United States Government Accountability Office

Report to Congressional Addressees

August 2017

SURPLUS MISSILE MOTORS

Sale Price Drives Potential Effects on DOD and Commercial Launch Providers

GAO-17-609

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GAO Highlights

Highlights of GAO-17-609, a report to congressional addressees

Why GAO Did This Study

The U.S. government spends over a billion dollars each year on launch activities as it strives to help develop a competitive market for space launches and assure its access to space. Among others, one launch option is to use vehicles derived from surplus ICBM motors such as those used on the Peacekeeper and Minuteman missiles. The Commercial Space Act of 1998 prohibits the use of these motors for commercial launches and limits their use in government launches in part to encourage the development of the commercial space launch industry in the United States. Legislative and policy changes would be needed to allow DOD to sell these motors for use on commercial launches.

The National Defense Authorization Act for Fiscal Year 2017 contains a provision for GAO to analyze the potential effects of allowing the use of surplus ICBM motors for commercial space launch. This report addresses (1) the options for pricing surplus ICBM motors; and (2) the potential benefits and challenges of allowing surplus ICBM motors to be used for commercial space launch.

GAO used Office of Management and Budget criteria to develop a range of breakeven prices, collected detailed motor storage and disposal costs from the Air Force, reviewed industry stakeholder responses to an Air Force request for information about other pricing methods, and interviewed DOD and industry officials.

What GAO Recommends

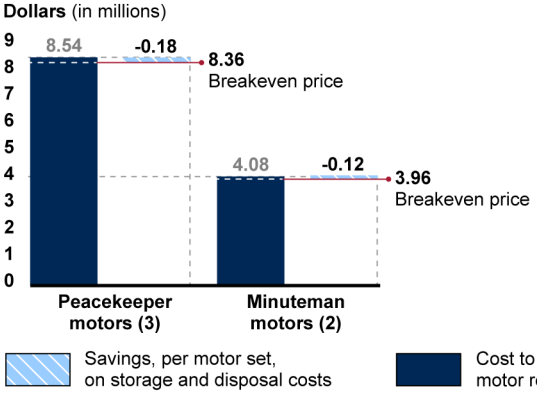
GAO is not making recommendations in this report.

View GAO-17-609. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

The Department of Defense (DOD) could use several methods to set the sale prices of surplus intercontinental ballistic missile (ICBM) motors that could be converted and used in vehicles for commercial launch if current rules prohibiting such sales were changed. One method would be to determine a breakeven price. Below this price, DOD would not recuperate its costs, and, above this price, DOD would potentially save. GAO estimated that DOD could sell three Peacekeeper motors—the number required for one launch, or, a "motor set"—at a breakeven price of about $8.36 million and two Minuteman II motors for about $3.96 million, as shown below. Other methods for determining motor prices, such as fair market value as described in the Federal Accounting Standards Advisory Board Handbook, resulted in stakeholder estimates ranging from $1.3 million per motor set to $11.2 million for a first stage Peacekeeper motor.

Estimated Per Motor Set Breakeven Price after Storage and Disposal Cost Avoidance Discount



Source: GAO analysis of Department of Defense data. | GAO-17-609

The prices at which surplus ICBM motors are sold is an important factor for determining the extent of potential benefits and challenges of allowing the motors to be used for commercial launch. Potential benefits include

- increasing the global competitiveness of U.S. launch services, and
- providing customers more launch options and greater flexibility.

Potential challenges include

- affecting private investment negatively, hindering innovation, and disrupting competition among emerging commercial space launch companies; and
- expanding the workload of the Air Force program office responsible for maintaining and refurbishing the motors.

Further, uncertainties in underlying assumptions and cost estimates—such as Peacekeeper motor storage and disposal costs—could hinder effective decision making. DOD is also conducting a study on the potential effects of allowing surplus ICBM motors to be used for commercial launch. Because DOD's study is not completed, it is not clear the extent to which its study addresses such uncertainties.

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Abbreviations

DOD	Department of Defense
EELV	Evolved Expendable Launch Vehicle
FAA	Federal Aviation Administration
FASAB	Federal Accounting Standards Advisory Board
ICBM	Intercontinental Ballistic Missile
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
RSLP	Air Force's Rocket Systems Launch Program

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August 16, 2017

Congressional Addressees

The U.S. government spends over a billion dollars each year on launch activities as it strives to help develop a competitive, commercial space launch industry from which it can assure its access to space and lower its launch costs. The Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) acquire launch services for a range of satellites and other payloads that vary by weight. Many of these launches use large launch vehicles capable of lofting heavier satellites weighing thousands of pounds. However, for low- and low to medium-weight satellites, these agencies pursue various launch strategies, including launching with other payloads, known as ride sharing, and launching on small and medium class commercial launch vehicles. Additionally, these agencies have the option to use launch vehicles derived from surplus intercontinental ballistic missile (ICBM) motors—that is, rocket motors that are no longer needed to support the active nuclear arsenal if they meet one of the exceptions contained in the Commercial Space Act of 1998.[1] Currently, the Air Force stores, maintains, and tests these motors to provide responsive space launch for the federal government.[2] The Air Force spends approximately $17 million each year on its stockpile of about 720 surplus ICBM motors to store the motors in bunkers, maintain facilities and equipment, conduct research to ensure the motors are aging safely, and, as the budget allows, dispose of motors that have become unusable.

[1]51 U.S.C. §§ 50131, 50132, 50134 and the 2013 National Space Transportation Policy. After the NASA Administrator or the Secretary of the Air Force determines one of the exceptions within the law can apply, the agency seeking to use the missile as a space transportation vehicle transmits to several congressional committees a certification that (1) the use of surplus ICBM missiles would result in cost savings to the U.S. government when compared to the cost of acquiring space transportation services from commercial providers; (2) that the use of the motors meets all of the mission requirements of the agency; (3) is consistent with international obligations of the United States, and; (4) is approved by the Secretary of Defense.

[2]The Air Force has developed several generations of ICBMs with the purpose of delivering nuclear weapons if needed. These systems served on “alert” as a deterrent to nuclear attack. According to the Air Force, as these systems aged, they were retired and replaced with newer systems. These retired ICBMs and their components, including the motors, were stored for future use or disposal in stockpiles.

Since the enactment of the Commercial Space Act of 1998, federal law has prohibited the use of surplus ICBM motors for commercial launches and limited their use for government launches, in part to encourage the development of the commercial space launch industry in the United States.[3] However, Congress has raised questions about whether law and policy should be changed to allow U.S. launch providers to purchase surplus ICBM motors from the Air Force and use them for launching commercial payloads, such as telecommunications or earth observation satellites.

There are widely varying views across the government and commercial industry on the potential economic and security effects of allowing the commercial use of surplus ICBM motors. The National Defense Authorization Act (NDAA) for Fiscal Year 2017 contains a provision for us to analyze such potential effects, including an evaluation of the effects, if any, on DOD, the commercial space launch industry, the solid rocket motor industrial base, national security, and any other areas the Comptroller General deems appropriate.[4] Because the prices at which DOD might sell its surplus ICBM motors for commercial launch are a key factor in assessing potential effects, this report addresses (1) the options for determining the selling prices for these motors; and (2) the potential benefits and challenges, including costs and savings, of allowing surplus ICBM motors to be used for commercial space launch.

To determine the options for pricing surplus ICBM motors, we reviewed the Federal Accounting Standards Advisory Board (FASAB) Handbook. We chose to analyze one of the options in-depth—the breakeven price, which falls under the fulfillment cost valuation method because it

[3]Pub. L. No. 105-303 (1998); 51 U.S.C. §§ 50131 & 50134. Government agencies generally must acquire space transportation services from US commercial providers, but may use the surplus motors under certain conditions. Agencies seeking to use surplus ICBM motor-based launch vehicles must receive approval from either the NASA Administrator or the Secretary of the Air Force and certify to Congress that the use of these launch vehicles meets all mission requirements, among other things.

[4]Pub. L. No. 114-328, § 1621 (2016). Additionally, the House Armed Services Committee Report to a bill for the FY2017 NDAA contained a provision for DOD to conduct a study on the effects of changing the law and policy to allow surplus motors to be used for commercial space launch and for us conduct an assessment of DOD's report. A related request from House leadership asked that DOD's study answer 10 questions related to the potential effects of using surplus ICBM motors for commercial launch and asked us to review DOD's study results. DOD's study is currently underway and DOD expects to complete its study later this year. Consequently, we did not assess DOD's study or its study efforts for this report.

represented a reasonable method for developing a potential motor price to inform our analysis. Additionally, we selected this option because the data were available with which to do the analysis. We used generally accepted economic principles for benefit-cost analysis, including Office of Management and Budget Circulars A-4 and A-94 to develop breakeven prices for which DOD could offer the motors. These breakeven prices, reflecting our calculations of the net present value of motor storage and disposal costs, are those at which DOD must sell the motors to cover the costs of transferring them to commercial launch providers.[5] We did not include sunk cost—that is, the costs previously incurred to develop, produce, and sustain the ICBM motors—but rather, we calculated potential prices based on fulfillment cost, which includes all costs that an entity will incur in fulfilling the promises that constitute a liability. These costs are the value to the entity of the resources that will be used in liquidating the entity's assumed liability. Because some costs vary depending on the number of projected launches of ICBM-based launch vehicles, we calculated a range of potential breakeven prices based on, among other things, low, medium, and high launch rates.

We collected from the Air Force detailed cost information associated with storing, testing, refurbishing, and disposing of surplus ICBM motors, and discussed with Air Force officials their future launch and motor disposal plans. We also obtained and evaluated motor transfer costs from two recent Air Force launch missions because they represent the most current cost data on transferring surplus ICBM motors for launch—that is, moving motors out of storage and preparing them to be integrated into a launch vehicle at the launch site. To assess the reliability of the motor storage and disposal cost data, we analyzed Air Force headquarters and Rocket Systems Launch Program (RSLP) office data, interviewed DOD officials, and reviewed detailed cost and launch schedule documentation. We corroborated the data, when possible, across at multiple Air Force and RSLP sources and conducted additional follow up interviews to gain additional insight. We determined that the data were sufficiently reliable for presenting the information contained in this report. Additionally, we reviewed FASAB criteria to understand other methods for determining the

[5]Net present value is the time value of money, that is, the value today (2017) of future cost of storing and decommissioning motors, based on the size of the ICBM inventory. The present value is the current value of a future amount or amounts, those amounts being decremented by a discount rate (such as the rate of inflation) to account for the time value of money. Net present value implies netting out the present value of both inflows and outflows.

value and price of surplus ICBM motors. We reviewed all 16 industry stakeholder responses to an August 4, 2016, Air Force request for information to understand other perspectives on motor pricing methodology.[6] Finally, we interviewed Rocket Systems Launch Program managers and contractor officials about processes and associated costs of processing the motors.

To determine the potential benefits and challenges of allowing surplus ICBM motors to be used for commercial launches, we interviewed a broad range of industry stakeholders including satellite manufacturers, launch providers, investors, and experts. To obtain a range of perspectives on the effects of changes to law and policy covering the transfer of surplus ICBM motors, we identified industry stakeholders based on our past and ongoing work, including U.S. government launch providers and emerging providers identified by the Federal Aviation Administration (FAA), NASA, and recommendations from experts. The industry stakeholders we interviewed represented the following categories (1) launch vehicle providers, (2) spaceports, (3) venture capitalists, (4) industry groups, (5) solid rocket motor industrial base, and (6) payload satellite companies. Their views are not generalizable. We also met with officials from NASA and the Departments of Commerce, State, and Transportation as well as officials from the Under Secretary for Defense for Acquisition, Technology, and Logistics; the Principal DOD Space Advisor; the Assistant Secretary of the Air Force for Space Acquisition; Missile Defense Agency; and the Air Force Space and Missile System Center's Rocket Systems Launch Program Office.

To evaluate the potential costs and savings of allowing surplus ICBM motors to be used for commercial space launch, we conducted a cost benefit analysis using Office of Management and Budget guidance and general economic principles. We estimated potential launch prices for a launch vehicle using surplus ICBM motors at our calculated breakeven motor prices and compared these prices to publicly available prices of current and emerging commercial launch vehicles. We also reviewed the

[6]U.S. Air Force, "Use of Excess ICBM Motors for Commercial Space Launches" Special Notice, Solicitation Number ICBM (El Segundo, Calif.: Aug. 4, 2016). The Air Force released this request for information to gain industry perspectives on the potential effects of allowing surplus ICBM motors to be used for commercial launch. Questions in the request for information covered the potential impact on existing or planned U.S. commercial launch capabilities to meet national security requirements, the health of the launch industry, and potential methods for pricing and making motors available to commercial entities.

industry responses to the Air Force request for information to ascertain industry views on the implications of allowing the commercial use of surplus ICBM motors. Further details on our scope and methodology can be found in appendix I.

