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Since 1975, upwards of 60 civilian aircraft have been hit by surface-to-air missile platforms known as man-portable air defense systems (MANPADS), resulting in the deaths of over 1,000 civilians. Terrorist groups like al-Qaeda, the Islamic State in Iraq and Syria, and Lebanese Hezbollah are thought to possess MANPADS, presenting an ongoing concern for civilian air travel in the modern political climate. Although a MANPADS attack on a civilian aircraft has not been attempted since 2007, the threat of MANPADS attacks remains, and so does the need to develop a better understanding of the security risks posed by these systems. The loss of life from a MANPADS incident could be severe and have grave international repercussions. The research summarized in this report aims to provide analysis of the key issues of this international security challenge.

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Acquisition and Use of MANPADS Against Commercial Aviation: Risks, Proliferation, Mitigation, and Cost of an Attack

ZIEGLER ET AL.

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Preface

In March 1975, an Air Vietnam passenger airliner was brought down after being shot with a man-portable air defense system (MANPADS). The resulting crash killed 26 crew members and passengers. Since then, upwards of 60 civilian aircraft have been hit by MANPADS, resulting in the deaths of over 1,000 civilians. Terrorist groups, such as al-Qaeda, the Islamic State in Iraq and Syria, and Hezbollah, are thought to possess MANPADS, presenting an ongoing concern for commercial aviation. Although a MANPADS attack on a civilian aircraft has not been attempted since 2007, the threat of MANPADS attacks remains, as does the need to develop a better understanding of the security risks posed by these systems. The loss of life from a MANPADS incident could be severe and have grave international repercussions. The research summarized in this report aims to provide analysis of the key issues of this international security challenge.

In addition to providing a general overview of MANPADS and their application, this report focuses on four areas:

1. trends in the use of MANPADS against civilian aviation
2. the current and evolving threat environment caused by the proliferation of MANPADS
3. the potential economic effects of an overseas attack on a commercial or government civilian aircraft
4. potential mitigation efforts to address the issue.

In examining these four issues, the authors aim to offer a useful resource for policymakers tasked with navigating this complex threat space.

This research was sponsored by the U.S. Department of State and conducted within the International Security and Defense Policy Center of the RAND National Security Research Division (NSRD). NSRD conducts research and analysis for the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the defense agencies, the Navy, the Marine Corps, the U.S. Coast Guard, the U.S. Intelligence Community, allied foreign governments, and foundations.

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Summary

Man-portable air defense systems (MANPADS) are surface-to-air missiles that can be transported and fired by individuals or small teams. Given their ease of use and relative accessibility, these weapons present a threat to civil, commercial, and military aviation. In the mid-1970s, nonstate armed groups (NSAGs) began operating these weapon systems in civil wars and other conflicts.

In addition to providing a general overview of MANPADS and their application, the research in this report is focused on the four following core areas:

1. the historical use of MANPADS against civilian aviation
2. the current threat environment caused by the proliferation of MANPADS and potential NSAG use of these weapons
3. the potential economic effects of an overseas attack on a commercial or government civilian aircraft
4. potential mitigation options.

Research Approach

RAND researchers leveraged both quantitative and qualitative research approaches for this report. We interviewed subject-matter experts on MANPADS. We drew on several sources to construct three new data sets. The first is an updated historical record of MANPADS attacks against civil aviation. We included information on country location and the environment in which the attack took place, including the presence of conflict and conflict intensity. These new data permit us to evaluate historical trends in MANPADS attacks. Second, we present data on NSAGs suspected of or known to have acquired MANPADS. We used these data to construct a qualitative MANPADS risk index that is informed by quantitative measures. This index reflects an NSAG's capability and intent to use MANPADS. We also gathered data on MANPADS stockpiles around the world. These data address both domestic production of MANPADS and their export. They also serve to inform our examination of mitigation options. We used these data to examine potential weapon leakage and state sponsorship of NSAGs in various unstable countries. We then used statistical analysis to leverage our historical attack data and country-specific information to construct a suite of econometric models to estimate the potential effect of a MANPADS attack on a country's economy.

Findings

The historical data on MANPADS attacks against civilian airliners by NSAGs (as collected since the 1970s) suggest several important trends:

- Most incidents occurred in Africa (64 percent); of these incidents, two-thirds occurred in southern Africa. Europe and Eurasia and South and Central Asia have also experienced MANPADS attacks.
- Most MANPADS attacks against civilian airliners occur in conflict zones. These attacks overwhelmingly occur during civil (as opposed to interstate) wars. In 37 percent of MANPADS attacks, an external force (a state supporting one side of a conflict with its own troops) was intervening in a civil conflict.
- Most attacks happened in the 1980s and 1990s, suggesting that Cold War and early post–Cold War competition and the associated conflicts spurred the MANPADS threat during this era.

The NSAG risk index we construct offers a framework for evaluating the risk of groups' use of MANPADS against commercial aviation. Several patterns emerge from the index:

- Fifty-seven NSAGs are confirmed to possess or suspected to possess MANPADS. Many of these groups have demonstrated the capability to use them. Moreover, several of these groups have used these systems against military targets, and some of the most capable groups exhibit little concern for the loss of civilian life.
- Four of the five highest-scoring groups in this index—the Islamic State of Iraq and Syria, Hayat Tahrir al-Sham, other Syrian opposition groups (considered as a whole), and the Kurdistan Workers' Party—are based in the Middle East. Although the Middle East, north Africa, and the Sahel have not experienced many MANPADS attacks against civilian aircraft, this framework suggests that the Middle East is at the greatest risk for future attacks.

Our collection of proliferation and stockpile data reveals several important factors concerning potential leakage. MANPADS have the potential to fall into the hands of NSAGs via various mechanisms. This is most likely in fragile, war-prone states. Leakage findings include the following:

- The most unstable countries with the highest number of MANPADS are Libya and Syria. The former possesses roughly 21,000 systems, and the latter has more than 17,000. The next most unstable countries with high numbers of MANPADS are Iraq, Pakistan, and North Korea. Afghanistan and Venezuela are also highly unstable countries with thousands of MANPADS.
- The export of these weapons is also a potential risk. Russia is far and away the single largest exporter of MANPADS, with more than 10,000 systems sold from 2010 to 2018. Among the countries purchasing Russian MANPADS are Iraq, Venezuela, Kazakhstan, Qatar, and Libya.
- Of the top five exporting countries, China sells MANPADS to the most unstable countries. These unstable countries include Bangladesh, Pakistan, Sudan, South Sudan, and

Cameroon. Moreover, China has—at least licitly—exported exclusively more-advanced MANPADS.

MANPADS attacks, along with the local and global policy responses to them, have the potential to affect economies in both the short and long term. These consequences might be local to the attack, affecting economic growth, or have indirect international consequences through changes in trade with other countries, foreign direct investment, or international tourism. The econometric models we developed do not identify a single effect of MANPADS attacks on economic outcomes; they do point to a strong, and statistically significant, relationship between attacks on aircraft in flight and decreases in gross domestic product (GDP). Economic effects (or the lack thereof) include the following:

- A MANPADS-like attack on an aircraft is associated with a 1.4-percent decrease in GDP.
- We do not find a statistically significant relationship between attacks on aircraft and other economic indicators, such as foreign direct investment and trade.
- The majority of MANPADS attacks occur in countries suffering state-based conflicts; a MANPADS-like attack on a civilian aircraft in such an environment is still likely to negatively affect a country's economy even further.

Multiple mitigation options can be used to reduce the risk of an attack. They can be categorized by the following objectives (examples of each option are provided later in the text):

- disrupting or degrading NSAG ability to operate by seizing assets, extraditing and prosecuting leaders, and military actions
- preventing the acquisition or transfer of MANPADS to NSAGs by negotiating export restrictions or interdicting shipments
- preventing weapon employment through the use of flight restrictions, technical-use controls, airport vulnerability assessments, and altering aircraft flight operations
- reducing the likelihood of a successful attack with both ground-based and aircraft countermeasures
- limiting aircraft damage from successful attacks by modifying aircraft
- managing the consequences of a successful attack on an aircraft by improving the emergency response.

These options should be pursued as part of a wider strategy to lower risk.

Implications

MANPADS pose varying degrees of danger to civilian aviation around the world. The risk is not uniform nor particularly pronounced. Comparatively few MANPADS attacks on civilian aircraft (relative to other types of aircraft attacks) have occurred since the first successful one over four decades ago, and an attack has not transpired in roughly a dozen years. Nevertheless, many nonstate actors involved in violent conflicts possess MANPADS and the possible intent to use them against civilian aviation. Unstable countries continue to stockpile these systems, and producer countries (such as China and Russia) have shown little compunction in selling them to unstable regimes, so it is not difficult to imagine scenarios of MANPADS attacks against civilian airliners. Efforts to mitigate this risk should be informed by the preponderance of data and evidence about it. We present many mitigation options in this report.

As we demonstrate, a MANPADS attack against civilian aviation could result in significant loss of life and economic stability. Commensurate effort and resources should be devoted to preventing such an outcome.

Acknowledgments

The authors of this report thank the U.S. Government Interagency MANPADS Task Force for commissioning this study. Particular appreciation is owed to the U.S. Department of State's Bureau for Political Military Affairs, the component of the interagency task force that oversaw the work. In addition to the sponsor, we thank the U.S. government officials interviewed for this project who provided their expertise and insights.

We also benefitted enormously from the expertise of our RAND Corporation colleagues, including James Chow, whose original study of the economic consequences of a MANPADS attack and options for mitigating it informed our own thinking on this dimension of the issue; Katherine Wu, who created many of the visual depictions of the data in the report; Chandler Sachs, who contributed as a research assistant; and Silas Dustin and Thomas Whittaker, who provided editing and formatting assistance.

Finally, the authors wish to thank Alan Vick and Howard Shatz, whose reviewer comments and insights greatly strengthened the report.

Abbreviations

ACD	Armed Conflict Database
BCU	battery cooling unit
BICC	Bonn International Center for Conversion
DHS	U.S. Department of Homeland Security
DIRCM	directed infrared countermeasures
FAA	Federal Aviation Administration
FDI	foreign direct investment
FSI	Fragile States Index
FTO	foreign terrorist organization
GDP	gross domestic product
GED	Georeferenced Event Dataset
GTD	Global Terrorism Database
HEL	high energy laser
HTS	Hayat Tahrir Al-Sham
IR	infrared
IRST	infrared search and track
ISIS	Islamic State in Iraq and Syria
LAIRCM	Large Aircraft Infrared Counter Measure
LTTE	Liberation Tigers of Tamil Eelam
MANPADS	man-portable air defense systems
MAV	MANPADS Assist Visit
MWS	missile warning system

NOTAM	Notification to Airmen
NSAG	nonstate armed group
PCA	Propulsion Controlled Aircraft
PFLP	Popular Front for the Liberation of Palestine
PKK	Kurdistan Workers' Party (Partiya Karkerên Kurdistanê)
PSSM	physical storage stockpile management
QW	Qian Wei
SDGT	Specially Designated Global Terrorists
SFAR	Special Federal Aviation Regulation
SHiELD	Self-Protect High-Energy Laser Demonstrator
SIPRI	Stockholm International Peace Research Institute
SPLA	Sudan People's Liberation Army
THEL	Tactical High Energy Laser
UCDP	Uppsala Conflict Data Program
UNCTAD	United Nations Conference on Trade and Development
UNITA	National Union for the Total Independence of Angola
UWSA	United Wa State Army
ZIPRA	Zimbabwe People's Revolutionary Army

CHAPTER ONE

Introduction

Man-portable air defense systems (MANPADS) are surface-to-air missiles that are easy to transport and can be fired by individuals or small teams. Designed to counter aerial threats, MANPADS were introduced by the United States and the Soviet Union in the 1960s for use by infantry. Since then, as many as 20 nations have developed the capacity to produce MANPADS; these nations have manufactured approximately 1 million MANPADS for national defense and export. The U.S. government estimates that as many as 750,000 MANPADS likely remain in inventories worldwide.[1]

Given their ease of use and their widespread proliferation, MANPADS present a threat to civil, commercial, and military aviation. With only moderate training, terrorists or other nonstate actors can and have used these weapons against both military and civilian aircraft. In 1973, the Black September terrorist group attempted to use MANPADS to shoot down the aircraft of then–Israeli Prime Minister Golda Meir in Rome.[2] During the 1970s, nonstate armed groups (NSAGs) began to use MANPADS in civil wars and other conflicts of varying intensity in such countries as Angola and Mozambique.[3] North Vietnamese forces also resorted to MANPADS use, downing an Air Vietnam DC-4 in 1975. Today, the world's most capable terrorist groups—including al-Qaida, the Islamic State in Iraq and Syria (ISIS), and Hezbollah—are thought to have MANPADS.

An attack on a civilian aircraft has not been attempted since 2007. However, the consequences of such an attack could be far-reaching. MANPADS attacks have killed more than 1,000 crew members and passengers, and their use could result in significant economic costs.[4] In this report, we evaluate both the historical use of these weapons against civilian aviation and the state of the current MANPADS threat. We further present various mitigation options based on the data and the current proliferation status of these weapons. We also analyze the potential economic effect of an overseas attack on a commercial or government civilian aircraft. This report presents findings from study.

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1 Small Arms Survey, "Armed Groups' Holding of Guided Light Weapons," webpage, undated.

2 Black September was a militant Palestinian group formed in the early 1970s. The group was responsible for the 1972 terrorist attack at the Munich Olympic Games.

3 When discussing the risk posed by MANPADS, we use the term *NSAGs* for two reasons. First, the official U.S. government designation of *foreign terrorist organizations* (FTOs) only came into being in 1997. Our historical treatment extends to the early 1970s, resulting in a more than two-decade gap when the FTO designation had yet to come into effect. Second, some NSAGs (e.g., the Houthis) are hostile toward the United States and are thought to possess MANPADS, but they are not designated as FTOs. Occasionally, we use the terms *terrorist* and *terrorist group*, but only in reference to official FTOs.

4 National Consortium for the Study of Terrorism and Responses to Terrorism, Global Terrorism Database (GTD), July 2018.

Organization of This Report

In Chapter Two, we offer an introduction to the functional aspects of MANPADS, the constituent parts of the launcher and missile, the various generations of MANPADS, and their related components. We also discuss their ease of use and identify critical components that might cause the system malfunctions.

In Chapter Three, we present and analyze data about MANPADS attacks against civilian airliners. We collected and catalogued data from several sources to form a new and updated list of relevant attacks from 1973 to 2018. We assess major trends and prominent features that emerged from our analysis, including the geography of prior attacks, the intensity of any associated state-based conflict (when relevant), where the attacks occurred, the types of aircraft targeted, and the resultant physical damage and casualties. [5]

In Chapter Four, we present new data on the NSAGs known to or suspected to possess MANPADS. We use these data to develop a framework for estimating the risk of groups employing MANPADS against commercial aviation.

In Chapter Five, we seek to develop a better understanding of potential stockpile leakage by cataloging proliferation of MANPADS across the globe. This chapter specifically covers emerging issues and risks from MANPADS within the context of state fragility. We probe the risk of potential MANPADS use in the future against civilian aviation by examining weapon stockpiles worldwide. Because of the proliferation of weapons, these platforms have the potential to fall into the hands of NSAGs via various mechanisms.

Chapter Six probes the economic effect of an overseas MANPADS attack. In addition to the costs inflicted from an attack itself, the resulting local and global policy responses could affect economies over both the short and long term.

Chapter Seven addresses various mitigation measures to deal with the threat. We consider a range of measures, from options for preventing NSAGs from operating effectively to options for managing the consequences of a MANPADS attack.

Chapter Eight provides our conclusions.

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5 We use the term *state-based conflict* to refer to a conflict that includes the government of a state as one of the parties to the conflict and results in at least 1,000 deaths in the country in a given year.

CHAPTER TWO

Characterizing MANPADS

MANPADS are short-range surface-to-air missiles used to intercept fixed- and rotary-wing aircraft in flight. They are designed to be used by one person or a small team. They can be shoulder-fired, attached to a tripod or stand, or mounted on a vehicle or other structure to increase stability. They can also be fired from boats or ships. MANPADS have a maximum range of 5 miles (8 km) and can engage targets effectively at altitudes of approximately 15,000 feet (4.5 km) or more.[1]

Shoulder-fired MANPADS typically are 5–6 feet in length (1.5–1.8 m); they are about 3 inches (7.6 cm) in diameter and weigh about 33–42 pounds (15–19 kg).[2] These MANPADS have small, portable cases, allowing quick assembly and easy concealment and transportation.

The design and configuration of a MANPADS are largely driven by the type of guidance system. Most MANPADS have passive homing systems. These "fire and forget" MANPADS do not require the user to guide the missile to the target. Instead, infrared (IR) seekers detect and track the target aircraft through its radiation emissions. The passive homing makes it difficult for the target's crew to detect the incoming MANPADS. Examples of IR-seeking MANPADS include the Russian Igla-S and the U.S. Stinger.

Command-guided MANPADS, which require the operator to guide the missile to the target, are less common. Generally, command-guided MANPADS rely on a beam-riding configuration, in which the operator must "paint" the target aircraft (keep the laser beam on the target) until the missile impacts.[3] These systems have evolved separately from IR-seeking systems and are distinct from them in several ways. Command-guided MANPADS systems are generally heavier and require a tripod or mount. However, their missiles are generally lighter because they do not have IR seekers. Moreover, command-guided MANPADS are generally more difficult to operate, often requiring a crew. Two families of command-guided MANPADS exist—the British Blowpipe, Javelin, Starburst, and Starstreak series, and the Swedish RBS-70 series, which is produced by Saab-Bofors.[4]

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1 Some MANPADS are technically capable of reaching targets flying as high as 26,000 feet (8 km). However, MANPADS are not generally designed to engage targets at such altitudes, and a successful engagement against a commercial airliner flying at 20,000 feet or higher is highly unlikely. See U.S. Department of State, Bureau of Political-Military Affairs, *Man-Portable Air Defense Systems & Anti-Tank Guided Missiles Recognition Training*, Washington, D.C., undated, pp. 7–58.

2 U.S. Department of State, Bureau of Political-Military Affairs, undated.

3 A third type of guidance, known as semiactive homing, is employed by the Qian Wei (QW)-3 MANPADS. It is the only MANPADS known to use this type of guidance system (Jane's by IHS Markit, "QW-3," webpage, May 8, 2019).

4 Matt Schroeder, *The MANPADS Threat and International Efforts to Address It: Ten Years After Mombasa*, Washington, D.C.: Federation of American Scientists, August 2013, pp. 6–7; Saab, "Saab Unveil New RBS 70 NG," press release, September 13, 2011.

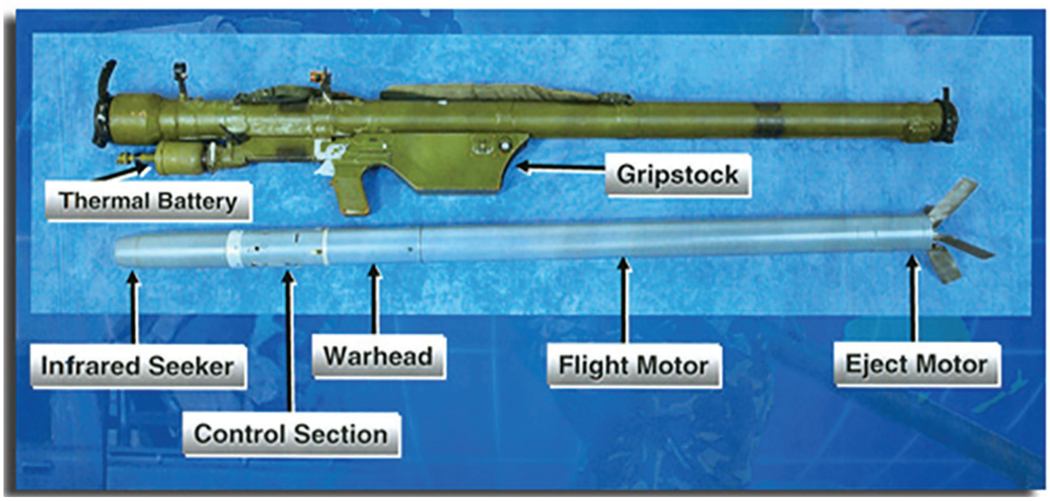
MANPADS Components

Although the technology has evolved significantly, shoulder-fired MANPADS have adhered to the same basic configuration over time. Typically, a MANPADS is composed of a launch tube (an elongated cylinder containing a prepackaged missile); a thermal battery (or battery coolant unit); and a firing mechanism, called a gripstock. The missile has five sections: the IR seeker, a control section, a warhead, a flight motor, and an eject motor. Figure 2.1 depicts a typical MANPADS system (in this case, a SA-7b) and its components.

Launch tubes are generally made of hardened plastic and Kevlar and are hermetically sealed to reduce environmental contamination.[5] They are normally thrown away after missile launch.

The battery provides sufficient power for prelaunch tasks, such as spinning up the missile's gyroscope, activating the onboard thermal battery or generator, and igniting the ejection motor.[6] Battery coolant units (BCUs) are used for MANPADS equipped with cooled IR seekers. They supply gas coolant to the missile's seeker in addition to electrical power.[7] The shelf life of batteries varies, but there are reports of batteries providing enough charge to launch an SA-7 more than 25 years old.[8] Batteries generally provide enough charge for only one shot.[9] As battery life is one of the most significant constraints on MANPADS use, terrorist organizations

Figure 2.1
MANPADS Components



SOURCE: U.S. Department of State, Bureau of International Security and Nonproliferation and Bureau of Political-Military Affairs, "The MANPADS Menace: Combating the Threat to Global Aviation from Man-Portable Air Defense Systems," fact sheet, September 20, 2005.

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5 U.S. Department of State, Bureau of Political-Military Affairs, undated, p. 55; Thomas B. Hunter, "Proliferation of MANPADS," *Jane's Intelligence Review*, Vol. 13, No. 9, September 2001, p. 43.

6 Jose Rufas, *Improvised Batteries for Man Portable Air Defense (MANPAD) Systems Report*, Madrid: Counter Improvised Explosive Device Center of Excellence, December 22, 2016; John Lyons, Duncan Long, and Richard Chait, *Critical Technology Events in the Development of the Stinger and Javelin Missile Systems: Project Hindsight Revisited*, Washington, D.C.: Center for Technology and National Security Policy, National Defense University, No. 33, July 2006.

7 U.S. Department of State, Bureau of Political-Military Affairs, undated, p. 57.

8 Rufas, 2016.

9 Rufas, 2016.

often craft their own from the batteries of computers, cameras, cars, and motorcycles. These can be used with older MANPADS, such as the SA-7, that operate with thermal batteries.[10] This use of nonstandard batteries is particularly concerning, as it offers longevity to weapon systems that otherwise would be inoperable.[11]

Composed of a firing mechanism (the trigger) and a stock, most MANPADS gripstocks are similar in design. The stock attaches to the launch tube, often with a clip. MANPADS firing mechanisms engage the thermal battery or BCU and launch the missile. They resemble a pistol or rifle trigger assembly and, just as with a pistol or a rifle, engage the weapon system. Gripstocks are typically the only reusable MANPADS component. They generally are designed for a specific type of MANPADS and are not interchangeable between types.[12]

MANPADS Generations

The U.S. Department of Defense divides MANPADS into five categories, or *generations*. The key distinction between each generation is the technology of the weapon and its initial operational capability date. Among the various MANPADS available today, first-generation systems are the least sophisticated, and fourth-generation systems are the most advanced. (Although fifth-generation systems, such as the QW-4, are reportedly under development, at the time of writing, no fifth-generation shoulder-fired MANPADS were actually in service.) As systems have improved, they generally have become easier to use. This is especially true of Russian-built MANPADS.[13] More recent systems, like third- and fourth-generation MANPADS, require less training to assemble and use.[14] Some newer systems, such as the third-generation SA-24, are highly automated—the operator simply points and shoots.

First-generation MANPADS, the most common of which is the SA-7, were first fielded in the late 1960s and are the oldest, most widely proliferated MANPADS.[15] They possess no counter-countermeasures and are rear-aspect, or "tail chase," weapons. Rear-aspect weapons can only acquire a target aircraft from behind, after it has moved past the operator. First-generation MANPADS are more difficult to use than their newer counterparts, requiring a higher level of user training and skill to engage a target.[16] Their seekers are also susceptible to confusion by background radiation, lowering the probability of successful engagement. Flares and other countermeasures are highly effective against these systems.

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10 James C. "Chris" Whitmire, *Shoulder Launched Missiles (A.K.A. MANPADS): The Ominous Threat to Commercial Aviation*, Maxwell Air Force Base, Ala.: U.S. Air Force Counterproliferation Center, No. 37, December 2006.

11 U.S. Department of State, Bureau of Political-Military Affairs, undated, p. 58.

12 U.S. Department of State, Bureau of Political-Military Affairs, undated, p. 6.

13 Interview with U.S. government subject-matter experts, December 13, 2018.

14 More-recent generations require less expertise to operate, and online videos provide tutorials for the assembly and use of newer systems. While the basic premise and use of these weapons has not changed much, the technology associated with them has; see Michael Ashkenazi, Princess Mawuena Amuzu, Jan Grebe, Christof Kögler, and Marc Kösling, *MANPADS: A Terrorist Threat to Civilian Aviation?* Bonn, Germany: Bonn International Center for Conversion, Brief 47, February 2013.

15 U.S. Department of State, Bureau of Political-Military Affairs, undated, pp. 6–7.

16 Interview with U.S. government subject-matter experts, December 13, 2018.

Second-generation MANPADS, such as the SA-16, generally have greater acquisition and engagement ranges and more-effective warheads. Significantly, they can acquire targets from the side and front; this "all-aspect" feature makes targets easier to engage, as the weapon operator does not need to be positioned behind passing aircraft.[17] However, this generation of MANPADS does not possess any counter-countermeasures.[18] Flares and other countermeasures are therefore still particularly effective against them.

Third-generation MANPADS, such as the SA-18, are all-aspect weapons equipped with IR counter-countermeasures that are capable of distinguishing a flare from an aircraft. However, they can have difficulty defeating multiple flares.[19] The newer Russian systems in this category, such as the SA-24, are easier to use and require less training and assembly time, allowing the user to fire at a faster pace.

Fourth-generation MANPADS, such as the FN-6, are dramatically more sophisticated than previous generations. They use microprocessing for their seeker function and feature advanced IR counter-countermeasures.[20] Newer fourth-generation MANPADS, such as the Chinese FN-16 and the Russian Verba, have multispectral IR/ultraviolet seekers, which further complicates countermeasure development.

In the future, fifth-generation MANPADS are expected to be equipped with imaging seekers, which could further enhance MANPADS' counter-countermeasure and clutter rejection capabilities. Moreover, these seekers could enable aim-point selection capabilities, thereby increasing lethality. There are no fifth-generation shoulder-fired MANPADS known to be in production today.[21]

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[17] U.S. Department of State, Bureau of Political-Military Affairs, undated, p. 8.

[18] Interview with U.S. government subject-matter experts, December 13, 2018.

[19] Interview with U.S. government subject-matter experts, December 13, 2018.

[20] Interview with U.S. government subject-matter experts, December 13, 2018.

[21] Interview with U.S. government subject-matter experts, December 13, 2018.

CHAPTER THREE

Historical Use of MANPADS

Overview

We assessed major trends and prominent features that emerge on MANPADS attacks by NSAGs against civilian airliners from 1973 to 2018, including the geography of the attacks, the intensity of conflict (when applicable), the types of aircraft targeted, and the physical damage and human loss incurred. Although future incidents of MANPADS against civilian aircraft might not resemble past attacks, it is nonetheless useful to place the MANPADS threat in historical context, as several important consistencies emerge.[1]

The data that inform this chapter are from three main sources. The first includes a list of incidents compiled in a 2013 report by the Bonn International Center for Conversion (BICC).[2] The second is a review of the Aviation Security Network database.[3] We also draw upon the GTD, which includes information regarding terrorist attacks worldwide from 1970 to 2017.[4] Aggregating between these sources yielded 65 recorded MANPADS attacks against civilian airliners. In 56 of the 65 incidents, multiple sources corroborate the incidents. However, in the remaining nine incidents, only one of the three main data sources captured the attack. In those instances, RAND researchers conducted Internet searches to confirm the attack did occur. Finally, minor discrepancies exist in the reporting for several of the attacks. The most common discrepancies are slight differences in the attack date or in the number of fatalities.

