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1899 Pennsylvania Ave., Suite 520
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For More Information:
Keith W. Crane, Project Leader
kcrane@ida.org, 202-419-3736

Mark J. Lewis, Director, IDA Science and Technology Policy Institute
mjlewis@ida.org, 202-419-5491

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Executive Summary

The Federal Government has retired several hundred solid-fueled intercontinental ballistic missiles (ICBMs) over the decades. U.S. space policy allows for the use of the rocket motors from these excess ICBM assets for launches of government payloads, but not for commercial payloads. The recent emergence of new commercial launch providers and capabilities has triggered a review of how the government accounts for the value of these assets. As a result, the the IDA Science and Technology Policy Institute (STPI) was asked to provide alternative estimates of the value of solid-fuel rocket motors from excess ICBMs.

Background

As of June 2016, rocket motors from 60 Peacekeeper ICBMs and 171 Minutemen II ICBMs were available to U.S. companies for launching government payloads. Following a competition, U.S. Air Force employees refurbish the rocket motors and the government transports and positions the rocket motors for assembly into the launch vehicle by the company that won the competition. The government retains ownership of the motors until launch, and the cost of refurbishment and transportation is deducted from the bid price.

Currently, the government levies no other charges or accounts for any inherent value of the excess rocket motors. Orbital ATK is the only company to date that has designed and built a family of launch vehicles that use excess ICBM rocket motors; the Federal government may be capturing part of the value of the rocket motors provided to Orbital ATK in the form of a cheaper bid price from the company. How much of this value the government is capturing, if any, depends on the competition Orbital ATK faces when it bids for launches.

To ensure that the government is not inadvertently favoring one supplier over others, the Federal Government may wish to charge users for the value of excess ICBM rocket motors.

Estimated Value of Excess ICBM Rocket Motors

STPI used four different methodologies to estimate the value of excess Peacekeeper and Minuteman II missiles, the estimates from which are provided below.

1. Replacement cost: $16.4 million fiscal year (FY) 2016 dollars for both Peacekeeper and Minuteman II missiles.

2. Depreciated value = $15.4 million FY 2016 dollars (Peacekeeper) and $0 (Minuteman II).
3. Value of constituent parts method: $1.3 million FY 2016 dollars (Peacekeeper) and $0.6 million FY 2016 dollars (Minuteman II).
4. Market value method: minimum bid price of $11.7 million FY 2016 dollars (Peacekeeper) and $2.2 million FY 2016 dollars (Minuteman II).

None of these methodologies yields the “right” answer; each has strengths and weaknesses, and each is appropriate under different conditions.

Contents

A. Objective

For several decades, the U.S. government has used solid-fuel rocket motors from excess intercontinental ballistic missiles (ICBM) assets to reliably and cost-effectively launch government payloads, as permitted by U.S. space policy. The emergence of new launch providers and capabilities has triggered a review of how the government accounts for the value of these assets. For this project, the IDA Science and Technology Policy Institute (STPI) prepared estimates of the value of rocket motors from excess ICBMs. STPI used four alternative methodologies to estimate the value of these rocket motors. The methodologies are listed below:

1. Replacement cost
2. Depreciated value
3. Value of constituent parts
4. Market value

B. Background

Because of technological obsolescence, force posture decisions, and arms control agreements, the Federal Government has retired several hundred solid-fueled ICBMs over the decades. Each of these missiles is powered by three or more rocket motors. Because of the longevity of solid-fuel rocket motors, the government has substantial numbers of excess rocket motors in storage at Hill Air Force Base in Utah.

U.S. space policy allows for the use of the rocket motors from these excess ICBM assets for launches of government payloads, but not for commercial payloads. Policy and law (U.S. Code Title 51, Section 50134) prohibit the use of surplus rocket motors in commercial launches in an effort to preserve a "level playing field" in the commercial payload launch market.