We conducted this performance audit from June 2016 to August 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Encouraging Competition and Launch Vehicle Development to Assure Access to Space

The U.S. government has sought to help develop a competitive launch industry from which it can acquire launch services in order to lower the price of space launch and assure its access to space.[7] The Air Force's Evolved Expendable Launch Vehicle (EELV) program is responsible for acquiring intermediate to heavy U.S. national security space launches for DOD and the intelligence community and has recently implemented a competitive strategy for acquiring launch services by allowing certified commercial providers to compete for certain national security launch opportunities.[8] DOD has historically relied on the EELV program's intermediate and heavy launch vehicles to place its national security satellites into desired orbits. These launch missions have typically taken 2-3 years from initial order to launch date. Additionally, DOD has been striving for over 10 years to develop launch systems that can deliver smaller payloads into orbit more quickly. For example, as we reported in 2015, the Air Force's Operationally Responsive Space office is one of several efforts underway to develop or demonstrate low-cost responsive

[7]Pub. L. No. 105-303 (1998) and the 2013 National Space Transportation Policy.

[8]Payloads on launches are generally distinguished by their weight, called a payload mass class. There is no widely accepted definition for mass class, in particular for small payloads that continually evolve with advances in technology. In this report, small payloads are those weighing approximately 1 to 1,200kg while medium payloads are those weighing from 1,201kg to 2,500kg. Intermediate, large, and heavy payloads are those weighing more than 2,500 kg.

launch capabilities for small to medium satellites.[9] The Operationally Responsive Space office uses ICBM motor-based launch vehicles, among others, to deliver quick-response space-based capabilities with small satellites.

NASA has also sought to acquire launch services from multiple providers to reduce launch costs and meet the needs of a diverse set of civil objectives. For example, in 2006, NASA started the Commercial Orbital Transportation Services program and provided several commercial companies funding under Space Act agreements to help develop and demonstrate cargo transport capabilities using commercial space transportation systems. NASA now uses commercial resupply services contracts to deliver cargo to the International Space Station.[10] Additionally, in an effort to facilitate private investment into small launch vehicles, in 2015, NASA awarded multiple Venture Class Launch Service contracts to provide access to low-Earth orbit for small satellites.[11] This effort is to demonstrate dedicated launch capabilities for small payloads that NASA anticipates it will require on a regular basis for future missions.

The U.S. government has also strived to encourage the growth of the commercial space launch industry by limiting government activities that might interfere with market forces. The 1994 National Space Transportation Policy and Fact Sheet stated that U.S. government agencies shall purchase commercially available U.S. space transportation products and services to the fullest extent feasible and generally prohibited the use of surplus ICBM motors for launch unless certain conditions were met.[12] According to Department of Commerce officials,

[9]GAO, *Space Acquisitions: GAO Assessment of DOD Responsive Launch Report*, GAO-16-156R (Washington, D.C.: Oct. 29, 2015).

[10]Pub. L. No. 85-568, § 203 (1958). This act is commonly referred to as the Space Act and agreements signed utilizing NASA's other transaction authority are known as Space Act agreements. These types of agreements are not considered procurement contracts, and are therefore generally not subject to those federal laws and regulations that apply to procurement contracts.

[11]Low-Earth orbit is the region of space up to an altitude of approximately 1,500 miles.

[12]These conditions included (1) the payload supports the sponsoring agency's mission; (2) the use of the motors is consistent with international obligations, including the Missile Technology Control Regime guidelines and the Strategic Arms Reduction Treaty (START) agreements; and, (3) The sponsoring agency must certify the use of surplus motors results in a cost savings to the U.S. government relative to the use of available commercial launch services that would also meet mission requirements, including performance, schedule, and risk.

this policy continued the generally agreed upon practice that has been in place since the early 1990s to prohibit the use of surplus ICBM motors for private purposes. The Commercial Space Act of 1998 prohibited the commercial use of surplus ICBM motors and directed government agencies to purchase and use commercial services with only limited exceptions. Further, the 2010 National Space Policy directs the government to develop government launch systems only when doing so is necessary to assure and sustain reliable and efficient access to space and there is no U.S. commercial system available. The 2010 policy also instructs agencies to refrain from conducting U.S. government space activities that preclude, discourage, or compete with U.S. commercial space activities, unless required by national security or public safety.[13] The 2013 National Space Transportation Policy directs agencies to foster and cultivate innovation and entrepreneurship in the U.S. commercial space transportation sector. Members of the Federal Aviation Administration Commercial Space Transportation Advisory Committee and other industry stakeholders have said that eliminating the prohibition on the commercial use of surplus ICBM motors may harm the commercial launch industry. Department of Transportation officials said that using surplus ICBM motors is not innovative and that these motors are old technology. In response to a House Armed Services Committee report to a bill for the NDAA for Fiscal Year 2017 and an associated House member request for detailed information on the costs and benefits, the Air Force is also studying the potential effects of changing law and policy to allow surplus ICBM motors to be used on commercial launches and expects to complete its study later this year. According to Air Force and DOD officials, if law and policy are changed to allow surplus ICBM motors to be used for commercial space launches, DOD plans to use the results of the Air Force study to make a recommendation as to how sales to commercial providers should be implemented.

Surplus Intercontinental Ballistic Missile Motors

According to the Air Force, it spends, on average, approximately $17 million each year on its stockpile of about 720 surplus ICBM motors. This amount includes the cost of storing the motors in bunkers, maintaining facilities and equipment, ensuring the motors are aging and being stored safely, and, as the budget allows, destroying and disposing of motors that can no longer be safely used. The majority of the stockpile is made up of surplus Peacekeeper and Minuteman II motors. According to the Air

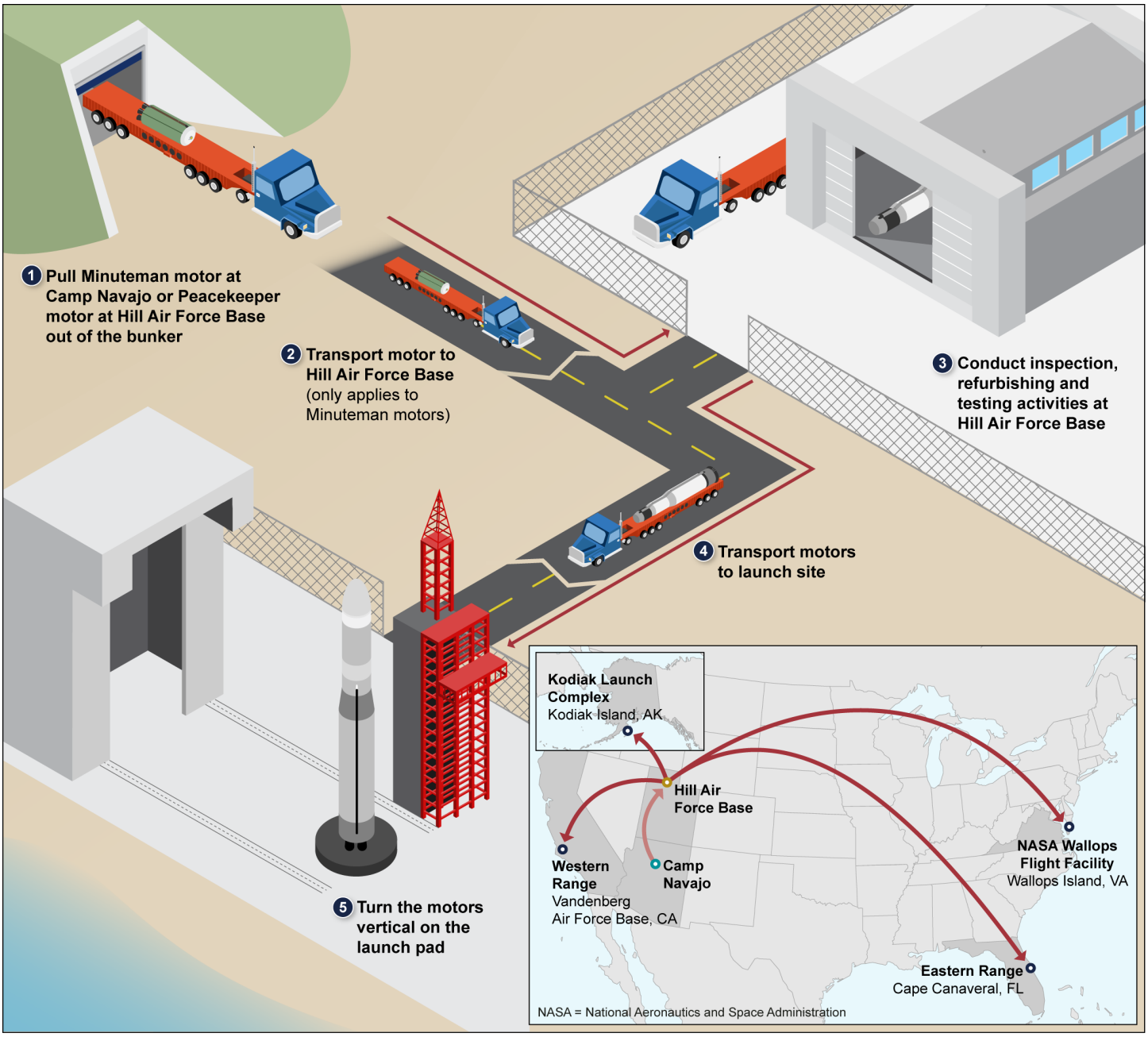
[13]National Space Policy of the United States of America,10, (June 28, 2010).

Force, these motors were designed to be used for active ICBM missiles but were placed into storage starting in the mid-1990s to early 2000s when they were no longer needed for nuclear deterrence. Newer systems came online and treaties—such as the Strategic Arms Reduction Treaty of 1991 and the New START of 2010—resulted in Arms control agreements with Russia (formerly the Soviet Union) that initiated the reduction of strategic force assets, including ICBMs, according to Department of State officials.[14]

The Air Force's Rocket Systems Launch Program (RSLP) oversees— at Camp Navajo, Arizona and Hill Air Force Base in Utah— storing, maintaining, testing, and preparing motors to support government launches. The program office is to conduct these activities in accordance with existing nuclear non-proliferation rules, including a requirement to maintain control over the motors at all times. Figure 1 is a notional depiction of the process to transfer a set of motors from a storage bunker to the launch site.

[14]In addition to the Minuteman II and Peacekeeper motors, DOD's surplus ICBM stockpile also includes other associated stages that are intended for weapon delivery but not for space launches. Minuteman III higher stage motors are also in storage. However, according to officials at the Department of State, these motors are still covered by New START. Surplus ICBM motors are stored in bunkers at Camp Navajo, Arizona and Hill Air Force Base, Utah. Minuteman II and III motors were originally manufactured in the 1960s while Peacekeeper motors were manufactured in the 1980s.

Figure 1: Notional Depiction of Transfer Process from Bunker to Launch Site



Source: GAO analysis of Rocket System Launch Program office data (data and images); MapResources (map). | GAO-17-609

A set of Peacekeeper or Minuteman II motors provides lower stage propulsion for ICBM motor-based launch vehicles. Peacekeeper motors typically are grouped in sets of three while Minuteman II motors are grouped in sets of two. To prepare motors for launch, the RSLP office first selects a suitable set of motors based on the type of launch vehicle and the payload capability needs of missions. Officials then use specialized equipment and facilities at Hill Air Force Base to refurbish the motors for flight before transporting them to the launch site. The launch service provider then integrates the higher stages, control section, fairing, and payload onto the motor stack.

According to RSLP officials, they also monitor the stockpile of motors for those that can no longer be used for launch because of cracks in the propellant, discoloration and smell, or other issues related to age and condition. The RSLP office destroys non-operational motors, as its budget allows after it has funded all other motor-related activities, either through static fire, by exploding the motors, or by contracting to have the propellant—ammonium perchlorate—removed and the motor casings buried or cut up and sold for scrap. Since 2011, the RSLP office has destroyed 369 Minuteman II motors, but it has not yet destroyed any Peacekeeper motors because they are relatively new motors and have not yet displayed signs of aging.

Current ICBM Motor-based Launch Vehicles

The main government customers of ICBM motor-based launch vehicles are within DOD—including the Air Force, Defense Advanced Research Projects Agency, Missile Defense Agency, and National Reconnaissance Office.[15] Currently, Orbital ATK is the sole U.S. provider of ICBM motor-based space launch vehicles, of which there are two basic configurations:

- The Minotaur I, first launched in 2000, uses two surplus Minuteman II motors for its first and second propulsion stages and uses two or three new solid rocket motors for higher-stage propulsion. This vehicle is capable of launching small payloads, such as cube satellites and other technology development efforts that weigh up to about 500 kilograms (kg). Since 2000, there have been 11 space launches using this vehicle.