The first reported attack occurred in 1973, and the last documented attack of this type occurred in 2007, although our data runs through 2018. We note that the data do not include NSAG attacks on military aircraft, such as a Syrian armed group's downing of a Russian fighter jet over Idlib Province in February 2018.[5] The data also do not encompass NSAGs' use of nonportable air defense systems to target civilian airliners, such as the July 2014 downing of the Malaysian Airlines flight over Ukraine, which is believed to have been struck by a missile

1 By *historical context*, we mean the conditions under which each attack took place in a given country in a given year. The next section of the report treats emerging trends in the MANPADS threat that could change the characteristics of the future threat.

2 The BICC report presents an assessment of the MANPADS threat to civilian airliners at the behest of the German Federal Foreign Office. See Ashkenazi et al., 2013, p. 28.

3 The Aviation Security Network's database of airline incidents can be sorted by those aircraft struck by surface to air fire; see Aviation Safety Network, "Shot Down from the Ground," webpage, undated.

4 National Consortium for the Study of Terrorism and Responses to Terrorism, 2018.

5 "Russian Sukhoi Fighter Jet Shot Down in Syria's Idlib," *AlJazeera.com*, February 4, 2018.

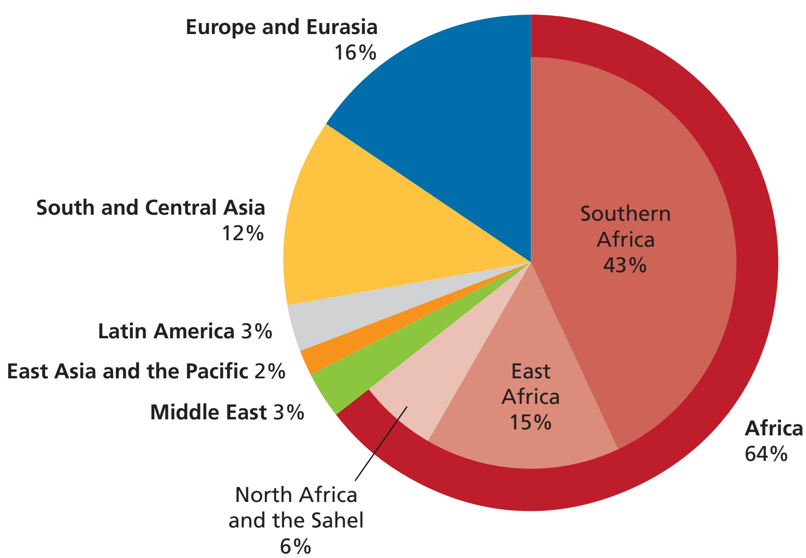
from a vehicle-mounted Buk air defense system.[6] The data do include date of attack, aircraft targeted, engine type, deaths, attackers, type of weapon used, phase of flight, point of impact, and outcome (i.e., landed, crashed). The full list of attacks and associated information can be found in Appendix A.

Geography of Attacks

Several obvious patterns emerge from an examination of the data of MANPADS attacks against civilian airliners. From a geographic perspective, Africa emerges as the location of most incidents. Sixty-four percent of attacks in our database occurred there. Of these incidents, two-thirds occurred in sub-Saharan Africa. It is worth noting that while Africa has been the site of 42 MANPADS attacks against civilian airliners, no other geographic region has been the site of more than ten attacks (Figure 3.1).

It is also worth highlighting that 22 of the African incidents occurred in a single country—Angola. All of these attacks are believed to have been perpetrated by the National Union for the Total Independence of Angola (UNITA). This group was a key player in a multiparty civil war that lasted from 1975 until roughly 2002. The Angolan conflict began between two former liberation movements—the People's Movement for the Liberation of Angola and UNITA—upon the country's independence from Portugal. The conflict eventually emerged into a major Cold War battle ground between the United States and Soviet Union. A regional power (South Africa), aligned with the U.S.-supported UNITA, fought against factions backed by the Soviet Union and Cuba. U.S. assistance to UNITA included Stinger MANPADS, which were used in two attacks (the only two attacks in which this weapon is known to have been used against

Figure 3.1
Geography of MANPADS Attacks (1973–2007)



6 Andrew E. Kramer, "Russian Military Supplied Missile That Shot Down Malaysian Jet, Prosecutors Say," *New York Times*, May 24, 2018.

civilian aircraft). In the other 20 attacks in Angola, the MANPADS model used is unknown. There have been no MANPADS attacks in Angola since the civil war concluded in 2002.

Eastern Africa is the other African subregion that has experienced large numbers of MANPADS attacks against civilian aircraft. It has been the site of ten such attacks, more than the number of attacks perpetrated in the Middle East, East Asia, and Latin America combined. Unlike southern Africa, in which most attacks were in one country and by one group (UNITA), in eastern Africa, incidents have occurred in four different countries—Chad, Sudan, Kenya, and Somalia—and were carried out by six known NSAGs.

Outside Africa, Europe and Eurasia and South and Central Asia are notable for MANPADS attacks against civilian aircraft. These two regions have been the site of ten and eight attacks, respectively. The attack pattern in South and Central Asia resembles that of southern Africa, as the incidents are clustered in a single country mired in a proxy war; seven of eight attacks occurred in Afghanistan in the 1980s and early 1990s. All these attacks are believed to have been carried out by Afghan rebels, including by U.S.-supported mujahideen. As in Angola, the MANPADS models used in attacks in Afghanistan are frequently unknown. However, U.S.-provided Stingers were used in the three incidents in which the MANPADS type can be identified. In Europe and Eurasia, half of the MANPADS attacks against civilian airliners (five of ten) occurred in the breakaway region of Abkhazia in Georgia. The perpetrators were Abkhazian separatists, a movement supported by Russia. Unsurprisingly, the identifiable MANPADS in those incidents were all Russian-made SA-7s.

Figure 3.2 offers a global overview of the locations of all 65 attacks in our data set.

Conflict Type and Intensity

As the previous section suggests, most MANPADS attacks against civilian airliners occur in conflict zones. These attacks overwhelmingly occur during civil, rather than in interstate, wars. To more precisely determine if a country was afflicted by a civil conflict during the time of a MANPADS attack, we used the Armed Conflict Dataset (ACD) from the Uppsala Conflict Data Program (UCDP).[7] Of the 65 incidents in RAND's data set, 59 occurred during a war, and all but one of those wars were civil wars. Put the opposite way, fewer than 10 percent of attacks occurred in countries at peace. The wars where MANPADS attacks occur also tend to be high-intensity wars. If we define high-intensity as involving least 1,000 battle deaths in a conflict year, 42 attacks (65 percent of all attacks) occurred during a high-intensity conflict.

Of further significance is the role of third-party actors in many of these wars. In 37 percent of attacks, there was an external intervener (a state supporting one side of the conflict with its own troops).[8] This figure likely understates the role of foreign involvement, as data

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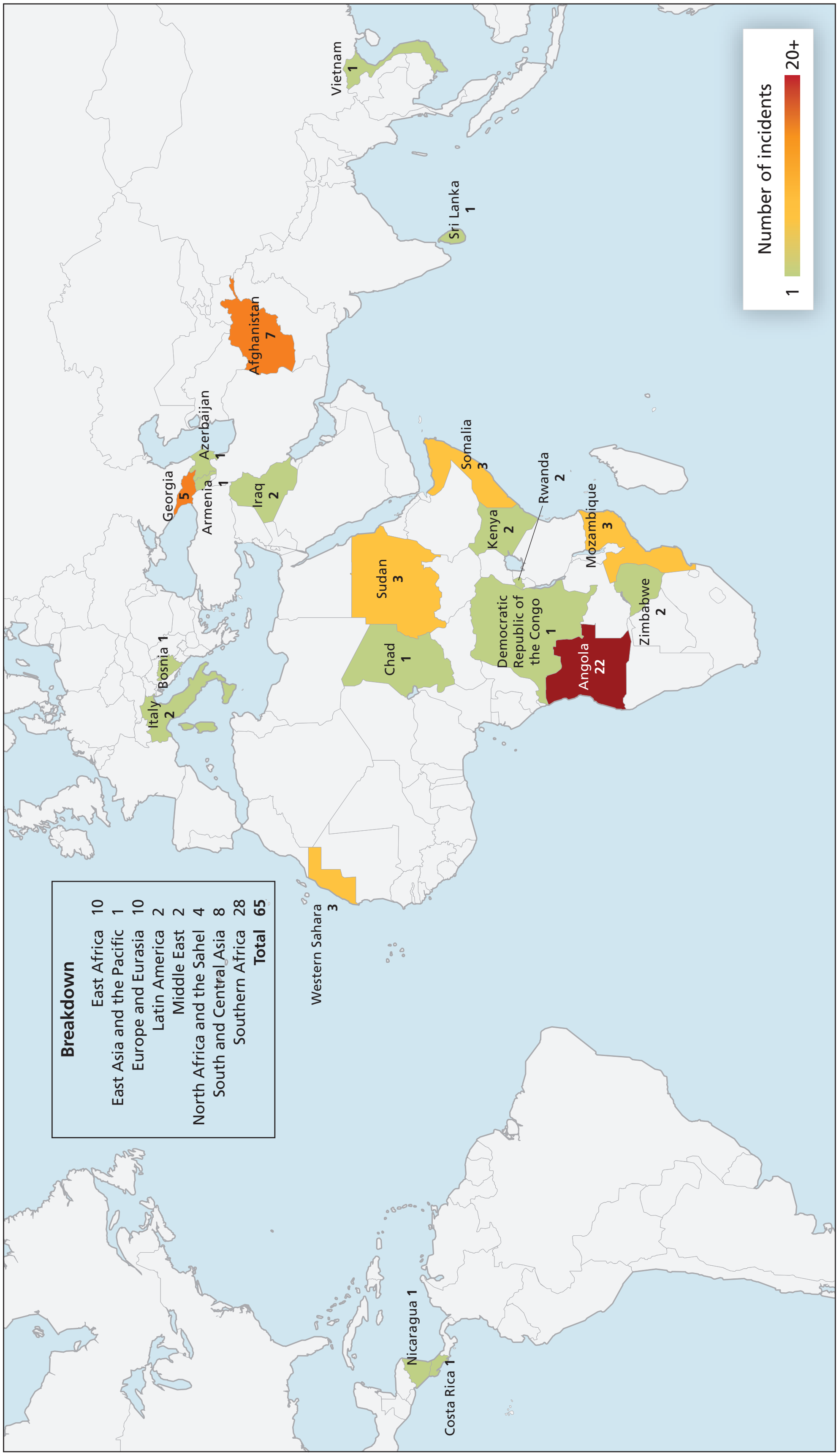
7 We used the updated data (version 81.1) from the original data release (Nils Petter Gleditsch, Peter Wallensteen, Mikael Eriksson, Margareta Sollenberg, and Håvard Strand, "Armed Conflict 1946–2001: A New Dataset," *Journal of Peace Research*, Vol. 39, No. 5, September 1, 2002, pp. 615–637). The data set defines a conflict as "a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths." The data set is available at Mihai Croicu and Ralph Sundberg, "Uppsala Conflict Data Program Georeferenced Event Data set Polygon Global Version 19.1," Uppsala, Sweden: Department of Peace and Conflict Research, Uppsala University, 2012; the data span the years 1946 to 2017.

8 In the data, these states are coded as *SideA2nd* and *SideB2nd*, which enter the conflict "with troops" to actively support one side or another. See Gleditsch et al., 2002, for more details.

Figure 3.2
Global MANPADS Attacks

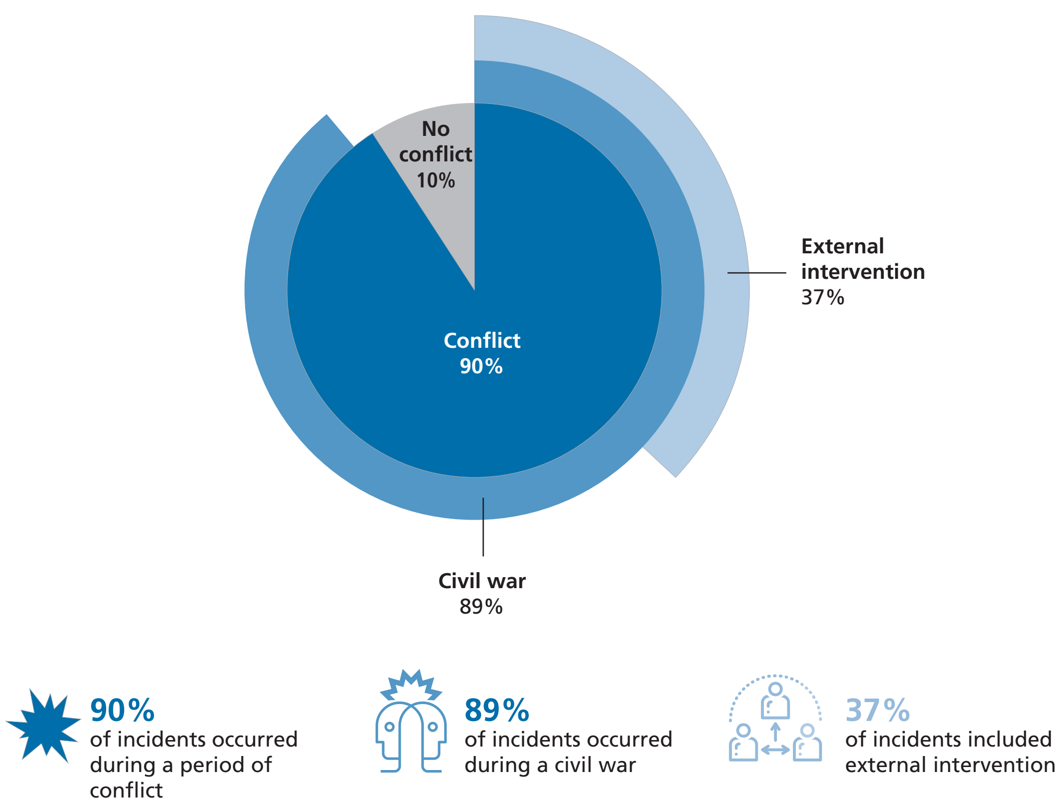


on external intervention only applies to states that have deployed forces to the conflict in the year the attack occurs. In many incidents, the perpetrator had strong links to and a history of receiving assistance from a state sponsor (e.g., Abkhazian separatists' ties to Russia), even if it did not receive troop deployments from this sponsor. In other cases, the attack occurred after external interveners withdrew (e.g., Angola from 1990–1998), but the perpetrators had previously received foreign assistance. Figure 3.3 presents a visual depiction of the prevalence of MANPADS attacks in conflict zones, as well as those conflicts with external intervention.

Attacks Over Time

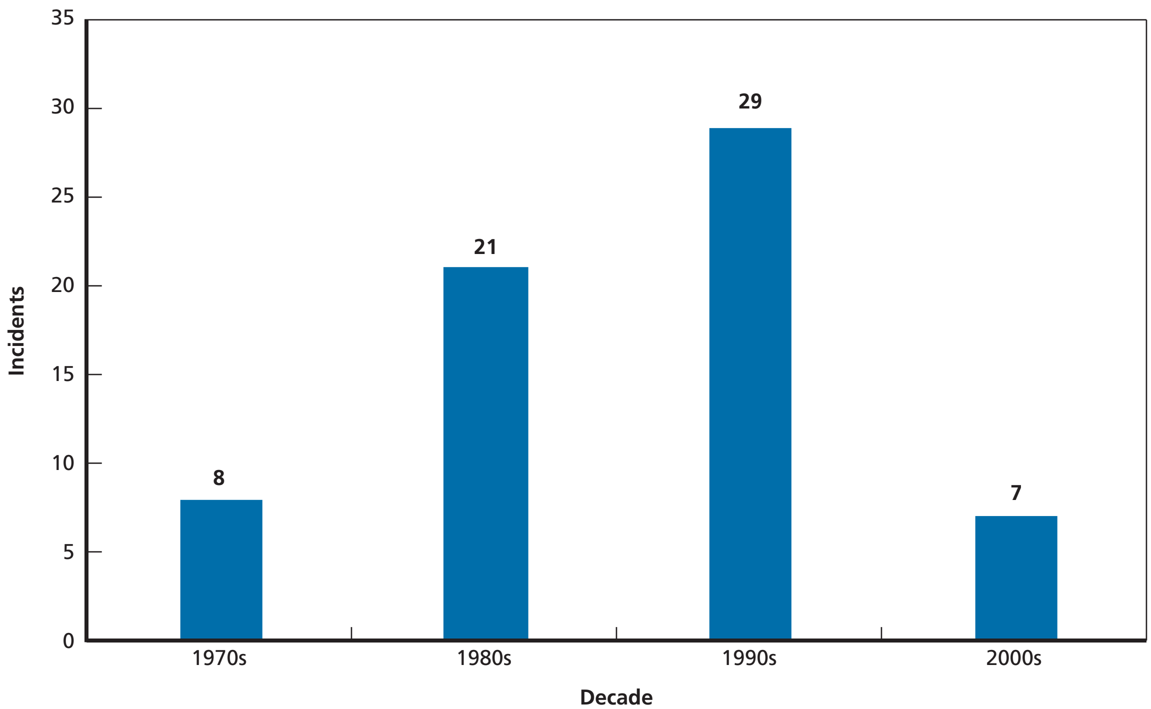
Examining the frequency of attacks over time shows that the attacks are not evenly distributed over time (Figure 3.4). The two decades with the highest numbers of MANPADS incidents against civilian aircraft were the 1980s and 1990s, suggesting that Cold War competition and its associated conflicts were likely underlying factors. Even before the 1980s, Cold War competition played a part; the earliest and deadliest attacks in the 1970s were carried out by the Zimbabwe People's Revolutionary Army (ZIPRA), which received support from the Soviet Union. In the 1980s, 21 attacks occurred. In the 1990s, 29 attacks occurred, and most of those incidents—21 of 29—occurred in the context of unresolved conflicts from the Cold War (e.g., Angola, Afghanistan) or in conflicts related to the Soviet Union's breakup (Abkhazia).

Figure 3.3
MANPADS Attacks and Conflict Prevalence



SOURCE: RAND analysis and Gleditsch et al., 2002.

Figure 3.4
Number of MANPADS Attacks by Decade



A second important finding about MANPADS attack frequency is that NSAGs often carry out repeat attacks within a short time frame. For instance, the Palestinian group Black September attempted two MANPADS attacks in Italy within a year. Afghan Mujahideen carried out repeat attacks on multiple occasions; UNITA launched four MANPADS attacks within a space of four months in 1991; and Abkhazian separatists attempted five MANPADS attacks within three months in 1993.

MANPADS Type, Targets Engaged, and Effects

Public reporting usually does not include information on the MANPADS type used in an attack against a civilian aircraft. In less than half of all incidents—26 of 65—are the MANPADS type known. In at least 16 of the 25 incidents in which model type is known, the Russian-made SA-7 (a first-generation MANPADS) is believed to have been the weapon used. In seven incidents, U.S.-made Stingers (a third-generation MANPADS) is believed to have been used. That said, the precise ratio of Russian to U.S. manufactured systems used in historical attacks is unknown. However, many of the attacks in which the MANPADS model could not be identified occurred in Angola and Afghanistan, places in which NSAGs received U.S. support. That applies to 22 of the incidents in which the MANPADS type could not be identified.

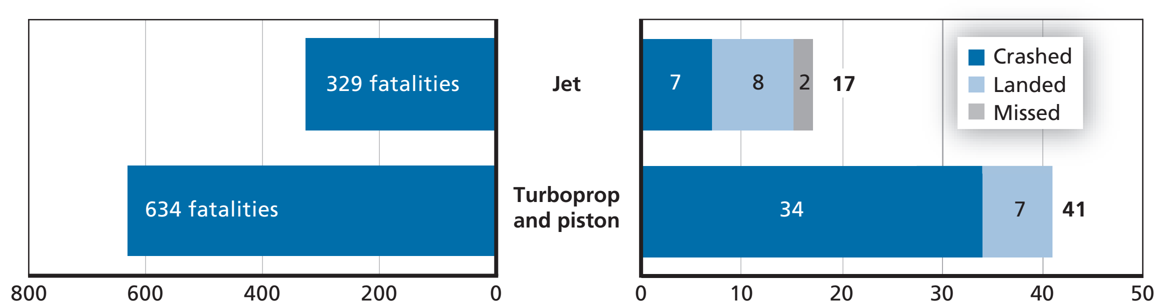
As previously noted, MANPADS are generally categorized by generation, with later generations being more sophisticated. The majority of the attacks in which the MANPADS model is known are believed to have been carried out with first-generation systems. However, in nine attacks, the perpetrators used an SA-16 (a second-generation system), a Stinger (a third-generation system), or an SA-18 (a third-generation system).[9]

Another matter of interest concerns the selection of targets. We distinguish between the type of aircraft targeted in an attack—turboprops or piston-engine planes and jets. In 63 percent of attacks, the target was either a turboprop or piston-engine plane. These aircraft fly considerably slower and lower than aircraft using jet engines, likely making them easier to successfully target. Attackers also had a much higher success rate in striking this target set. In 34 of 41 attacks, the plane crashed, resulting in a total of 634 deaths. In the 17 attacks against planes with jet engines, only seven crashed. However, these seven crashes killed 329 people, considerably more per successful attack than attacks against turboprop and piston engines. Larger jets are less vulnerable to MANPADS, but they usually carry more passengers, making an attack that much more lethal. Figure 3.5 summarizes these findings.

The historical data show that higher-intensity conflicts were overwhelmingly the sites of MANPADS attacks against civilian airliners. Most of these attacks took place in southern Africa. External intervention by other countries into civil conflicts was also a key feature of many attacks. Many attacks were repeat attacks carried out in the 1980s and 1990s.

Fortunately, NSAG use of MANPADS against civilian aircraft is uncommon. Since the first attack of this type was recorded, there have been an average of 1.4 attacks annually. The number of attacks has fallen in recent years; 2018 was the 11th consecutive year without an attack on a civilian airliner. However, as the next chapter of the report illustrates, vigilance is necessary. Although MANPADS attacks against civilian aircraft are relatively rare, the attacks that do succeed are quite lethal. The 65 attacks killed over 1,000 people. On two occasions, more than 100 passengers were killed in single incidents. Moreover, the 2011 Arab Uprisings have led to leakage of MANPADS from stores in Libya and Syria, and two recent attacks, a 2007 incident in Somalia and a 2002 incident in Kenya, were carried out by NSAGs.

Figure 3.5
MANPADS Attack by Aircraft Type and Fatalities



SOURCE: The attacks total 58, rather than 65, because three attacks were foiled "left of launch" and four attacks involved an unknown airplane engine type. We note that these statistics might reflect the fact that turboprops might make up a higher proportion of aircraft in less-developed, war-torn countries.

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9 There is also a tenth incident—the 2003 attack on a DHL cargo plane in Iraq—which could have involved a second-generation MANPADS.

CHAPTER FOUR

NSAG Risk Index

This chapter presents a framework for analyzing the risk of NSAGs using MANPADS against commercial aviation. We built the index around a comprehensive list of 57 NSAGs that have either been suspected of acquiring or known to acquired MANPADS.[1] This index can be used in several ways. The risk index can help the U.S. government's interagency MANPADS Task Force prioritize abatement measures, allocate engagement and programs with foreign partners across regions, and focus the collection and analysis of indications and warning (I&W) information. For example, the risk index can help offices like the Department of State's Bureau for Political Military Affairs prioritize programming in East Africa, South Asia, or other regions. Similarly, the Transportation Security Administration could use the risk index to select partner engagements for raising threat awareness. In addition, U.S. Intelligence Community components that track MANPADS threats could incorporate these indications and warnings into the design of their own collection requirements.

Approach

The basic methodological approach that lies behind the index is that the risk of an NSAG using MANPADS against commercial aviation is a function of two independent components: *capability* and *intent*. Certain NSAGs possess the required capability to conduct a MANPADS attack against a civilian aircraft, just as certain NSAGs are highly interested in conducting such an attack. However, carrying out a successful MANPADS attack on commercial aviation requires both components. Separating the two factors of risk allows for a refined focus on a subset of groups that possess both attributes. Importantly, this two-pronged approach allows us to draw attention to which missing factor (a gap in capability or a lack of intent) might currently prevent an NSAG from engaging in these types of attacks. This information may also help inform the design of mitigation measures calibrated to specific NSAGs.

We highlight that the indicators of capability and intent used in the NSAG risk index are confined to publicly available information. We do not consider indicators that could be more reliable measures of risk but for which data are not available or prohibitively difficult to collect. For example, during the 2013–2014 French intervention in Mali, instructions written by

[1] NSAG data were drawn from multiple sources: a keyword search on the Jane's Information Group website (Jane's by IHS Markit, homepage, undated); Small Arms Survey, *Armed Groups and Guided Light Weapons: 2014 Update with MENA Focus*, Geneva, Switzerland, No. 47, December 2014; U.S. Department of State, Bureau of Political-Military Affairs, undated; Ashkenazi et al., 2013, p. 28; and Michael Knights, "The Houthi War Machine: From Guerilla War to State Capture," *CTC Sentinel*, Vol. 11, No. 8, September 2018, pp. 15–23.

al-Qaida in the Islamic Maghreb for using MANPADS were uncovered.[2] Such instructions would be an excellent indicator of capability—as they suggest at least rudimentary training—and potential intent. However, it would be incredibly difficult to use this information as part of our index, as comparable examples could not be easily collected across the spectrum of terrorist groups. Instead, our index is composed of indicator questions that are easily observed across groups.

We first describe the index's capability component. It is a composite of the answers to four interrogatives or indicator questions. All the groups in the index were either suspected or known to have acquired MANPADS.

The first interrogative is composed of two related questions: (1) Is the NSAG confirmed to have acquired a MANPADS or only suspected of acquisition? and (2) Which generation of MANPADS system is the group thought to or known to possess? The second interrogative examines whether the NSAG receives state support and, more specifically, whether it receives weapons transfers. This is important because, although NSAGs can acquire MANPADS by looting weapons stores or through the black market, our historic attack data suggest that most NSAGs obtain MANPADS through foreign patrons. The third interrogative asks if the NSAG has previously used MANPADS, either against military or civil aviation. The fourth interrogative addresses operational tempo, asking if the NSAG has conducted ten or more terrorist attacks in the last year.[3]

The coding is trichotomous; NSAGs are coded with a 0, 1, or 2 or 1, 2, or 3 for every indicator.[4] For example, if an NSAG is only suspected to have acquired MANPADS, the group receives 1 for the first capability question. If the NSAG is confirmed to possess first- or second-generation MANPADS, the group is coded as a 2 for that question. If the NSAG is confirmed to possess third- or fourth-generation MANPADS, the NSAG receives a 3 for that category. This trichotomous coding is applied to all questions. Figure 4.1 summarizes this coding approach.

The second component of the index captures intent (see Figure 4.2). The first indicator of intent asks if the NSAG is involved in a current conflict or in one that has ended within the past five or ten years.[5] Again, the choice of indicators is informed by the historical record, in which 90 percent of attacks occurred during a conflict; the majority of these attacks happened during high-intensity civil wars. The second indicator asks whether the NSAG has previously targeted *commercial* aviation with MANPADS. The distinction between this indicator and the related one in the capability component is that this question addresses a group's *intent* to specifically target civilian aviation. The third indicator asks if the NSAG has a past history of attacking aviation or airport infrastructure with weapons of any type (e.g., rocket-propelled grenades, antitank guided missiles, bombings, small-arms attacks).[6] The fourth indicator asks whether the NSAG has killed large numbers of civilians in an attack; such mass killings indicate that the group tolerates or even seeks a large number of civilian deaths in its targeting. As

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2 Rukmini Callimachi, "Mali Manual Suggests Al-Qaida Has Feared Weapon," Associated Press, June 11, 2013.