The government has made excess rocket motors from two of the missiles held in storage, the Peacekeeper and the Minuteman II, available to U.S. companies to use in rockets launching government payloads.[1] As of June 2016, rocket motors from 60 Peacekeeper ICBMs and 171 Minutemen II ICBMs were in storage (Table A-1 in Appendix A). Because the Minuteman III is still deployed, Minuteman III missiles are

[1] Since the early 1970s, rocket motors from retired Minuteman I and II missiles have been used for rockets for experimental and test purposes, like boosting targets or interceptor vehicles for antiballistic missile defense tests. Examples of such vehicles include the Space Vector Aries, Coleman Hera, Orbital Sciences Corporation's SR19 and Storm, Lockheed Martin's Payload Launch Vehicle, and Coleman's Short-Range Air Launch Target and Long-Range Air Launch Target rockets. These activities appear to have used all retired Minuteman I missiles, as no Minuteman I missiles are currently listed in storage.

being kept in storage for testing and spare parts for the time being. Under one option for the continuation of the land-based ICBM force, Minuteman III would remain the sole missile in this force (Caston et al. 2014). If the Minuteman III remains the sole U.S. land-based ICBM, Minuteman III missiles would be unlikely to become available for uses other than for testing, replacement, or spare parts for the foreseeable future.

To this point in time, only one company, Orbital ATK, has designed and built a family of launch vehicles, the Minotaur series, incorporating ICBM rocket motors. The Minotaur I has four stages. It uses the M55 (the first-stage rocket motor of the Minuteman II), and the SR19 (the second stage rocket motor), for its first and second stages, respectively, and it uses commercial rocket motors or engines for the third and fourth stages. The Minotaur IV, IV Plus, V, and VI use the first, second, and third stage rocket motors of the Peacemaker (SR-118, SR-119, and SR-120), for their first, second, and third stages, and they use commercial engines for the fourth or higher stages.[2]

Orbital ATK competes with other potential launch providers to launch government payloads with the Minotaur launch vehicles. If Orbital ATK wins a bid, the government does not transfer rocket motors to Orbital ATK, but retains ownership of all the rocket motors through launch. U.S. Air Force employees at the Air Force's depot at Hill Air Force Base in Utah refurbish the rocket motors for Orbital ATK (or potentially any other company that wins bids that include the use of rocket motors from excess ICBMs). The government then transports the refurbished rocket motors to the assembly site of the launch vehicle and positions the rocket motors for assembly into the launch vehicle. The government deducts the cost of refurbishment and transportation from the bid price.

Currently, the government levies no other charges or accounts for any inherent value of the excess rocket motors, but may be capturing at least part of the value of the rocket motors provided to Orbital ATK in the form of a cheaper bid price from the company. How much of this value the government is capturing, if any, depends on the competition Orbital ATK faces when it bids for launches.

C. Valuing Excess Intercontinental Ballistic Missiles

The Federal Government may wish to charge users for the value of excess ICBM rocket motors. Such charges could serve to achieve the national policy goal of ensuring

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[2] Orbital ATK uses commercial rocket motors for the fourth stage of the Minotaur IV (Orion-38) and the Minotaur IV+ (Star-48V). Commercial rocket motors are also used on those Minotaur variants that have a fifth stage. Because the Minotaur C, which has a payload similar to those of the Minotaur IV and IV+, is built for commercial launches, rocket motors from excess ICBMs cannot be used on this launch vehicle for legal reasons. The Minotaur C uses the Castor 120, based on the Peacemaker's SR-118, for its first stage; the Orion-50 rocket motor for the second and third stages; and the Orion-38 for the fourth stage.

that the government is not favoring one supplier over others, even if inadvertently, in bids for launch services.

The question, "What is the value of excess ICBM rocket motors?" can be answered using a variety of different methodologies. Below are estimates of the value of excess Peacekeeper and Minuteman II missiles based on the four different methodologies previously identified. Note that none of the methodologies yields a "right" answer; each has strengths and weaknesses, and each is appropriate under different conditions.