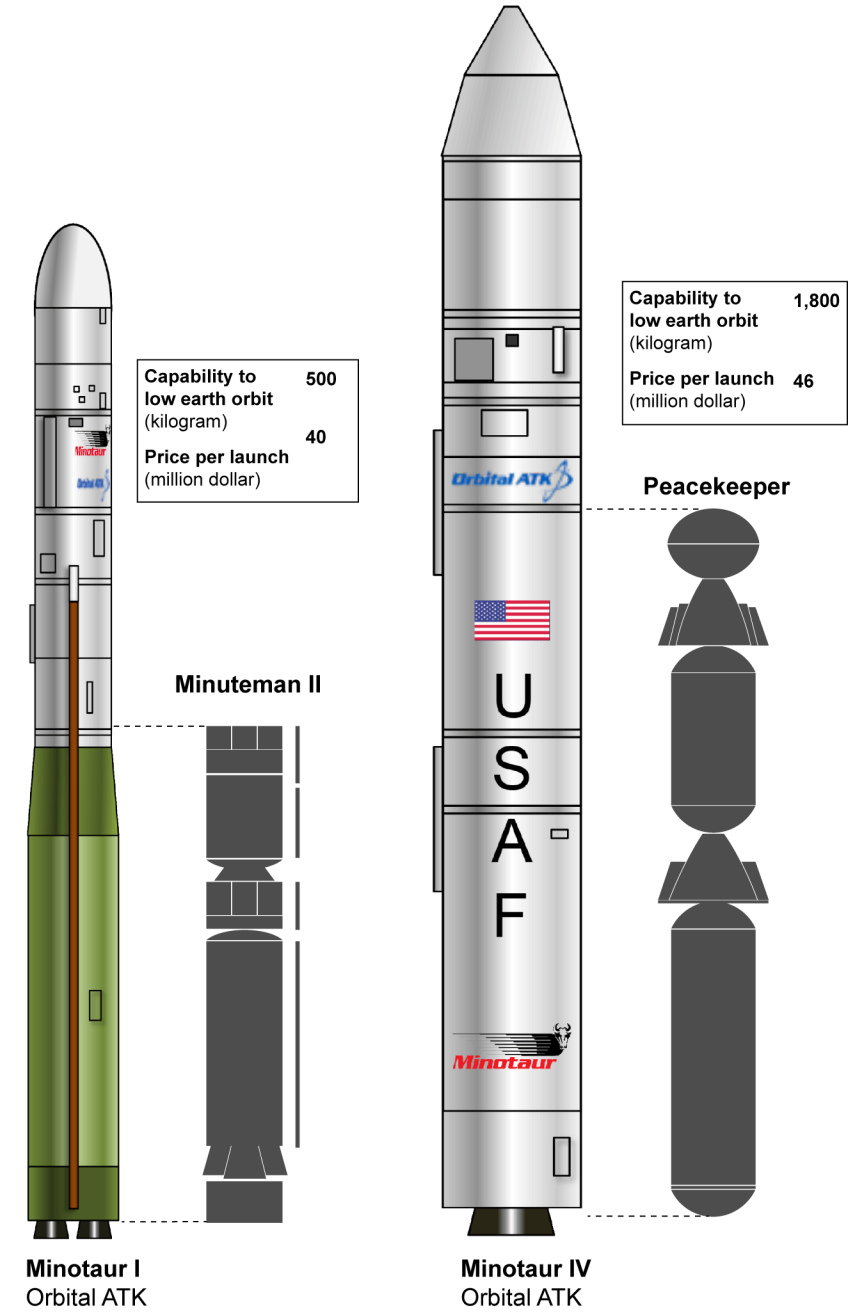
[15]NASA used a Minotaur V launch vehicle to deliver one mission in 2013. According to NASA, the use of this launch vehicle was in compliance with law and policy, under the exception that no cost effective U.S. commercial capability that met mission requirements was reasonably available when needed.

- The Minotaur IV, first launched in 2010, uses three Peacekeeper motors for first, second, and third stage propulsion and one to two new solid rocket motors for higher-stage propulsion. This vehicle is capable of launching medium payloads, such as space surveillance and other earth observation satellites that range from about 500kg to 2000kg.[16] Since 2010, there have been 3 space launches using this vehicle.

Figure 2 shows the maximum payload weight capabilities and launch costs for these two launch vehicles.

[16]Orbital ATK has other designs of ICBM motor-based launch vehicles using up to four surplus Peacekeeper motors for lower stage propulsion. However, some of them have not been flown yet.

Figure 2: Surplus Intercontinental Ballistic Motor-Based Launch Vehicles



Source: GAO depiction of launch provider and Air Force data. | GAO-17-609

Global Launch Vehicles, Commercial Demand, and Launch Prices

Well-established and new, start-up satellite companies are expected to drive demand for launch in the low- and medium-weight payload classes over the next 10-15 years, according to the FAA. For example, according to the FAA's 2017 Annual Compendium on Commercial Space Transportation, the average number of international commercial launches going to non-geosynchronous orbits, including the subset of low Earth orbits expected to be served by new commercial small launch vehicles, will grow from 7 launches per year over the last 10 years to 21 launches per year for the next 10 years.[17] While about 70 percent of those launches will launch on medium to heavy capability launch vehicles, according to the FAA, companies launching new Earth observation constellations plan to use commercial small launch vehicles currently in development to launch about 30 percent of forecasted launches.[18] In 2016 there were 85 global satellite launches, 21 of which were considered commercial and, of these commercial launches, U.S. providers performed 11.[19] Currently, there is only one U.S.-based commercial launch vehicle—Orbital ATK's Pegasus XL—that can provide dedicated launch for small satellites.[20] Other options for access to space for small payloads include launching as a secondary payload on a larger launch vehicle, aggregating them with other small payloads on a larger launch vehicle, or launching aboard foreign launch vehicles. Existing global launch vehicles and prices are presented in appendix II.

In recent years, a number of companies have begun to develop small launch vehicles to support what they expect to be an increase in demand for small, dedicated commercial payload launches. According to Department of Commerce officials, the emergence of new small launch

[17]Geosynchronous Earth orbit (GEO) is a broad category used for any circular orbit at an altitude of 35,852 km with a low inclination (i.e., near or on the equator). Non-geosynchronous Earth orbit satellites are those in orbits other than GEO, such as satellites located in low Earth orbit, medium Earth orbit, or Sun Synchronous Orbit.

[18]Federal Aviation Administration, Office of Commercial Space Transportation, *The Annual Compendium of Commercial Space Transportation: 2017*, (Washington, D.C.: January 2017). According to the FAA, the forecast is a projection of market demand and not a prediction of how many launches will actually occur.

[19]Commercial launches are those that are open to international competition or licensed by the FAA.

[20]However, Rocket Lab USA's Electron launch vehicle and Virgin Galactic's LauncherOne are to conduct their demonstration launches under NASA's Venture Class Launch System effort in calendar year 2018. According to the FAA, the majority of the estimated 2,390 payloads will launch on medium to heavy capability launch vehicles.

vehicles is mainly the result of investment and technology development in the United States. Entrepreneurs have announced plans to launch multi-satellite broadband constellations to provide Internet access in remote regions of the Earth. These constellations consist of hundreds to thousands of satellites, in some cases weighing between 100 to 200 kilograms each. Although the FAA expects nearly 1,500 commercial remote sensing satellites to drive launch demand through 2026, in most cases they will be launched as secondary payloads. According to the FAA however, this may change as new small launch vehicles become available over the next few years. Several emerging providers began conducting test flights in 2017 and some plan to begin carrying commercial payloads in 2018. These providers plan to launch individual small satellites at a high rate in order to keep prices low.[21] However, launch demand is historically difficult to predict in the non-geosynchronous orbit market, as many of the companies driving this forecasted demand are new and their business plans have yet to be proven.

Options for Determining the Selling Prices for Surplus ICBM Motors

Several methodologies could be used to determine the sales prices of surplus ICBM motors. The price at which surplus ICBM motors are sold is an important factor for determining the extent of potential benefits and challenges of allowing the motors to be used for commercial launch. The pricing methodology that we used in our analysis was to determine breakeven prices—that is, prices at which DOD could sell the motors and "breakeven" with, or recuperate, the costs it incurs to transfer them, while discounting from that price any potential savings DOD could achieve by avoiding future storage and disposal costs. However, the breakeven price is just one of several methods that DOD could use to set the sales prices of surplus ICBM motors. For example, industry stakeholders, in response to the Air Force's request for information, provided written input to the Air Force stating that the sales prices should be based on methods for determining the value of an asset in the FASAB Handbook, such as the

[21]See appendix II for a list of existing commercial launch vehicles and emerging launch provider vehicles.

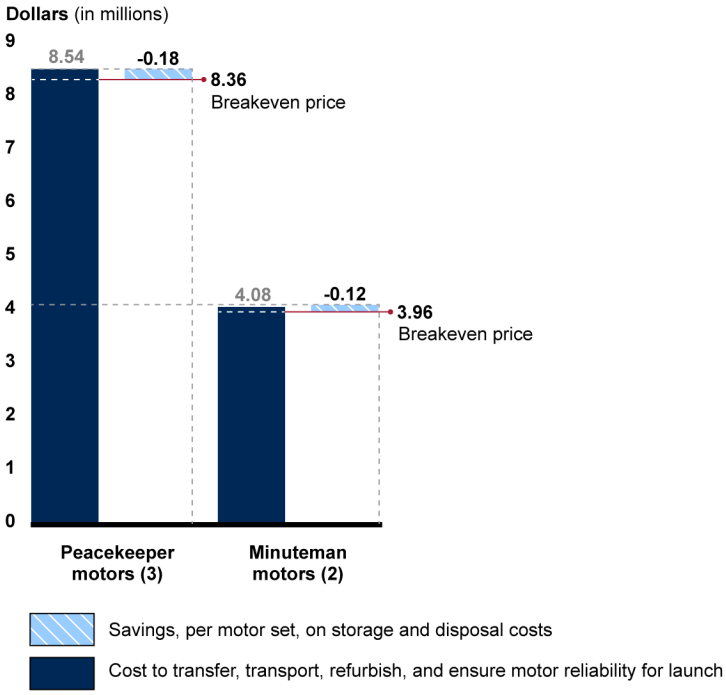
fair market values or prices of comparable new commercially available motors.[22]

Breakeven Price Analysis

The breakeven price is the price at which DOD could sell surplus ICBM motors, recuperate the costs to transfer the motors for launch, and account for savings from avoiding storage and disposal costs had the motors not been used for space launch. Below this price, DOD would not recuperate its costs, and, above this price, DOD would potentially achieve savings. We estimated that DOD could sell three Peacekeeper motors or two Minuteman II motors—the numbers required for one launch—at a breakeven price of about $8.36 million or $3.96 million, respectively. Figure 3 shows the estimated price points per motor set at which DOD could lose money, breakeven with its motor transfer costs, or achieve savings; based on our launch demand, storage cost, and disposal plan assumptions.

[22]The Federal Accounting Standards Advisory Board (FASAB) Handbook defines five methods for calculating the value of assets, including: (1) Fulfillment Cost; (2) Fair Value (Fair Market Value); (3) Replacement Cost; (4) Value in Use; and (5) Settlement Amount. See, FASAB Handbook Statement of Federal Accounting Standards 48: Opening Balances, SFFAS48, version 15 (June 2016); see also, Statement of Federal Financial Accounting Concepts 7: *Measurement of the Elements of Accrual-Basis Financial Statements in Periods After Initial Recording*.

Figure 3: Estimated per Motor Set Breakeven Price after Storage and Disposal Cost Avoidance Discount



Source: GAO analysis of Department of Defense data. | GAO-17-609

Table 1 provides a more detailed breakdown of how we calculated the breakeven prices.

Table 1: Surplus Intercontinental Ballistic Missile Motor Breakeven Prices

Peacekeeper motors		**Costs and savings**[b]
Operationally Responsive Space-5 transfer cost total (dollars)		$8,539,000
Reliability of Flight	4,454,000	
Motor Refurbishment	838,000	
Motor Transportation	1,291,000	
Other Mission Costs[a]	1,956,000	
Storage and disposal savings per launch		-183,000
Peacekeeper breakeven price per launch		**8,356,000**
Minuteman II motors		**Costs and savings**

Operationally Responsive Space- 3 transfer cost total		$4,079,000
Reliability of Flight	1,656,000	
Motor Refurbishment	456,000	
Motor Transportation	127,000	
Other Mission Costs	1,840,000	
Storage and disposal savings per launch		-116,000
Minuteman breakeven price per launch		**3,963,000**

Source: GAO analysis of Department of Defense storage and disposal data. | GAO-17-609

[a]Other mission costs include mission assurance, program management administration costs, and costs associated with Hill Air Force Base and launch site personnel.