3 To code this indicator, we relied on data from the National Consortium for the Study of Terrorism and Responses to Terrorism, 2018.

4 We use 0, 1, or 2 when some portion of the NSAGs have not engaged in the relevant activity. For instance, because not all NSAGs in the index have used MANPADS against civil aviation, a 0 is possible for that category.

5 We code the five- or ten-year cutoffs using Gleditsch et al., 2002.

6 To code this indicator, we relied on data from the National Consortium for the Study of Terrorism and Responses to Terrorism, 2018.

Figure 4.1
Capability Index Questions

Capability Indicators
❑ Is NSAG suspected or known to have acquired MANPADS? What generation? Score: Only suspected =1; Confirmed 1st or 2nd Gen =2; Confirmed 3rd or 4th Gen =3
❑ Does NSAG receive state support? If so, does such support include weapons transfers? Score: No state support =0; State support (no weapons) =1; State support with weapons =2
❑ Has NSAG employed MANPADS in attack on aviation? Score: No attacks =0; 1 attack =1; ≥ 2 attacks =2
❑ Has NSAG conducted frequent terrorist attacks in the last year? Score: 0-9 attacks =1; 10-24 attacks =2; ≥ 25 attacks =3
❑ Sum of Capability Scores (0-10)

Figure 4.2
Intent Index Questions

Intent Indicators
❑ Is NSAG active in current or prior conflict? Score: Not active in conflict (within 10 years) =0; Active in conflict (within 6-10 years) =1; Active in conflict (within 5 years) =2
❑ Has NSAG used MANPADS in attack on civil aviation? Score: No attacks =0; Failed attack =1; Successful attack(s) =2
❑ Has NSAG attacked airports/aircraft with other weapons? Score: No attacks =0; 1-5 attacks =1; ≥ 6 attacks =2
❑ Has NSAG killed large numbers of civilians in a single attack? Score: No attack killing at least 50 civilians =1; Killed between 50 and 99 civilians in an attack =2; ≥ 100 civilians killed in an attack =3
❑ Sum of Intent Scores (0-9)

MANPADS attacks against civilian aircraft obviously are meant to cause civilian fatalities, it is important to distinguish between groups that show little compunction in killing civilians (e.g., al-Shabaab) and those that have shown some inclination to avoid large-scale civilian fatalities (e.g., the Provisional Irish Republican Army). Like the intent questions, these are subjected to a trichotomous coding of 0, 1, or 2 or 1, 2, or 3.

The trichotomous coding for the intent questions enables more precise distinctions between groups than a binary coding scheme. For the first question, a 0 indicates that the NSAG has not participated in a conflict in the past ten years, a 1 indicates that the NSAG has participated in a conflict within six to ten years, and a 2 indicates that the NSAG has participated in a conflict within the past five years. For the second question, a 0 denotes that the NSAG has not attempted an attack, a 1 indicates that the NSAG has attempted an attack (but the missile missed the target or the plot was thwarted prior to launch), and a 2 indicates that the NSAG has successfully struck a commercial plane with MANPADS. For the third question, if the NSAG has not attempted to attack these targets, it is coded as a 0; if the NSAG has conducted one to five attacks of this variety, it is coded as a 1; and if the NSAG has conducted six or more such attacks, it is coded as a 2. For the final question, a 0 denotes that the NSAG has not executed an attack killing at least 50 civilians, a 1 indicates that the NSAG has killed 50 to 99 civilians in a single attack, and a 2 indicates the NSAG has killed 100 or more civilians in an attack. There are four indicator questions for each component (capability and intent), and a 2 or a 3 is the highest score for each question. The maximum score an NSAG could receive on the capability component is a 10, and the maximum score on the intent component is a 9. The higher the score, the greater the associated risk that the NSAG might conduct a MANPADS attack against civilian aviation. Because there is likely disagreement over which individual factors are the most important reflection of risk, we intentionally do not adopt a subjective weighting system and present the scores for each group as the single sum of all questions. Finally, the framework is designed to be capable of incorporating more groups that become suspected of or confirmed as acquiring MANPADS.

Outcome of the NSAG Risk Index

Table 4.1 presents the comprehensive list of the 57 NSAGs in the index and their associated risk scores across the two components. As a visual aid for interpreting the results, all cells are color coded: Red cells correspond to scores of 2 for the trichotomous coding of 0, 1, or 2, and 3 for the trichotomous coding of 1, 2, or 3; orange cells correspond to a score of 1 or a 2, depending on which trichotomous coding is applied; and yellow cells indicate a score of 1 or 0, depending on the same consideration. The groups are also presented in order (highest to lowest) when their capability and intent scores are summed.[7]

Several important patterns emerge from the NSAG risk index. The first is that, although the Middle East and North Africa and the Sahel have not been frequent sites of historic attacks, these regions might have the greatest risk of future attacks. Historically, sub-Saharan Africa, East Africa, Europe and Eurasia, and South and Central Asia were the most frequent sites of MANPADS attacks on commercial aviation. However, four of the top five highest scoring groups in this index—ISIS, Hayat Tahrir Al-Sham (HTS), other Syrian opposition groups, and the Kurdistan Workers' Party (Partiya Karkerên Kurdistanê; PKK)—are primarily based in the Middle East.[8] The only non–Middle Eastern group in the top five, al-Shabaab, is an al-Qaida affiliate that operates just outside the region in Somalia. Table 4.2 depicts the regional breakdown of NSAGs confirmed or suspected to have acquired MANPADS.

A second finding with important policy considerations is that U.S. and partner governments involved in mitigating this threat should consider groups with a large differential between their capability and intent scores for clues as to which mitigation measures are best tailored to NSAGs of specific types. For instance, some groups score relatively low on capability, but relatively high on intent. This suggests that key mitigation measures could emphasize

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7 We do so for ordering purposes only. Other mechanisms for ordering may be more appropriate depending on which factors are deemed more or less salient indicators of risk.

8 Table 4.1 uses the name Al-Nusra Front, in accordance with the U.S. Department of State's FTO list (see U.S. Department of State, "Foreign Terrorist Organizations," webpage, undated). Al-Nusra Front, an al-Qaida affiliate fighting against the Syrian regime, functioned under that name until July 2016, when the organization rebranded as Jabhat Fatah al-Sham. The group rebranded again in January 2017, adopting the name "Hayat Tahrir al-Sham." The Department of State amended its May 2014 designation of al-Nusra Front to include HTS on May 31, 2018 (see U.S. Department of State, Office of the Spokesperson, "Amendments to the Terrorist Designations of al-Nusrah Front," May 31, 2018).

Table 4.1
Risk Index for NSAG Use of MANPADS Against Civilian Airliners

		Indicators of Capability					Indicators of Intent					
NSAG	Country of Operation	Has NSAG Acquired MANPADS? (i)	Does NSAG Receive State Support? (ii)	Has NSAG Used MANPADS in Attack on Aviation? (iii)	Has NSAG Conducted Terrorist Attacks in the Last Year? (iv)	Sum of Capability Scores (v)	Is NSAG Active in Current or Recent Conflict? (vi)	Has NSAG Used MANPADS Against Civil Aviation? (vii)	Has NSAG Attacked Airports/ Aircraft with Other Weapons? (viii)	Has NSAG Killed More than 50 Civilians in Single Attack? (ix)	Sum of Intent Scores (x)	Sum of Capabilities and Intent Scores (xi)
Al-Nusra Front	Syria	3	2	2	3	10	2	0	1	3	6	16
Syrian opposition	Syria	3	2	2	3	10	2	0	1	3	6	16
Al-Shabaab (AS)	Somalia	3	0	1	3	7	2	2	2	3	9	16
National Union for the Total Independence of Angola (UNITA)	Angola	3	2	2	1	8	0	2	2	3	7	15
Taliban	Afghanistan	3	2	0	3	8	2	0	2	3	7	15
Islamic State of Iraq and the Levant (ISIL)	Syria and Iraq	3	0	2	3	8	2	0	2	3	7	15
PKK	Turkey and Iraq	3	2	1	3	9	2	0	2	2	6	15
Ukrainian NSAGs	Ukraine	3	2	0	3	8	2	0	2	3	7	15
Houthis	Yemen	3	2	0	3	8	2	0	2	2	6	14
Liberation Tigers of Tamil Eelam (LTTE)	Sri Lanka	2	2	1	1	6	1	2	1	3	7	13
Tehrik-e Taliban Pakistan (TTP)	Pakistan and Afghanistan	2	2	1	3	8	2	0	0	3	5	13
Libyan NSAGs	Libya	2	2	1	3	8	2	0	2	1	5	13
ISIL Sinai Province	Egypt	3	0	1	3	7	2	0	1	3	6	13

Table 4.1–Continued

		Indicators of Capability					Indicators of Intent					
NSAG	Country of Operation	Has NSAG Acquired MANPADS? (i)	Does NSAG Receive State Support? (ii)	Has NSAG Used MANPADS in Attack on Aviation? (iii)	Has NSAG Conducted Terrorist Attacks in the Last Year? (iv)	Sum of Capability Scores (v)	Is NSAG Active in Current or Recent Conflict? (vi)	Has NSAG Used MANPADS Against Civil Aviation? (vii)	Has NSAG Attacked Airports/ Aircraft with Other Weapons? (viii)	Has NSAG Killed More than 50 Civilians in Single Attack? (ix)	Sum of Intent Scores (x)	Sum of Capabilities and Intent Scores (xi)
Hizballah	Lebanon	3	2	0	1	6	2	0	2	3	7	13
Revolutionary Armed Forces of Colombia (FARC)	Colombia	3	1	1	1	6	2	0	2	3	7	13
Sudan People's Liberation Army (SPLA)	South Sudan	2	2	2	1	7	2	2	1	1	6	13
Al-Qa'ida in the Arabian Peninsula (AQAP)	Yemen	2	0	0	3	5	2	0	2	3	7	12
Hizb-i-Islami - Gulbuddin (HIG) (xii)	Afghanistan	2	2	1	1	6	2	2	1	1	6	12
Popular Front for the Liberation of Palestine (PFLP) (xii)	Israel and Palestinian Territories	1	2	0	1	4	2	1	2	2	7	11
Rwanda Patriotic Front (RPF)	Rwanda	2	2	2	1	7	0	2	0	2	4	11
Polisario Front	Western Sahara	2	2	2	1	7	0	2	0	1	3	10
Islamic Army in Iraq (IAI)	Iraq	2	0	2	1	5	1	2	1	1	5	10
Lord's Resistance Army (LRA)	Uganda, South Sudan. DRC, and CAR	1	2	0	2	5	2	0	0	3	5	10

Table 4.1–Continued

		Indicators of Capability					Indicators of Intent					
NSAG	Country of Operation	Has NSAG Acquired MANPADS? (i)	Does NSAG Receive State Support? (ii)	Has NSAG Used MANPADS in Attack on Aviation? (iii)	Has NSAG Conducted Terrorist Attacks in the Last Year? (iv)	Sum of Capability Scores (v)	Is NSAG Active in Current or Recent Conflict? (vi)	Has NSAG Used MANPADS Against Civil Aviation? (vii)	Has NSAG Attacked Airports/ Aircraft with Other Weapons? (viii)	Has NSAG Killed More than 50 Civilians in Single Attack? (ix)	Sum of Intent Scores (x)	Sum of Capabilities and Intent Scores (xi)
Democratic Republic of the Congo Insurgents	DRC	1	2	0	3	6	2	0	0	1	3	9
Hizbul Mujahideen (HM)	Jammu and Kashmir	1	2	0	3	6	2	0	0	1	3	9
Palestinian Islamic Jihad (PIJ)	Israel and Palestinian Territories	3	2	0	1	6	2	0	0	1	3	9
National Liberation Army (ELN)	Colombia	1	0	0	3	4	2	0	2	1	5	9
Oromo Liberation Front (OLF)	Ethiopia	1	2	0	1	4	2	0	0	3	5	9
Somali National Movement (SNM)	Somalia	2	2	1	1	6	0	2	0	1	3	9
Ansar al-Sharia in Benghazi	Libya	2	0	0	1	3	2	0	2	1	5	8
Chechen NSAG	Russia	1	0	0	2	3	2	0	0	3	5	8
Burundi NSAG	Burundi	1	1	0	2	4	2	0	0	1	3	7
Al-Qa'ida in the Islamic Maghreb (AQIM)	Algeria, Mali, Niger, and Libya	2	0	0	1	3	2	0	1	1	4	7
Armed Islamic Group (GIA)	Algeria	1	1	0	1	3	0	0	1	3	4	7

Table 4.1—Continued

		Indicators of Capability					Indicators of Intent					
NSAG	Country of Operation	Has NSAG Acquired MANPADS? (i)	Does NSAG Receive State Support? (ii)	Has NSAG Used MANPADS in Attack on Aviation? (iii)	Has NSAG Conducted Terrorist Attacks in the Last Year? (iv)	Sum of Capability Scores (v)	Is NSAG Active in Current or Recent Conflict? (vi)	Has NSAG Used MANPADS Against Civil Aviation? (vii)	Has NSAG Attacked Airports/ Aircraft with Other Weapons? (viii)	Has NSAG Killed More than 50 Civilians in Single Attack? (ix)	Sum of Intent Scores (x)	Sum of Capabilities and Intent Scores (xi)
Ansar al-Islam (AAI)	Iraq	3	0	1	1	5	1	0	0	1	2	7
Hamas	Israel and Palestinian Territories	1	1	0	1	3	2	0	1	1	4	7
United Wa State Army (UWSA)	Myanmar	3	2	0	1	6	0	0	0	1	1	7
Sudanese Revolutionary Front	Sudan	1	2	0	1	4	2	0	0	1	3	7
Harakat-ul-Mujahidin (HuM)	Jammu and Kashmir	1	2	0	1	4	0	0	1	1	2	6
Ansar al-Sharia in Tunisia (AST)	Tunisia	2	0	0	1	3	2	0	0	1	3	6
February 17th Martyrs Brigade	Libya	2	0	0	1	3	2	0	0	1	3	6
Al-Nasser Salah al-Deen Brigades (xii)	Israel and Palestinian Territories	1	1	0	1	3	2	0	0	1	3	6
Provisional Irish Republican Army (PIRA)	Ireland and United Kingdom	2	1	0	1	4	0	0	1	1	2	6
Khmer Rouge	Cambodia	1	2	0	1	4	0	0	1	1	2	6

Table 4.1–Continued

NSAG	Country of Operation	Indicators of Capability					Indicators of Intent					
		Has NSAG Acquired MANPADS? (i)	Does NSAG Receive State Support? (ii)	Has NSAG Used MANPADS in Attack on Aviation? (iii)	Has NSAG Conducted Terrorist Attacks in the Last Year? (iv)	Sum of Capability Scores (v)	Is NSAG Active in Current or Recent Conflict? (vi)	Has NSAG Used MANPADS Against Civil Aviation? (vii)	Has NSAG Attacked Airports/ Aircraft with Other Weapons? (viii)	Has NSAG Killed More than 50 Civilians in Single Attack? (ix)	Sum of Intent Scores (x)	Sum of Capabilities and Intent Scores (xi)
Movement for the Oneness and Jihad in West Africa (MUJAO) (xii)	Algeria, Mali, and Niger	1	0	0	1	2	2	0	1	1	4	6
Caucasus Emirate	Russia	1	0	0	1	2	2	0	1	1	4	6
Basque Fatherland and Liberty (ETA)	Spain	1	1	0	1	3	0	0	1	1	2	5
Kosovo Liberation Army	Kosovo	1	2	0	1	4	0	0	0	1	1	5
National Liberation Army	Macedonia	3	0	0	1	4	0	0	0	1	1	5
Shan State Army	Myanmar	1	2	0	1	4	0	0	0	1	1	5
National Movement for the Liberation of Azawad (MNLA)	Mali	1	0	0	1	2	2	0	0	1	3	5
Al-Ansar Brigades (xii)	Israel and Palestinian Territories	1	0	0	1	2	2	0	0	1	3	5
Hutu NSAG	Rwanda	1	0	0	1	2	0	0	0	3	3	5
United Somali Congress–Somali Salvation Alliance	Somalia	1	1	0	1	3	0	0	0	1	1	4

Table 4.1–Continued

		Indicators of Capability					Indicators of Intent					
NSAG	Country of Operation	Has NSAG Acquired MANPADS? (i)	Does NSAG Receive State Support? (ii)	Has NSAG Used MANPADS in Attack on Aviation? (iii)	Has NSAG Conducted Terrorist Attacks in the Last Year? (iv)	Sum of Capability Scores (v)	Is NSAG Active in Current or Recent Conflict? (vi)	Has NSAG Used MANPADS Against Civil Aviation? (vii)	Has NSAG Attacked Airports/ Aircraft with Other Weapons? (viii)	Has NSAG Killed More than 50 Civilians in Single Attack? (ix)	Sum of Intent Scores (x)	Sum of Capabilities and Intent Scores (xi)
Jumbish-e-Mili	Afghanistan	1	0	0	1	2	0	0	0	1	1	3
Rally for Democratic Forces (RaFD)	Chad	1	0	0	1	2	0	0	0	1	1	3
Somali National Alliance (SNA)	Somalia	1	0	0	1	2	0	0	0	1	1	3

NOTES: For the NSAGs in this table that are designated FTOs, we have used the spelling found in the most recent U.S. Department of State Country Reports on Terrorism. For NSAGs that are not FTOs, we have used our judgment to select the most recognizable name of the group.
(i) Red: confirmed to possess third- or fourth-generation MANPADS and is scored as a 3; orange: confirmed to possess first- and second-generation MANPADS and is scored as a 2; yellow: suspected to have acquired MANPADS and is scored as a 1.
(ii) Red: receives weapons and logistics aid and is scored as a 2; orange: receives nonweapons and logistics aid and is scored as a 1; yellow: receives no state support and is scored as a 0.
(iii) Red: NSAG has executed multiple MANPADS attacks on aviation of any type, whether civil or military, fixed or rotary wing, and is scored as a 2; orange: NSAG has used MANPADS against only one aviation target of any type and is scored as a 1; yellow: NSAG has never used MANPADS against an aviation target and is scored as a 0.
(iv) Red means NSAG has conducted 25 or more terrorist attacks in 2017 and is scored as a 3; orange means 10–24 attacks in 2017 and is scored as a 2; yellow means 0–9 attacks in 2017 and is scored as a 1.
(v) Scores of 7–10 are coded as red; scores of 4–6 are coded as orange; scores of 0–3 are coded as yellow.*
(vi) Red: NSAG is active in a current conflict or participated in a conflict terminated within the past 5 years and is scored as a 2; orange: NSAG participated in a conflict that terminated 6–10 years ago and is scored as a 1; yellow: NSAG has not participated in a conflict in the past 10 years and is scored as a 0.
(vii) Red: NSAG successfully struck a civilian aircraft with MANPADS and is scored as a 2; orange: NSAG attempted a MANPADS attack but missed or the attack was foiled and is scored as a 1; yellow: NSAG has never attempted an attack and is scored as a 0.
(viii) Red: NSAG has conducted 6 or more attacks on airports or aircraft in its history and is scored as a 2; orange: NSAG has conducted 1–5 attacks on airports or aircraft and is scored as a 1; yellow: NSAG has never conducted an attack on airports or aircraft and is scored as a 0.
(ix) Red: NSAG has conducted an attack resulting in 100+ deaths and is scored as a 3; orange: NSAG has conducted an attack resulting in 50–99 deaths and is scored as a 2; yellow: NSAG has not conducted an attack resulting in at least 50 deaths and is scored as a 1.
(x) Scores of 7–9 are coded as red; scores of 4–6 are coded as orange; scores of 0–3 are coded as yellow.
(xi) Scores of 13–19 are coded as red; scores of 8–12 are coded as orange; scores of 0–7 are coded as yellow.
(xii) Some NSAGs included in the Risk Index were not indicated as active within the last 10 years in the UCDP ACD due to the groups causing fewer than 50 battlefield deaths. However, we choose to code these groups as “active in current or recent conflict,” as they played an active, albeit minor, role in a recent conflict.
* We use 2017 as a measure of terrorist activity; as of the time of writing, the GTD was current only up to 2017.

Table 4.2
Regional Breakdown of NSAGs

Region	Number of NSAGs
North Africa and the Sahel	13
Middle East	12
East Africa	8
South and Central Asia	8
Europe and Eurasia	8
East Asia and the Pacific	3
Sub-Saharan Africa	3
Latin America	2

denying these groups access to equipment and training and freedom of movement near commercial aviation. Other groups, such as the United Wa State Army (UWSA), which operates in Myanmar, score relatively high on capability but not on intent. For groups with this type of profile, the key mitigation measures might involve maintaining the underlying conditions that lower intent (e.g., ceasefires, opportunities for inclusion, strong group command and control).

A final observation is the still-considerable risk of future MANPADS attacks against civilian aircraft, even though such an attack has not occurred in more than a decade. Fifty-seven NSAGs are suspected or confirmed to possess MANPADS, and many of these groups have demonstrated the capability to execute such an attack. Moreover, several NSAGs have been using MANPADS against military targets, and some of the most capable groups exhibit little concern for the loss of civilian life.

Limitations

We highlight two limitations to our index. First, because we partially constructed the index around the empirical record of past attacks, the index will not necessarily capture any major shift in MANPADS usage. As an example, the historic record suggests that state sponsorship, often in the form of support during a proxy war, is an important indicator of risk. However, if NSAGs eschew state support in favor of raiding MANPADS stockpiles or buying from the black market, the index's current indicators of access would be invalidated. Similarly, the historic record suggests that NSAGs most often use MANPADS attacks against civilian aircraft in the context of civil war. If the basic relationship between conflict and MANPADS usage changes, the risk index would not be well calibrated to this new environment.

The second limitation is that the index is based on open-source information about NSAGs that already are suspected or confirmed to have acquired MANPADS. Many more groups could pose a threat, but there is no open-source information about their access to MANPADS. Lashkar-e-Tayyiba, which perpetrated the 2008 Mumbai attacks, is a notable example of a terrorist group in this category. Moreover, a heretofore unknown NSAG could acquire and use MANPADS. For instance, Venezuela is believed to have the largest stockpiles of MANPADS in Latin America, and the country exhibits many of the indicators associated with the onset of civil war.[9] With the continued unrest in Venezuela, trained soldiers could defect to opposition groups. Furthermore, many of Venezuela's MANPADS are of relatively sophisticated third-generation SA-24s. This scenario would appear to raise the risk of MANPADS use against civilian aircraft in Venezuela, but it would not be reflected in our NSAG risk index, which is driven by the characteristics of existing NSAGs, not by state characteristics.

Motivated in part by these limitations, we present updated information on MANPADS stockpiles—both imported and domestic—in the following chapter. We pair this information with an indicator of state fragility to help assess countries and areas potentially at risk of MANPADS attacks.

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9 Girish Gupta, "Exclusive: Venezuela Holds 5,000 Russian Surface-to-Air MANPADS Missiles," Reuters, May 22, 2017.

CHAPTER FIVE

MANPADS Stockpiles and State Fragility

This chapter details weapon stockpiles worldwide to help evaluate the risk of potential MANPADS use against civilian aviation. Depending on the proliferation of weapons, they may fall into the hands of NSAGs via various mechanisms. We examine two of them below. The first is the possibility that NSAGs acquire the systems though stockpile leakage. This is most likely to occur in unstable states. For this reason, we pair MANPADS proliferation with a state fragility index. The second is that MANPADS are delivered to NSAGs via state support from producer or exporter countries. We conclude with a discussion of emerging issues to watch.

We gathered data on worldwide MANPADS stockpiles by country. This data was drawn from three sources: (1) the Stockholm International Peace Research Institute (SIPRI) Arms Transfers Database, (2) Ashkenazi et al., 2013, and (3) Jane's by IHS Markit.

Appendix B contains a complete list of all country stockpile numbers. It also indicates which countries are known producers of MANPADS.

Stockpile Leakage in Fragile States

Countries with MANPADS stockpiles are not all equally prone to internal instability and potential weapons leakage. Internal instability has various sources, such as ethnic tensions, religious differences, and competition over resources. To address this variation, we use a country-specific indicator of state stability known as the Fragile States Index (FSI). Based on a conflict assessment framework, the FSI is intended to ascertain the vulnerability of state collapse in 178 countries. It contains 12 conflict risk indicators spread across four main areas of interest: state cohesion, economics and development, political stability, and social pressures.[1] The scores from each of the component indicators are then triangulated based on three streams of data—quantitative, qualitative, and expert validation—to produce a final index score. These scores range from ten to 120; the lower the score, the less fragile the country. In 2019, Finland had the lowest score (16.9), while Yemen earned the highest (113.5).

Table 5.1 presents the countries that possess at least 1,000 MANPADS (along with the system types) and have an FSI score of 70 or greater. FSI ratings between 70–89.9 are coded as yellow, 90–99.9 as orange, and 100 and above as red, and countries are broken into tiers corresponding to their respective FSI scores.

As is evident in the table, some highly fragile states possess these weapons in the many thousands. Syria is the most unstable country in the table, with an FSI score of 111.5; it also

1 For more details on the FSI, see Fund for Peace, *Fragile States Index Annual Report 2019*, Washington, D.C., 2019.

Table 5.1
MANPADS Stockpiles and State Fragility

FSI Ratings		Country	Total Systems	FSI Score	Systems in Country
		United States	50,000–90,000	38.0	SA-16, SA-18, Stinger
	100+	Syria	17,210	111.5	SA-7, SA-14, SA-18, SA-24, FN-6
		Afghanistan	4,500	105.0	Redeye, HN-5A, SA-7, SA-14, SA-16, Stinger, Blowpipe
	90–99.9	Iraq	9,700	99.1	HN-5A, SA-7, SA-14, SA-16, SA-24, Stinger, Misagh-1
		Ethiopia	1,700	94.2	SA-7
		Pakistan	8,091	94.2	HN-5A, Anza-MK I, SA-16, Anza-MK II, Anza-MK III, QW-1, Stinger, Mistral, FN-6, RBS-70
		North Korea	7,000	92.7	HN-5A, SA-7, SA-14, SA-16
		Libya	21,482	92.2	SA-7, SA-14, SA-24, FN-6
	70–89.9	Venezuela	4,500	89.3	SA-18, SA-24, Mistral, RBS-70
		Egypt	12,664	88.4	SA-7, Ayn al-Saqr, SA-18, SA-24, Stinger
		Angola	1,760	87.8	SA-7, SA-14, SA-16, Stinger
		Iran	5,400	83.0	HN-5A, SA-7, SA-14, SA-18, QW-1, QW-11, Misagh-1, Misagh-2, SA-24, Stinger, RBS-70
		Cambodia	1,283	82.5	SA-7, HN-5A, FN-6
		Turkey	6,448	80.3	Redeye, SA-7, SA-18, Stinger
		Nicaragua	2,427	78.1	Redeye, SA-7, SA-14, SA-16
		Israel	1,839	76.5	Redeye, SA-7, Stinger
		Jordan	2,960	75.9	Redeye, SA-7, SA-14, SA-16, SA-18, SA-24, QW-2, Mistral, Starburst
		Algeria	1,000	75.4	SA-7, QW-2
		Russia	46,000–140,000	74.7	SA-7, SA-14, SA-16, SA-18, SA-24, SA-29
		India	13,395	74.4	SA-7, SA-14, SA-16, SA-18, SA-24, Stinger, Mistral
		Azerbaijan	1,018	73.2	SA-7, SA-16, SA-14, SA-18, SA-24
		Thailand	1,946	73.1	Redeye, HN-5A, QW-18, SA-24, Mistral, Blowpipe, Starstreak, RBS-70
		China	46,000	71.1	SA-7, HN-5, QW-1, QW-2, QW-3, QW-4, QW-11, QW-18, FN-6, FN-16
		Ukraine	1,210	71.0	SA-7, SA-14, SA-16, SA-18
		Indonesia	1,722	70.4	SA-16, QW-3, Grom-2, Mistral, Chiron, Starstreak, RBS-70
		Saudi Arabia	3,730	70.4	Redeye, SA-16, Stinger, Mistral

SOURCE: SIPRI Arms Transfer Database, March 11, 2019; Ashkenazi et al., 2013; Jane's by IHS Markit, undated; and The Military Balance 2019, The International Institute for Strategic Studies.

