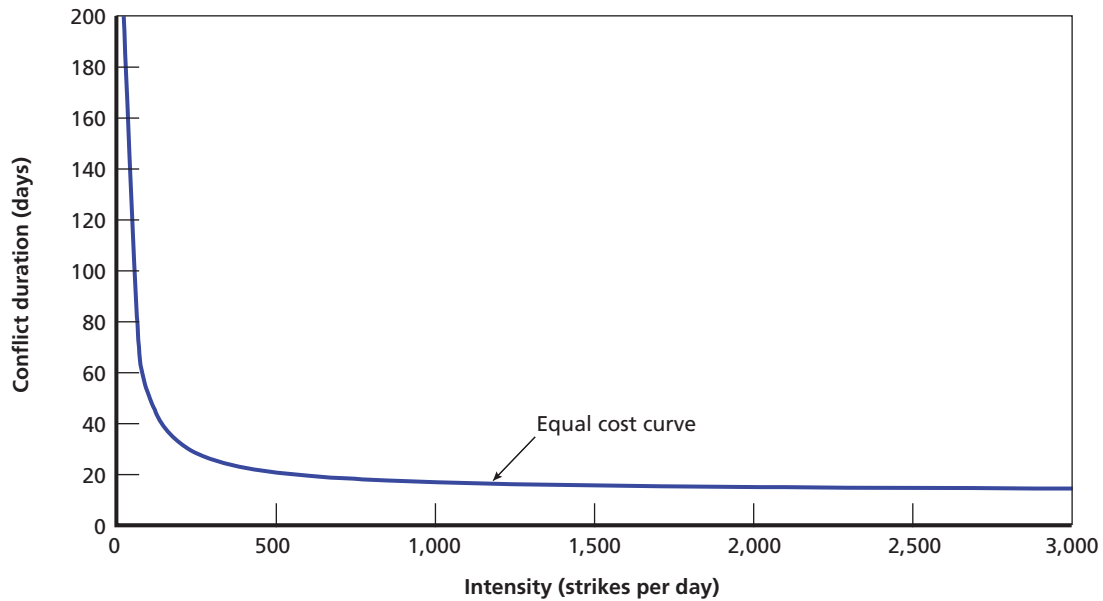


Figure C.2
Case with \$3-Billion (procurement) Bomber with 40 Weapons



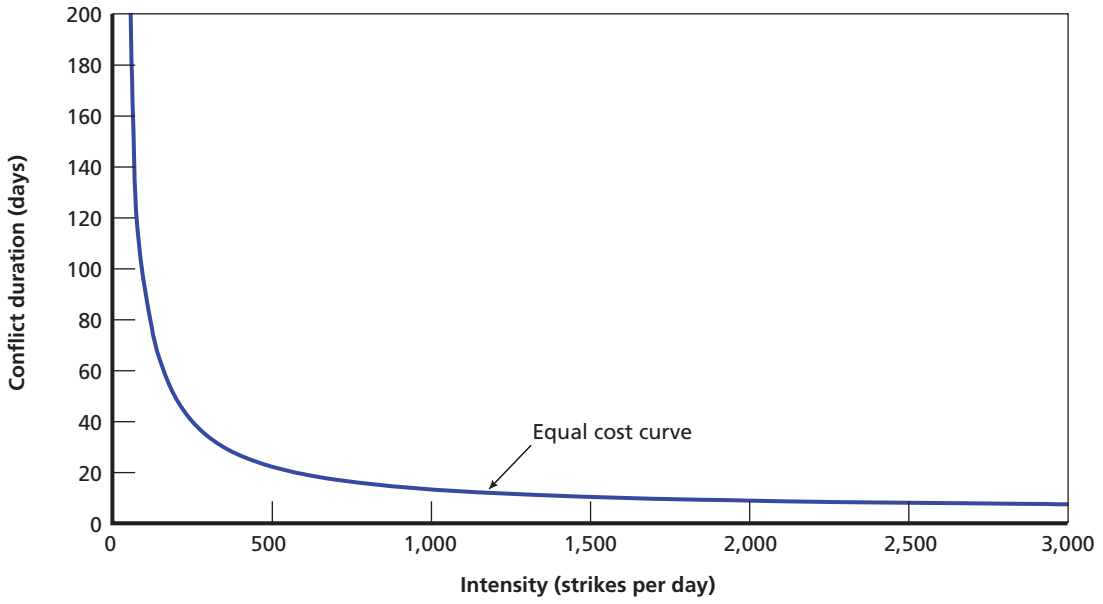
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Figure C.3 shows a case in which we have doubled the development cost of a new aircraft, to \$40 billion. This change moves the left side of the indifference curve somewhat to the right, almost to the point representing bomber operations in Operation Enduring Freedom. The point is that, if Enduring Freedom is the biggest war for which the nation needs to prepare and if penetrating aircraft would indeed require such a large development cost, the United States should be indifferent as to whether it buys penetrating aircraft or cruise missiles.