[b]Numbers may not be exact due to rounding. This table presents a medium launch rate. The medium launch rate represents three government and two commercial launches per year using the surplus ICBM motors.

The RSLP office incurs costs each year to store, dispose of, and transfer motors for launch, which it could recuperate if it sold motors at a breakeven price:

- **Motor Transfer:** We found that the cost of transferring motors (transfer costs) ranges from approximately $4.1 million to $8.5 million, depending on the motors used and other mission details. [23] According to the RSLP office, transfer costs vary from mission to mission depending on the number and type of motors required, the location of the launch site, and other factors. Transfer costs include ensuring that the motors will be reliable for launch, refurbishment to ensure flightworthiness, transportation between the motor storage facility and the launch site, and other mission costs. According to DOD, it spends approximately $4.5 million per Peacekeeper motor set and $1.7 million per Minuteman II motor set to ensure that the motors will be reliable during flight—referred to as Reliability of Flight. This involves static fire testing to assess how well the motors are aging.[24]

[23]The cost to prepare motors for launch is based on a recent and upcoming mission – the ORS-3 launch, which used two Minuteman II motors for its 2013 launch and the ORS-5 launch, which will use three Peacekeeper motors and is planned for 2017.

[24]Safety of Storage costs of about $2.8 million per year are a part of DOD's Aging and Surveillance program. We did not consider these costs in our breakeven price analysis because they are fixed, relatively small, and it is unclear at what point DOD could start seeing savings

Additionally, DOD is responsible for restoring motors to flightworthy status (known as "refurbishment") and this must be completed on the motors before they are transferred to the launch site. Refurbishment costs per launch are roughly $840,000 for a set of 3 Peacekeeper motors to $460,000 for a set of 2 Minuteman II motors. Transportation costs are approximately $1.3 million per Peacekeeper motor set and approximately $130,000 per Minuteman II motor set. Other mission specific costs that are included in the cost to transfer the motors include those for activities such as mission assurance, program management, and facilities and civilian salaries at Hill Air Force Base.

- **Motor Storage and Disposal:** We found DOD spends about $5.8 million to store Minuteman II motors and $2 million to store Peacekeeper motors each year. Motors are stored under environmentally controlled conditions at Hill Air Force Base in Utah and Camp Navajo in Arizona until required for use. It costs DOD approximately $317,000 to dispose of a set of Peacekeeper motors and approximately $105,000 to dispose of a set of Minuteman II motors. The Air Force avoids annual storage and disposal costs over time as the motor stockpile is depleted at about $183,000 per Peacekeeper motor set and about $116,000 per Minuteman II motor set, which is reflected in the breakeven price as savings. The number of expected future launches affects potential storage and disposal cost savings to DOD because if more motors are used—either through launch or disposal, the bunkers in which the motors are stored are emptied more quickly. We estimated that under the current government only scenario, the stockpile of Peacekeeper motors would be depleted in 13-22 years and the Minuteman II motors in 9-10 years. Under a scenario in which motors are also used for commercial launches, Peacekeeper motors may be depleted more quickly—in 11-13 years. The stockpile of Minuteman II motors is depleted in 9 years under a commercial scenario as well because the number of motors that are disposed of each year is relatively high compared to the number of motors that could be used for government and commercial launches.

Our breakeven price calculations rely on assumptions and estimates—based on information we received from the RSLP office—for factors such as future launch demand, transfer costs, disposal costs and schedules, and the specific transfer activities for which the Air Force would be responsible.[25] Differing assumptions would likely cause the breakeven

[25]A detailed description and list of our assumptions and methodology is provided in appendix I.

prices to change. For example, if launch demand is much lower or higher than current assumptions, consequent changes to storage and disposal costs would affect savings estimates. Additionally, if some motor transfer activities the Air Force currently conducts, such as transporting the motors to the launch site, are instead performed by the companies that purchase the motors, breakeven prices could decrease. As the Air Force seeks to complete its study and determine a price at which it could sell surplus ICBM motors, the assumptions it makes about costs and future launch demand could significantly change the price points of the motors.

Options for Pricing Surplus ICBM Motors Varied across Industry Stakeholders

In addition to breakeven pricing methodology, there are additional options available for determining sales prices for surplus ICBM motors. In response to the Air Force's August 2016 request for information, industry stakeholders proposed that the Air Force use various options for valuing the motors, which resulted in prices ranging from $1.3 million for a set of Peacekeeper motors to $11.2 million for a Peacekeeper first stage motor.[26] These options included basing the price on the comparable selling price of existing equivalent motors and using the price at which current buyers are willing to purchase the motors. Five respondents out of 16 proposed prices for Peacekeeper motors. For example, one respondent suggested $11.2 million for a first stage Peacekeeper motor, stating that Peacekeeper motors should be based on the comparable selling price of existing and comparable new solid rocket motors. This respondent pointed to a provision in the FASAB guidance that states that the fair value of an asset or liability may be measured at the market value in established markets, such as for those of certain investments or debt securities, or it may be estimated when there is no active market. As such, this respondent stated in both its response and during an interview with us that there is an active market for the Castor 120 motor—the commercial equivalent of the Peacekeeper ICBM motor—that can be used to value the Peacekeeper motor. This respondent estimated the current fair market value for a Castor 120 motors at about $11.2 million as of August 2016. One respondent said that the selling price of the motors should reflect some or all of the historical storage and disposal costs

[26]Industry stakeholders represent Request for Information (RFI) respondents from DOD's August 2016 request for information asking for industry perspective on the potential effects of allowing surplus ICBM motors to be used for commercial launch. Of the 16 RFI stakeholder respondents, 12 opposed, three were in favor, and one respondent showed neutrality toward a potential change in policy regarding the sale of surplus ICBM motors for commercial use.

incurred from the time the motors were determined to no longer be needed for active nuclear deterrence until present day.[27]

One respondent suggested that DOD should sell a set of three Peacekeeper motors for about $1.3 million. According to this respondent, the motors are not an asset that should be sold at a high price, but rather a liability that requires funds to support storage, security, safe handling, and ultimately require an expensive disposal process. This respondent stated that fair value of the motors is the price at which current buyers are willing to purchase the motors.[28] However, officials at the Department of Commerce with expertise on international trade and the commercial space launch industry stated that selling a motor to a purchaser for less than a price that covers the motor's costs and expenses could result in a subsidy to the purchaser, which may violate U.S. international trade obligations.[29]

Potential Benefits and Challenges of Selling Surplus ICBM Motors for Commercial Launch

Based on our analysis of the potential effects of selling surplus ICBM motors to launch providers for commercial launches, there are both benefits and challenges. Allowing U.S. companies to use surplus ICBM motors for commercial space launch could benefit the U.S. commercial launch sector by increasing the global competitiveness of U.S. launch services, providing U.S.-based launch customers more launch options and greater flexibility, and increasing demand for newly-manufactured solid rocket motors. DOD may also benefit through increased opportunities to utilize its personnel with specialized motor handling skills and offset some of the fixed costs to maintain the safety of the motors if

[27]One RFI respondent suggested the price range of a set of Peacekeeper motors from $58.5 million to $60.3 million. This range was based on several assumptions, such as the surplus motors being decommissioned in 2005 and 13 years of accounting for aging and surveillance costs for a 2018 mission, for a total of $58.5 million. In adding refurbishment and paint costs, the respondent estimated a total price of $60.3 million. This estimated price was outside of the range of the other respondents.

[28]The Statement of Federal Financial Accounting Standards 48 states that the fair value is the amount at which an asset or liability could be exchanged in a current transaction between willing parties, other than in a forced or liquidation sale.

[29]The World Trade Organization overview of the Agreement on Subsidies and Countervailing Measures (SCM Agreement) provides that the agreement generally addresses multilateral disciplines regulating the provision of subsidies, and the use of countervailing measure to offset injury caused by subsidized imports. These rules are enforced through invocation of the World Trade Organization dispute settlement mechanism.

commercial launches drive an overall increase in launch demand. However, the commercial use of surplus ICBM motors could create challenges, such as discouraging private investment and disrupting competition among emerging commercial space launch companies. Moreover, DOD may encounter challenges balancing an expanded workload with its other essential missions and tasks and determining the price of the motors. Furthermore, additional analysis is important to address several unknowns, such as whether or not a potential commercial provider could take control of the motors earlier on in the process or how, if at all, the RSLP office may be affected if demand for surplus ICBM motor-based launch vehicles is different than expected. Because the use of surplus ICBM motors for commercial launches may create competition for existing and emerging commercial space launch providers, the degree to which these benefits and challenges are realized largely depends on price at which DOD sells the motors. Specifically, the effects are likely to be more significant if DOD sells the motors at a price that allows one or a small number of providers to offer launch services at prices lower than those of existing and emerging commercial launch providers.

Commercial Use of ICBM Motors Has Several Potential Benefits

Increased Launch Capability, Competitiveness, and Flexibility

Allowing the use of surplus ICBM motors for commercial space launch could increase domestic launch capability to low-Earth orbit and the global competitiveness of U.S. launch companies. Additionally, ICBM motor-based vehicles could provide launch customers with more options from which to choose launch services as well as greater schedule flexibility. Since 2014, U.S. companies have captured a greater share of the global launch market through, in part, the introduction of new large payload launch vehicles. Currently, however, domestic commercially available launch vehicles in the small to medium payload launch capability cost more per kilogram of payload than similar options from foreign launch providers. Per kilogram launch prices, as shown in table 2, are estimates based on publicly available information. According to Department of Transportation officials, the price a launch customer ultimately pays depends on a range of factors, including mission

objectives and market conditions. Launch prices may also differ between primary and secondary payloads.[30]

Table 2: Current Small to Medium Commercial Launch Vehicle Providers Capability and Price

Launch vehicle name	Operator	Total launch cost (million dollars)	Range of capability to low-Earth orbit (kilogram)	Range of price per kilogram (dollars)
Domestic launch provider				
Minotaur-C	Orbital ATK	40-50	1,278-1,458	31,299-34,294
Pegasus XL	Orbital ATK	40	450	88,889
Foreign launch provider				
Dnepr	ISC Kosmotras	29	3,200	9,063
Epsilon	Japan Aerospace Exploration Agency	39	700-1,200	32,500
Polar Satellite Launch Vehicle	India Space Research Organization/Antrix	21-31	3,250	6,462-9,538
Rockot	Eurockot	41.8	1,820-2,150	19,442-22,976
Soyuz 2	Arianespace	80	4,850	16,495
Vega	Arianespace	37	1,963	18,849

Source: GAO analysis of Federal Aviation Administration data. | GAO-17-609

According to DOD, since fiscal year 2006, foreign launch providers have aggregated about 100 U.S.-manufactured payloads that could have been launched by a U.S. launch vehicle. It is not clear how many ICBM-based commercial launches would have been needed to serve these 100 payloads, as approximately 90 percent of them were 150 kg or less and thus were likely aggregated to varying degrees on a medium or large launch vehicle.[31] However, the benefit of increasing U.S. launch service global competitiveness as a result of allowing commercial use of surplus

[30]As we found in 2016, the European Union, Russia, India, Japan, China, and the United States have operational space capabilities for launching civil, government, military, and commercial payloads. Foreign launch providers generally receive some support from their respective governments through provision of launch vehicle research and development funding, direct payments to cover launch system operating costs, government-provided infrastructure, government ownership, government as a customer, or indemnity insurance. GAO, *Evolved Expendable Launch Vehicle*, GAO-16-661R (Washington, D.C.: July 22, 2016).

[31]Of the remaining 10 percent, about 8 percent (8 of 97) of these payloads were in the 400kg to 1000kg range, while 2 percent of launches were in the 1000kg to 1800kg range and thus would be more likely to launch as a primary or single payload.

ICBM motors may be limited. According to the FAA, domestic launch capability may soon become more robust and competitive because of the emergence of new space launch providers and vehicles. Specifically, several U.S. companies developing launch vehicles and related technologies to provide low- and medium-weight payload launch capabilities began conducting test flights in 2017 and some plan to begin carrying commercial payloads as early as next year. Table 17 in appendix II provides a list of emerging launch vehicle providers.

Allowing the use of surplus ICBM motors for commercial launches could further benefit the commercial space sector by providing U.S.-based launch customers more options and flexibility from which to choose launch services. As we reported in July 2016, customers select from available launch providers based on a number of factors, including price, capability, and reliability of the launch vehicle.[32] Another factor that customers consider is the location of the launch. Some satellite manufacturers and other potential customers of launch services we interviewed said they prefer a domestic provider and may be willing to pay a higher price for a domestic launch depending on factors such as lower licensing costs and simpler, lower-cost logistics.