NOTE: FSI ratings between 70–89.9 are coded as yellow, 90–99.9 as orange, and 100+ as red.

possesses more than 17,000 MANPADS. Libya, another highly fragile state, possesses more than 21,000 MANPADS. These countries' combination of instability and possession of thousands of MANPADS suggest that they likely have the highest risk for stockpile leakage; we know that MANPADS leakage has already occurred in Libya and might have occurred in Syria. Egypt, which possesses thousands of MANPADS, presents some risk as well. Its regime is currently under social pressures. The majority of Libya, Syria, and Egypt's stockpiles are first-generation MANPADS (SA-7 and Sakr Eye), although all three states possess smaller numbers of more advanced systems. Also of note, Iraq and Pakistan present some concern, given the high numbers of systems they have. Afghanistan and Venezuela are also highly unstable countries with thousands of MANPADS.

State-to-State Transfers of MANPADS

Most countries in possession of MANPADS purchase them from other states. Table 5.2 shows the top 11 exporter countries of MANPADS between 2010 and 2018, along with the median FSI of the countries to which they sell. A few points are worth highlighting. First, Russia is far and away the single largest exporter of MANPADS, with more than 10,000 systems sold. Among the countries purchasing Russian MANPADS are Iraq, Venezuela, Kazakhstan, Qatar, and Libya. The United States, France, China, and the United Kingdom are the next most prolific exporters. However, of the top five exporters, China is the country selling MANPADS to the most unstable countries. The median FSI score of countries purchasing MANPADS from China is just over 86. This includes Bangladesh, Pakistan, Sudan, South Sudan and Cameroon. Moreover, China has—at least licitly—exported exclusively more advanced third- and fourth-generation MANPADS, and seven of China's last ten sales since 2010 have

Table 5.2
MANPADS Exports, 2010–2018

Exporter	Total Number of Exports	Median FSI of Recipient
Russia	10,015	72.2
United States	1,669	61.8
France	1,434	68.1
China	1,206	86.1
United Kingdom	880	77.0
Sweden	535	43.0
Denmark	221	32.6
Ukraine	150	88.4
Poland	140	43.2
South Korea	80	80.6
Belgium	25	50.7

SOURCE: The MANPADS stockpile data was drawn from multiple sources, including SIPRI, 2019; Ashkenazi et al., 2013; and Jane's by IHS Markit, 2019.

been fourth-generation FN-6s. (Of note, Ukraine has sold second-generation systems to Chad and Botswana, which accounts for the highest median FSI of its recipients.)[2]

In addition to licit state-to-state transfers, some states have attempted to illicitly transfer weapons to NSAGs. These transfers are covert; as such, analysts are only aware of the portion of those attempts that were discovered. One of the states believed to be involved in such illicit transfers is Iran; several of the NSAGs Iran supports are known to or suspected to have acquired MANPADS, including Hezbollah, Hamas, Palestinian Islamic Jihad, and the Houthis (see Table 4.1).[3]

Not all illicit transfers from states to NSAGs are direct; a state might work through one or more intermediary states to complete the transfer. For example, North Korea has attempted to illicitly transfer weapons to Iran, which Tehran could then provide to its NSAG affiliates.[4] Qatar is also believed to have purchased MANPADS for Syrian NSAGs via Sudan; the MANPADS were ultimately delivered to Syrian rebel groups via shipments to Turkey.[5] In these schemes, an intermediary state with territory contiguous to the NSAG (e.g., Turkey and Syria, Sudan and Libya) is advantageous, as it facilitates the ultimate transfer to the NSAG by allowing overland transport.

In addition to states trafficking in MANPADS, arms traders might traffic MANPADS without state backing. For instance, in 2012 the Lebanese Navy intercepted a ship that embarked from Libya loaded with MANPADS believed to be destined for Syria.[6] A Syrian citizen, who has been implicated in previous episodes of arms trafficking, owned the vessel, and this person was convicted in absentia by Lebanon for arms trafficking in this instance.[7] In addition, the UWSA in Myanmar historically obtains its MANPADS, SA-7s, from Cambodian sources.[8] However, since at least 2013, the UWSA has increasingly procured arms from Chinese arms dealers, who have reportedly provided the group with "upgraded Chinese-built SAMs," likely fourth-generation FN-6 MANPADS.[9]

Emerging Issues

Preventing further proliferation of MANPADS will not only require understanding how the supply chain has worked previously, but how the motivations and means of proliferation might evolve given broader changes in the international security environment. One emerging issue

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2 With the exception of Pakistan, Qatar, and Turkey, there is a notable absence of known state supporters of NSAGs exporting MANPADS. For instance, Iran is absent from the list. However, Iranian shipments of MANPADS to Hezbollah, Hamas, Kataib Hezbollah, and possibly the Houthis would be illicit and therefore not reflected in the SIPRI data.

3 The precise means by which these four groups acquired MANPADS is unknown, and some or all of it could have been acquired through suppliers other than Iran.

4 U.S. Department of State, Bureau of Political-Military Affairs, undated.

5 C. J. Chivers and Eric Schmitt, "Arms Shipments Seen from Sudan to Syria Rebels," *New York Times*, August 12, 2013.

6 Jeremy Binnie, "Igla-S Missiles Found in Libya Arms Shipment," *Jane's Defence Weekly*, April 18, 2013.

7 Hamoud Almahmoud, Delphine Reuter, Catalin Prisacariu, Giampaolo Musumeci, Frédéric Loore, Jean-Yves Tistaert, Nikolia Apostolou, and Safak Timur, "Pirates of the Mediterranean Sea," *Arab Reporters for Investigative Journalism*, March 6, 2016.

8 Jane's by IHS Markit, "United Wa State Army (UWSA)," webpage, July 25, 2013.

9 Jane's by IHS Markit, 2013; U.S. State Department, Bureau of Political-Military Affairs, undated, p. 34.

is the increase in the number of states that have acquired significant stockpiles of MANPADS but are not party to international agreements that are used to build norms against proliferation. Some of these states may also have domestic production capabilities. States with significant stockpiles or domestic production include Egypt, Iran, and Pakistan. None of these three states are signatories to the Wassenaar Arrangement that establishes export controls for conventional weapons. There are 42 signatories to Wassenaar, but only nine of its signatories are non–Organisation for Economic Co-operation and Development countries.[10] This raises questions as to whether international norms around preventing NSAGs from acquiring MANPADS are developing among the set of countries most likely to be proliferators.

Another issue to watch is whether foreign terrorist fighter flows increase the transfer of knowledge of MANPADS use. The precise number of foreign terrorist fighters who traveled to battlefields in Iraq and Syria is unknown, but the United Nations cites estimates that there were about 30,000–40,000 fighters from 120 countries.[11] Some foreign terrorist fighters were killed on the battlefield and others were incarcerated, but some returned to their home countries or fled to third countries. In both Iraq and Syria, MANPADS have proliferated and been used on the battlefield by ISIS and other insurgent groups. An unknown number of foreign terrorist fighters might have acquired experience operating these systems and could seek to apply their knowledge in their home countries or in third countries.

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[10] They are Argentina, Bulgaria, Croatia, India, Malta, Romania, Russian Federation, South Africa, and Ukraine.

[11] United Nations Security Council, Counter-Terrorism Committee Executive Directorate, *The Challenge of Returning and Relocating Foreign Terrorist Fighters: Research Perspectives*, New York, March 2018.

CHAPTER SIX

Economic Consequences of MANPADS Attacks

MANPADS attacks against civilian aircraft, coupled with the local and global policy responses to them, can affect economies over both the short and long term. These consequences might affect local economic growth or have indirect international consequences through changes in trade with other countries, foreign direct investment, or international visitors. However, it is difficult to estimate the economic consequences of such attacks because they generally occur in areas where violence is already high; we have to distinguish between the effects of MANPADS attacks against civilian aircraft from the general effects of terrorism and conflict. In addition, the economic consequences of an attack might be tied to the resulting policy effects. For example, after 9/11, U.S. airspace was closed for two days; many of the estimates of the economic consequences of the attacks are based on that closure.[1] Our methodology attempts to reconcile how different targets of terrorist attacks and types of conflicts differentially affect an economy.

Three general approaches that have been used to characterize and estimate the economic consequences of MANPADS attacks.[2] Much of this literature was written after 9/11. The first approach focuses on calculating the costs of an attack based on the direct loss of life and property, along with the indirect economic effects of changes in air travel caused by policy responses or changes in demand. Much of this work links the changes in travel demand to changes in the macroeconomy using regional or national level models. However, one problem with this literature is that the policy response might drive economic results more than the original attack. A second, related approach uses stated preference techniques to estimate households' willingness to pay for changes in security protocols to decrease the likelihood of future attacks. Importantly, some of this work considers protocols that are a direct response to potential MANPADS attacks. Therefore, specific estimates do exist for MANPADS attacks against civilian aircraft, although the results usually involve economic effects in the United States. The third approach considers the effects of terrorism more broadly on a range of economic indicators such as gross domestic product (GDP), economic growth, trade, and tourism.

Our analysis aims to provide a broad suite of estimates of the economic consequences not directly attributable to policy responses to a MANPADS attack against civilian aircraft. Our goal is to be able to estimate the economic effects if a MANPADS attack were to take place for locations around the world. We constructed a unified data set of economic, terrorism, and conflict variables and consider alternative mechanisms through which a MANPADS attack may affect an economy. Our aim is to produce as consistent an estimate as possible of the effects of a MANPADS attack on the economy of the country in which the attack occurs. Our approach

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1 For example, Chow et al., 2005.

2 The following section discusses each of these research programs in more detail and offers specific examples.

estimates the relationship between MANPADS attacks and multiple dimensions of potential economic consequences. As discussed in previous chapters, there are a limited number of documented MANPADS attacks against civilian aircraft, which restricts our ability to draw significant conclusions based on statistical models about the economic consequences of such attacks. Therefore, we expand our consideration to general terrorist attacks on aircraft in flight, which we expect would have similar consequences in terms of damage to an aircraft, casualties, and economic harm.

In the next section, we provide a brief review of the three approaches, with attention given to tourism responses. A follow-on section provides an overview of our econometric approach. This is followed by a discussion of the data set we constructed for this analysis and our results. We conclude with a discussion of our findings and of the limitations of our approach.

Literature Review

The first stream of literature is focused on estimating the cost, in terms of the loss of life and property, directly attributable to an attack together with the macroeconomic consequences of a policy response and the potential change in air travel demand.[3] The second stream of literature focuses on estimating household willingness to pay for increases in airport security protocols aimed at reducing the probability of a successful attack on airplanes. The last stream of literature combines a variety of economic variables with a set of different terrorism-related variables to estimate how terrorism affects an economy.

Direct Effects and Macroeconomic Policy Responses

Chow et al. consider the economic consequences of a MANPADS attack that downs a commercial airliner in the United States. The authors estimate the total economic costs by adding three categories of costs: (1) the direct lost value of capital and life, (2) losses to airlines and passengers from a shutdown of the U.S. air travel system in the immediate aftermath, and (3) longer-term losses stemming from reduced demand for airline services. Their estimates of the shutdown and demand effects are based on the policy and traveler responses to the 9/11 attacks. Despite the researchers' focus on MANPADS, the economic estimates are agnostic with respect to how an attack is carried out.[4]

The direct cost estimate is about $1 billion per downed commercial airliner—the sum of the cost of the aircraft itself (about $200–250 million) and the estimated economic value of the lost passenger lives. Placing a monetary value on human life involves an "uncomfortable calculation," the authors acknowledge, but is necessary to evaluate policy tradeoffs. They use an estimate of $2–2.5 million per life, based partly on payouts from the 9/11 Victim Compensation Fund, and assume that a downed aircraft would have about 300 passengers.

Chow et al. estimate that the indirect economic costs, resulting from a shutdown of the U.S. air travel system for a period and lingering reluctance to fly, would far exceed the direct

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[3] In most cases, authors opt for one of two approaches with respect to the policy response: a two-day closure of airspace (as with the 9/11 attacks) or, as a potential upper bound, a weeklong closure of airspace. In addition, many authors use the observed decline in demand for air travel after 9/11 to estimate long-term effects. These changes in demand are estimate against a counterfactual of no attack.

[4] Chow et al., 2005.

costs.[5] These costs are the sum of lost consumer and producer surplus—what consumers would have been willing to pay to avoid a shutdown or to feel comfortable flying again—as well as operating losses incurred by the airlines. Core results suggest losses from a shutdown (assumed to last a week) of $3.4 billion and losses in subsequent months stemming from reduced demand for air travel (assumed to be a net reduction in demand of 15 percent lasting for six months) of $12.4 billion, for a total indirect loss of $15.8 billion. These results, the authors note, are roughly consistent with the consequences of the 9/11 attacks. The authors present two alternate scenarios: a one-day shutdown that results in a 10-percent net reduction in air travel for the next two weeks (indirect loss of $1.4 billion) and a one-month shutdown that results in a 25-percent net reduction in air travel for the next year and-a-half (indirect loss of $70.7 billion).

In this framework, the *policy response* in terms of the duration of a shutdown and the *passenger response* after air service resumes are critical determinants of the estimated effect. Should a MANPADS attack have a less pronounced policy or passenger response, for example if law enforcement is able to apprehend the attackers quickly and officials can assure the public that air travel is safe, the estimated economic impact would be lower.[6] Several other studies published after 9/11 provide estimates of the economic costs of terrorist attacks on the U.S. airline industry, albeit without using a MANPADS attack as the entry point.[7] The results vary widely, reflecting their different assumptions and what types of effects they include.

Balvanyos and Lave estimate that the downing of a large passenger aircraft that led to a two-and-a-half-day air system shutdown would cost $6.3 billion—$1 billion for the aircraft, $1.6 billion in costs to the airline industry itself and the industries that supply it (e.g., fuel suppliers), and $4.75 billion in lost consumer surplus.[8]

Santos and Haimes use a standard macroeconomic model of the U.S. economy—an input-output model—to estimate the effect of a decrease in demand for air travel on interconnected industry sectors in the U.S. economy, similar to the supplier effect portion of the Balvanyos and Lave estimate.[9] They find that a 10-percent reduction in demand for air travel for a year would result in costs of about $14 billion when including just the direct effect on the airline industry and the indirect effect on industries that supply goods and services to it. These costs would rise to about $43 billion after accounting for the effects on workers in affected industries and on other industries in the broader U.S. economy.

Gordon et al. also use input-output analysis to estimate economic costs, modeling a one-week U.S. air system shutdown followed by a decrease in demand over two years that tracks with the post-9/11 experience. Their estimates of economic costs range from $214 billion to $420 billion, depending on modeling assumptions and which categories of effects are included. The lower estimate excludes effects from the lower household incomes of workers in directly and indirectly affected industries, and it assumes that demand for telecommunications services would rise by 25 percent during the time air travel was shut down, partially offsetting the costs.

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5 Chow et al., 2005.

6 Chow et al., 2005.

7 Chow et al., 2005.

8 Tunde Balvanyos and Lester B. Lave, *The Economic Implications of Terrorist Attack on Commercial Aviation in the USA*, Los Angeles: Center for Risk and Economic Analysis of Terrorism Events, University of Southern California, Nonpublished Research Reports, Paper 39, September 4, 2005.

9 Joost R. Santos and Yacov Y. Haimes, "Modeling the Demand Reduction Input-Output (I-O) Inoperability Due to Terrorism of Interconnected Structures," *Risk Analysis*, Vol. 24, No. 6, December 2004; Balvanyos and Lave, 2005.

The higher estimate includes the effect on household income (known as the "induced" effect) and assumes that demand for telecommunications services would rise by just 5 percent during the shutdown. In both scenarios, the rise in demand for telecommunications services is assumed to recede over the subsequent two-year period as demand for air travel returns to normal.[10]

Although many authors use the 9/11 attacks as a proxy for potential terrorist attacks' effect on air travel behavior, the scale of that attack was much larger than any of the MANPADS attacks on civilian aircraft discussed previously in this report. Therefore, we test the behavioral response by air passengers using an example attack similar to a potential MANPADS attack—the downing of Malaysia Airline Flight 17 in 2014 by a ground-to-air missile while flying over Ukraine en route to the Netherlands. Using Eurostat data from 2008 through 2017, we estimate the effect of this attack on air passenger behavior.[11] Using two different specifications, we find no effect of the attack on either aggregate European Union data or on Netherlands-specific passenger data. This suggests that an attack on the scale of a MANPADS attack would not have the same impact on air travel demand as the 9/11 attacks. This is in line with the literature discussed below, which finds that more economically developed countries may be better able to absorb isolated terrorist attacks.

Stated Preference Methods

An alternate approach to characterizing the economic consequences of a MANPADS attack explored in the literature is to estimate how much households would be willing to pay for countermeasures that reduce the likelihood or mitigate the effect of an attack. This line of work generally uses a stated preference conjoint survey, also known as a discrete choice experiment. This method presents survey respondents with a discrete set of policy alternatives to determine how they make tradeoffs among them.[12] Smith et al., for example, use this method to estimate that households would be willing to pay $100–220 annually for laser jamming systems designed to defend against MANPADS attacks on U.S. airliners. They would be willing to pay a lesser amount for two alternative policy options—one to increase pilot training and better protect fuel tanks and another to expand patrols near large airports in areas that could serve as MANPADS launch sites. The survey provided respondents with background information on the MANPADS threat to commercial aviation, citing an estimate that "a 10 percent decline in airline travel reduces economic activity by about $40 billion a year" (consistent with the higher-end Santos and Haimes estimate). Notably, it emphasized that an individual's chances of being on a flight that is attacked is "very, very small," while "one successful attack would affect everyone in the [United States]."[13]

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[10] Peter Gordon, James E. Moore, II, Ji Young Park, and Harry W. Richardson, "The Economic Impacts of a Terrorist Attack on the U.S. Commercial Aviation System," *Risk Analysis*, Vol. 27, No. 3, June 2007, pp. 505–512.

[11] EU Open Data Portal, "Air Passenger Transport by Reporting Country," March 2019.

[12] A stated preference conjoint survey is a tool for placing a monetary value on public goods (e.g., a clean environment, transportation infrastructure); "a well-designed contingent valuation survey must convey to respondents that the government is considering implementing a policy and that their responses to the questions in the survey will be used to help inform that decision" (Richard T. Carson, "Contingent Valuation: A Practical Alternative When Prices Aren't Available," *Journal of Economic Perspectives*, Vol. 26, No. 4, Fall 2012, pp. 27–42).

[13] V. Kerry Smith, Carol Mansfield, and Laurel Clayton, "Valuing a Homeland Security Policy: Countermeasures for the Threats from Shoulder Mounted Missiles," *Journal of Risk and Uncertainty*, Vol. 38, No. 3, June, 2009; Santos and Haimes, 2004.

The survey, fielded in 2006, determined that individuals were willing to pay the most for the laser jamming systems; presenting the funding source as a gas tax, rather than an income tax, yielded a higher willingness to pay (based on respondent-provided information on typical gas expenses). Willingness to pay also varied by household income level and degree of risk tolerance. Smith et al. present a summary result of a willingness to pay for the laser jamming systems of $100–220 per household per year. This would equate to approximately $12.6–27.2 billion annually.[14]

Veisten et al. also consider the willingness to pay for enhanced airport security but with a focus on passenger screening rather than physical defenses on airplanes as in Smith et al.[15] Their focus is on valuation of risk-based screening, in which precleared passengers would face minimal screening, "normal" passengers might be subject to increased screening, and unknown or watchlisted passengers would undergo even further screening. Their estimates suggest that precleared passengers have a willingness to pay to avoid risk-based screening on the order of €2–12 per trip, and normal passengers have a willingness to pay of €16–30 per trip, consistent with increased security protocols for this group. Nguyen, Rosoff, and John consider the trade-off between equity and airport security. Importantly, their findings suggest that risk-based programs that are based on suspicious behavioral indicators (individual-specific) are valued much higher than those based on demographic indicators.[16]

Econometric-Based Approaches

The third strand of literature uses econometric approaches that employ cross-country, cross-year data to estimate the relationship between alternative measures of economic effect and terrorist attacks and conflict. The underlying theoretical argument given by Becker and Murphy is that because terrorist attacks are small relative to the size of an economy (specifically capital stocks), they should have small economic consequences. Much of the work in this area attempts to estimate whether this is the case for a variety of different measures of economic effect.[17] There is considerable literature in this area; we summarize some of the highlights. The difference between much of the work considered here and our analysis is that the former efforts do not disaggregate *how* the attack was carried out or the attack targets. Our approach attempts to examine how alternative types of attacks and targets produce different economic outcomes.

Abadie and Gardeazabal have argued that since capital is mobile, longer-term consequences may be considerably larger than what Becker and Murphy have argued. For example, Abadie and Gardeazabal argue that sustained terrorist conflicts in the Basque economy may reduce per capita GDP by as much as 10 percentage points.[18] Abadie and Gardeazabal estimate

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14 Smith, Mansfield, and Clayton, 2009.

15 Knut Veisten, Stefan Flügel, and Torkel Bjørnskau, "Public's Trade-off Between a New Risk-Based Airport Screening and Asserted Terror Risk Impact: A Stated Choice Survey from Norway," *Journal of Transportation Technologies*, Vol. 1, April 2011.

16 Kenneth D. Nguyen, Heather Rosoff, and Richard S. John, "Valuing Equal Protection in Aviation Security Screening," *Risk Analysis*, Vol. 37, No. 12, December 2017. The authors are making the distinction between choosing people randomly from those that are acting suspiciously, such as perceived fear or stress, and choosing on the basis of demographic indicators, such as race or ethnicity.

17 Gary S. Becker and Kevin M. Murphy, "Prosperity Will Rise Out of the Ashes," *Wall Street Journal*, October 29, 2001.

18 Alberto Abadie and Javier Gardeazabal, "The Economic Costs of Conflict: A Case Study of the Basque Country," *American Economic Review*, Vol. 93, No. 1, March 2003.

that a one-standard-deviation increase in the intensity of terrorism reduces net foreign direct investment (FDI) by 5 percent.[19] Gaibulloev and Sandler estimate that an additional terrorist attack per million people reduces GDP growth on the order of 1.5 percent for countries in Asia. Effects differ in developed and developing countries; developed countries can absorb the effects of terrorist attacks.[20] Gaibulloev and Sandler extend this work to countries in Africa and consider the differences between domestic and transnational terrorism, finding that only transnational terrorist events had a significantly negative effect on economic growth.[21] Consistent with this work, Meierrieks and Gries find that there are significant differences across time and space with respect to terrorist attacks on growth. They argue that there is a distinction between the economic effects during the Cold War compared with post–Cold War periods, and that African and Islamic countries experience differential effects compared to the rest of the world.[22] Bandyopadhyay et al. find there are significant declines in FDI with increases in domestic terrorist incidents per capita.[23]

In addition to these more standard measures of economic consequences of terrorism, some literature examines the relationship between terrorism and tourism. Liu and Pratt estimate the long- and short-run tourism effects from terrorism. For most countries, they find there are no long-run effects except for Colombia, France, Hong Kong, Guyana, Ireland, Latvia, Nepal, Saudi Arabia, and Thailand; except for Colombia, the effects were very small. The short-run effects suggest that, on average, a 1-percent increase in the growth rate of terrorism decreases the growth rate of tourism by 0.015 percent. However, significant differences exist across countries. Specifically, there were large short-term effects for Yemen, Haiti, Mozambique, the Central African Republic, Colombia, Israel, Pakistan and the Philippines. In total, this suggests that tourism is remarkably resilient to terrorism.[24] In a similar vein, Saha and Yap suggest that political instability matters considerably more than terrorism with respect to tourism.[25]

None of the studies we reviewed consider the potential effect of *how* an attack was carried out or *what* the target was. Our approach is to consider the role of MANPADS attacks specifically and attacks on aircraft in flight generally to gain a better understanding of the potential economic consequences of MANPADS attacks. Given the relative rareness of MANPADS attacks against civilian aircraft, expanding to a broader set of attacks (on aircraft in flight, regardless of the weapon used) was necessary to produce justifiable estimates.

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[19] Alberto Abadie and Javier Gardeazabal, "Terrorism and the World Economy," *European Economic Review*, Vol. 52, No. 1, January 2008.

[20] Khushrav Gaibulloev and Todd Sandler, "The Impact of Terrorism and Conflicts on Growth in Asia," *Economics & Politics*, Vol. 21, No. 3, November 2009.

[21] Khushrav Gaibulloev and Todd Sandler, "The Adverse Effects of Transnational and Domestic Terrorism on Growth in Africa," *Journal of Peace Research*, Vol. 48, No. 3, May 2011.

[22] Daniel Meierrieks and Thomas Gries, "Economic Performance and Terrorist Activity in Latin America," *Defence and Peace Economics*, Vol. 23, No. 5, October 2012.

[23] Subhayu Bandyopadhyay, Todd Sandler, and Javed Younas, "Foreign Direct Investment, Aid, and Terrorism," *Oxford Economic Papers*, Vol. 66, No. 1, January 2014.

[24] Anyu Liu and Stephen Pratt, "Tourism's Vulnerability and Resilience to Terrorism," *Tourism Management*, Vol. 60, June 2017.

[25] Shrabani Saha and Ghialy Yap, "The Moderation Effects of Political Instability and Terrorism on Tourism Development: A Cross-Country Panel Analysis," *Journal of Travel Research*, Vol. 53, No. 4, July 2014.

Econometric Approach

Our general approach is to estimate the effects of MANPADS attacks on a suite of economic variables, including GDP, FDI, and total trade, while controlling for levels of violence from terrorist and nonterrorist sources and various economic stock variables that are likely to affect economic outcomes at the country-year level. The data, described in the next section, allow us to exploit a panel data structure to control both for time invariant country characteristics and global economic trends over time. The following equation provides the general form of the estimating equation.

$$Y_{it} = \beta_0 + \beta_1 \bullet MANPADS_{it} + \beta_3 + Violence_{it} + \beta_4 \bullet Capital_{it} + \eta_i + \gamma_t + \in_{it}$$

In the equation, Y_{it} represents the economic indicator under examination. The $i = 1, \ldots, N$ subscripts indicate countries, and $t = 1, \ldots, T$ indexes the time periods. Our main covariate of interest is the variable $MANPADS_{it}$, which specifies the number of MANPADS attacks that occur in country i in time period t. $Violence_{it}$ is a vector of country-year characteristics of violence including several measures of armed conflicts, a measure of general terrorism, and measures of attacks on air infrastructure generally and specifically on aircraft in flight. $Capital_{it}$ is a vector of country-year characteristics that controls for capital stocks commonly associated with economic development. η_i is a set of time-invariant, country-level fixed effects that control for characteristics of a country that do not vary over time such as location and whether the country has resource reserves. γ_t is a set of time-specific fixed effects that controls for the global economic conditions such as widespread recessions and changes in treaties. Finally, $\in_{it}$ is a stochastic error term. We estimate the equation above for the suite of economic variables in logs because we expect that all of the economic variables are nonstationary. Additionally, we include a one-year lagged dependent variable on the right-hand side to further control for nonstationarity.

Data Sources

We use a variety of data sources to control for as many aspects of violence and determinants of economic outcomes as possible. Our aim is to construct a country-year panel data set of economic variables, violence variables, and MANPADS attacks that will allow us to estimate the equation above for a suite of economic variables. Our analysis focuses on the period from 1989 to the present, a decision driven both by the coverage range of the data set that facilitates the construction of country-year variables that control for conflict activity and by expectation that economic effects of attacks in the post–Cold War world have more predictive power than those in earlier eras. Despite this focus on the past 30 years, there are nonetheless gaps in our data, and the scope of the analysis varies by the economic variable under consideration.[26] In addition, some countries enter the data set at different times, resulting in an unbalanced panel. For countries that have ceased to exist, we lack data for many control variables; we exclude them from our analysis.[27]

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26 For example, much of the GDP and other economic data for countries at war are missing.