1. Replacement Cost

The estimated replacement cost value of the rocket motors from both the Peacekeeper and the Minuteman II is estimated to be $16.4 million fiscal year (FY) 2016 dollars.

Replacement cost is the cost of replacing an item today. In the case of a weapon system currently in production, like the F-35 Lightening fighter, replacement cost would be the latest price at which the plane had been purchased. When the weapon is no longer in production, like the Peacekeeper or the Minuteman II, replacement cost is generally estimated using the purchase price of the last few items that were procured, inflated to current year dollars using Department of Defense (DoD) procurement price indices. If this information is unavailable or if it is not clear that the listed purchase price encompassed all payments for the weapon, analysts often use either the price of an analogous item or the historical average cost per weapon.

An analog to the rocket motors in the two missiles is the propulsion system of the Trident II D-5 submarine-launched ballistic missile. The Trident II D-5 uses a three-stage solid-fuel propulsion system. This missile is currently being upgraded by the U.S. Navy. As part of the upgrade, the rocket motors are being continuously replaced. In 2016, the average cost charged by the contractor, Lockheed Martin, for the three new rocket motors in the Trident II D-5 was $16.4 million (DoD 2016b).

This number can be compared with an estimate of the cost of the commercial rocket motors used on the Minotaur C. According to the *Encyclopedia Astronautica*, the unit cost for the Castor 120, the commercial version of the SR-118, would be about $3.5 million if produced in volume production, but $7.5 million if only one motor were produced annually (*Encyclopedia Astronautica* undated).[3] Minotaur launches have been running at one or two a year, not enough for volume production, so the higher number seems more appropriate for estimating costs. The Orion-50, which powers the second and third stages, costs less than the Castor 120 because it is smaller, although exact cost figures were unavailable. However, assuming Orion-50 rocket motors cost more than half the $7.5 million estimate for the Castor 120, yields an estimate commensurate with the cost of the three new rocket

[3] These cost figures appear to be hypothetical, not based on actual contracts.

motors for the Trident II D-5. Because the cost number for the three new rocket motors for the Trident II D-5 are taken from official U.S. budget documents, that number served as the estimate of replacement cost.

Although the Minotaur I uses only the first and second stage rocket motors of the Minuteman II, while the Minotaur IV and other variants use the first, second, and third stage motors of the Peacekeeper, it is hard to envision ways in which the third stage rocket motors of the Minuteman II could be put to other uses. Accordingly, the $16.4 million figure was used for the value of the rocket motors from both the Minuteman II and the Peacekeeper.

According to information from an ongoing study by the U.S. Air Force, the government has paid from $51 million to $75 million per launch for launches of the Minotaur IV, IV Plus, and V. In July 2015, Orbital ATK won a contract for a Minotaur IV launch of a military space-based space surveillance satellite for $23.6 million (Clark 2015). At a price of $16.4 million, charging this much for the excess rocket motors would have increased Orbital ATK's bids for launch by 22 to 70 percent, although the U.S. government would have recouped the increase in the bids through the sale of the surplus rocket motors.

Launch costs for the Minotaur I, which uses rocket motors from the Minuteman II, have ranged from $19 million to $32 million before deducting refurbishment and transportation charges. Adding a $16.4 million charge for the rocket motors from the Minuteman II would have raised the bid into a range of $35 million to $48 million, of which the government would recoup $16.4 million in charges for the rocket motors.

The Minotaur I has a payload capacity of 580 kilograms to low Earth orbit (LEO). Orbital ATK manufacturers a launch vehicle, the Pegasus, with a somewhat smaller payload, 450 kilograms to LEO. The government will pay Orbital ATK $56.3 million for the Pegasus to take the Ionospheric Connection Explorer into orbit in 2017 (NASA 2014). Adding the cost of the surplus rocket motors to the cost of the Minotaur I would still be less than the cost of the Pegasus launch.