Increasing the domestic launch capability could also help launch customers gain greater schedule certainty. Specifically, launch customers may have stringent schedule requirements and must select a launch vehicle that will deliver their payload to the desired orbit. According to several experts we interviewed, customers with smaller payloads often choose to launch as a secondary or aggregated payload on a larger launch vehicle. They said that this likely reduces the customer's costs, since aggregated payload customers share launch costs, but it may also create schedule uncertainty. For example, customers who choose to aggregate their payload with others may not be able to determine the planned launch date, which may then be delayed if one or more of the other aggregated payloads are not ready in time. In contrast, as a sole or primary payload, the customer typically has more control over the launch schedule. However, there are indications that the domestic launch market is already responding to this type of customer demand. Several emerging space launch providers we spoke with said providing customers greater schedule flexibility is a key component of their business strategy and an

[32]GAO-16-661R

important factor that distinguishes them from many existing launch providers.

Increased Demand for Newly Manufactured Solid Rocket Motors

The use of surplus ICBM motors for commercial space launches could provide the U.S. solid rocket motor industrial base a limited benefit by increasing demand for newly manufactured solid rocket motors, helping ensure that these assets remain available to support government space launches and other missions.[33] As we have reported in the past, Congress and DOD have identified the health of the solid rocket motor industrial base as an area of concern.[34] According to Institute for Defense Analyses research, there were six U.S. solid rocket motor suppliers in the mid-1990s, but these six are now consolidated into two remaining entities—Aerojet Rocketdyne and Orbital ATK.[35] These manufacturers are dependent on a single U.S. company to provide the main ingredient for the solid rocket motor propellant, ammonium perchlorate.[36]

In recent years, demand for solid rocket motor fuel has dropped because, among other things, NASA retired its Space Shuttle program in 2011, which historically comprised most of the demand for solid rocket motors. According to the Institute for Defense Analyses, the Space Shuttle program was responsible for as much as 90 percent or more of the total U.S. demand for large solid rocket motor propellant from 1990 to 2010.[37] However, the Institute reported that since the end of the Space Shuttle program, annual demand for solid rocket motor propellant has dropped from more than 20 million pounds to about 5 million pounds and is

[33]In addition to space launch, DOD's 2009 *Solid Rocket Motor Industrial Capabilities Report* states that solid rocket motors are required for strategic, missile defense, and other tactical systems. The report also notes that the government uses surplus ballistic missile assets, including solid rocket motors, for target vehicles and to support technology demonstration flights, among other things. Department of Defense, Office of the Under Secretary of Defense for Acquisition, Technology & Logistics, Industrial Policy, *SRM Industrial Capabilities Report to Congress, Redacted Version* (June 2009).

[34]GAO, *Evolved Expendable Launch Vehicle: DOD Is Addressing Knowledge Gaps in Its New Acquisition Strategy*, GAO-12-822 (Washington, D.C.: July 26, 2012).

[35]Brian Gladstone, Brandon Gould, and Prashant Patel, "Evaluating Solid Rocket Motor Industrial Base Consolidation Scenarios*", Institute for Defense Analyses: Research Notes* (Spring 2016).

[36]Some foreign companies also produce ammonium perchlorate, but American Pacific, a U.S. corporation, is the only company certified to provide ammonium perchlorate for government launches.

[37]Gladstone, Gould, and Patel, "Evaluating Solid Rocket Motor Industrial Base," 27.

expected to drop further, creating excess capacity throughout the solid rocket motor industrial base. Since at least 2009, DOD has identified the solid rocket motor industrial base as being particularly risky for programs that require solid rocket motors because decreased production has made the remaining two solid rocket motor suppliers even more vulnerable, among other things. However, according to NASA officials, they expect demand for solid rocket motor propellant to increase in the future as their Space Launch System becomes operational. Each Space Launch System launch requires two solid rocket motors that each contains approximately one million pounds of propellant, for a total usage of two million pounds per launch.

Increased use of surplus ICBM motors for commercial or government launch could provide a limited benefit to the solid rocket motor industrial base through greater use of manufacturing equipment, personnel, and processes. Due to differences in design and payload delivery, surplus ICBM motors cannot be used for higher stage propulsion on space launch vehicles. As a result, the use of an ICBM motor-based launch vehicle creates demand for one or more newly manufactured higher stage solid rocket motors. For example, the Minotaur I and Minotaur IV launch vehicles require one to two newly manufactured higher stage solid rocket motors. However, the commercial use of surplus ICBM motors, in comparison to historical demand from NASA and other government missions, is likely to have a limited benefit on the solid rocket motor industrial base. For example, the two higher stages of a Minotaur I or the single higher stage of a Minotaur IV use 10,362 and 1,698 pounds of propellant, respectively. In comparison, each of the two reusable solid rocket motors that launched the final version of NASA's Space Shuttle burned about 1.1 million pounds of propellant. At most, depending on the type of launch vehicle, the use of surplus ICBM motors for commercial launch would create demand for two to four newly manufactured higher stage solid rocket motors and roughly 3,400-20,700 pounds of propellant.

Increased Opportunities for DOD Personnel with Specialized Skills

Greater use of surplus ICBM motor-based launch vehicles could support U.S. efforts to assure its access to space by increasing opportunities for DOD personnel to utilize specialized skills. Air Force officials told us that increased use of surplus ICBM motors, whether for government or commercial launch, would provide program personnel beneficial opportunities to exercise specialized skills, including those for handling, transferring, and modifying surplus ICBM assets. DOD and Air Force officials we spoke with said that a consistent launch rate is an important factor in helping maintain these specialized skills. Since 2000, the government has used ICBM motor-based launch vehicles 15 times in

support of a variety of space launch missions; however, the launch pace has declined.[38] For example, from 2000 to 2011, the Air Force launched 13 space missions using ICBM motor-based launch vehicles. From 2012 to present, the Air Force launched 2 space missions and plans to launch 1 mission each year in 2017 and 2018. One of these planned launches includes the Operationally Responsive Space-5 mission planned for August 2017. If government launch demand continues at a rate of one to two launches per year or declines further, commercial launches using surplus ICBM motors would provide additional opportunities for DOD to employ skilled personnel. However, Air Force officials recently told us that there are indications of additional government demand for launches using surplus ICBM motors beginning around 2020 that could increase the launch rate to two to three per year (an increase that would require processing two to six additional motors).

Potential Cost Avoidance for DOD

The use of ICBM motors for commercial launches could provide a benefit to DOD by offsetting some of the roughly $17 million DOD spends each year storing, maintaining, and destroying surplus ICBM motors. DOD incurs additional costs for refurbishing and ensuring the flightworthiness of motors selected for space launch. These costs are reimbursed by the government customer and vary by mission. Currently, the cost to ensure the safety of motors in storage—approximately $2.8 million for Peacekeeper and Minuteman II motors—is divided among government launch customers. According to the Air Force, allowing commercial launch providers to purchase and use surplus ICBM motors would further disperse these costs, slightly lowering launch costs to the government. However, the cost of storing surplus ICBM motors in bunkers cannot be directly apportioned to each motor and DOD would achieve savings only over many years. Specifically, RSLP office officials told us that they typically group surplus motors according to stage and store them as a set of six or more in bunkers. Therefore, to achieve a meaningful reduction in storage costs, they said that DOD would need to eliminate the inventory of an entire bunker of similar motors. For example, clearing a single bunker of six first stage motors would require six separate space launches.

[38]These missions include testing and technology development for launching NASA and DOD cube satellites and other small to medium satellites.

Commercial Use of ICBM Motors Has Several Potential Challenges

Decline in Private Investment Opportunities for Commercial Launch Providers

Allowing the use of surplus ICBM motors for commercial launch could create challenges for the commercial space sector, such as discouraging private investment for emerging commercial space companies currently developing launch vehicles. Investment in new commercial space companies has grown significantly in recent years and this trend appears to be accelerating. From 2000 through 2015, new commercial space companies received about $13.3 billion in investments, including debt financing, and approximately 20 percent of that total investment came in 2015, the most recent year for which data are available.[39] Officials from several commercial space launch companies, both existing and emerging, we spoke with cited these levels of increased investment as evidence that validates current law and policy that limit the use of surplus ICBM motors to special circumstances. Several commercial launch providers and an organization representing several hundred investors in commercial space companies told us that allowing the use of surplus ICBM motors for commercial launches would add uncertainty to the commercial space market, complicating their business decisions. According to the Tauri Group, which gathers data and conducts analyses for several federal agencies, investors in commercial space companies consider the potential demand for a company's product or service when deciding whether to make an investment. Representatives from the Tauri Group and an emerging launch provider told us that changing law and policy to allow the commercial use of surplus ICBM motors could also discourage investment by signaling to companies and investors that the government may intervene in the market in the future. NASA officials said that allowing the use of these motors may stifle innovation in the commercial space sector. They told us that emerging small launch providers are basing their business cases on making innovations in manufacturing and design of liquid rocket engines and that if emerging launch providers fail due to market pressures caused by the use of surplus ICBM motor-based launch vehicles, innovation in propulsion may be stifled.

[39]The Tauri Group, *Start Up Space: Rising Investment in Commercial Space Ventures* (Alexandria, Va: 2016). According to the Tauri Group, these new commercial space companies include launch vehicle providers as well as satellite, ground equipment, and other space-based system manufacturers.

Disruption of Competition Opportunities for Emerging Launch Providers

Allowing the use of surplus ICBM motors for commercial launches could disrupt competition among emerging providers. Several respondents to the Air Force's August 2016 request for information stated that the availability of surplus ICBM motors may erect unfair barriers to entry in the space launch market and discourage investment in new space launch vehicles. We found that the price for a launch using surplus ICBM motors—assuming the motors are available to commercial customers at a breakeven price roughly equal to DOD's costs to prepare the ICBM motors for launch—would be about $27,000 per kilogram of payload for Peacekeeper motor-based vehicles and about $71,000 per kilogram for Minuteman II motor-based vehicles.[40] These estimates assume the launch vehicles are at full capability. Although the actual price of a launch varies based on several factors, including the providers' strategies for increasing their share of the launch market, these price estimates may be useful in illustrating how the potential prices of a surplus ICBM motor-based launch vehicles might compare with those of existing and emerging providers.[41] Table 3 presents the price per kilogram for a Peacekeeper-based and Minuteman II-based launch vehicle.

Table 3: ICBM Motor-based Launch Vehicle Cost per Kilogram (kg)

Type of launch vehicle	Breakeven price for ICBM motors (million dollars)	Commercial higher stage motor(s) cost (million dollars)	Total propulsion cost (million dollars)	Estimated total launch cost (million dollars)	Full capability launch price per kilogram (dollars)[a]
Peacekeeper-based vehicle	8.4	1.2	9.6	47.8	27,000
Minuteman II-based vehicle	4.0	3.1	7.1	35.3	71,000

Source: GAO analysis of Department of Defense cost information. | GAO-17-609

Notes: Numbers may not be exact due to rounding.

[a]Estimated total launch cost assumes that the price ratio for total propulsion cost and total launch cost for ICBM motor-based launch vehicles will roughly match historical averages of about 20 percent of total launch cost for other types of launch vehicles.

The price per payload kilogram for a launch using Peacekeeper based launch vehicle is in a similar range with the planned future launch prices for emerging launch vehicle providers. Emerging providers developing launch vehicles with capability between 1 kilogram and 2,000 kilograms

[40]These price estimates assume that the price ratio for propulsion and total launch for ICBM motor-based launch vehicles will roughly match historical averages of about 20 percent of total launch cost for other launch vehicles. For more information, see appendix I.

[41]For detailed analysis and assumptions, see appendix I.

are estimating their launch prices to be between about $10,000 and $55,000 per payload kilogram.[42] Among these emerging providers, several estimate their launch prices will be between $20,000 and $30,000 per kilogram. Many of the emerging providers are designing small launch vehicles to provide dedicated launch services. However, one company we spoke with plans to start with a small launch vehicle but eventually offer launches for medium payloads on new, non-ICBM motor-based vehicles at capabilities close to a Peacekeeper motor-based vehicle. As satellite manufacturers examine the launch vehicle market from which they will choose a launch, they may choose the slightly lower priced ICBM motor-based vehicle to aggregate multiple small satellites on one launch vehicle at its highest capability. Conversely, the sale of surplus ICBM motors at the breakeven price for the surplus motors and the cost of higher stage propulsion may not have an effect on existing providers because the price per payload kilogram of a launch vehicle using surplus Peacekeeper motors—approximately $27,000 at its highest capability—is still significantly higher than the launch prices of most existing launch providers, with some exceptions. However, the extent of effects to existing providers would be dependent on the price that the launch provider chooses to offer. A commercial launch provider is likely unwilling to purchase Minuteman II motors at the breakeven price we calculated because the estimated price per payload kilogram of a launch using Minuteman II motors is significantly higher than and not competitive with both emerging and most existing launch vehicles. However, a commercial launch provider may be willing to purchase Peacekeeper motors at the breakeven price we calculated and sell launches for an aggregation of small payloads, or compete at the low end of the medium class launch market to launch the smaller medium class payloads. Table 17 in appendix II provides the price per payload kilogram for emerging launch vehicles in development, and Table 4 below provides the price per kilogram for existing commercially available launch vehicles.