27 Countries that subsequently split into multiple countries are likewise excluded from the analysis for years prior to the split—for example, Sudan prior to the independence of South Sudan in 2011. This is because terrorism and conflict data for these countries are reported based on the country as it existed at each point in time, whereas economic control variables are reported for earlier years based on the *current* territory of the country.

Our starting point for the data set is the RAND data for the 65 MANPADS attacks on civilian airliners that have taken place from 1973 to the present. This data set is then combined with the GTD.[28] Of the 65 MANPADS attacks in our data set, 20 also appear in the GTD, including 15 of the 38 attacks since 1989.[29] From this aggregate database, we construct a series of country-year variables that tally the number of terrorist attacks overall, attacks with a target type of airport or aircraft, attacks with a target subtype of aircraft (i.e., aircraft in flight), and MANPADS attacks. In this categorization scheme, attacks on airports or aircraft are a subset of all terrorist attacks, attacks on aircraft in flight are a subset of all airport or aircraft attacks generally, and MANPADS attacks are a subset of all attacks on aircraft in flight.[30]

Similar to previous chapters, we use data from the UCDP to construct a series of variables that denote conflicts in country *i* in year *t*. However, to focus narrowly on the degree of conflict activity in the country itself, we draw on UCDP's data set of individual incidents of violence occurring in the context of conflicts—the GED, which covers 1989 to 2017.[31] The GED compiles observations resulting in conflict-related deaths that form the basis of three separate and aggregated UCDP data sets: the ACD, a data set of state-based conflicts (at least one party to the conflict is the government of a state);[32] the Nonstate Conflict Data Set (neither party to the conflict is a government of a state); and the One-Sided Violence Data Set (attacks on civilians either by a government or another formally organized group). The advantage of the GED is that it lists the country location of the deaths, facilitating a tally of country-year deaths per conflict, as opposed to the other UCDP data sets, which report by-year deaths at the *conflict-year* level across all countries party to the conflict, some of which may experience little to no in-country conflict activity or associated economic harm.[33]

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28 National Consortium for the Study of Terrorism and Responses to Terrorism, 2018. Note that 1993 is missing from the GTD data, though country-level summary data on the number of attacks and number killed or injured in these attacks is included separately in the GTD codebook. We impute 1993 values for attacks by type (airports or aircraft, generally, and aircraft in flight, specifically) by calculating country-level historical average shares over the 1989–2017 period (excluding 1993) and applying these shares to the totals for 1993. For the two countries with MANPADS attacks from our MANPADS attack data set occurring in 1993, we require that the imputed counts at least match the number of MANPADS attacks.

29 In one instance, an attack reported as one observation in the GTD was listed as two separate MANPADS attacks. We count these as two attacks in our merged data set and count these two among the 20 that overlap (as well as the 15 since 1989 that overlap) between the GTD and the data set described previously. We eliminate duplicate entries so that overlapping entries are not counted twice.

30 A couple of caveats merit mention. First, we note that we impose this hierarchy for MANPADS attacks from our MANPADS data set described previously. In eight of the 20 overlapping incidents, the attack target type reported in the GTD was other than "airport or aircraft" (most commonly reported as on "government") and we recoded the variables such that these were included as attacks on airports and aircraft in general and on aircraft in flight in particular. Also, in some instances, incidents of NSAG MANPADS attacks on civilian airliners (from the RAND data set presented here) may not be considered terrorism by some definitions, for example if they occurred in the context of an intrastate conflict. For our analytical purposes, we make the assumption that their economic effect is equivalent, and thus include all 65 MANPADS attack observations alongside our GTD data. We include several controls for in-country conflict activity derived from a separate data source to avoid conflating the effect of a MANPADS attack with the effect of the underlying conflict.

31 The data are an updated version (18.1) of those in Ralph Sundberg and Erik Melander, "Introducing the UCDP Georeferenced Event Data set," *Journal of Peace Research*, Vol. 50, No. 4, July 2013.

32 This data set, which extends back to 1946, is the source used in Chapter One to characterize whether MANPADS attacks on civilian airliners occurred in countries in a conflict.

33 For example, in UCDP's ACD, the United States is listed as a party to a conflict from 2001–2017, despite there being few if any conflict-related deaths in the United States in most years since 2001. We construct our data set such that countries

For each of the three categories of conflicts (state-based, nonstate, and one-sided violence), we construct two country-year variables: one that tallies the number of active conflicts that resulted in 25 or more conflict-related deaths in the country in the year, and one that counts the number of these conflicts that resulted in at least 1,000 such deaths, which we identify as "major" conflicts.[34] Ultimately, we convert these variables to binary indicators for our core analysis. We also use the GED to construct country-year variables for the number of deaths by conflict type.[35]

Together, the GTD and UCDP data sets allow us to control for conflicts and for terrorist activity that might not be associated with conflicts. In addition, the nesting of attacks may allow us to attribute the different dimensions of a MANPADS attack. For example, MANPADS attacks are attacks on aircraft in flight, which are attacks on airports or aircraft in general, which are a subset of all terrorist attacks. These attacks might or might not occur in countries engaged in a conflict. In addition, since there are comparatively few documented MANPADS attacks on civilian aircraft, we might be able to use attacks on aircraft in flight (of which there are more) to consider the consequences of attacks similar to MANPADS attacks but carried out through different methods. Therefore, we may be able to shed light on the possible effect of a MANPADS-like attack on countries that have not experienced such attacks.

The economic variables we use in our models come from a variety of sources. GDP data are from the World Bank, and typically are available from 1960–2017 with some variation by country.[36] Trade data are from the United Nations Comtrade Database.[37] We use only the aggregate imports and exports from the Comtrade database (commodity-specific trade could be considered in the future). The Comtrade data are generally available from 1988–2017, but considerable variability exists by reporting county. The FDI data are available from the United Nations Conference on Trade and Development (UNCTAD).[38] UNCTAD provides the flow and stock of FDI within a country as well as what is sent abroad. For our purposes, we focus on stock within a country. The UNCTAD data are generally available from 1970–2016, although this varies by country. Finally, we use additional data from the World Bank to control for other determinants of economic outcomes: population, working-age population, inflation rate, and per capita telephone lines (which is meant to control for telecommunications generally). These additional World Bank data also are generally available from 1960–2017, although this varies considerably by variable. Summary statistics of variables included in our core econometric model appear in Table 6.1.

Results

Our analysis separately considers each of the economic variables of GDP, total trade, and FDI, although we do use GDP as a control in regressions for the other economic variables because

that are the location of conflict activity (i.e., where conflict-related deaths occur) will flag as experiencing conflict, while countries in a conflict with few to no deaths occurring on their own soil will not.

34 In all cases, we rely in the "best (most likely)" estimate of deaths from the GED, rather than the separately reported "lowest reliable" and "highest reliable" fatality estimates.

35 The variables that tally deaths by conflict type are used in sensitivity analyses but not in our core analysis.

36 The World Bank, "GDP (Constant 2010 US$)," 2019. We use a measure of GDP in constant 2010 U.S. dollars.

37 United Nations, United Nations Comtrade Database, undated.

38 United Nations Conference on Trade and Development, *2018 Handbook of Statistics*, Geneva, Switzerland, 2018.

Table 6.1
Descriptive Statistics for Variables Used in Economic Analysis, 1989–2017

Variable	n	Mean	Standard Deviation	Minimum	Median	Maximum	Source
GDP (thousands, 2010 dollars)	5,332	$296,495,840	$1,185,981,952	$21,442	$17,187,922	$17,300,000,768	World Bank
Total trade (thousands)	3,772	$134,450,208	$372,319,584	$98	$12,577,495	$4,301,527,552	Comtrade
FDI in stock (thousands)	5,267	$67,564,176	$291,585,888	$0	$3,431,089	$7,807,031,808	UNCTAD
Terrorist attacks	6,366	23.38	137.05	0	0	3,933	GTD
Terrorist attacks on airports or aircraft	6,366	0.12	0.63	0	0	20	GTD
Terrorist attacks on aircraft in flight	6,366	0.04	0.25	0	0	5	GTD
MANPADS attacks on civilian airliners	6,366	0.01	0.12	0	0	5	GTD, BICC, Sponsor
State-based conflicts	6,366	0.18	0.59	0	0	8	UCDP GED
Major state-based conflicts	6,366	0.03	0.19	0	0	3	UCDP GED
Nonstate conflicts	6,366	0.14	0.76	0	0	13	UCDP GED
Major nonstate conflicts	6,366	0.00	0.05	0	0	1	UCDP GED
One-sided violence conflicts	6,366	0.15	0.58	0	0	11	UCDP GED
Major one-sided violence conflicts	6,366	0.01	0.11	0	0	3	UCDP GED
Population	6,023	30,112,522	121,235,440	8,947	5,288,720	1,386,395,008	World Bank
Working-age population	5,376	21,528,258	85,627,576	39,812	4,079,083	996,046,592	World Bank
Inflation rate	4,760	28.6%	400.9%	–18.1%	4.2%	23,773.1%	World Bank
Telephone lines per 1,000 people	5,802	19.4	20.4	0.0	11.9	132.7	World Bank

SOURCES: The World Bank, undated; United Nations, undated; United Nations Conference on Trade and Development, 2018; National Consortium for the Study of Terrorism and Responses to Terrorism, 2018; Ashkenazi et al., 2013; Croicu and Sundberg, 2012.

NOTE: A conflict involves 25 or more in-country deaths in the year and a major conflict involves 1,000 or more in-country deaths in the year.

we expect that the size of an economy is associated with both trade and FDI. In addition, we exploit the nested structure of some our terrorism-related violence variables. That is, MANPADS attacks are attacks on aircraft in flight, which are attacks on airports or aircraft, which are terrorist attacks. The basic idea is to better understand the additionality of an attack on a specific target type (aircraft in flight) together with how the attack was carried out (MANPADS).

Our initial estimate simply regresses the natural log of GDP on MANPADS attacks, with controls for violence (both from terrorism and conflict activity) and economic inputs. As noted previously, we use the dichotomous versions of state-based conflicts, major state-based conflicts, nonstate conflicts, major nonstate conflicts, one-sided conflicts, and major one-sided conflicts rather than total counts of each. The terrorism variables of MANPADS attack, attack on aircraft in flight, airport or aircraft attack, and terrorist attack are count versions of these variables, allowing us to estimate the effect of individual attacks. We include all of the economic controls, as well as year fixed effects, country fixed effects, and lagged dependent variables, to control for potential nonstationarity of the dependent variable.[39] We calculate robust standard errors clustered by country.

The "GDP" column of Table 6.2 provides the results for this initial regression. Importantly, MANPADS attacks do not appear to have a significant effect on GDP when we control for other terrorist activity and conflicts that are occurring within a country. As such, we estimate the same model but drop the MANPADS variable. Since MANPADS attacks are attacks on aircraft in flight, the results in the "GDP w/o MANPADS" column of Table 6.2 for the aircraft attack variable may serve as a proxy for the effects of a MANPADS attack. Removing the MANPADS variable allows for a more-complete capturing of the effect of attacks on aircraft in flight on GDP, and it also allows us to expand our sample size of attacks on which our estimates are based beyond the small number of MANPADS attacks from 1989 to the present.[40] The statistically significant results suggest that, independent of how the attack was carried out, terrorist attacks on aircraft in flight decrease GDP by about 1.4 percent (95 percent confidence interval of 0.3 percent to 2.5 percent). The variable for attacks on airports or aircraft in general appears to mitigate some of this effect, suggesting that attacks on air infrastructure other than those on aircraft in flight may be associated with less economic harm. However, being in a major state-based conflict more than offsets these estimates, as we discuss below.[41]

We repeat the analysis above for total trade and the stock of FDI, with one exception: We do not report the results for trade with the MANPADS variable included in the model because it is based on a single MANPADS incident for which we have trade data. Table 6.3 presents these results: The leftmost column shows the estimate for trade (excluding the MANPADS

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39 We performed a Hausman test on country random versus fixed effects and we reject random effects in favor fixed effects for all specifications.

40 Our regression model requires country years to have data for all included variables in order to contribute to the results. Of the 38 MANPADS incidents from 1989 to the present, 18 attacks across 11 country years are included in the GDP model. Expanding the analysis to consider attacks on aircraft in flight regardless of how an attack is carried out allows us to capture 168 attacks across 134 country years, lending greater credibility to the estimates of economic effect derived from the specification that excludes the MANPADS variable.

41 Given the lagged dependent variable inclusion on the right-hand side, these estimates are inconsistent. To correct for this, we have estimated the same model using the Arellano-Bover estimates that correct for this inconsistency. The original estimate of 0.01425 increases to 0.01428 but falls within the error bounds. As such, we do not report these results. We have similarly estimated all the other regressions using the Arellano-Bover approach and find similar results. We thank the reviewer for pointing this out.

Table 6.2
GDP Regression Results

Variable	GDP	GDP w/o MANPADS
MANPADS	−0.014 (1.04)	
Aircraft attack	−0.011 (1.63)	−0.014** (2.525)
Airport/aircraft attack	0.0046* (1.68)	0.0047* (1.716)
Terrorist attack	3.1×10^{-5}*** (2.797)	3.1×10^{-5}*** (2.914)
Conflict controls	Yes	Yes
Economic controls	Yes	Yes
Econometric controls	Yes	Yes
Number of observations	4,315	4,315
R-squared	0.981	0.981
Number of countries	176	176

NOTE: t-statistics appear in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Table 6.3
Regression Results for Trade and FDI

Variable	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS		0.48 (1.476)	
Aircraft attack	0.0022 (0.178)	0.42 (1.50	0.052** (2.18)
Airport/aircraft attack	−0.00062 (0.111)	−0.0068 (0.947)	−0.0072 (1.038)
Terrorist attack	1.2×10^{-5} (0.501)	-3.5×10^{-5} (1.151)	-3.9×10^{-5} (1.27)
Conflict controls	Yes	Yes	Yes
Economic controls	Yes	Yes	Yes
Econometric controls	Yes	Yes	Yes
Number of observations	3,088	4,100	4,100
R-squared	0.95	0.96	0.96
Number of countries	170	177	177

NOTE: t-statistics appear in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

variable), and the middle and rightmost columns present the estimates for the stock of FDI in the country. There appears to be no relationship between attacks on aircraft or terrorism generally on trade. It appears that the presence of conflict, and not terrorism specifically, is how trade is affected. For FDI, there does appear to be an effect, but in the opposite direction: The coefficient on aircraft attack is positive and significant when we do not include the MANPADS variable.

We have leveraged several different specifications in terms of the control variables, using both dichotomous and count specifications of the conflict variables, as well as versions of these variables that use counts of deaths by conflict type as controls. The results are robust to these specifications.[42] We also estimated versions of the models that use dichotomous terrorism-related variables (i.e., was there a MANPADS attack in the country year). In the model for GDP including a MANPADS indicator, the coefficient on this indicator is significant and negative, though it is not robust to the exclusion of either Angola in 1993 or Iraq in 2003, nor to the inclusion of count versions of the other measures of terrorism that control for the level of terrorist activity in the country year. Additionally, because the GTD data for 1993 only contains the number of terrorist attacks and not the specifics of these attack, we have used two approaches to interpolate these data and the results do not change with the exception that some of the model specifications are sensitive to the inclusion or exclusion of Angola in 1993.

Discussion

Our results suggest that while there may not be a separate effect on economic outcomes correlated to MANPADS attacks, there does appear to be a relationship between attacks on aircraft in flight and GDP, with such an attack associated with a 1.4-percent decrease in GDP (with a range of between 0.3 percent and 2.5 percent). Therefore, it might not be how the attack was carried out (i.e., with a MANPADS) but the attack target that affects the result for GDP. Combining these results with the results for FDI and trade, it appears that attacks on aircraft affect the output of the economy through domestic rather than international channels, since we identify no negative, significant relationship between aircraft attacks and FDI or trade, after controlling for GDP and other economic inputs.

Potentially more important is that the existence of a major state-based conflict (1,000 or more conflict-related deaths in the country location in the year) reduces most of the economic outcomes on the order of 4 to 8 percent.[43] Hence, conflict generally has a far more important effect on an economy. As much of the terrorism literature has stated, developed countries without conflict can absorb almost all terrorist activities. In developing countries with underlying conflict, terrorism is just another manifestation of the underlying conflict. As described in Chapter Three, we note that the vast majority of the MANPADS attacks on civilian airliners in our data set occurred in countries undergoing state-based conflict. Of the 18 MANPADS attacks since 1989 with sufficient country-year data, all but one occurred in a country in a state-based conflict with 25 or more in-country deaths in the year, and 15 were in a country in a major state-based conflict. Of the 168 attacks on aircraft in flight in our GDP analysis, 103 occurred in countries in a state-based conflict, and 50 were in countries in a major state-based conflict.

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[42] A table of these alternative specifications is included in Appendix C.

[43] These values are included in the tables in Appendix C.

Limitations

There are several provisos to our analyses. First, and most importantly, our economic variables are self-reported. In countries that have underlying conflict, data may not be available or may be of poor quality. For example, there exists little to no data in Syria for the last decade. Economic data are also unavailable for countries that have ceased to exist, such as the Soviet Union, East Germany, and Yugoslavia. Given our results, we do not know the direction of bias. Second, the temporal scope of our country by year panel data set was driven by the years for which appropriate control variables were available, which restricted our analysis to 1989 to the present. We do not believe this constitutes a major threat to the validity of our results, partly because we typically lacked much of the economic data for earlier years, and partly because incidents in the post–Cold War world may be a more appropriate comparator in any case.

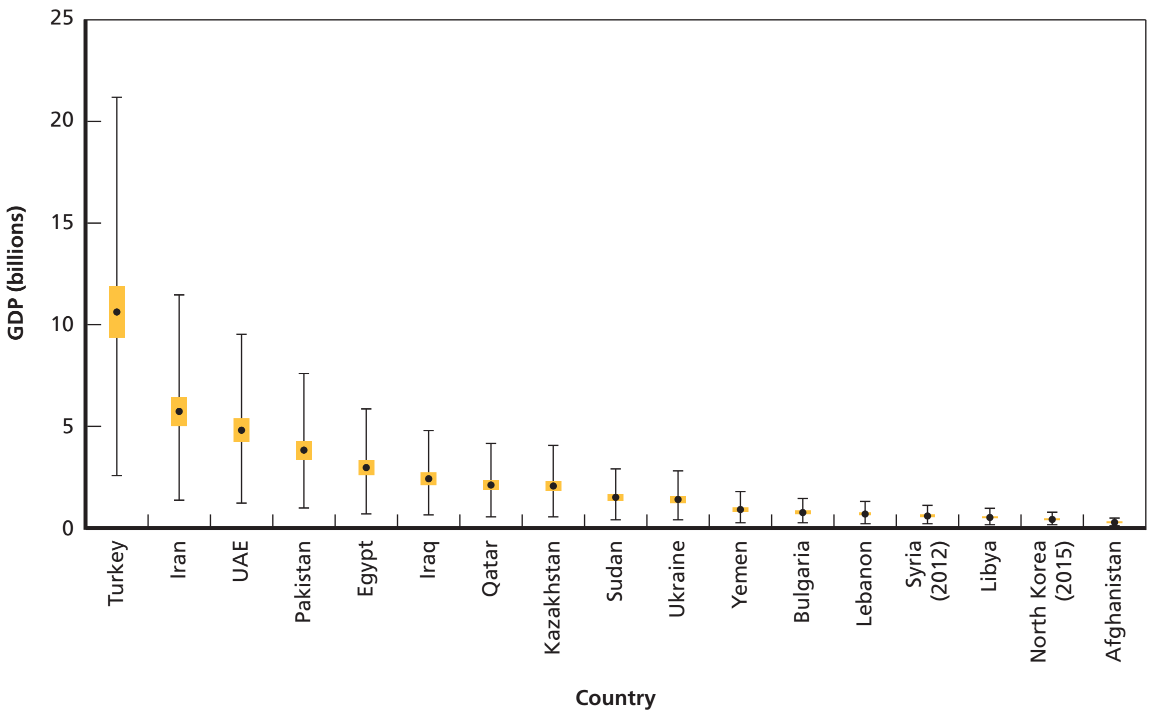
Third, although the GTD data are the best available for tracking terrorist attacks, it is neither comprehensive nor fully consistent with other possible interpretations and measures of terrorist activity. For example, most MANPADS attacks on civilian airliners identified in previous chapters did not appear in the GTD, while others did appear but were coded as attacks on a target type of "government (diplomatic)" or "government (general)," rather than on airports and aircraft. We recode the MANPADS attacks to fit within our nested structure of attack types, but we are unable to determine the extent to which other attacks on airports or aircraft are coded as attacks on a different target type. We cannot know how our results might change if we were able to include these attacks among our set of attacks on airports and aircraft generally or aircraft in flight. The GTD also is missing more granular details on terrorist attacks for 1993, as mentioned previously.

Finally, with respect to both the GTD and the UCDP conflict data, we assume that an absence of reported terrorist attacks or conflict activity in a country in a given year means that there was none. Underreporting or data quality issues could mean that terrorism and conflict levels are higher than they appear to be in our data.

Potential Effects

This suite of models suggests that, on average, a MANPADS-like attack reduces a country's GDP by roughly 1.4 percent—a result that is statistically significant. To put this in perspective, we have selected a sample of "high risk" countries to demonstrate the estimated effect potential of an attack as intimated by our modeling effort. We selected this sample of countries from three sources. The first is the list of countries possessing between 5,000 and 9,999 MANPADS and having FSI scores of at least 70 (as shown in Table 5.1). The second source is our NSAG risk index. Specifically, we identified the primary country locations of the top ten NSAGs in our index (Table 4.1). Finally, we selected countries identified as suppliers of the weapon in previous attacks (Bulgaria, Ukraine, Kazakhstan) or those with of proliferation history of MANPADS to civil wars (Qatar and the United Arab Emirates [UAE]). We also include Sudan for its role as a conduit for arms to Libya and Syria. These high-risk countries combine two of our previous analytical efforts to produce a plausible list of countries where a MANPADS attack might happen. Figure 6.1 lists each country and shows the estimated effect of an attack predicated on a 1.4-percent loss in GDP. These figures are notional and intended to be illustrative of the potential cost range of a MANPADS-like attack. The actual cost of an attack would be highly dependent on location, and, as noted earlier, more-developed countries would likely be more resilient to an attack.

Figure 6.1
Notional Economic Effect Estimates of MANPADS-Like Attacks in Several Countries



NOTE: Calculations based on 0.3 percent, 1.4 percent, and 2.5 percent of country GDP in 2017 (except where otherwise noted).

CHAPTER SEVEN

MANPADS Mitigation Options

Options for mitigating MANPADS attacks range from ways to prevent terrorist groups from operating effectively to changes in contingency response planning to limit casualties and damage to physical structures. Casting a wide net, this chapter presents various options and a general assessment of their effectiveness. We lay out potential options along with the expected risks and benefits of each of them. We categorize these measures into six groups. We arrange them in order of engagement, from well before MANPADS acquisition to after a successful attack. Although all involve U.S. action, the cooperation of partner nations is essential for the great majority of them.

1. **Disrupting or degrading NSAG operations.** These options are designed to limit the ability of NSAGs to operate effectively. They include seizing assets, extraditing and prosecuting group members, prosecuting entities that do business with them, and capturing or killing group members.
2. **Preventing MANPADS acquisition.** These options are focused on preventing MANPADS transfers to NSAGs by using export control agreements, interdiction, weapon storage and monitoring, weapon recognition and disablement training, and market reduction activities.
3. **Preventing MANPADS employment.** These options limit the ability of NSAGs to use weapons by using flight restrictions to limit aircraft exposure, technical-use controls, airport vulnerability evaluations, and changes in aircraft flight operations.
4. **Reducing likelihood of a successful attack.** These options are designed to reduce the chance that a missile will hit an aircraft. They include the use of ground-based countermeasures and aircraft countermeasures.
5. **Limiting aircraft damage from a successful attack.** These options are intended to reduce aircraft vulnerability to an attack. They include hardening aircraft structures; replacing oxygen in fuel tanks with inert gases to reduce the likelihood of fires; adding redundant, isolated flight control systems; and changing pilot training.
6. **Managing consequences.** These options are designed to limit losses from an attack in which an aircraft is damaged or lost. They include contingency planning and disaster response activities.

Disrupt or Degrade NSAG Operations

The first category of mitigation options is focused on limiting the ability of NSAGs to operate effectively. These measures in this category are not necessarily focused on the MANPADS threat. Rather they degrade the overall capabilities and freedom of movement of terrorist groups, which can have a positive effect in reducing the ability of these groups to acquire and use MANPADS. These activities, which include several types, have been ongoing for decades and include (1) asset seizure/trade prohibition, (2) extradition/prosecution, and (3) direct action.

Asset Seizure/Trade Prohibition

The Department of State designates organizations that plan and carry out terrorist attacks as FTOs and (with the Department of Treasury) Specially Designated Global Terrorists (SDGTs). In 2019, 68 organizations were classified as FTOs; more organizations and individuals classified as SDGTs. They include NSAGs, such as al-Qaida, and state organizations, such as the Islamic Revolutionary Guard Corps (a branch of the Iranian military).[1] Organizations on this list and those connected to them are subject to criminal prosecution and other sanctions. Those providing material support or resources to these organizations can be prosecuted. Members or representatives of these organizations cannot travel to the United States. U.S. financial institutions must retain control of assets in which the FTO has an interest.

The Treasury Department's Office of Foreign Asset Control enforces economic sanctions against SDGTs. These sanctions are enacted under Executive Order 13224, which was signed in 2001 and updated in 2019. In 2018, over $46 million of terrorist groups' funds had been blocked, preventing those organizations from gaining access. Furthermore, almost $217 million in assets controlled by countries designated as state sponsors of terrorism have been blocked.[2]

Under the same order, the Treasury Department can impose sanctions on individuals and organizations conducting business with terrorist organizations. In September 2019, it designated 15 individuals and organizations affiliated with Hamas, ISIS, and the Islamic Revolutionary Guard Corps–Qods Force as terrorists and terrorist groups. This action allowed the assets of those entities to be blocked and those that engage in certain transactions with them could be subject to sanctions or enforcement actions.[3]

Extradition/Prosecution

The United States also uses bilateral agreements to extradite terrorist suspects to the United States to face criminal prosecution. These measures have proven effective in the past. In 2012, Abu Hamza Masri, a radical Muslim cleric accused of orchestrating the kidnapping of tourists in Yemen that left four dead and providing material and other support to anti-U.S. jihadists

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[1] U.S. Department of State, Bureau of Counterterrorism and Countering Violent Extremism, *Foreign Terrorist Organizations*, Washington, D.C., 2019.

[2] U.S. Department of the Treasury, Office of Foreign Assets Control, *Terrorist Assets Report Calendar Year 2018*, Washington, D.C., 2018.

[3] U.S. Department of the Treasury, Office of Foreign Assets Control, "Treasury Targets Wide Range of Terrorists and Their Supporters Using Enhanced Counterterrorism Sanction Authorities," press release, Washington, D.C., September 10, 2019.

in Afghanistan and Pakistan, was extradited from the United Kingdom to the United States.[4] He was convicted and sentenced to life in prison in 2014.[5] More recently, Algerian national Ali Charaf Damache was extradited from Spain to the United States in 2017. Damache was tried in U.S. federal court and sentenced to 15 years for supporting and conspiring to commit acts of terrorism the following year.[6]

Direct Action

The United States has carried out hundreds of operations to capture or kill NSAG leaders and operatives since 2001.[7] Perhaps the most prominent of these operations occurred in 2011, when U.S. special operations forces killed al-Qaida founder Osama bin Laden at his compound in Abbottabad, Pakistan. In 2019, Jamal al-Badawi, who had been indicted in a U.S. court for his role in the 1998 attack on the USS *Cole*, was killed in an air strike.[8] ISIS leader Abu Bakr al-Baghdadi was killed during a U.S. special operations forces raid in October of the same year.[9]

Preventing MANPADS Acquisition

The second category of MANPADS mitigation measures is directly aimed at abating the MANPADS threat by denying NSAGs the ability to acquire these systems. These measures include export controls, interdiction, MANPADS inventory reductions, weapon storage and monitoring, MANPADS recognition and disablement training, and market reductions.