The previous excursions have all made penetrating aircraft more expensive. Figure C.4 illustrates a case in which the cost of cruise missiles is double that of our baseline case. This lowers the indifference curve significantly.

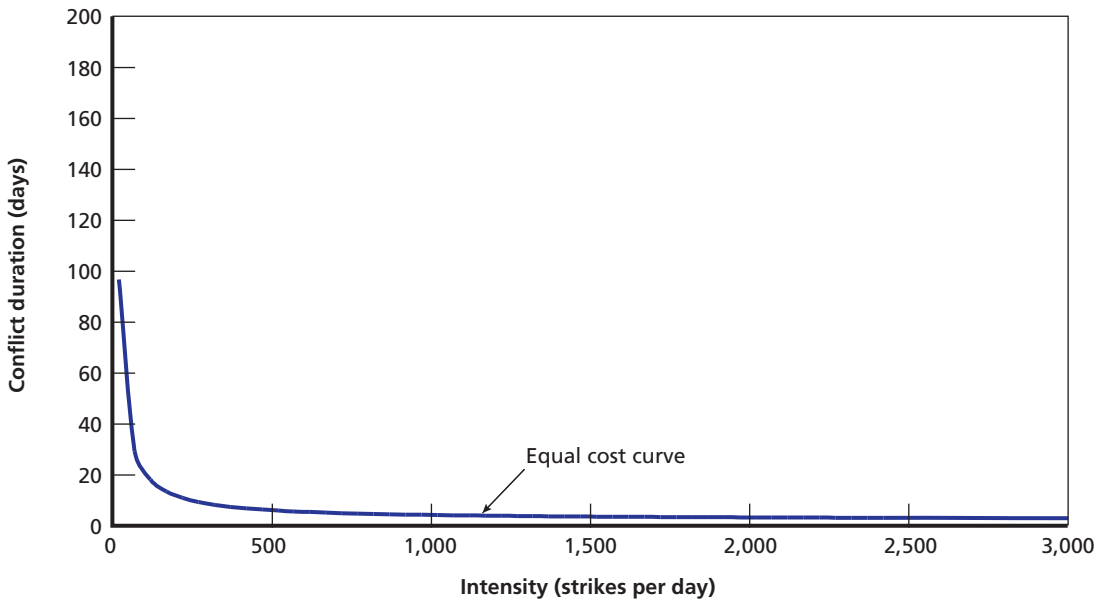
The larger point here is that none of these excursions really changed the overall result much. The cases that were above the curve, major theater wars, were all above the curve in each case. The limited strike cases, such as Desert Fox, were all below the line in each excursion. So the overall conclusion of the report, that it is not economically wise to rely primarily on cruise missiles if one needs to prepare for the sort of conflicts that have occurred in the past, remains the same.

Figure C.3
Case with Doubled Reusable Aircraft Procurement Cost



RAND TR1230-C.3

Figure C.4
Case with Doubled Cruise Missile Procurement Cost



RAND TR1230-C.4

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