[42]In addition, one emerging launch provider estimates its launch price per kilogram to be $125,000, which is significantly outside the range of other launch provider's estimates.

Table 4: Existing Commercially Available Global Launch Vehicles Price and Derived Price per Kilogram to Low-Earth Orbit

Launch vehicle name	Operator	Total launch cost (million dollars)	Range of capability to low-Earth orbit (kilogram)	Range of price per kilogram(dollars)
Domestic launch provider				
Antares	Orbital ATK	80-85	6,200-6,600	12,879-12,903
Atlas V	United Launch Alliance (ULA)/Lockheed Martin Commercial Launch Services	137-179	8,123-18,814	9,514-16,866
Delta IV Medium/Heavy	ULA	164-400	9,420-28,790	13,894-17,410
Falcon 9	SpaceX	61.2	22,800	2,864
Minotaur-C	Orbital ATK	40-50	1,278-1,458	31,299-34,294
Pegasus XL	Orbital ATK	40	450	88,889
Foreign launch provider				
Ariane 5 ECA	Arianespace	178	21,000	8,476
Dnepr	ISC Kosmotras	29	3,200	9,063
Epsilon	Japan Aerospace Exploration Agency	39	700-1,200	32,500-55,714
Geosynchronous Satellite Launch Vehicle	India Space Research Organization (ISRO)/Antrix	47	5,000	9,400
H-IIA/B	Mitsubishi Heavy Industries Launch Services	90-112.5	10,000-16,500	6,818-9,000
Long March 2D	People's Liberation Army (PLA)/China Great Wall Industry Corporation (CGWIC)	30	3,500	8,571
Long March 3A	PLA/CGWIC	70	8,500	8,235
Proton M	VKS/Roscosmos/International Launch Services	65	23,000	2,826
Polar Satellite Launch Vehicle	ISRO/Antrix	21-31	3,250	6,642-9,538
Rockot	VKS/Eurockot	41.8	1,820-2,150	19,442-22,976
Soyuz 2	Arianespace	80	4,850	16,495
Vega	Arianespace	37	1,963	18,849

Source: GAO analysis of Federal Aviation Administration data. | GAO-17-609

According to Department of Commerce officials, allowing commercial launch providers to purchase surplus ICBM motors at a low price may also disrupt competition by lowering costs for one or a small number of launch providers. While the Air Force could make surplus motors available to a broad range of commercial launch providers, because of technical and financial barriers, the companies most likely to purchase the motors are those who have existing launch vehicles that can accommodate the motors without major modification. Only one company

we spoke with expressed interest in purchasing surplus ICBM motors and has the capability to integrate the motors in an existing launch vehicle. Several other companies we spoke with told us that, in comparison to newer, less expensive liquid propulsion motors, surplus ICBM motors use old technology, and that it would not be cost effective for them to develop new launch vehicles or convert existing launch vehicles to use the motors. Specifically, representatives from one company we spoke with estimated that it could cost $50 million to $60 million to convert an existing launch system in order to use surplus ICBM motors as lower stage propulsion. Moreover, these representatives said that designing and building a new launch system that uses surplus ICBM motors could cost nearly $400 million.

Limited Motor Processing Resources Challenge DOD

DOD may encounter challenges balancing an expanded workload with its other essential missions and tasks. Specifically, DOD officials told us that their current year plans call for refurbishment of about 11 motors for government missions and static fire tests, but that this level of productivity has created schedule pressures and required personnel to work overtime. Despite these efforts, officials said they expect delivery of one motor to be at least 2 weeks late. Although RSLP officials estimate that they have the capacity to process about 15 motors per year based on historical information and current personnel resources, it would be challenging to maintain this level of productivity. RSLP officials told us that increasing their office's ability to process more than 15 motors per year would require significant additional resources. For example, officials said that hypothetically doubling the number of motors they are able to process each year would require adding a minimum of five persons to the program office, investments in additional handling and testing equipment costing about $2 million, and investments of about $5 million in buildings and equipment to expand motor transfer capacity at Hill Air Force Base. Additional analysis of the detailed costs and payment arrangements with potential commercial providers is important in order to determine how such increases would affect the breakeven prices for the Air Force. Furthermore, officials said that negotiating terms and conditions with commercial launch providers and then executing related financial transactions would be challenging without additional resources.

Uncertainties Pose Challenges for Effective Decision Making

Officials conducting the Air Force study told us that they would need to gather additional details and conduct additional analysis beyond the price of the motors if law and policy are changed to allow surplus ICBM motors to be made available for commercial launches, as illustrated in the examples below:

- Study officials said that further analysis would be required for allowing commercial providers to take control of the surplus ICBM motors prior to delivering the motor to the launch site for integration into the launch vehicle. Although the RSLP office performs a significant amount of refurbishment work on the motor, an RSLP official told us some of the work could be performed by the commercial entity after transfer. However, according to Air Force officials conducting the study, its analysis of the potential use of surplus ICBM motors for commercial launches assumes that the Air Force maintains control and supervision of engines, including all necessary maintenance, refurbishment, and transfer activities, until the motors are delivered to the launch vehicle at the launch site. These officials said that this is to ensure that the motors remain safe and to avoid a breach of non-proliferation obligations and treaties. A DOD official told us that if a commercial provider were to take possession of the motors earlier in the transfer process, the Air Force would need to determine how national security, particularly treaty obligations and other munitions control regimes, would be affected. Additionally, RSLP officials told us that transferring the motors earlier on in the process may affect their costs; however, such a determination requires additional analysis.
- Although the Air Force has developed estimates for Peacekeeper motor storage and disposal costs, because of budget structures and a healthy motor stockpile, the detailed costs are unknown. For example, the cost to store Peacekeeper motors at Hill Air Force base is paid for, among many other things, by the Hill Air Force Base budget, not by the RSLP office. Additionally, no Peacekeeper motors have been disposed of due to aging issues, so the RSLP office has not yet determined, in detail, the exact process for safely destroying a Peacekeeper motor. RSLP officials told us that a “pathfinder” study would be required to establish the requirements and details to dispose of a Peacekeeper motor at an additional cost of about $500,000. As Peacekeeper motors begin to fail testing and the stockpile shows signs of aging, there may be budget and workforce implications, as the stockpile is depleted more quickly than currently planned.
- Further analysis on the potential effects to RSLP office costs and personnel is important if future demand for government missions that use surplus ICBM motor-based launch vehicles is different than expected. As discussed earlier in this report, future demand for launches using surplus ICBM motors would affect the potential costs and benefits to the Air Force. For example, under a scenario in which there is low government demand for ICBM motor-based launches, allowing commercial use of ICBM motors may provide a benefit to the Air Force by helping it maintain its specialized workforce and facilities.

However, the Air Force recently updated its estimates of future demand to include several planned government missions that will likely use ICBM motor-based launch vehicles at a level sufficient to keep its workforce in use without commercial launches.

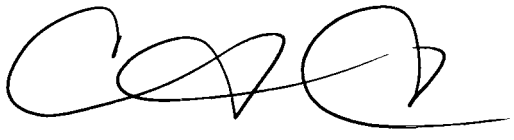
The Air Force plans to complete its study on the potential effects of allowing surplus ICBM motors to be used for commercial launch later this year. Because its study is not completed, it is not clear the extent to which it addresses these uncertainties. A detailed analysis of future potential scenarios is important for informing the way forward for the Air Force if law and policy change to allow surplus ICBM motors to be sold to commercial providers for launch. After the Air Force completes its study, the House Armed Services Committee Report to a bill for the fiscal year 2017 NDAA contained a provision for us to conduct an assessment of DOD's report. As such, we are not making recommendations in this report.

Agency Comments

We are not making recommendations in this report. We provided a draft of this report to the Departments of Defense, Commerce, State, and Transportation; and NASA for comment. We received technical comments on this report from the Departments of Defense, Commerce, and Transportation; and NASA, which we incorporated as appropriate. The Department of State did not provide comments.

We are sending copies of this report to appropriate congressional committees; the Secretary of Defense, the Secretary of the Air Force, the NASA Administrator; and the Secretaries of Commerce, Transportation, and State. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix III.



Cristina T. Chaplain
Director, Acquisition and Sourcing Management

List of Addressees

The Honorable John McCain
Chairman
The Honorable Jack Reed
Ranking Member
Committee on Armed Services
United States Senate

The Honorable John Thune
Chairman
The Honorable Bill Nelson
Ranking Member
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Thad Cochran
Chairman
The Honorable Richard Durbin
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Kevin McCarthy
Majority Leader
House of Representatives

The Honorable Mac Thornberry
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The Honorable Eddie Bernice Johnson
Ranking Member
Committee on Science, Space, and Technology
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The Honorable Kay Granger
Chairwoman
The Honorable Pete Visclosky
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

The Honorable Rob Bishop
House of Representatives

The Honorable Jim Bridenstine
House of Representatives

Appendix I: Objectives, Scope, and Methodology

The National Defense Authorization Act (NDAA) for Fiscal Year 2017 contains a provision for us to analyze the potential effects of allowing the use of surplus Intercontinental Ballistic Missile (ICBM) motors for commercial launch purposes, including an evaluation of the effects, if any, of allowing such use on national security, the Department of Defense (DOD), the solid rocket motor industrial base, the commercial space launch market, and any other areas the Comptroller General considers appropriate.[1] We assessed: (1) the options for determining the selling prices for these motors; and (2) the potential benefits and challenges, including savings and costs, of allowing surplus ICBM motors to be used for commercial space launch.

To address these objectives, we reviewed relevant laws and policies, such as the Commercial Space Act of 1998 and National Space Transportation Policies from 1994 through 2013. We also met with officials at the office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) and its office of Manufacturing and Industrial Base Policy, the office of the Principal DOD Space Advisor, Missile Defense Agency, the Assistant Secretary of the Air Force for Space Acquisition (SAF/AQS), and the Air Force Rocket Systems Launch Program (RSLP) office. Additionally we met with officials at the Departments of Commerce, Transportation, and State; and National Aeronautics and Space Administration (NASA). We interviewed and reviewed documentation submitted to us by commercial space industry stakeholders, including launch providers, satellite manufacturers, and an earth observation services company. We met with one venture capitalist whose company makes investments in the commercial space industry, an association of launch providers, and independent experts and researchers with expertise in the commercial space launch industry and history of surplus ICBM motors. We also reviewed all 16 industry stakeholder responses to an August 4, 2016 Air Force request for

[1]The House Armed Services Committee Report to a bill for the fiscal year 2017 NDAA contained a provision for DOD to conduct a study on the effects and for us conduct an assessment of DOD's report. In addition, a request letter from House members asked DOD and us to study this issue. However, DOD has not completed its report and so we did not assess its study in this report.

information on issues related to potentially making surplus ICBM motors available to providers for commercial launch.[2]

To determine the options for pricing surplus ICBM motors, we used generally accepted economic principles for benefit-cost analysis, including Office of Management and Budget Circulars A-4 and A-94 to conduct an assessment of potential economic effects. To begin that assessment, we developed breakeven prices for which DOD could offer the motors. These breakeven prices, reflecting our calculations of the net present value of motor storage and disposal costs, are those at which DOD must sell the motors to cover the costs of transferring them to commercial launch providers. We did not include sunk costs, as in the costs incurred to develop, produce, and sustain the surplus ICBM motors, but, rather, we calculated potential prices based on fulfillment cost, which includes all costs that an entity will incur in fulfilling the promises that constitute a liability. These costs are the value to the entity of the resources that will be used in liquidating the entity's assumed liability.[3] We collected from the Air Force detailed cost information associated with storing, testing, refurbishing, and disposing surplus ICBM motors, and discussed with Air Force officials their future launch and motor disposal plans. We also obtained and evaluated motor transfer costs from two recent and ongoing Air Force launch missions because they represent the most current cost data on transferring surplus ICBM motors for launch—that is, moving motors out of storage and preparing them to be integrated into a launch vehicle at the launch site. A detailed, step-by-step analysis of our economic assessment is provided in the following section. Additionally, we reviewed Federal Accounting Standards Advisory Board (FASAB) criteria to understand other methods for determining the value and price of surplus ICBM motors.