Export Controls

The United States has negotiated and signed agreements designed to prevent NSAGs from obtaining MANPADS. The Wassenaar Arrangement, approved in 1996 by 33 countries, was designed to promote transparency and greater responsibility in transfer of conventional arms and dual-use goods and technologies.[10] In 2003, the Wassenaar Arrangement published the *Elements of Export Controls of Man Portable Air Defense Systems (MANPADS)*.[11] This document defines the components needed for effective export control of MANPADS, including written verification of receipt of MANPADS shipments, serial number audits for all exported firing

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4 Tina Susman, "Radical Muslim Cleric Extradited from Britain Appears in U.S. Court," *Los Angeles Times*, October 6, 2012.

5 Ray Sanchez, "Radical Cleric Abu Hamza al-Masri Sentenced to Life in Prison," CNN, January 9, 2015.

6 U.S. Attorney's Office, Eastern District of Pennsylvania, "Algerian Terrorist is Sentenced to 15 Years' Imprisonment," press release, October 30, 2018.

7 Director of National Intelligence, "Summary of Information Regarding U.S. Counterterrorism Strikes Outside Areas of Active Hostilities," Washington, D.C., press release, undated.

8 Mary Milliken and Phil Stewart, "U.S. Says Suspected USS Cole Bombing Planner Killed in Yemen Strike," Reuters, January 6, 2019.

9 Rukmini Callimachi and Falih Hassan, "Abu Bakr al-Baghdadi, ISIS Leader Known for His Brutality, Is Dead at 48," *New York Times*, October 27, 2019.

10 Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, "What Is the Wassenaar Arrangement?" webpage, last updated August 9, 2019.

11 Government Accountability Office, *Nonproliferation: Further Improvements Needed in U.S. Efforts to Counter Threats from Man-Portable Air Defense Systems,* Washington, D.C., GAO-04-519, 2004.

mechanisms and missiles, and monthly inventory checks for weapons in storage.[12] At least 95 countries have adopted the elements in some form. Most of the major producers and exporters have agreed to export controls consistent with the elements. However, there are notable exceptions. These include China, a country with a history of exporting MANPADS to fragile regimes, as well as Pakistan, Egypt, Qatar, and the United Arab Emirates.

Subsequent agreements have embraced and extended the Wassenaar Arrangement. In 2003, the Asia-Pacific Economic Cooperation forum pledged to curb terrorist threats to commercial aviation by MANPADS by adopting export controls, securing stockpiles, and taking action to regulate production and prevent transfers to nonstate end users.[13] It also pledged to exchange information on these efforts. In 2004, the Organization for Security and Cooperation in Europe decided to promote comprehensive export controls for MANPADS.[14] In 2006, it published an appendix detailing best practices for securing MANPADS stockpiles.[15]

Although the United States has led the way in terms of monitoring, not all producers and exporters have been as rigorous. Much of the monitoring and enforcement process for the elements is under- or unfunded by the exporting countries.[16] Expanding the signatories of the Wassenaar Arrangement to include key countries identified in Chapters Four and Five, as well as providing technological and financial assistance to increase monitoring of stockpiles, might provide a means to reduce proliferation of MANPADS. Discouraging exports of truly man-portable systems could also help. Nations could be encouraged to procure MANPADS variants that can only be fired from vehicles instead. Such restrictions would have a limited effect on state militaries, which could easily operate these vehicles. However, these systems would be far more difficult for NSAGs to conceal and transport, which could reduce NSAGs' demand for these weapons.[17]

Interdiction

The United States also has used its military forces and those of its partners to interdict weapons being transferred to NSAGs and states that support them. These measures have proven fruitful. For example, in 2009, Thai military forces, acting on a tip from the United States, seized 40 tons of weaponry from a North Korean Il-76 cargo plane. These weapons, which were believed to be destined for Iran, included MANPADS.[18] In 2012, the Lebanese Navy intercepted the *Letfallah II* that embarked from Libya loaded with MANPADS and other arms believed to

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12 Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, 2019.

13 Asia-Pacific Economic Cooperation, "Bangkok Declaration on Partnership for the Future," Bangkok, 2003.

14 Organization for Security and Cooperation in Europe, *Decision No. 7/03 Man-Portable Air Defence Systems*, Vienna, 2003.

15 Organization for Security and Cooperation in Europe, *Best Practice Guide on National Procedures for Stockpile Management and Security Annex C: Man-Portable Air Defence Systems (MANPADS)*, Vienna, 2006.

16 Matt Schroeder, "Countering the MANPADS Threat: Strategies for Success," *Arms Control Association*, undated.

17 As some systems, such as the FIM-92 Stinger, have been designed to operate in man portable-, ground vehicle-, and air-launched configurations, modifications may be needed to ensure that they can only be launched from ground vehicles.

18 BBC News, "Thailand Seizes 'Arms Plane Flying from North Korea,'" December 12, 2009.

be destined for Syria.[19] In 2013, U.S. and Yemeni forces seized arms shipments on an Iranian dhow off the Yemeni coast. In the shipment were 10 Chinese-made QW-1M MANPADS.[20]

Other weapons have also been seized. In April 2015, U.S. Navy ships in the Indian Ocean intercepted a ship carrying coastal defense cruise missiles, antitank weapons, and assault rifles bound for Houthi rebels in Yemen.[21]

MANPADS Inventory Reductions

The United States has also worked with countries to reduce their stocks of MANPADS. Over 40,000 MANPADS have been destroyed since 2003 under a program run by the U.S. Department of State's Bureau of Political-Military Affairs Office of Weapons Removal and Abatement. Most of these weapons were first-generation systems in the inventories of Eastern European countries.

In this program, U.S. officials work with foreign countries to reduce their stock of MANPADS. These officials assist the countries in determining if their MANPADS inventories are appropriate to meet their defense requirements. In cases where there are excess inventories, U.S. officials can provide assistance in eliminating the excess missiles. This typically takes the form of using the missiles in live-fire exercises or rendering the weapons inoperable. The United States provides funding to pay for weapons demolition and improvements in weapon storage to encourage destruction of these excess weapons. For example, in Mauritania, 300 MANPADS were destroyed with U.S. assistance between 1999 and 2018.[22]

Weapon Storage and Monitoring

The Bureau of Political-Military Affairs Office of Weapons Removal and Abatement also works with foreign nations to improve physical storage stockpile management (PSSM) of MANPADS (and other conventional weapons), limiting the likelihood that these weapons will fall into the hands of NSAGs. The United States has funded new and upgraded weapon storage facilities, video monitoring systems, for those facilities and trained personnel in dozens of countries. For example, in the Democratic Republic of the Congo, the United States funded upgrades to 71 weapon storage facilities and trained 185 personnel between 2002 and 2018.[23] In Chad, the United States supported the construction or refurbishing of 19 armories and the training of personnel.

Countries are encouraged to store MANPADS components separately to limit the risk of losses if a single facility is compromised. They are also encouraged to conduct regular inspections to ensure the security of their systems and components.

PSSM improvements are often tied to weapons reductions, with countries agreeing to reduce their inventories in exchange for improvements in physical storage facilities, monitoring systems, training, or other assistance.

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[19] Binnie, 2013.

[20] Robert F. Worth and C. J. Chivers, "Seized Chinese Weapons Raise Concerns on Iran," *New York Times*, March 2013.

[21] Courtney Kube, "U.S. Officials: Iran Supplying Weapons to Yemen's Houthi Rebels," *NBC News*, October 27, 2016.

[22] U.S. Department of State Bureau of Political-Military Affairs Office of Weapons Removal and Abatement, *To Walk the Earth in Safety*, Washington, D.C.: Department of State, 18th edition, January-December 2019.

[23] U.S. Department of State Bureau of Political-Military Affairs Office of Weapons Removal and Abatement, 2019.

Efforts to improve PSSM offer benefits to both the host country, the United States, and the world at large. However, these efforts are limited in size, scope, and access. Some of the countries in which PSSM problems are greatest have poor relationships with the United States and might be unwilling to allow U.S. inspectors access to their armories or accept U.S. funding to improve weapon security. Finally, state collapse (e.g., Libya) or the state's loss of control over territory (e.g., Syria) can lead to stockpile leakage. Better PSSM reduces the risk of MANPADS leakage, but it cannot be eliminated under these circumstances.

MANPADS Recognition and Disablement Training

As we noted earlier, MANPADS are relatively small and easy to conceal and transport. They can be carried in the trunk of a car or large travel case. The smuggling of MANPADS across national borders by NSAGs has been a concern for decades.[24] To limit the movement of MANPADS, the Department of State funds training programs to improve the ability of border and other security personnel to identify these systems and their components. Security personnel are trained to record key markings (such as serial numbers) from each component photograph and preserve any accompanying documents and report such information up their chain of command. Security personnel are also trained to render the systems inoperable by destroying critical components. These efforts have increased in recent years. In 2018, the Department of State trained 482 personnel from 16 countries in 31 sessions.[25] In 2019, the Department of State estimated that it would train 660 personnel in 45 sessions. Moreover, the emphasis in 2019 has shifted toward "train the trainer" engagements, which enable partner nations to build their own indigenous training capacity. Train-the-trainer programs have the benefit of being more sustainable, scalable, and cost effective, providing the training to many more inspectors at a lower cost.

These activities could be particularly effective in states bordering countries engaged in civil war. In Libya and Syria, the failure of the central government to maintain control over state armories led to large-scale looting, resulting in the loss of tens of thousands of MANPADS. Venezuela, which has thousands of advanced SA-24 MANPADS, may experience a similar breakdown. Training the customs and other law enforcement entities of Colombia, Brazil, and Guyana could limit the movement of MANPADS in the region should they fall into the hands of NSAGs.

Market Reductions

Market mechanisms may provide a path forward to decreasing the availability of illicit MANPADS. Market reductions have been used in previous efforts by the U.S. government and allies overseas. Market mechanisms offer a cost-effective way to reduce the quantities of non-state controlled MANPADS while making it more costly for NSAGs to acquire these systems. These market mechanisms are complements to other approaches. They may be particularly important for specific countries of concern.

Once MANPADS are outside of state control, U.S. and allied countries could acquire them from black markets and either return them to appropriately secured stockpiles or render

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24 MANPADS have been smuggled across national borders since at least 1973, when they were intended for use in a terrorist attack on an airliner in Rome. The plot was foiled in its final stages. For more information on the movement and use of these weapons, see Ashkenazi et al., 2013.

25 U.S. Department of State personnel, email correspondence with the authors, October 23, 2019.

them inert.[26] Doing so reduces the supply of MANPADS available for purchase by NSAGs. Although these programs are unlikely to eliminate supply, they could drive up prices for the remaining MANPADS, which might place them beyond the financial means of NSAGs or lead NSAGs to forgo their purchase in favor of other systems. Under this type of schema, a government would openly advertise that it is willing to purchase weapons from non-state actors (without consequences to those who sell them back).

These programs have been used in multiple locations. In 2003, the Coalition Provisional Authority in Iraq established an acquisition program. In one instance, over 200 SA-7 missiles were acquired from a single individual at a price of approximately $250 per weapon.[27] Another report suggests higher prices may have been more typical: $1,500 for a complete SA-7 (first-generation) and $10,000 for a complete SA-14 or SA-16 (second-generation).[28] Overall, prices ranged from less than $250 to more than $100,000 depending on location and generation of the MANPADS.[29] These prices could be used as baseline prices for a voluntary acquisition program elsewhere.[30] Further, in 2011, the U.S. government worked with the Libyan government to purchase MANPADS from militias.[31]

Several points need to be considered when considering a voluntary acquisition program. Any such program would likely require a stable partner government. These requirements apply to few countries and thus, while market reduction programs are a potentially useful tool, they only have a limited application. Unfortunately, a burgeoning market for MANPADS might be an indicator of weak governance, civil conflict, or both. These difficulties notwithstanding, it is worthwhile to consider how a purchasing program in a given country should, in theory, affect the price of MANPADS and the quantity available.

A basic supply and demand model is useful for this purpose. Such a model is illustrated in Figure 7.1. We assume that in a given country, the quantity of MANPADS available is fixed in the short term. This implies a vertical supply curve. We further assume a standard downward sloping demand curve, implying that at lower prices more will be purchased. MANPADS will be priced at the intersection of the supply and demand curve. Before any market reduction effort, this is represented as price p^* and quantity q^*. Purchasing MANPADS for their removal causes a leftward shift in the supply curve to $\hat{q}$. This shift would increase the market price for MANPADS from p^* to $\hat{p}$.

Basic economic theory suggests that purchasing programs should increase the price of the weapon. The price increase will depend on demand elasticity, which is the responsiveness of quantity demanded to price changes (represented in a graph by the steepness of the demand curve). If demand is inelastic, meaning buyers are willing to pay much higher prices, a market removal mechanism could inflate the costs of MANPADS considerably. Such buys

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26 We use the term *black markets* to refer to markets that allow the exchange of goods that cannot typically be freely traded in developed countries. These markets might operate in the open, unrestricted by law enforcement or other state agencies.

27 Matt Schroeder, "Iraq's Looted Arms Depots: What the GAO Didn't Mention," *Federation of American Scientists,* April 9, 2007.

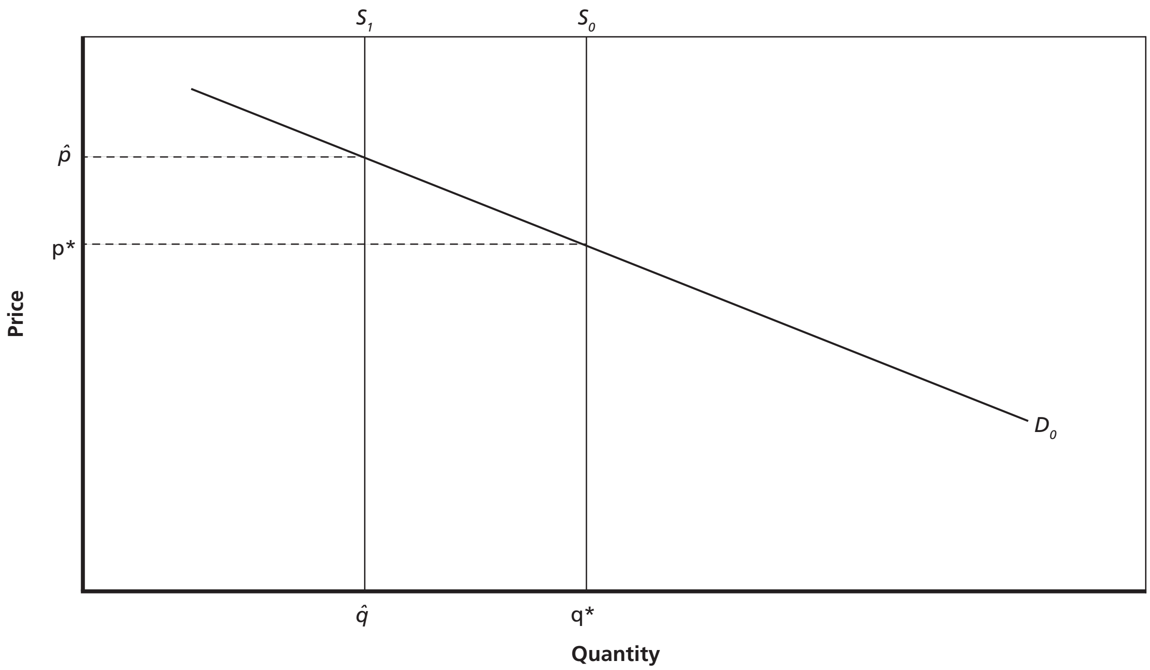
28 Schroeder, undated.

29 Schroeder, undated.

30 Matt Schroeder, "Black Market Prices for Man-Portable Air Defense Systems," *Federation of American Scientists*, June 2010.

31 C. J. Chivers, "How to Control Libya Missiles? Buy Them Up," *New York Times*, December 22, 2011.

Figure 7.1
Theoretical Effect of a Market Reduction on Price



SOURCE: Authors' interpretation of the (black) market for MANPADS.
NOTE: A voluntary acquisition program for MANPADS would shift the supply curve from S_0 to S_1, causing a price increase from p* to $\hat{p}$.

may be a cost-effective approach for retiring first- and second-generation MANPADS. However, recent experiences suggest that more-sophisticated systems might be prohibitively expensive to acquire and retire through such a program.

Weapon purchasing programs are not without risk. Increasing prices could incentivize corrupt officials to pilfer MANPADS from government stockpiles and sell them, offsetting the market reduction. Further, higher MANPADS prices in one region could prompt an influx of weapons from neighboring regions, reducing or eliminating the reduction in the supply of weapons in the targeted region.

Further, the introduction of an acquisition program could prompt other participants in the MANPADS market to become active purchasers, given buyers' anticipation that the window is closing on MANPADS availability or that MANPADS purchased today can be resold at a higher price in the future. This was precisely what transpired in Iraq during a MANPADS purchasing program in 2003. Cash-rich al-Qaida in Iraq purchased MANPADS at twice the "buyback" price on offer and distributed them to insurgent cells.[32] These purchases at above market prices imply that the effectiveness of removal efforts may be more limited, or that the leftward shift in the supply curve will be less than anticipated.

Another possible consequence of this type of program is that payments for MANPADS could be used by sellers to acquire other weapons. In that case, the market removal program would only be shifting risk from one attack type to another. In the worst case, the capabilities

32 Schroeder, undated.

of an NSAG might actually increase, because they would have effectively traded or upgraded MANPADS for different systems that have greater military utility. Therefore, when considering such a program, the context, capabilities, and intent of the NSAG, as well as careful vetting of the sellers, might be paramount to realizing the intended outcome.

Weapon acquisition programs can provide a cost-effective means of reducing the supply of MANPADS available to NSAGs, particularly for older weapon systems. However, they could have some negative effects, including theft from government stockpiles, inflows of weapons from neighboring regions, stockpiling of weapons by wealthier NSAGs, and inadvertent enhancement of other capabilities of NSAGs.

Preventing MANPADS Employment

The third category of mitigation measures include options that limit the ability of NSAGs to use weapons through flight restrictions to limit aircraft exposure, technical-use controls, airport vulnerability evaluations/mitigation, and changes in aircraft flight operations.

Airspace Flight Restrictions

Perhaps the only way to ensure that commercial aircraft are not targeted by MANPADS is to prevent aircraft from flying in airspace in which those systems are a threat. The Federal Aviation Administration (FAA), in coordination with other U.S. government agencies, provides a risk assessment of the threats to commercial aircraft around the world. It issues Notifications to Airmen (NOTAMs) that advise commercial carriers and general aviation (e.g., business jet operators) to avoid particular airspaces in certain countries and prohibits these operators from flying in specified airspaces. Compliance with advisory NOTAMs is voluntary; compliance with prohibitions is compulsory. Failure to comply with the prohibitions can result in large fines. In October 2019, advisory NOTAMs were in effect in Afghanistan, the Sinai Peninsula, Kenya, and Iran, among other countries. Prohibitions were in effect in parts of Libya, parts of Iran, and all of Venezuela.

In addition, the FAA issues Special Federal Aviation Regulations (SFARs) that restrict flights in regions of specific countries or within the entire country. These are typically defined in terms of altitude and region, with flights prevented from operating below the specified threshold in that region. Compliance with SFARs is mandatory for all U.S. operators and foreign carrier flights operating under code-sharing agreements with U.S. carriers.[33] In October 2019, SFARs were in effect for Iran, Libya, North Korea, Somalia, Syria, parts of Ukraine, and Yemen.

NOTAMs and SFARs are developed based on a series of criteria that include the intent of state and nonstate actors in a given region to attack commercial aircraft, their capability to do so, and the consequence of such an attack. When issued, they represent the consensus views of the U.S. government. NOTAMs and SFARs are available to the public through the FAA website and distributed electronically to commercial and general aviation operators. In general,

[33] A code-share agreement is a flight in which multiple airlines, operating under a partnership agreement, sell tickets to a single flight. While the flight may be owned and operated by a single carrier, for regulatory purposes, it is considered a U.S. carrier if one of the partners is a U.S. registered airline. Such a flight would have to follow prohibition NOTAMs and SFARs. A foreign carrier may operate code-share and non–code share flights.

NOTAMs are the first advisory to be issued when threat reporting arises, and SFARs follow if the threat persists and the affected countries fail to address it.

The primary responsibility for monitoring threats to aviation safety in a given country falls to that country. The FAA only issues NOTAMs and SFARs when the reporting for a country is unavailable or inadequate. For example, there are no NOTAMs or SFARs for Saudi Arabia, despite ongoing hostilities between that country and the Houthi organization in Yemen that have resulted in ballistic missile attacks on airports in Saudi Arabia; the Saudi government has issued its own NOTAM in this case.

Technical-Use Controls

Safety features or "smart gun" technologies also could limit the ability of NSAGs to use MANPADS. These could involve modifying the weapons so that physical or digital keys are needed to disable a security device and use the weapon. These keys could be kept separate from the MANPADS themselves, limiting the damage potential from the loss of the weapons.

Such a system could take two forms. One could permanently disable the weapon if the key were removed in an unauthorized way. A second approach would require a key to be used just before shooting. Both of these modifications could be relatively inexpensive and should have little effect on the ability of state entities, which would have access to the keys. The former, which would be used as weapons were taken out of storage, might be more acceptable to military forces than the latter, which could hinder weapon use in the heat of battle.

Airport MANPADS Vulnerability Evaluation/Mitigation

The Transportation Security Administration's Law Enforcement/Federal Air Marshal Service conducts MANPADS vulnerability assessments at airports in the United States and around the world. These assessments, known as MANPADS Assist Visits (MAVs), help local authorities identify potential security vulnerabilities in and around airports and recommend mitigation measures. These assessments can reduce commercial aircraft vulnerability to attack during critical phases of flight. When possible, these assessments are performed as part of a train-the-trainer engagement. This provides the partners with the capability to perform these assessments for themselves and the potential to sustain that capability over the longer term. Since 2003, the Transportation Security Administration has conducted MAVs and train-the-trainer engagements at over 80 airports in 51 different countries, focusing on last points of departure for the United States.[34] These visits also include MANPADS Recognition Training.

However, while these evaluations may be useful in limiting access to potential launch sites from closer ranges, they cannot fully mitigate the MANPADS threat on their own. Aircraft may have to fly several miles within a potential MANPADS engagement zone during landing and takeoff. For an airport with a single runway, the potential missile launch region could be as large as 300 square miles, extending far beyond the boundaries of the airport itself.[35] RAND found that the potential launch region for targeting airliners flying into and out of Los Angeles International Airport could be as large as 870 square miles for a first-generation MANPADS and 4,600 square miles for a third-generation MANPADS.[36]

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[34] U.S. Department of State Bureau of Political-Military Affairs Office of Weapons Removal and Abatement, 2019.

[35] Ashkenazi et al., 2013.

[36] Chow et al., 2005.

Changes in Flight Operations

Military aircraft can use alternative takeoff and landing procedures to limit their exposure to MANPADS in conflict zones. These can involve short ground rolls, rapid climbouts, and spiral descents. Commercial pilots could conceivably use similar procedures. However, doing so could increase fuel consumption, increasing costs and reducing range and/or payload. As the pilots would only use these techniques periodically, it may also increase risk. Further, doing so could complicate air traffic management and increase the risk of accidents, because not all aircraft may be using this approach. Thus, these procedures might not provide a net benefit.

These measures, however, may be appropriate and effective in limited contexts. For example, flights approaching Israel's Ben Gurion airport use paths of descent that avoid flying at low altitudes over Palestinian population centers, reducing the exposure of planes to potential ground fire.[37]

Reducing the Likelihood of a Successful Attack

There are several options to reduce the likelihood that a targeted commercial aircraft will be intercepted by a MANPADS.[38] They include ground and aircraft countermeasure systems designed to divert the MANPADS away from the aircraft and those designed to destroy the missile in flight.

Ground Countermeasures

Infrared Decoys

Positioning infrared decoys that produce signatures similar to those of jet engines at multiple locations at an airport could provide some protection against first- and second-generation MANPADS while the aircraft are taking off and landing.

These decoys would only provide protection in the immediate vicinity of the airport and to aircraft flying at very low altitudes. Aircraft would continue to be vulnerable in other stages of flight. Further, these decoys are unlikely to be effective against later-generation threats.[39]

High-Energy Lasers

Ground-based high-energy lasers (HELs) could also be used to defend aircraft against MANPADS.[40] Northrop Grumman's Tactical High Energy Laser (THEL) testbed destroyed 46 mortars, rockets, and other artillery projectiles in tests between 2001 and 2005.[41] A similar system incorporating an infrared search and track (IRST) system to acquire and track the missile and a high-energy laser to destroy it could protect aircraft at or in the vicinity of an airport

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[37] Yaniv Kubovich, "Low Approach Over Palestinian Towns Exposes Planes Landing in Israel to Ground Fire," *Haaretz*, July 22, 2019.

[38] The discussion of countermeasures was drawn from Chow et al., 2005; U.S. Department of Homeland Security (DHS), Science and Technology Directorate, *Counter-MANPADS Program Results; Fiscal Year 2008 Report to Congress*, Washington, D.C., 2010; and Ashkenazi et al., 2013.

[39] Ashkenazi et al., 2013.

[40] Other ground-based defenses using directed energy weapons, including high-power microwave systems, could be used the same way. For information on one such system, see Pat Host, "U.S. Air Force Awards Raytheon High-Power Microwave Device Contract," *Jane's Defence Weekly*, September 25, 2019.

[41] Northrop Grumman, "Chemical High-Energy Laser System," webpage, undated.

against MANPADS threats. The system would have to be connected to the airport's radar network to ensure that other aircraft were not affected. If flight corridors could be adjusted to keep aircraft above MANPADS range except when landing and taking off, as few as three of these systems could provide protection out to a range of 5 km.[42] If changes in the flight corridors were impossible, many more would be needed.

HEL system development has continued since the initial THEL demonstrations. The Army is developing the Multi-Mission High Energy Laser, a system designed to be carried on a Stryker wheeled vehicle. It combines wide- and narrow-field-of-view IRSTs with a 50-kilowatt ruggedized fiber laser. It is designed to protect Army forces against rocket, artillery, mortar, unmanned aircraft systems, and fixed- and rotary-wing aircraft. It will be demonstrated against a variety of targets in 2021.[43] A truck-based 100-kilowatt system will be tested the following year.[44] These systems should also be effective against MANPADS.

HEL systems, which are designed to destroy the missile, have the advantage of being able to address the full spectrum of MANPADS threats. In contrast, other countermeasure systems are designed to deceive the missile seeker. They vary in effectiveness, depending on the seeker type and the effectiveness of the missile's IR counter-countermeasures.

HEL systems also have critical disadvantages. A given system can only engage a single missile at a time and could be overwhelmed by attacks by multiple missiles. They can also damage the eyesight of personnel on board the aircraft, although this can be mitigated to some degree by restricting engagement zones to those in which there is little risk of damage. Perhaps most important, they require a clear line of sight to the target and can only defend relatively small zones around airports. Further, large numbers of these systems would have to be procured and operated at locations overseas to address the highest threat areas. This might not be feasible in many areas.

Aircraft Countermeasures

Aircraft countermeasures can be broken into three broad classes: flares, directed infrared countermeasures (DIRCM), and HELs. These systems are typically used in conjunction with a missile warning system (MWS) to identify the threat and employ the countermeasures. The MWS can generate false alarms, increasing countermeasure system utilization, increasing costs and the rate of failure. False alarms can also cause the pilots to rapidly change course to try to limit the effectiveness of the perceived missile attacks, possibly increasing risks. Therefore, ensuring high MWS reliability is a high priority.