2. Depreciated Value

The estimated depreciated value of the Peacekeeper is $15.4 million FY 2016 dollars and that of the Minuteman II is zero dollars.

Depreciation of the value of an asset reflects reductions in the value of the asset over time due to wear and tear, technological obsolescence, or a reduction in the remaining life of the asset. Although the life of missiles can be extended by refurbishing them, the average service life of a rocket motor ranges from 25 years to 50 years (Airforce-Technology.com 2013). The Peacekeeper was first deployed in December 1986 and deployment continued into 1987, so 30 years have passed since first deployment and 29 years from last deployment.

In a report published in 2014, the RAND Corporation analyzed options for preserving ground-based nuclear ICBMs (Caston et al. 2014). As part of the analysis, the authors collected budget data on expenditures for developing and manufacturing the Peacekeeper missile. The RAND team estimated that the procurement cost of the Peacekeeper averaged $172 million FY 2012 dollars per missile (Caston et al. 2014, 101). Inflating FY 2012 dollars to FY 2016 dollars using the DoD procurement price inflator yields an average cost of $184 million in FY 2016 dollars. Another estimate for the flyaway cost (purchase price of a single missile) was for $20 million in FY 1982 dollars, which is equivalent to $42 million in FY 2016 dollars (Nuclear Weapon Archive undated). Because this other source provided no document or citation for this number, the RAND estimate was used for the cost of the Peacekeeper.

For its research on the value of surplus ICBMs, the U.S. Air Force calculated that propulsion systems account for about 20 percent of the total cost of launch services. Multiplying $184 million FY 2016 dollars by 20 percent yields an estimate for the value of Peacekeeper rocket motors of $36.7 million. Using straight-line depreciation from the first year of deployment and assuming a service life of 50 years, the value of rocket motors from the Peacekeeper in 2016 would be 40 percent of their original value of $36.7 million, or $15.4 million FY 2016 dollars.

The Minuteman II was first deployed in 1965; deployment was completed in 1967. Assuming a 50-year life span, as of 2017, all of the Minuteman II missiles will have been fully depreciated, so the depreciated value of the missile is zero dollars.

3. Value of Constituent Parts

The estimated value of the constituent parts of the Peacekeeper is $1.273 million FY 2016 dollars and of the Minuteman II is $574 thousand FY 2016 dollars.

The value of constituent parts, commonly referred to as the "scrap value," is the residual value of the components and materials used to manufacture the missile. In the cases of the Minuteman II and the Peacekeeper, the scrap value is the value of the materials only; other components cannot be sold for scrap because of national security concerns. When the U.S. Air Force disposes of a missile, sensitive components, like guidance systems, are kept by the government. The propellant and, potentially, the rocket casings can be sold for scrap, however.

The rocket motors in a Peacekeeper contain 105,531 pounds of ammonium perchlorate fuel and those in Minuteman II, 42,472 pounds. According to the U.S. Air Force, DoD ascribes a market price of $15 per pound for ammonium perchlorate, generating a scrap value of $1,582,965 for the fuel in the Peacekeeper and $637,080 for the fuel in the Minuteman II.

In the case of the Peacekeeper, there appears to be no scrap value for the rocket casings because they are made of composite materials, including Kevlar, making it difficult to extract materials for scrap. Information on the materials used for the casings of the three stages of the Minuteman II was not available. For the sake of analysis, the casing of the first stage booster for the Minuteman II was assumed to consist of high-grade steel, and the casings for the other two stages, of titanium. Ninety-five percent of the mass of the boosters was assumed to consist of propellant and the remaining five percent, of the casing (Caston et al. 2014, 54). Under these assumptions, the casings could yield 1,243 pounds of high-grade steel from the first stage and 438 pounds of titanium from the other two stages. At $1 a pound for high-grade scrap steel and $3 a pound for titanium (Firefox Enterprises undated), the potential additional value from the casing would run $2,500. Ongoing U.S. Air Force research assigns no value for the casings from the Minuteman II.