[2]U.S. Air Force, "Use of Excess ICBM Motors for Commercial Space Launches" Special Notice, Solicitation Number ICBM (El Segundo, Calif.: Aug. 4, 2016). The Air Force released this request for information to gain industry perspective on the potential effects of allowing surplus ICBM motors to be used for commercial launch. Questions in the request for information covered effects to national security, the health of the launch industry, and potential methods for pricing and making motors available to commercial entities.

[3]Net present value is the time value of money, that is, the value today (2017) of future cost of storing and decommissioning motors, based on the size of the ICBM inventory. The present value is the current value of a future amount or amounts, those amounts being decremented by a discount rate (such as the rate of inflation) to account for the time value of money. Net present value implies netting out the present value of both inflows and outflows.

To determine the potential benefits and challenges of allowing surplus ICBM motors to be used for commercial launches, we conducted an assessment of potential economic effects, detailed below, using Office of Management and Budget (OMB) guidance and generally accepted economic principles for conducting a cost benefit analysis. We reviewed DOD's documentation on storing, maintaining, refurbishing, and transferring surplus ICBM motors. For example, we reviewed RSLP program office briefing slides and SAF/AQS responses to our questions. We interviewed DOD officials who were familiar with the use of surplus ICBM motors for government launches under current law and who would be responsible for their potential use to provide commercial launch. To obtain a range of perspectives on the effects of changes to law and policy covering the transfer of surplus ICBM motors, we identified representation among specific categories of industry stakeholders from which to select industry stakeholders for interviews. These categories covered (1) launch vehicle providers, (2) spaceports, (3) venture capitalists, (4) industry groups, (5) solid rocket motor industrial base, and (6) payload satellite companies. We interviewed 20 stakeholders and entities that represented a wide range of viewpoints on potential change in policy for surplus ICBM motors to be used for commercial use.[4] We analyzed the interview results to identify patterns and themes and attributed the responses to the categories of entities rather than to individuals or specific organizations. These stakeholder views are not generalizable across the industry but do provide a range of perspectives. We estimated potential launch prices for launch vehicles using surplus ICBM motors at our calculated breakeven motor prices and compared these prices to publicly available prices of current and emerging commercial launch vehicles. Additionally, we reviewed and applied federal guidance on conducting cost-benefit analyses.[5]

To assess the reliability of the motor storage and disposal cost data, we analyzed Air Force headquarter and RSLP's program office data, interviewed DOD officials, and reviewed detailed cost and launch schedule documentation. We corroborated the data, when possible, across at multiple Air Force and RSLP sources and conducted additional follow up interviews to gain additional insight. To assess the reliability of commercial space launch price and forecast data, we interviewed officials

[4]We conducted 20 interviews with non-governmental entities and 12 government entities.

[5]OMB Circular A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs

at the Federal Aviation Administration, the Tauri Group (which collects worldwide commercial space launch data), and corroborated the data with space launch experts when possible. We determined that the data were sufficiently reliable for presenting the information contained in this report.

Economic Assessment of Potential Effects

To address both of our study objectives, we conducted an economic assessment of potential effects using generally accepted economic principles for cost benefit analysis, including Office of Management and Budget Circulars A-4 and A-94. Specifically, we identified the key elements needed for analyzing the potential economic effects by; (1) defining our objective and scope; (2) conducting an analysis of effects, where we described our analytical choices and assumptions used; (3) considering a range of alternatives; (4) conducting a breakeven price analysis; (5) conducting a sensitivity analysis; and (6) documenting our analysis.

Objective and Scope: This element of an economic assessment is the first step in assessing potential economic effects and helped us determine a method by which to develop a potential surplus ICBM motor price and a range of potential effects. The scope of our review consisted of both surplus Peacekeeper and Minuteman motors currently in inventory because DOD officials told us these are the only motors relevant for consideration for potential commercial use in the United States market, may be used for testing, or destroyed. According to the Air Force, at the time of our review, there were 186 Peacekeeper motors and 537 Minuteman II motors in inventory.

Analysis of Effects and Assumptions: This element helped us determine a method by which to develop potential surplus ICBM motor prices and a range of potential effects. During this step, we described the data, analytical choices, and assumptions used. We used motor cost and storage data provided by the RSLP office as well as information about future launch demand using surplus ICBM motor-based vehicles. We chose to analyze the difference between two scenarios: the status quo and a potential future where motors may be used for commercial launches. Specifically, we calculated the net present value of storage and disposal costs under a status quo scenario reflective of current law and policy that allows some government launches using surplus ICBM motors. We then compared the status quo model to the net present value of storage and disposal costs under a range of scenarios that may reflect a change in law and policy to allow surplus motors to be used for commercial launches.

We made several assumptions, such as, the number of test fires consisting of one motor every year, the real discount factors for the surplus ICBM motors, and the number of motors being launched for government missions until the stockpile was depleted. We made these assumptions based on information provided by the RSLP office. The assumptions are identified in table 5 below:

Table 5: Assumptions Used in Economic Analysis

Peacekeeper motors assumptions	Minuteman motors assumptions
• Number of motors in current inventory: 186	• Number of motors in current inventory: 537
• Cost to decommission motors: $317,000 as the sum of SR118 ($111,000), SR119 ($108,000) and SR120 ($98,000)	• Cost to decommission motors: $105,000 as the sum of MM1 ($58,000) +MM2 ($47,000)
• Storage cost: calculated as proportional to the cost to store Minuteman II at $2 million per year or, approximately $32,402 for a set of 3 motors.	• Storage cost: calculated as the ratio of total cost to store minuteman motors ($5.8 million) divided by the number of Minuteman II motors equals $10,801 per motor, or, approximately $21,601 for a set of 2 motors.
• Number of motors decommissioned (destroyed) per year: 3	• Number of motors decommissioned (destroyed) per year: 49
• Number of motors launched per year for government: 12 (high), 9 (mid), 6 (low)	• Number of motors launched per year for government: 8 (high), 6 (mid), 4 (low)
• Number of motors launched per year for commercial scenario: 3, 6, 6.	• Number of motors launched per year for commercial scenario: 2, 4, 4.
• No Peacekeepers will be decommissioned for the next 10 years.	• Minuteman II motors will be decommissioned at the same rate as they currently are at about 49 per year.
• Transfer cost assumed the same as currently paid by government clients. At $8.5 million from ORS-5. It includes transportation, refurbishing and reliability test among other categories).	• Transfer cost assumed the same as currently paid by government clients. At $4.1 million from ORS-3. It includes transportation, refurbishing and reliability test among other categories).
• Higher stage cost: Minotaur IV uses a commercial motor valued at approximately $1.2 million	• Higher stage cost: Minotaur I uses two commercial motors valued at approximately $3.1 million
• Discount factor equals 7 percent	• Discount factor equals 7 percent
• Test fires: one motor every other year	• Test fires: one motor every other year
• All motors would be either used or decommissioned (destroyed).	• All motors would be either used or decommissioned (destroyed).

Source: GAO analysis of Air Force data and OMB guidance on discount factors. | GAO-17-609

Note: We chose a range of motor demand for the commercial launch scenario based on the Rocket System Launch Program office's estimated ability to process a maximum of 15 motors per year. We chose a higher end of 15 Peacekeeper motors and 10 Minuteman II motors and a lower end of 9 Peacekeeper motors and 8 Minuteman II motors.

Range of Alternatives: We considered a range of relevant alternatives. Because some costs vary depending on the number of projected launches of ICBM-based launch vehicles, we calculated a range of potential breakeven prices based on, among other things, low, medium, and high launch rates. We started by modeling the current expected numbers of future launches and decommissioning of motors and

compared them with scenarios that assume different commercial and government demand for motors and calculated the associated annual cost to store and decommission motors. We analyzed the storage and disposal costs for the 186 Peacekeeper and 537 Minuteman motors in inventory, and estimated breakeven prices under the three different launch rate scenarios.

Breakeven Price Analysis: As one method of pricing the motors, we calculated breakeven prices—the prices at which DOD covers its costs for transferring the motors for launch minus the costs avoided (or saved) depleting the stockpile more quickly. In other words, this is the potential price at which DOD could break even. We estimated a breakeven price where DOD would be indifferent between continuing with the current schedule or providing commercial launches. We calculated the total net present value of motor storage and disposal costs and then broke the total down to a per motor set cost savings and subtracted that from the cost to transfer a set of motors to a government entity for a launch. In conducting our breakeven analysis for the surplus ICBM motors, we relied primarily on RSLP office data. We did not develop our own source data for development of motor prices although we did develop assumptions about future government and commercial launch demand based on RSLP program office statements.

We determined that the breakeven price for three Peacekeeper motors ranges from about $8.3 to $8.4 million. The breakeven price for two Minuteman motors ranges from about $3.9 million to $4 million. Table 6 shows the breakeven price for a set of three Peacekeeper motors and a set of two Minuteman II motors, along with the cost of commercial higher stage motors.

Table 6: Surplus ICBM Motor Breakeven Prices

	High launch rate	Medium launch rate	Low launch rate
Peacekeeper breakeven price			
ORS 5 transfer cost	$8,539,000	$8,539,000	$8,539,000
Storage and disposal savings per launch	- 169,000	-183,000	-196,000
Potential DOD breakeven price	**$8,370,000**	**$8,356,000**	**$8,343,000**
Minuteman breakeven price			

	High launch rate	Medium launch rate	Low launch rate
ORS 3 transfer cost	$4,079,000	$4,079,000	$4,079,000
Storage and disposal Savings per launch	-101,000	-116,000	-115,000
Potential DOD breakeven price	**$3,978,000**	**$3,963,000**	**$3,964,000**

Source: GAO analysis of Air Force data. | GAO-17-609

Notes: The breakeven price for the Peacekeeper motor set assumes that 3 Peacekeeper motors are disposed each year and presents different levels of government use of the motors, depending on expected future government launch demand: low, medium, and high. Number of Peacekeeper motors launch per year for government: 12 (high), 9 (mid), 6 (low). Number of Minuteman motors launched per year for government: 8 (high), 6 (mid), 4 (low).

Tables 7 through 12 show the step-by-step results of calculating the per motor net present value of storage and disposal costs for each motor type under the status quo and commercial scenarios followed by the total cost avoidance and resulting breakeven price per motor set— that is, for three Peacekeeper motors and two Minuteman II motors.

Peacekeeper motors The current net present value storage and disposal cost of the status quo (only government launches of surplus ICBM-based vehicles) is between $10.3 million and $15.8 million. It would take DOD 13 to 22 years to deplete the ICBM inventory. Tables 7 and 8 show for Peacekeeper and Minuteman II, respectively, the net present value of the storage and disposal costs under the status quo scenario, with no commercial launches, for the motor stockpile as follows:

Table 7: Net Present Value of Storage and Disposal Costs for the Surplus Peacekeeper Motor Stockpile under Status Quo (Government Launches Only)

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Number of Peacekeeper motors launched per year	12	9	6
Total undiscounted cost for all Peacekeepers in storage	14,760,000	19,720,000	27,650,000
Total net present value cost for all Peacekeeper motors in storage (discounted 7 percent)	10,340,000	12,700,000	15,830,000
Number of years to deplete surplus	13	17	22

Source: GAO analysis of Air Force data. | GAO-17-609

Minuteman II motors The current net present value storage and disposal cost of the status quo is between $36.4 million and $38.7 million, and it would take DOD 9-10 years to deplete the ICBM inventory.

Table 8: Net Present Value of Storage and Disposal Costs for Surplus Minuteman II Motor Stockpile under Status Quo (Government Launches Only)

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Number of Minuteman II motors launched per year	8	6	4
Total undiscounted cost per motor	47,960,000	49,980,000	51,920,000
Total net present value cost per motor (discounted 7 percent)	36,410,000	37,580,000	38,710,000
Number of years to deplete surplus	9	9	10

Source: GAO analysis of Air Force data. | GAO-17-609

Tables 9 and 10 show calculations of the total net present value of storage and disposal costs for each motor type in the stockpile under a commercial launch scenario across a range of assumed numbers of government and commercial launches. If commercial launches are allowed, the net present value of storage and disposal costs of Peacekeeper motors for DOD would be $8.5 million to $10.3 million with the rest of the cost being absorbed as a discount from the price for commercial launches, and it would take 11 to 13 years to deplete the inventory of ICBM motors.