Flares

Flares, which can simulate the spectral signature of an aircraft engine, can be very effective against some types of MANPADS, particularly older systems.[45] They are generally less

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42 See Chow et al., 2005, for more information. Flight corridors would have to be adjusted to limit the amount of time aircraft spent in descent and ascent.

43 Army Space and Missile Defense Command, *Multi-Mission High Energy Laser (MMHEL)*, Huntsville, Ala., undated.

44 Sydney J. Freedberg, Jr., "Army: 50 kW Laser Stryker by 2021, 100 kW FMTV Truck by 2022," *Breaking Defense*, August 10, 2017.

45 Pyrophoric chaff can also be effective against some types of MANPADS and are considered in this discussion as well. For a detailed discussion of the effects of different types of flares and other expendable countermeasures against the different generations of MANPADS, see Chow et al., 2005.

effective against third- and fourth-generation systems, which are equipped with IR counter-countermeasures. Flares are ineffective against advanced imaging MANPADS or command-guided systems.[46]

Flares can be used preemptively or reactively. Given the relative rarity of MANPADS use against commercial aircraft, preemptive use is likely to be impractical. Reactive use requires the integration of an MWS to identify the threat and use countermeasures.

Incorporating MWS and flare dispensers increases aircraft cost, weight, and drag. The increase in weight and drag increases fuel burn. Adding flares increases maintenance requirements, and system failures reduce aircraft availability. In addition, flares can create a fire hazard when employed from low altitudes.

Directed Infrared Countermeasures

The second class of aircraft countermeasures combines an MWS with a laser jamming system. These systems detect and track the missile as it approaches the aircraft. The laser then illuminates the missile seeker, substituting a modulated signal to cause the missile to divert from the target.[47] A multiband laser (or group of lasers) is needed to provide coverage against multiple MANPADS types and to defeat narrowband optical filters on some seekers.

These systems have been tested on commercial aircraft. DHS tested two systems against 29 MANPADS.[48] One DIRCM system was built by BAE Systems North America. It was tested on three American Airlines 767-200 passenger aircraft. The other was built by Northrop Grumman. It was tested on ten Federal Express MD-10 cargo aircraft. Over the course of the tests, the aircraft accumulated a total of 16,000 flight hours beginning in 2006. DHS found that both the BAE and Northrop Grumman systems met effectiveness requirements.[49]

DIRCM systems can be effective against most MANPADS.[50] Their effectiveness against advanced imaging threats is uncertain. They are not effective against command-guided systems. Unless they feature multiple turrets, DIRCM systems can only defend against one MANPADS missile at a time and could potentially be saturated by a salvo of missiles. As with flare systems, incorporating a DIRCM system increases aircraft cost, weight, and drag and reduces aircraft availability. The increase in weight and drag increases fuel burn and operating costs with it. As with chaff and flares, adding DIRCM increases maintenance requirements, while system failures reduce aircraft availability.[51]

Equipping large numbers of commercial aircraft would come at a high cost. In 2005, RAND found that the cost of equipping 6,800 commercial aircraft and operating them for ten

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[46] Although flares could have some effect on advanced imaging systems, such an effect is likely to be very limited.

[47] Chow et al., 2005.

[48] Department of Homeland Security, Science and Technology Directorate, 2010.

[49] The types of MANPADS that were tested were not specified in the redacted version of the DHS report we reviewed. See DHS, 2010, for more information.

[50] The Large Aircraft Infrared Counter Measure (LAIRCM) is the primary DIRCM system in service today. LAIRCM is an autonomous system composed of a missile warning system, processor, controller, and laser transmitter. It is installed on over four hundred U.S. Air Force C-5, C-17, C-130, C-37, C-40, and CV-22 aircraft. The same systems could be adapted for use on commercial airliners. This has already been done on the C-40, a militarized version of the Boeing 737.

[51] DHS found that airlines can integrate DIRCM system without significant effects on operations but that neither system met reliability requirements. See DHS, 2010, for more information. We have also identified system DIRCM reliability as a primary concern.

years would be approximately $59.6 billion in fiscal year 2020 dollars.[52] In 2010, DHS found that equipping 3,636 airliners with countermeasure systems capable of defeating MANPADS and operating them for ten years would cost $30.7 billion in fiscal year 2020 dollars.[53]

High-Energy Lasers

HELs can also be used on aircraft. The YAL-1, mounted on a modified Boeing 747, was designed to destroy ballistic missiles in flight. This system was tested but did not become operational. In 2017, an AH-64 attack helicopter acquired and hit an airborne target with a HEL.[54] At some point, it might be possible to use HELs to defend against MANPADS attacks.

However, these systems are much larger than DIRCM systems and have not been incorporated in defensive systems on aircraft to date. The Air Force Research Laboratory's Self-Protect High-Energy Laser Demonstrator (SHiELD) program is developing a podded laser weapon for fighter aircraft that will be capable of protecting the aircraft from incoming surface-to-air and air-to-air missiles. A high-power flight demonstration is planned for fiscal year 2021. If successful, the SHiELD concept could be adapted to protect large transport aircraft.[55]

Countermeasures Summary

The effectiveness of the different classes of countermeasures against different MANPADS threats is summarized in Table 7.1. Flares can be effective against first- and second-generation MANPADS, such as the SA-7 and SA-14, which have been widely proliferated. They could also potentially be effective against third- and fourth-generation systems, assuming the development of flare patterns that can overcome IR counter-countermeasures. DIRCM systems can be effective against the first three generations of MANPADS[56] and could potentially also be effective against fourth-generation systems. Flares are ineffective against fifth-generation systems, which have imaging seekers, and the effectiveness of DIRCM systems against fifth-generation systems is likely to be limited at best. Neither flares nor DIRCM systems are effective against command-guided systems.

Finally, HEL systems, which can destroy missiles in flight, could be effective against all MANPADS. However, they have not been demonstrated in this role and would only be able to protect aircraft during limited portions of the flight. Finally, deploying ground-based HEL systems might not be feasible in areas where the MANPADS risk is greatest because of a lack of access and other concerns.

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52 We generated cost estimates based on a scaled LAIRCM system. The actual value to add this capability to the entire fleet was $38.3 billion in fiscal year 2003 dollars; we converted these to fiscal year 2020 dollars using the deflators in the Fiscal Year 2020 National Defense Budget Estimates. See Chow et al., 2005, and Office of the Under Secretary of Defense (Comptroller), *National Defense Budget Estimates for FY 2020*, Washington, D.C., May 2019, for more information.

53 The actual value presented in the report was $25.75 billion in fiscal year 2010 dollars. These were converted to fiscal year 2020 dollars based on the economy-wide deflator in the National Defense Budget Estimates. See DHS, 2010, for more information.

54 Raytheon, "Laser Strike: A High Energy Laser Mounted on a Helicopter Shoots a Target in a Ground-Breaking Test," webpage, June 26, 2017.

55 Rachel S. Cohen, "Experimental Laser Weapon Downs Multiple Missiles in Test," *Air Force Magazine*, May 3, 2019.

56 Chow et al., 2005.

Table 7.1
Summary of MANPADS Countermeasures

				Countermeasure		
MANPADS Type	**Examples**	**Seeker Capability**	**Proliferation**	**Flares**	**DIRCM**	**HEL**
1st generation	SA-7	Rear aspect, no IRCCM	Very wide			
2nd generation	SA-14	All aspect, no IRCCM	Very wide			
3rd generation	SA-18	All aspect, IRCCM	Wide			
4th generation	FN-6	All aspect, advanced IRCCM	Some			
5th generation	QW-4	All aspect, imaging	None			
Command-guided	Blowpipe	N/A	Very limited			

SOURCE: Adapted from Chow et al., 2005, and Ashkenazi et al., 2013.
NOTES: Green = demonstrated effectiveness; yellow = possible effectiveness; orange = limited effectiveness; red = ineffective. IRCCM = IR countermeasures.

Other Considerations

The effectiveness of most ground- and aircraft-based countermeasure systems depends to a great degree on intelligence assessments of threat MANPADS systems. Some countermeasure systems require periodic updates to remain effective. Furthermore, they rely on sensitive technologies, including sensor processing algorithms and HEL generation systems. If these systems fall into the hands of adversaries, they could be exploited, allowing adversaries to modify existing MANPADS or develop future versions capable of defeating them.

U.S. military forces protect these systems by limiting access to them. Commercial operators might not be able to provide the same level of security, particularly when operating in overseas locations, where the threat appears to be greatest. This problem could be particularly challenging for ground-based systems, which would remain in those locations indefinitely.

Related regulatory issues would have to be addressed. International Traffic in Arms Regulation and Export Administration Regulations prohibit commercial aircraft equipped with MANPADS countermeasure systems from international operations without the appropriate licenses.[57] Changes in these regulations or large numbers of licenses would be needed to allow aircraft to support commercial operations.

Limiting the Damage from a Successful Attack

These options are intended to reduce damage to an aircraft that has been hit. They include aircraft modifications (e.g., hardening aircraft structures; replacing oxygen in fuel tanks with inert gases to reduce the likelihood of fires; adding redundant, isolated flight control systems) and changes to pilot training.

[57] DHS, 2010.

Aircraft Modifications

Another class of mitigation option focuses on limiting the damage to commercial aircraft from a successful MANPADS attack. The historical data on MANPADS attacks suggest that the likelihood of a civilian jet aircraft retaining sufficient functionality to land after being hit by a MANPADS is approximately 50 percent.[58] Many options have been suggested to improve the odds, including hardening aircraft structures, isolating redundant hydraulic lines and flight control linkages, improving fire suppression, and adding inert gases to fuel tanks.[59] Improvements to pilot training have also been suggested.[60]

The results of various analyses and combat data suggest that the most likely impact point for a MANPADS is on an aircraft engine.[61] The engines of most modern jet airliners are mounted underneath the wings. Strengthening the surrounding wings and structure could be cost prohibitive, especially retrofitting existing fleets.[62] Operating costs could also increase because of additional weight.

Adding redundant critical avionics and flight controls and separating these systems could reduce the likelihood of a single missile impact disabling them all at once. However, modern commercial airliners are typically designed with redundancy already, and it is difficult to assess the degree of improvement to commercial aircraft survivability that such enhancements could offer. A technology that could potentially offer a significant enhancement is the Propulsion Controlled Aircraft (PCA) system, a computer-aided engine control system that enables pilots to fly and land an aircraft safely when its normal flight control surfaces are degraded or inoperable. Developed by the National Aeronautics and Space Administration, PCA technology has been successfully demonstrated on a range of aircraft, including large transports.[63] Moreover, PCA technology would also be useful in situations where a mechanical failure led to the loss of flight controls. Similar to aircraft hardening, this type of mitigation would most easily be incorporated into new designs; retrofitting existing aircraft could prove cost prohibitive. Therefore, the introduction of improved safety features could be limited by aircraft fleet turnover and take many years.

Fuel tank inerting systems prevent the ignition of flammable vapors by replacing oxygen in the fuel tank with an inert gas, such as nitrogen. This could reduce the risk of fire in the event of a MANPADS attack. In 2008, the FAA mandated that all new aircraft carrying 30 passengers or more must include technology designed to significantly reduce the risk of center fuel tank fires, like the one that destroyed TWA 800 in 1996, within two years. The rule stipulated that passenger aircraft built after 1991 must be retrofitted with such technology. At the time of the announcement, it was estimated that the cost of retrofitting existing aircraft could

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[58] Historic attacks have largely been conducted using first generation MANPADS. Future attacks using more advanced MANPADS would presumably increase the number of attacks leading to crashes.

[59] See Chow et al., 2005, and Christopher Bolkcom and Bartholomew Elias, *Homeland Security: Protecting Airliners from Terrorist Missiles*, Washington, D.C.: Congressional Research Service, February 16, 2006.

[60] Bolkcom and Elias, 2006, and Ted McKenna, "'Get Real,' Say Airline Reps About MANPADS," *Journal of Electronic Defense*, Vol. 29, No. 6, June 2006, pp. 18–20.

[61] Greg Czarnecki, John Haas, Brian Sexton, Joe Manchor, and Gautam Shah, "Large Engine Vulnerability to MANPADS," *Aircraft Survivability*, Spring 2014, pp. 6–11.

[62] Bolkcom and Elias, 2006, and Ashkenazi et al., 2013.

[63] Air Line Pilots Association, *White Paper: Recommendations for Countermeasures to Man-Portable Air Defense Systems (MANPADS)*, Washington, D.C., July 2008.

range from $150,000 to $400,000 per aircraft.[64] The rule was expected to cost U.S. airlines approximately $435 million to retrofit 2,730 Boeing and Airbus aircraft.[65] Further improvements to bring fuel inerting standards for commercial aircraft up to those for military aircraft are possible, although the cost-effectiveness of pursuing such an enhancement is uncertain.

Pilot Training

Changes in pilot training could also improve commercial aircraft survivability in the event of a MANPADS attack. Airline pilots are trained to fly with one engine inoperable, even during critical phases of flight, such as takeoff and landing. This training should provide at least some carryover benefit for situations involving the loss of an engine because of a MANPADS strike. However, an assessment of the vulnerability of the turbofan engines used by large commercial aircraft to MANPADS suggest that pilots should be ready for situations in which they experience a loss of thrust, an engine fire, and degraded flight control simultaneously.[66] It is also worth noting that the last two attacks involving MANPADS hits on civilian aircraft—the 2003 attack on a DHL A300 in Baghdad and the 2007 attack on an IL-76 in Mogadishu—featured weapons striking the wings. In the former case, the crew was able to recover and safely land the aircraft. The latter resulted in the loss of the aircraft and crew. This highlights the potential utility of training aircrew on "throttles-only control" (i.e., using thrust and/or differential thrust when the normal flight control systems are degraded or inoperable).

While enhancements to pilot training could improve the likelihood that an aircraft recovers after a MANPADS strike, it is not entirely clear how much additional training would be required for aircrews to become proficient in such situations. For situations in which normal flight control surfaces are degraded or inoperable, simulator tests have demonstrated that throttles-only control techniques could enable aircrews to maintain gross control for a range of large transport aircraft; however, landing safely was very challenging.[67] Developing and sustaining aircrew proficiency in such techniques could potentially require significant resources. The appetite of commercial airlines to incorporate such training into their programs is unclear.

Consequence Management

In the event of damage to an aircraft or the loss of an aircraft, steps can be taken to limit loss of life. Contingency response planning that efficiently allocated emergency responders and available hospitals to a given incident could allow police, firefighters, and ambulances to rapidly get to the aircraft, treat injured crew and passengers on the scene, and move the injured to hospitals or other facilities to receive treatment. Firefighters might be able to limit the spread of fire

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64 John Croft, "US FAA to Issue Final Fuel Inerting Rule," *FlightGlobal*, July 17, 2008.

65 Croft, 2008.

66 This assessment was a collaborative effort involving U.S. Department of Defense Joint Live Fire, DHS, Air Force Life Cycle Management Center, 96th Test Group, Naval Air Warfare Center, National Aeronautics and Space Administration, and General Electric Aircraft Engines. It combined a range of techniques including detailed modeling and live-fire testing. See Czarnecki et al., 2014.

67 Simulation testing included the Boeing 727, 737, 747, 757, 767, 777, MD-11, MD-90, and C-17, as well as the Airbus A320 and A300 transports; see Kerry Wilson, "DHS Counter-MANPADS Programs," *Aircraft Survivability*, Fall 2010, pp. 12–16.

and the damage to surrounding areas. Effective responses by emergency responders could limit the loss of life in a MANPADS attack.

However, as the greatest MANPADS threats are overseas, the ability of the United States to influence contingency response planning is limited, much as it has been with airport security evaluations. Nonetheless, training programs, sharing best practices, and information exchanges between U.S. emergency responders and their foreign counterparts would not hurt, and it could improve consequence management in the event of a MANPADS attack.

Summary

The United States has many options for mitigating the MANPADS threat to commercial aviation. They range from those designed to limit the ability of NSAGs to operate effectively to ones that can reduce the consequences of a successful attack. Many of these options are already being pursued.

U.S. government agencies have aggressively targeted NSAGs for decades, seizing assets, extraditing and prosecuting group members, and prosecuting entities that do business with them. U.S. military forces have captured and killed NSAG members.

The United States has tried to prevent NSAGs from acquiring MANPADS by negotiating export control agreements, interdicting weapons shipments, and working to improve weapon storage and monitoring. It also has funded weapon recognition and disablement training to increase the likelihood that MANPADS will be intercepted by local authorities. It has bought weapons on the open market in conflict zones to prevent them from falling into the hands of NSAGs.

The United States has issued airspace notifications and restrictions, reducing or eliminating the risk of MANPADS attacks in countries and regions of particular concern. It has also conducted airport vulnerability evaluations to improve security at foreign airports.

The United States has investigated incorporating countermeasures on commercial aircraft to defend against the MANPADS threat. The United States has conducted limited tests of these systems. Assessments have generally been favorable. However, the costs of introducing these systems on the U.S. commercial fleet would be in the tens of billions of dollars. Doing so would require accepting some security risks. Implementing ground-based solutions could require deploying large numbers of sophisticated sensor and directed-energy systems and may not be feasible in the regions where they are most needed. It would also require accepting security risk.

The United States has mandated the incorporation of systems to reduce the risk of fires in fuel tanks. This can also reduce the risk of catastrophic damage in the event of a MANPADS attack. Changes in flight control systems and pilot training could also reduce these risks.

Finally, improved contingency planning and enhanced emergency response capabilities might reduce loss of life in an attack by more rapidly and more effectively utilizing available medical and other resources.[68] They include contingency planning and disaster response activities.

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[68] For example, a contingency plan to rapidly move the injured to suitable treatment centers could avoid potential delays that could result from having to devise such a plan in real time. More rapid treatment could reduce the expected loss of life and number of permanent injuries.

Multilayered Options

The United States has pursued many policies to reduce the likelihood of MANPADS attacks on commercial aircraft. They include policies to disrupt or degrade NSAG operations writ large, preventing NSAGs from acquiring MANPADS, preventing weapon employment, limiting the likelihood of successful weapon employment, and limiting damage from a successful attack. We assessed a wide variety of policy options in our literature search and discussions with government subject matter experts. Alone, none of them offer a failsafe solution for preventing MANPADS attacks. Moreover, because the effectiveness, feasibly and associated costs vary across the options laid out above, we suggest that a combination of mitigating options is advisable. Where one effort fails, another may succeed. Therefore the current mix of policies, which make up a multilayered approach, should be continued and in places expanded, as we note below.

New export controls could focus on ensuring transparency and accountability, with the acquiring nation agreeing to regular inspections by a trusted third party. Accountability implies some sanction of the exporter and/or importer should they violate the agreed to controls, for instance, by punishing a state importer which knowingly transferred MANPADS to an NSAG. The least coercive measures might be publicly shaming violators or denying them representation in international fora (e.g., the G20). More-coercive approaches could include limiting the sale of dual-use technology to violators. Alternatively, cooperation on counterproliferation could be incentivized by linking the sale and subsequent sustainment of countermeasure systems for protecting head-of-state aircraft to, for instance, membership in the Wassenaar Arrangement and abiding by its strictures.

MANPADS risk can also be "bought down" through additional security measures installed in the MANPADS systems themselves. Security devices could be installed in new production MANPADS to reduce the risk that they could be used by NSAGs. The advantage of this approach is that if MANPADS were unintentionally diverted to an NSAG—for example, by leakage from a stockpile—the MANPADS could be remotely disabled even if authorities were unable to recover the system.

Efforts to reduce excess or obsolete state MANPADS inventories and improve security should continue and possibly be expanded. It also might be possible to incorporate security devices on existing MANPADS to further improve security. Although given the challenge of getting states to retroactively fit aging MANPADS with new safety technology, simple steps, like establishing the practice of storing launchers separately from missiles, may be more realistic. Airport vulnerability assessment visits, implementation of airport security upgrades, and training in MANPADS recognition and disablement should also be continued and expanded to further reduce the threat to commercial aviation.

An approach tying U.S. economic assistance, military assistance, and other U.S. government engagement to progress in these objectives could be advantageous. Programs to reduce or secure MANPADS inventories are largely focused only on these objectives. U.S. economic assistance, military assistance, and other types of engagements are treated separately. A more integrated approach could create options for progress that might not otherwise be available. Of course, these objectives would have to be weighed against other policy objectives on a case-by-case basis. If the United States found willing partners, particularly among the major producers of MANPADS, they could pool their leverage in order to reduce MANPADS risk. As cooperation between the United States and its adversaries after the end of the Cold War demonstrates, Washington could find common ground on narrow issues of mutual concern, even with its global competitors (i.e., Russia, China). Indeed, as the bombing of the Russian airliner over Sharm El Sheikh demonstrates, Russian citizens are also the victims of vulnerability in airline security; as the enormous boom in Chinese tourism continues, its citizens' travel to other parts of the globe will increasingly expose China to these same risks.

Implementing countermeasures does not appear justified. Ground-based systems have not been demonstrated as useful in this role. Large numbers would be needed to defend airports in regions where MANPADS attacks are most likely to occur. Access to those regions might not be feasible. Equipping commercial aircraft with countermeasures could cost tens of billions of dollars. Implementing either systems would require accepting security risks.

Monitoring the results can help achieve and maintain consistency. Mitigating the MANPADS threat will require a persistent focus. The MANPADS threat will continue to evolve over time. Newer, more capable systems will become available. NSAGs will seek to acquire and employ them. Cooperation in controlling exports of these systems and, at times, actions to interdict shipments will be needed. The United States and its partners must continue to monitor the evolution of the threat, improve safeguards where possible, and take action when needed.

CHAPTER EIGHT

Conclusions

MANPADS pose potential danger of varying degree to civilian aviation around the world. This report has presented several empirically based ways to gauge the risk of MANPADS to civilian aviation by region. It has also estimated the potential cost of an attack based on historical data. We highlight several key takeaways.

First, the data suggest that historically, MANPADS have overwhelmingly been used to target commercial aircraft in conflict settings, primarily those of higher intensity. Moreover, most of the incidents took place in Africa, particularly southern Africa. External intervention by other countries into these civil conflicts was also a key feature of many attacks. Many attacks were also repeat attacks carried out in the 1980s and 1990s. While these trends are suggestive, we reiterate that there is no guarantee that a future attack will resemble past incidents.

Second, we developed a MANPADS risk index centered around NSAGs. To inform the index, we sought factors that would be reflective of a group's *intent* and *capability* to employ MANPADS. Again, we used both historical and current publicly available data to construct the index. The index features 57 NSAGs, primarily from the Middle East and North Africa. Four of the top five highest scoring groups in index—ISIS, HTS, other Syrian opposition groups, and the PKK—are primarily based in the Middle East.

Third, Russia and China not only possess the most MANPADS, they are the two states historically most willing to sell them to countries of questionable internal stability. This includes some of the most fragile and war-racked countries, such as Sudan, South Sudan, and Libya. It also includes known supporters of NSAGs, such as Pakistan and Qatar. Moreover, of the countries that possess considerable stockpiles of MANPADS, some of them are currently beset with instability. Chief among these are Syria, Afghanistan, and Venezuela.

Fourth, although our econometric models did not identify singular effect on economic outcomes correlated to MANPADS attacks, they did point to a strong relationship between attacks on aircraft in flight and GDP. An attack of this type is associated with a (statistically significant) 1.4-percent decrease in GDP. We did not find a statistically significant relationship between attacks on aircraft in flight and other economic indicators, such as FDI and trade. In addition, the pernicious effect that conflict has on an economy remains a concern. The majority of MANPADS attacks have transpired in countries suffering state-based conflicts; a MANPADS-like attack on a civilian aircraft in such an environment is likely to negatively affect a country even further.

The risk of a MANPADS attack to civil aviation is as easy to blow out of proportion as it is to dismiss outright. There have been few attacks over four decades, and an attack has not transpired in roughly a dozen years. However, as we have clearly demonstrated here, ample nonstate actors active in conflict settings possess this weapon capability and have demonstrated the potential intent to use it to the harm of civilians. Furthermore, unstable countries continue to stockpile these systems, and producer countries such as China and Russia have shown little compunction in selling them to unstable regimes. From this, it is not difficult to imagine deadly scenarios involving civilian airline passengers and MANPADS use.

The combination of options used by the U.S. government to mitigate the MANPADS threat creates a robust, relatively fault-tolerant system. For example, if efforts to capture or prosecute NSAG leaders and seize their assets fail, export controls could still prevent NSAGs from acquiring MANPADS, mitigating the threat. Similarly, if export controls fail, NOTAMs and SFARs prohibiting U.S.-registered carriers from operating in areas where NSAGs threaten commercial aviation should effectively neutralize the threat.

We have emphasized a multilayered approach to reduce the risk of a MANPADS attack. The MANPADS threat will not disappear. The United States should work with partners to further restrict MANPADS exports and increase transparency and accountability for those that remain. It should work to implement security measures to reduce the likelihood that stolen weapons can be successfully employed. It should also work with partner countries to reduce stocks and improve physical security on a country-by-country basis. Although the likelihood of an attack appears to be low, the political and economic fallout from a MANPADS attack on a commercial aircraft would be substantial. Commensurate efforts and resources should be devoted to preventing such an outcome.

APPENDIX A

RAND Database of MANPADS Attacks

Table A.1 presents the conflicts included in the RAND database of MANPADS attacks. Table A.2 is the list of the included attacks.

Table A.1
Conflicts

Number	Date	Location	Conflict	High-Intensity Conflict	Low-Intensity Conflict
1	1/15/73	Italy	No conflict	No	No
2	9/5/1973	Italy	No conflict	No	No
3	3/14/1975	Vietnam	Interstate conflict	Yes	No
4	1/25/1976	Kenya	No conflict	No	No
5	1/29/1978	Chad	Civil war	Yes	No
6	9/3/1978	Zimbabwe	Civil war	Yes	No
7	4/15/1979	Mozambique	Civil war	No	Yes
8	2/12/1979	Zimbabwe	Civil war	Yes	No
9	5/16/1981	Angola	Civil war	Yes	No
10	8/1/1981	Mozambique	Civil war	Yes	No
11	11/8/1983	Angola	Civil war	Yes	No
12	2/9/1984	Angola	Civil war	Yes	No
13	9/21/1984	Afghanistan	Civil war	Yes	No
14	2/24/1985	Western Sahara	No conflict	No	Yes
15	9/4/1985	Afghanistan	Civil war	Yes	No
16	6/8/1986	Angola	Civil war	Yes	No
17	8/16/1986	Sudan	Civil war	Yes	No
18	10/5/1986	Nicaragua	Civil war	Yes	No
19	5/5/1987	Sudan	Civil war	Yes	No
20	2/9/1987	Afghanistan	Civil war	Yes	No
21	6/11/1987	Afghanistan	Civil war	Yes	No
22	10/14/1987	Angola	Civil war	Yes	No

Table A.1—Continued

Number	Date	Location	Conflict	High-Intensity Conflict	Low-Intensity Conflict
23	11/9/1987	Mozambique	Civil war	Yes	No
24	12/21/1987	Costa Rica	No conflict	No	No
25	4/11/1988	Afghanistan	Civil war	Yes	No
26	12/8/1988	Western Sahara	Civil war	No	Yes
27	12/8/1988	Western Sahara	Civil war	No	Yes
28	6/28/1989	Somalia	Civil war	No	Yes
29	12/21/1989	Sudan	Civil war	Yes	No
30	1/5/1990	Angola	Civil war	Yes	No
31	6/12/1990	Afghanistan	Civil war	No	Yes
32	2/22/1991	Angola	Civil war	No	Yes
33	3/16/1991	Angola	Civil war	No	Yes
34	4/1/1991	Angola	Civil war	No	Yes
35	6/10/1991	Angola	Civil war	No	Yes
36	9/10/1991	Rwanda	Civil war	No	Yes
37	9/17/1991	Somalia	Civil war	Yes	No
38	1/28/1992	Azerbaijan	Civil war	Yes	No
39	3/27/1992	Armenia	No conflict	No	No
40	5/29/1992	Afghanistan	Civil war	Yes	No
41	9/3/1992	Bosnia	Civil war	Yes	No
42	4/5/1993	Angola	Civil war	Yes	No
43	4/26/1993	Angola	Civil war	Yes	No
44	6/25/1993	Georgia	Civil war	Yes	No
45	7/22/1993	Georgia	Civil war	Yes	No
46	9/20/1993	Georgia	Civil war	Yes	No
47	9/21/1993	Georgia	Civil war	Yes	No
48	9/22/1993	Georgia	Civil war	Yes	No
49	4/6/1994	Rwanda	Civil war	Yes	No
50	1/28/1995	Angola	Civil war	No	Yes
51	9/2/1998	Angola	Civil war	Yes	No
52	9/29/1998	Sri Lanka	Civil war	No	Yes
53	10/10/1998	Democratic Republic of the Congo	Civil war	No	Yes
54	12/14/1998	Angola	Civil war	Yes	No

Table A.1—Continued

Number	Date	Location	Conflict	High-Intensity Conflict	Low-Intensity Conflict
55	12/26/1998	Angola	Civil war	Yes	No
56	1/2/1999	Angola	Civil war	Yes	No
57	5/12/1999	Angola	Civil war	Yes	No
58	7/1/1999	Angola	Civil war	Yes	No
59	6/8/2001	Angola	Civil war	Yes	No
60	6/16/2001	Angola	Civil war	Yes	No
61	6/16/2001	Angola	Civil war	Yes	No
62	11/28/2002	Kenya	No conflict	No	No
63	11/22/2003	Iraq	Civil war	Yes	No
64	3/23/2007	Somalia	Civil war	Yes	No
65	8/13/2007	Iraq	Civil war	Yes	No

SOURCES: UCDP, *UCDP/PRIO Armed Conflict Dataset Codebook*, Version 4-2015, Centre for the Study of Civil Wars, International Peace Research Institute, 2015.