Before the propellant can be sold, it has to be extracted from the rocket motors. The government has to dispose of the remaining parts of the missiles as well. According to ongoing U.S. Air Force research on the value of surplus ICBM motors, it costs $310,315 to dismantle and dispose of a Peacemaker missile and $65,594 to dismantle and dispose of a Minuteman II. Subtracting those costs from the total scrap value yields a net scrap value of $1,273,000 for the Peacemaker and $574,000 for the Minuteman II.

4. Market Value

A minimum bid price for the Peacekeeper could be set at $11.7 million FY 2016 dollars, and that for the Minuteman II, $2.2 million FY 2016 dollars.

Market value is the amount that can be obtained for surplus rocket motors from a sale on the open market. For some items, like commodities, market prices are well defined, but the price of items such as rocket motors, for which there are no established markets, are often established through auctions. The auction is a mechanism through which both the price that potential purchasers are willing to pay for an item and the price at which the seller is willing to part with the item are revealed.

Thus far only Orbital ATK has used excess ICBM rocket motors in its launch vehicles, making it difficult to use an auction to elicit a market price. In the absence of a competitor, Orbital ATK will seek to pay the lowest price possible for excess rocket motors. Two approaches could be used in an effort to elicit Orbital ATK's reservation price, the highest price Orbital ATK would be willing to pay for the rocket motors. One approach would be for the Federal Government to set a minimum bid price. This mechanism would protect the government from the sale of an asset at a price substantially lower than the price that the buyer would have been willing to pay if the buyer had faced competition from others. If the minimum bid price is set too high, however, Orbital ATK will not bid for the launch. The second approach would be for the U.S. government to commit to a series of auctions over an extended period of time, signaling to potential new

bidders that there will be a steady, continued supply of used rocket motors from excess ICBMs. In light of this commitment, new bidders may find it worth their while to develop launch vehicles that could use these rocket motors. Eventually, these new entrants would compete with Orbital ATK to purchase these rocket motors at auction.

To set a minimum price for an auction, the government would need to estimate the value that Orbital ATK ascribes to the excess rocket motors that it has been able to procure. As noted above, for its research on the value of surplus ICBMs, the U.S. Air Force calculated that propulsion systems account for about 20 percent of the total cost of launch services. Four recent launches of the Minotaur IV, IV Plus, and V averaged $64 million per launch. Three recent launches of the Minotaur I averaged $26 million per launch. Taking 20 percent of these values yields estimated propulsion system costs of $12.9 million and $5.3 million, respectively.

The Minotaur I uses two Minuteman II rocket motors for stages one and two, but two commercial rocket motors for stages three and four, which, according to the Air Force, cost $3.1 million. To estimate the potential value to Orbital ATK of the two Minuteman rocket motors, the $3.1 million cost of the stage three and four motors was subtracted from the estimated cost of propulsion for the Minotaur I of $5.3 million, yielding a value for the Minuteman II rocket motors of $2.2 million.

The Minotaur IV, IV+, V, and VI use three rocket motors from the Peacekeeper for their first three stages and commercial rocket engines for the fourth and higher stages. According to the Air Force, the fourth stage of these various classes of Minotaur costs $1.2 million. To estimate the potential value to Orbital ATK of the three rocket motors from the Peacekeeper, the $1.2 million cost of the stage four engine was subtracted from the estimated cost of $12.9 million for propulsion for the Minotaur IV and other variants, yielding a value for the Peacekeeper rocket motors of $11.7 million.

D. Summary

Table 1 shows the estimates of value for both missiles using the four methodologies.