Table 9: Net Present Value of Storage and Disposal Costs for Surplus Peacekeeper Motor Stockpile Including Government and Commercial Launches

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Number of Peacekeeper motors launched per year for government	12	9	6
Number of Peacekeeper motors launched per year for commercial	3	6	6
Total undiscounted net present value of storage and disposal costs	**11,300,000**	**11,300,000**	**14,760,000**

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Total net present value of storage and disposal costs (discounted 7 percent)	**8,490,000**	**8,490,000**	**10,340,000**
Number of years to deplete stockpile	11	11	13

Source: GAO analysis of Air Force data. | GAO-17-609

If commercial launches are allowed, net present value of storage and disposal cost for Minuteman II motors for DOD would be $35.5 million to $36.4 million with the rest of the cost being absorbed as a discount from the price for commercial launches, and it would take 9 years to deplete the inventory of surplus ICBM motors.

Table 10: Net Present Value of Storage and Disposal Costs for Surplus Minuteman II Motor Stockpile Including Government and Commercial Launches

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Number of Minuteman II motors launched per year for government	8	6	4
Number of Minuteman II motors launched per year for commercial	2	4	4
Total undiscounted net present value of storage and disposal costs	**46,460,000**	**46,460,000**	**47,960,000**
Total net present value of storage and disposal costs (discounted 7 percent)	**35,500,000**	**35,500,000**	**36,410,000**
Number of years to deplete stockpile	9	9	9

Source: GAO analysis of Air Force data. | GAO-17-609

In order to find the prices at which the Air Force would be indifferent between maintaining the status quo and adding commercial launches, we found the difference between the net present value of the storage and disposal costs and then broke those costs down by motor set, as shown in tables 11 and 12.

Table 11: Difference Between Storage and Disposal Costs under Government Only and Commercial Launch Scenarios for Peacekeeper Motors

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Total net present value cost for all Peacekeeper motors in storage under status quo	**10,340,000**	**12,700,000**	**15,830,000**
Less total net present value of storage and disposal costs under government and commercial use	8,490,000	8,490,000	10,340,000
Difference in net present value	**1,860,000**	**4,210,000**	**5,490,000**
Divided by total commercial Peacekeeper motors launched	33	69	84
Storage and disposal savings per motor by commercial motors launched	56,000	61,000	65,000
Total storage and disposal savings per set of three motors	**169,000**	**183,000**	**196,000**

Source: GAO analysis of Air Force data. | GAO-17-609

Table 12: Difference Between Storage and Disposal Costs under Government Only and Commercial Launch Scenarios for Minuteman II Motors

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Total net present value cost for stockpile under status quo	**36,410,000**	**37,580,000**	**38,710,000**
Less total net present value of storage and disposal costs under government and commercial use	35,500,000	35,500,000	36,410,000
Difference in net present value	910,000	2,080,000	2,310,000
Divided by total commercial Minuteman II motors launched	18	36	40
Storage and disposal savings per motor by commercial motors launched	50,000	58,000	58,000

	High launch rate (USD)	Medium launch rate (USD)	Low launch rate (USD)
Total storage and disposal Savings per set of two motors	**101,000**	**116,000**	**115,000**

Source: GAO analysis of Air Force data. | GAO-17-609

Total Peacekeeper storage and disposal savings per motor set increases as demand for launches decreases because of the growth in the number of years it takes to deplete the stockpile. Total Minuteman II motor storage and disposal savings per motor set decreases as demand decreases because of the relatively low cost to store the motors, the large number of motors that are decommissioned each year —about 50—and the relatively small difference in number of years that it takes to deplete the stockpile of those motors.

Sensitivity Analysis: We used the sensitivity analysis element of an economic assessment to determine how the use of surplus ICBM motors for commercial launch may affect the commercial launch industry. We compared the cost per payload kilogram of an ICBM motor-based launch vehicle to the price per kilogram of commercial launches with publicly available price data. According to generally accepted economic principles, a sensitivity analysis adequately justifies the data, analytical choices, and assumptions used. It explicitly addresses how plausible adjustments to each important analytical choice and assumption affect the economic effects and results of the comparison of alternatives. Our analysis assessed quantitatively how the variability of the key uncertain data underlying the estimates of economic effects—like future launch demand and capacity that may be used on a launch vehicle—affects these economic effects and the results of the comparison of alternatives. The sensitivity analysis shows that the resulting price per kilogram is sensitive to assumptions about launch demand, resulting storage and disposal cost avoidance, and the resulting number of years until the motor stockpile is depleted. The parameters and results of our sensitivity analysis are below:

Peacekeeper Motors Sensitivity Analysis:

- Levels of government motors launched: 12 (high), 9 (mid), 6 (low)
- Levels of commercial motors launched: 3, 6, 6
- Payload capacity of 500 kilograms, 1,000 kilograms, and 1,800 kilograms.

Minuteman II Motors Sensitivity Analysis:

- Levels of government motors launched: 8 (high), 6 (mid), 4 (low)
- Levels of commercial motors launched: 2, 4, 4
- Payload capacity of 100 kilograms, 300 kilograms, and 500 kilograms.

We used a range of potential payload capacities that could be launched by a Peacekeeper or Minuteman II based launch vehicle and applied this variable across a range of potential future launches using the motors. We estimated the launch prices per kilogram by first adding to the breakeven prices the costs of the required higher stage propulsion and then applied a 20 percent factor to the totals in order to calculate launch prices. According to the Air Force, propulsion costs historically account for 20 percent of a launch vehicle's price and this is a reasonable assumption for projecting prices. Tables 13 and 14 show the resulting prices per launch after adding the higher stage and ICBM motor propulsion breakeven prices and applying the 20 percent factor.

Table 13: Calculation of Launch Prices Based on Surplus ICBM Motor Breakeven Prices and Higher Stage Commercial Motor Costs

Peacekeeper Derived Launch Price			
	High launch rate	**Medium launch rate**	**Low launch rate**
Potential DOD breakeven price	$8,370,000	$8,360,000	$8,340,000
Commercial Higher stage motor cost	$1,200,000	$1,200,000	$1,200,000
Total cost (breakeven price and higher stage)	**$9,570,000**	**$9,560,000**	**$9,540,000**
Price per launch (after applying 20 percent factor)	$47,850,000	$47,780,000	$47,710,000

Source: GAO analysis of Air Force data. | GAO-17-609

Table 14: Minuteman II Derived Launch Price

	High launch rate	Medium launch rate	Low launch rate
Potential DOD breakeven price	$3,980,000	$3,960,000	$3,960,000
Commercial higher stage motor cost	$3,100,000	$3,100,000	$3,100,000
Total cost (breakeven price and higher stage)	**$7,080,000**	**$7,060,000**	**$7,060,000**
Price per launch (after applying 20 percent factor)	$35,390,000	$35,320,000	$35,320,000

Source: GAO analysis of Air Force data. | GAO-17-609

We then divided the launch prices by the range of payload capacity. Tables 15 and 16 show the price per kilogram of launches using Peacekeeper and Minuteman II motors, respectively.

Table 15: Peacekeeper Sensitivity Analysis of Price per Kilogram

Payload capacity	High launch rate	Medium launch rate	Low launch rate
500 kilograms (low capacity)	$96,000	$96,000	$95,000
1,000 kilograms (mid capacity)	$48,000	$48,000	$48,000
1,800 kilograms (high capacity)	$27,000	$27,000	$27,000

Source: GAO analysis of Air Force data. | GAO-17-609

Table 16: Minuteman Sensitivity Analysis of Price per Kilogram

Payload capacity	High launch rate	Medium launch rate	Low launch rate
100 kilograms (low capacity)	$354,000	$353,000	$353,000
300 kilograms (mid capacity)	$118,000	$118,000	$118,000
500 kilograms (high capacity)	$71,000	$71,000	$71,000

Source: GAO analysis of Air Force data. | GAO-17-609

Documentation of Our Analysis: We concluded our assessment of potential surplus ICBM motor prices and resulting effects by documenting our analysis. Based upon the results of our assessment, the analysis can inform decision-makers and stakeholders about the potential economic effects of the action examined.

We conducted this performance audit from June 2016 to August 2017 in accordance with generally accepted government auditing standards.

Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Existing Global Commercial Launch Vehicles

Figure 4: Existing Global Commercial Launch Vehicles

Country	Vehicle	Launch Provider	Estimated price of launch (million USD)	Range of capability to LEO (kg)	Range of price per kilogram (USD)	2016 worldwide commercial launch events
China	Long March 2D	People's Liberation Army of China/ China Great Wall Industry Corporation	$30	3,500	8,571	0
	Long March 3A		$70	8,500	8,235	0
European Union[a]	Vega	Arianespace	$37	1,963	18,849	2
	Ariane 5		$178	21,000	8,476	6
	Soyuz 2		$80	4,850	16,495	0
India	PSLV	Indian Space Research Organization/Antrix	$21-31	3,250	6,462-9,538	0
	GSLV		$47	5,000	9,400	0
Japan	Epsilon	Japan Aerospace Exploration Agency	$39	700-1,200	55,714-32,500	0
	H-IIA/B	Mitsubishi Heavy Industries Launch Services	$90-112.5	10,000-16,500	9,000-6,818	0
Russia	Proton M	VKS/Roscosmos/International Launch Services (ILS)	$65	23,000	2,826	2
	Rockot	VKS/Eurockot	$41.8	1,820-2,150	22,976-19,442	0
	Dnepr	ISC Kosmotros	$29	3,200	9,063	0
USA	Falcon 9	SpaceX	$61.2	22,800	2,684	7
	Atlas V	ULA/Lockheed Martin Commercial Launch Services	$137-179	8,123-18,814	16,866-9,514	3
	Delta IV Medium/Heavy	United Launch Alliance (ULA)	$164-$400	9,420-28,790	17,410-13,894	0
	Minotaur-C	Orbital ATK	$40-$50	1,278-1,458	31,299-34,294	0
	Antares		$80-$85	6,200-6,600	12,903-12,879	1
	Pegasus XL		$40	450	88,889	0

Source: GAO summary of Federal Aviation Administration's data of the Annual Compendium of Commercial Space Transportation: 2017 Report. | GAO-17-609

[a]We refer to the European Union as a country in this report because Arianespace is the primary launch provider for the consortium of European member countries.

Table 17 presents emerging launch vehicles and planned launch prices.

Table 17: Emerging Launch Vehicle Providers

Launch vehicle name	Operator	Capability to low-Earth orbit (kilograms)	Price per launch (millions of dollars)	Price per kilogram capability range (dollars)
Alpha[a]	Firefly	400	$8.00	$20,000
Bagaveev	Bagaveev Corporation	10 (to SSO)	Unknown	-
Cab-3A	CubeCab	5	$0.25	$50,000
Demi-Sprite	Microcosm Inc./Scorpius Space Launch Company	160	$3.60	$22,500
Electron	Rocket Lab	150 (to SSO)	$4.90	$32,667
Falcon Heavy	SpaceX	53,000	$80-$270	$1,509-5094
GOLauncher-2	Generation Orbit	45	$2.50	$55,556
Haas 2CA	Aeronautics and Cosmonautics Romanian Association (ARCA) Space Corporation	100	$1	$10,000
Intrepid-1	Rocketcrafters	376	$5.40	$14,362
LauncherOne	Virgin Galactic	400	$10.00	$25,000
Minotaur VI	Orbital ATK	2,600	$60.00	$23,077
NEPTUNE N5	Interorbital Systems	40	$0.50	$12,500
New Glenn	Blue Origin	35,000-70,000	Undisclosed	-
Space Launch System	National Aeronautics and Space Administration	70,000-130,000	To Be Determined	-
Spyder	UP Aerospace	8	$1	$125,000
Stratolaunch	Stratolaunch Systems	3,000	Undisclosed	-
Super Strypi	Operationally Responsive Space Office/Sandia National Laboratory	320	To Be Determined	-
VALT	VALT Enterprises	Unknown	$1.70	-
Vector-H	Vector Space Systems	125	$3.00	$24,000
Vector-R	Vector Space Systems	60	$1.50	$25,000
Volant	bspace	215	Unknown	-
Vulcan	United Launch Alliance	9,370-18,510	$85-$260	$9,072-14,046
Wolverine	Vector Space Systems	45	$1	$22,222
XS-1	Defense Advanced Research Projects Agency	2,267	$5.00	$2,206

Source: GAO analysis of Federal Aviation Administration data, and publicly available information from company websites. | GAO-17-609

[a]Media reports state that Firefly assets and equipment were auctioned off in March 2017 after the company reportedly encountered financial difficulties.

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

In addition to the contact named above, Rich Horiuchi (Assistant Director), Erin Cohen (Analyst-in-Charge), Pedro Almoguera, Andrew Berglund, Stephanie Gustafson, Wendell Keith Hudson, Jordan Kudrna, and Jacqueline Wade made key contributions to this report.