Table 1. Summary of Value Estimates by Methodology (Millions of FY 2016 Dollars)

Methodology	Peacekeeper	Minuteman II
Replacement cost	$16.4	$16.4
Depreciated value	$15.4	$0.0
Value of constituent parts	$1.3	$0.6
Market value (minimum bid)	$11.7	$2.2

Appendix A.
Numbers of Rocket Motors Available from Excess Missiles

Since 1962, the United States has fielded a series of intercontinental ballistic missiles (ICBMs) powered by solid fuel rocket motors: Minuteman I, Minuteman II, Minuteman III, and MX or Peacekeeper. In compliance with nuclear arms control agreements with Russia and for purposes of modernization, the Federal Government has retired all of these missiles except for 450 refurbished Minuteman III ICBMs. The retired missiles and the rocket motors from which they are built are classified as excess ballistic missile assets.

The Department of Defense (DoD) keeps a database on all excess missiles and their component rocket motors. As of June 2016, the DoD listed the rocket motors in Table A-1 as "excess" and in storage. All of these rocket motors are in serviceable or "A" condition except those units identified as "repairable, but not serviceable."

Table A.1. Serviceable and Repairable Excess Rocket Motors in the U.S. Inventory

Missile	Rocket Motor	Original Manufacturer	Number
Peacekeeper	SR-118 (first stage)	Thiokol	55
Peacekeeper	SR-119 (second stage)	Aerojet General	60
Peacekeeper	SR-120 (third stage)	Hercules	59
Peacekeeper	Liquid fuel (fourth stage)	Rockedyne	21 (4 are repairable, but not serviceable)
Minuteman II	M55 (first stage)	Thiokol	89
Minuteman II	SR19 (second stage)	Aerojet General	156
Minuteman II	SR-73 (third stage)	Hercules	171
Minuteman III	M55 (first stage)	Thiokol	245
Minuteman III	SR-19-AJ-1 (second stage)	Aerojet General	147 (5 are repairable, but not serviceable)
Minuteman III	SR73-AJ/TC-1 (third stage)	Aerojet/Thiokol	121 (1 is reparable, but not serviceable)
Minuteman III	RS-14 (fourth stage)	Rockedyne	102 (5 are repairable, but not serviceable)

Source: DoD (2016a).

References

Airforce-Technology.com. 2013. "USAF Awards Rocket Systems Launch Support Contract to ATK." March 18. http://www.airforce-technology.com/news/newsusaf-rocket-systems-support-contract-atk.

Caston, Lauren, Robert S. Leonard, Christopher A. Mouton, Chad J. R. Ohlandt, S. Craig Moore, Raymond E. Conley, and Glenn Buchan. 2014. *The Future of the U.S. Intercontinental Ballistic Missile Force*. MG-1210-PAF. Santa Monica, California: The RAND Corporation.

Clark, Stephen. 2015. "Minotaur rocket selected to launch military satellite in 2017." *Spaceflight Now* (July 9, 2017). http://spaceflightnow.com/2015/07/09/minotaur-rocket-selected-to-launch-military-satellite-in-2017/.

Department of Defense (DoD). 2016a. Integrated Missile Database (IMDB) Asset List.

———. 2016b. "Trident II Mods Exhibit P-5a: Solid Rocket Motors." *Department of Defense Fiscal Year (FY) 2017 President's Budget Submission: Navy Justification Book Weapons Procurement, Navy*. Washington DC. Volume 1. p. 22.

Encyclopedia Astronautica. Undated. "Castor 120." http://www.astronautix.com/c/castor120.html.

Firefox Enterprises. Undated. "Chemicals." http://www.firefox-fx.com/ChemA.htm.

Nuclear Weapon Archive. Undated. "The Peacekeeper (MX) ICBM." http://nuclearweaponarchive.org/Usa/Weapons/Mx.html.

National Space and Aeronautics Administration (NASA). 2014. "NASA Awards Launch Services Contract for Ionospheric Connection Explorer." http://www.nasa.gov/press/2014/november/nasa-awards-launch-services-contract-for-ionospheric-connection-explorer/.