NOTE: The conflict intensity ranking corresponding with each MANPADS attack is based on the Uppsala Conflict Data Program's conflict coding system.

Table A.2
MANPADS Attack Incidents

Number	Date	Aircraft	Engine	Deaths	Attackers	Location	Weapon Used	Phase of Flight	Point of Impact	Outcome	Source
1	1/15/1973	Israeli Government Flight Boeing 707	4 jet engines	0	Black September	Italy	Unknown	Landing	N/A	Foiled in final minutes	BICC
2	9/5/1973	El Al Boeing 707	4 jet engines	0	Black September	Italy	Unknown	Unknown	N/A	Foiled in final minutes	BICC; GTD
3*	3/14/1975	Air Vietnam DC-4	4 turboprop engines	26	North Vietnamese Forces	Vietnam	SA-7	En route	Unknown	Crashed	BICC
4	1/25/1976	El Al Boeing 707	4 jet engines	0	Baader Meinhof and PFLP	Kenya	SA-7	Unknown	N/A	Foiled in final minutes	BICC; GTD
5	1/29/1978	French DC-4	2 piston engines	3	National Liberation Front of Chad	Chad	Unknown	Unknown	Unknown	Crashed	BICC; ASN
6	9/3/1978	Air Rhodesia Vickers 782D Viscount	4 turboprop engines	48	ZIPRA	Zimbabwe	SA-7	Takeoff	Right wing	Crashed	BICC; ASN
7	2/12/1979	Air Rhodesia Vickers 782D Viscount	4 turboprop engines	59	ZIPRA	Zimbabwe	SA-7	En route	Left engine	Crashed	BICC; ASN
8	4/15/1979	COMAG BN-2A-8 Islander	2 turboprop engines	0	Unknown	Mozambique	Unknown	Unknown	Right engine	Landed	ASN
9	5/16/1981	TAAG-Angola Airlines L-100-20 Hercules	4 turboprop engines	4	UNITA	Angola	Unknown	Approach	Unknown	Crashed	BICC; ASN
10	8/1/1981	C-47B-1-DK (DC-3)	2 turboprop engines	6	Unknown	Mozambique	Unknown	Unknown	Unknown	Crashed	ASN
11	11/8/1983	TAAG-Angola Airlines Boeing 737-2M2	2 jet engines	130	UNITA	Angola	Unknown	Initial climb	Unknown	Crashed	BICC
12	2/9/1984	TAAG-Angola Airlines Boeing 737-2M2	2 jet engines	0	UNITA	Angola	Unknown	Landing	Rear	Landed	BICC

Table A.2—Continued

Number	Date	Aircraft	Engine	Deaths	Attackers	Location	Weapon Used	Phase of Flight	Point of Impact	Outcome	Source
13	9/21/1984	Ariana Afghan Airlines McDonnell Douglas DC-10-30	3 jet engines	0	Afghan guerrillas	Afghanistan	Unknown	Unknown	Unknown	Landed	BICC; ASN
14	2/24/1985	Dornier 228-100	2 turboprop engines	3	Polisario Front	Western Sahara	Unknown	En route	Unknown	Crashed	ASN
15	9/4/1985	Bakhtar Afghan Airlines Antonov AN-26	2 turboprop engines	52	Hizb i-Islami	Afghanistan	Unknown	Takeoff	Unknown	Crashed	BICC; ASN
16	6/8/1986	TAAG-Angola Airlines L-100-20 Hercules	4 turboprop engines	0	UNITA	Angola	Unknown	Landing	Unknown	Crashed	ASN
17	8/16/1986	Sudan Airways Flight Fokker F-27 Friendship	2 turboprop engines	60	SPLA	Sudan	SA-7	Takeoff	Unknown	Crashed	BICC; ASN
18	10/5/1986	Corporate Air Services Fairchild C-123K Provider	2 piston engines	3	Sandinistas	Nicaragua	SA-7	En route	Unknown	Crashed	BICC; ASN
19	2/9/1987	Democratic Republic of Afghanistan Air Force AN-26	2 turboprop engines	36	Mujahedin	Afghanistan	Stinger	Initial climb	Unknown	Crashed	ASN
20	5/5/1987	Sudanese Aeronautical Services Airways Cessna 404 Titan II	2 turboprop engines	13	SPLA	Sudan	SA-7	Unknown	Unknown	Crashed	BICC
21	6/11/1987	Bakhtar Alwatana Airlines Antonov AN-26	2 turboprop engines	53	Afghan guerrillas	Afghanistan	Stinger	En route	Unknown	Crashed	BICC; ASN
22	10/14/1987	Zimex Aviation L-100-30 Hercules	4 turboprop engines	8	UNITA	Angola	Unknown	Takeoff	Unknown	Crashed	ASN

Table A.2—Continued

Number	Date	Aircraft	Engine	Deaths	Attackers	Location	Weapon Used	Phase of Flight	Point of Impact	Outcome	Source
23	11/9/1987	Air Malawi Shorts SC.7 Skyvan	2 turboprop engines	10	Mozambique Army	Mozambique	Unknown	En route	Unknown	Crashed	BICC; ASN
24	12/21/1987	Aeronica DC-6BF	4 turboprop engines	0	Unknown	Costa Rica	Redeye or SA-7	En route	Engine	Crashed	ASN?
25	4/11/1988	Bakhtar Alwatana Airlines Antonov AN-26	2 turboprop engines	29	Afghan NSAG	Afghanistan	Unknown	En route	Unknown	Crashed	BICC; GTD
26	12/8/1988	United States AID flight 1 T&G Aviation—Douglas DC-7CF	4 piston engines	5	Polisario Front	Western Sahara	SA-7	En route 11,000 ft	Engine	Crashed	BICC; ASN
27	12/8/1988	United States AID flight 2 T&G Aviation—Douglas DC-7CF	4 piston engines	0	Polisario Front	Western Sahara	SA-7	En route 11,000 ft	Engine	Landed	BICC; ASN
28	6/28/1989	Somalia Airlines Fokker F-27 Friendship 600RF	2 turboprop engines	30	Somali National Movement	Somalia	Unknown	En route	Unknown	Crashed	BICC; GTD
29	12/21/1989	Doctors Without Borders IRMA/ Britten-Norman BN-2A-9 Islander	2 piston engines	4	SPLA	Sudan	SA-7	Takeoff/ initial climb	Unknown	Crashed	BICC; ASN
30	1/5/1990	Angola Air L-100-30 Hercules	4 turboprop engines	0	UNITA	Angola	Unknown	En route	Right engine	Landed	ASN
31	6/12/1990	Aeroflot Uzbekistan Ilyushin Il-76MD	4 jet engines	0	Afghan guerrillas	Afghanistan	Stinger	En route	Engine	Landed	BICC; ASN
32	2/22/1991	National Air Force of Angola Antonov 26 Transport Flight	2 turboprop engines	47	UNITA	Angola	Unknown	Unknown	Unknown	Crashed	BICC; ASN

Table A.2—Continued

Number	Date	Aircraft	Engine	Deaths	Attackers	Location	Weapon Used	Phase of Flight	Point of Impact	Outcome	Source
33	3/16/1991	Transafrik Airlines Lockheed L-100 Hercules	4 turboprop engines	9	UNITA	Angola	Stinger	En route	Unknown	Crashed	BICC; ASN
34	4/1/1991	International Committee of the Red Cross flight DHC-6 Twin Otter 300	2 turboprop engines	0	UNITA	Angola	Unknown	En route	Left wing/ engine	Landed	BICC; ASN
35	6/10/1991	Angolan Government Contract Cargo Flight C-130	4 turboprop engines	7	UNITA	Angola	Stinger	Initial climb	Right wing	Crashed	BICC
36	9/10/1991	Scribe Airlift Cargo Zaire Fokker F-27	2 turboprop engines	0	Rwandan Patriotic Front	Rwanda	Unknown	En route	Unknown	Landed	ASN
37	9/17/1991	International Committee of the Red Cross Flight Dornier 228-201	2 turboprop engines	0	Unknown	Somalia	SA-7	En route	Unknown	Landed	BICC; ASN
38	1/28/1992	Azerbaijani Government Flight	Unknown	47	Armenian NSAG	Azerbaijan	Unknown	Unknown	Unknown	Crashed	BICC; GTD
39	3/27/1992	Armenian Airlines Yakovlev 40	3 jet engines	0	Unknown	Armenia	Unknown	Initial climb	Unknown	Landed	BICC; ASN
40	5/29/1992	Ariana Afghan Airlines TU-154M	3 jet engines	0	Mujahedin	Afghanistan	Unknown	Approach	Nose	Landed	ASN
41	9/3/1992	United Nations Flight Alenia G-222TCM	4 turboprop engines	4	Unknown	Bosnia	Stinger	En route	Unknown	Crashed	BICC; ASN
42	4/5/1993	United Nations Flight	Unknown	0	UNITA	Angola	Unknown	Unknown	Unknown	Landed	BICC
43	4/26/1993	United Nations Flight Antonov 12B	4 turboprop engines	1	UNITA	Angola	Unknown	En route	Engine	Crashed	BICC; ASN

Table A.2—Continued

Number	Date	Aircraft	Engine	Deaths	Attackers	Location	Weapon Used	Phase of Flight	Point of Impact	Outcome	Source
44	6/25/1993	Aeroflot Airlines IAI Arava	2 turboprop engines	0	Abkhazian NSAG	Georgia	SA-7	En route	Engine	Landed	BICC
45	7/22/1993	Tupolev TU-154 plane	3 jet engines	0	Abkhazian NSAG suspected	Georgia	Unknown	Approach	Engine	Landed	BICC
46	9/20/1993	Orbi Georgian Airways Tupolev 134A	2 jet engines	0	Abkhazian NSAG	Georgia	Unknown	Takeoff	Unknown	Crashed	BICC; ASN
47	9/21/1993	Transair Georgia Airlines Tupolev 134A	2 jet engines	27	Abkhazian NSAG	Georgia	SA-7	Approach	Unknown	Crashed	BICC; ASN
48	9/22/1993	Transair Georgia Airlines Tupolev 154B	3 jet engines	108	Abkhazian NSAG	Georgia	SA-7	Approach	Engine	Crashed	BICC
49	4/6/1994	Rwandan Government Dassault Falcon 50	3 jet engines	12	Rwandan Patriotic Front	Rwanda	SA-16	Approach	Left wing	Crashed	BICC; ASN
50	1/28/1995	SAL Beechcraft 200	2 turboprop engines	2	UNITA	Angola	Stinger	Initial climb	Right engine	Crashed	ASN
51	9/2/1998	Prestavia AN-26B	2 turboprop engines	24	UNITA	Angola	Unknown	En route	Engine	Crashed	ASN
52	9/29/1998	Lionair Flight Antonov 24RV	2 turboprop engines	55	LTTE	Sri Lanka	Unknown	En route	Unknown	Crashed	BICC; ASN
53	10/10/1998	Congo Airlines Boeing 727-30	3 jet engines	41	Tutsi NSAG	Democratic Republic of the Congo	SA-7	Initial climb	Center Engine	Crashed	BICC; ASN
54	12/14/1998	Khors AN-12BP	4 turboprop engines	10	UNITA	Angola	Unknown	En route	Unknown	Crashed	BICC; ASN
55	12/26/1998	United Nations Flight Hercules Lockheed L-100-30	4 turboprop engines	14	UNITA	Angola	Unknown	En route	Unknown	Crashed	BICC; ASN

Table A.2—Continued

Number	Date	Aircraft	Engine	Deaths	Attackers	Location	Weapon Used	Phase of Flight	Point of Impact	Outcome	Source
56	1/2/1999	United Nations Flight Hercules Lockheed C-130	4 turboprop engines	8	UNITA	Angola	Unknown	En route	Unknown	Crashed	BICC; ASN
57	5/12/1999	Avita Servicos Aéreos AN-26	2 turboprop engines	0	UNITA	Angola	Unknown	En route	Engine	Crashed	ASN
58	7/1/1999	AN-12B	4 turboprop engines	1	UNITA	Angola	Unknown	En route	Unknown	Crashed	ASN
59	6/8/2001	United Nations Flight Boeing 727-90C	3 jet engines	0	UNITA	Angola	Unknown	Approach	Engine	Landed	BICC; ASN
60	6/16/2001	United Nations Flight	Unknown	0	UNITA	Angola	Unknown	Unknown	Unknown	Landed	BICC
61	6/16/2001	United Nations Flight	Unknown	0	UNITA	Angola	Unknown	Unknown	Unknown	Landed	BICC
62	11/28/2002	Arkia Israeli Airlines Boeing 757-3E7	2 jet engines	0	Al-Qaida	Kenya	SA-7x2	Takeoff	N/A	Missile missed target	BICC; ASN
63	11/22/2003	DHL Cargo Flight Airbus A300B4-203F	2 jet engines	0	Islamic Army in Iraq	Iraq	SA-7; SA-14	Initial climb	Wing	Landed	BICC; ASN
64	3/23/2007	TransAVI Aexport Cargo Plane Ilyushin 76TD	4 jet engines	11	Al-Shabaab	Somalia	SA-18x2	Initial climb	Wing	Crashed	BICC; ASN
65	8/13/2007	Nordic Airways MD-83	2 jet engines	0	Iraqi NSAG	Iraq	Unknown	Takeoff	N/A	Missile missed target	BICC

SOURCES: The MANPADS attack data was drawn from a number of sources, including Ashkenazi et al., 2013 (BICC), Aviation Safety Network, undated (ASN), and the GTD.

* Subject-matter experts have some doubt as to whether this incident meets the inclusion criteria for this database. The aircraft might have been shot down by North Vietnamese government forces and not the Vietcong, in which case the incident would not meet the criterion if an attack by an NSAG. It could also be that mechanical failure, rather than a shoulder-fired surface-to-air missile, was the cause of the crash. We have chosen to keep the incident in our database for the sake of comprehensiveness, but we have lower confidence this incident meets all the inclusion criteria than the other 64 incidents in the database.

APPENDIX B

Country Stockpiles

Table B.1 presents the information from the RAND MANPADS country stockpile database.

Table B.1
RAND MANPADS Country Stockpile Database

Country	Total Systems in Country	FSI Rating (2019)
United States*	50,000–90,000	38.0
Russia*	46,000–140,000	74.7
China*	46,000	71.1
Germany*	28,791	24.7
Libya	21,482	92.2
Yugoslavia	20,000	67.0**
Syria	17,210	111.5
India	13,395	74.4
Egypt*	12,664	88.4
Poland*	11,400	42.8
Iraq	9,700	99.1
Czech Republic	8,290	37.6
Pakistan*	8,091	94.2
United Kingdom*	7,942	36.7
Bulgaria*	7,400	50.6
North Korea*	7,000	92.7
Vietnam	6,630	66.1
Turkey*	6,448	80.3
South Korea*	6,118	33.7
France*	5,850	32.0
Hungary	5,660	49.6
Romania	5,550	47.8

Table B.1—Continued

Country	Total Systems in Country	FSI Rating (2019)
Iran*	5,400	83.0
Norway	5,200	18.0
Afghanistan	4,500	105.0
Venezuela	4,500	89.3
Greece*	3,867	53.9
Saudi Arabia	3,730	70.4
Switzerland	3,500	18.7
Jordan	2,960	75.9
Taiwan	2,493	N/A***
Nicaragua	2,427	78.1
Netherlands*	2,246	24.8
Finland	2,156	16.9
Thailand	1,946	73.1
Israel	1,839	76.5
Canada	1,800	20.0
Malaysia	1,790	60.5
Angola	1,760	87.8
Indonesia	1,722	70.4
Ethiopia	1,700	94.2
Cuba	1,600	60.8
Kuwait	1,522	53.2
Singapore	1,400	28.1
Peru	1,358	68.2
United Arab Emirates	1,285	40.1
Cambodia	1,283	82.5
Mongolia	1,250	54.1
Ukraine	1,210	71.0
Denmark	1,083	19.5
Sweden*	1,083	20.3
Spain	1,040	40.7
Azerbaijan	1,018	73.2
Chile	1,008	38.9
Belgium	1,004	28.6

Table B.2—Continued

Country	Total Systems in Country	FSI Rating (2019)
Algeria	1,000	75.4
Oman	976	50.0
Japan	937	34.3
Armenia	800	66.7
Italy	786	43.8
Brazil	782	71.8
Qatar	745	45.4
Bangladesh	721	87.7
Sudan	675	108.0
Cyprus	654	57.8
Ecuador	634	71.2
Yemen	600	113.5
Australia	510	19.7
Lithuania	504	38.1
Austria	500	25.0
Lebanon	450	85.0
Serbia	376	68.0
Somalia	350	112.3
Argentina	320	46.0
Burundi	305	98.2
Mozambique	300	88.7
Tanzania	300	80.1
Tunisia	300	70.1
Botswana	285	59.5
Slovenia	276	28.0
Latvia	252	43.9
Eritrea	250	96.4
Guinea-Bissau	250	95.5
Laos	250	78.7
Morocco	235	73.0
Bahrain	231	63.8
Chad	220	108.5
Estonia	209	40.8

Table B.1—Continued

Country	Total Systems in Country	FSI Rating (2019)
Uganda	205	95.3
South Africa	204	71.1
Nigeria	200	98.5
El Salvador	165	69.8
Portugal	165	25.3
Myanmar	155	94.3
Colombia	140	75.7
Turkmenistan	138	71.4
Georgia	125	72.0
Slovakia	120	40.5
Albania	100	58.9
Ghana	100	65.9
Guinea	100	99.4
Guyana	100	68.2
Kenya	100	93.5
Mauritania	100	90.1
Zambia	100	85.7
Ireland	95	20.6
Brunei	72	57.5
Malawi	70	83.3
Gabon	60	70.5
Bolivia	58	72.9
Burkina Faso	55	83.9
Cameroon	50	97.0
Namibia	50	66.4
Seychelles	50	55.2
South Sudan	50	112.2
Mali	40	94.5
Mexico	30	69.7
Sri Lanka	30	84.0
New Zealand	27	20.1
Kazakhstan	20	61.6
Cote d'Ivoire	10	92.1

Table B.1—Continued

Country	Total Systems in Country	FSI Rating (2019)
Democratic Republic of the Congo	10	110.2
Macedonia	10	64.6
Philippines	10	83.1
Zimbabwe	10	99.5
Rwanda	5	87.5
Sierra Leone	5	86.8

SOURCE: The RAND MANPADS Country Stockpile data was drawn from multiple sources, including SIPRI, 2019; Ashkenazi et al., 2013; and Jane's by IHS Markit, 2019.

* State is a known producer of MANPADS; as such, stockpile information includes estimated domestic production.

** Stockpile numbers for Yugoslavia are historical and drawn from SIPRI's Arms Transfer Database. The FSI rating indicated is the average rating of the seven countries (Bosnia and Herzegovina, Croatia, Kosovo, Montenegro, North Macedonia, Serbia, and Slovenia) in which Yugoslavia is now dissolved.

*** The Fund for Peace does not provide an FSI rating for Taiwan.

APPENDIX C

Sensitivity Analyses of Economic Findings

Chapter Six described the data and methods we used to estimate the effect of MANPADS attacks and attacks on aircraft in flight (independently of how they are carried out) on three economic indicators: GDP, total trade, and FDI. Given that there have been relatively few MANPADS attacks, and even fewer occurred in countries with sufficient data to be captured in our econometric models, we believe that extending the analysis to consider the broader set of attacks on aircraft in flight both gives us more reliable estimates of economic effects and allows our findings to be applied to countries where MANPADS attacks have not occurred.

Our core findings were that a MANPADS attack does not have a statistically significant effect on these economic outcomes, but that an attack on an aircraft in flight (independent of how the attack is carried out) reduces GDP by 1.4 percent. Our model controlled for terrorism and conflict activity in the country, in addition to other determinants of economic outcomes, suggesting that the decline in GDP is the additional effect that derives from the aircraft attack. We found no negative, significant relationship between attacks on aircraft in flight and trade or FDI, indicating that the estimated reduction in GDP is through domestic rather than international channels. The presence of a major state-based conflict (with more than 1,000 deaths in the country in the year) overwhelms this effect, underscoring that general violence may be a more important driver of economic outcomes.

This appendix reports the results of several additional analyses we conducted that used different versions of the variables in our models or included a separate set of controls for terrorism or conflict activity. We summarized these results in the main body of this report and provide the details and data tables here. In general, our core findings are robust to these alternative model specifications, and importantly, the finding of a negative and statistically significant relationship between attacks on aircraft in flight and GDP in models that do not include the MANPADS variable holds across all specifications. The MANPADS results can be more sensitive to changes in model form, with some specifications yielding a statistically significant negative result for MANPADS attacks on GDP, though we reiterate that the very small sample size makes drawing conclusions from these findings problematic.

Core Results

We repeat below the results of our core model specification, including estimates for conflict variables excluded from the tables presented in the body of the paper. All model specifications presented in this appendix—the core model and those described below—use logged versions of the economic measures as the dependent variables and include one-year lags of the dependent variables to control for potential non-stationarity. The log of GDP is included as a control in all trade and FDI models, since we expect GDP to affect these measures; however, trade and FDI are only included in the models for which they are the outcome measures considered. All models include controls for inflation, the working-age share of the population, and telephone lines per capita. They also all include both country and year fixed effects as well as a stochastic error term. Standard errors are clustered by country.

The core model differs from the alternative specifications in terms of how the terrorism and conflict variables are constructed, and which are included in the regressions. The core model includes variables constructed as follows:

- **Count versions of terrorism variables:** MANPADS attacks, attacks on aircraft in flight, attacks on airport and aircraft generally, and all terrorist attacks
- **Dichotomous versions of conflict variables:** state-based conflicts, major state-based conflicts, nonstate conflicts, major nonstate conflicts, one-sided violence conflicts, and major one-sided violence conflicts
- **Noninteger imputed values for 1993:** because details of 1993 attacks are missing, we impute these values using the shares of all terrorist attacks across 1989 to 2017 (excluding 1993) that were on airports and aircraft generally and on aircraft in flight specifically; in the core model, we allow these values to be nonintegers.

Table C.1 presents these core results with and without the MANPADS variable. We do not report trade results that include the MANPADS variable because they are based on a single country year with data. The results show the statistically significant and negative 1.4-percent effect on GDP of an attack on an aircraft in flight in the regression that excludes the MANPADS variable. They also show the sharply negative and statistically significant effect of a major state-based conflict (i.e., a conflict that includes the government of a state as one of the parties to the conflict and that results in at least 1,000 deaths in the country in the year). Flagging for the major state-based conflict indicator is associated with a decline in GDP of between 4 and 8 percent depending on the economic outcome under consideration. Other types of conflicts appear to have a negative, albeit not statistically significant, effect on economic outcomes.

Alternative Specifications of Conflict Variables

The tables below show the results of four alternative model specifications that adjust how the conflict variables are constructed and which are included. Table C.2 shows the results of a regression that uses count versions of the six conflict variables in lieu of the dichotomous versions included in the core model, to test whether accounting for the possibility of being engaged in multiple conflicts (at least 25 killed in the conflict in the country year) or multiple major conflicts (at least 1,000 killed in the conflict in the country year) affects the results. Tables C.3 through C.5 show results when restricting the assessment to certain types of conflicts, using dichotomous versions of the conflict variables as in the core model. Table C.3 only includes the indicators for state-based and major state-based conflicts, Table C.4 only includes nonstate conflict indicators, and Table C.4 only includes indicators for one-sided violence conflicts.

When including count versions of the conflict variables, the results change little from the core model, although the economic and statistical significance of the aircraft attack variable

Table C.1
Core Regression Results

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0141			0.0480	
	(1.042)			(1.476)	
Aircraft attack	–0.0113	–0.0143**	0.00221	0.0422	0.0520**
	(1.629)	(2.525)	(0.178)	(1.498)	(2.197)
Airport/aircraft attack	0.00455*	0.00468*	–0.000620	–0.00675	–0.00719
	(1.676)	(1.716)	(0.111)	(0.947)	(1.038)
Terrorist attack	3.07e-05***	3.17e-05***	–1.18e-05	–3.53e-05	–3.94e-05
	(2.797)	(2.914)	(0.501)	(1.151)	(1.270)
State-based conflict	–0.00728	–0.00741	–0.0124	0.0366*	0.0370*
	(1.251)	(1.279)	(0.593)	(1.932)	(1.961)
Major state-based conflict	–0.0473***	–0.0482***	–0.0604***	–0.0810***	–0.0784***
	(2.651)	(2.694)	(3.043)	(3.159)	(2.963)
Nonstate conflict	–0.00828	–0.00806	–0.0371**	–0.0217	–0.0225
	(1.133)	(1.116)	(2.555)	(1.091)	(1.118)
Major nonstate conflict	–0.00539	–0.00478	0.0133	–0.0286	–0.0307
	(0.311)	(0.281)	(0.188)	(0.788)	(0.823)
One-sided violence conflict	–0.00239	–0.00236	0.00722	–0.00504	–0.00497
	(0.460)	(0.451)	(0.594)	(0.270)	(0.265)
Major one-sided violence conflict	–0.0212	–0.0227	–0.0108	–0.0417	–0.0363
	(0.775)	(0.824)	(0.140)	(1.142)	(1.006)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

in our GDP models increases modestly. Dropping the controls for some types of conflicts, as we do in the results in Tables C.3 through C.5, further raises the magnitude of the coefficient on aircraft attacks in the GDP model without MANPADS, suggesting that the full battery of conflict controls, as incorporated in the core model, might most appropriately adjust for violence in the country in a given year and isolate the additionality from a terrorist attack on an aircraft in flight. Also notable is that the coefficients on nonstate conflicts and one-sided violence conflicts tend to become more statistically significant in models that restrict the set of controls to those types of conflicts. The strong and statistically significant effect of major

Table C.2
Results Including Count Versions of Conflict Variables

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0137			0.0487	
	(1.080)			(1.491)	
Aircraft attack	–0.0118*	–0.0147***	0.00232	0.0418	0.0518**
	(1.751)	(2.709)	(0.191)	(1.454)	(2.147)
Airport/aircraft attack	0.00499*	0.00513*	–0.000863	–0.00702	–0.00750
	(1.810)	(1.847)	(0.153)	(0.998)	(1.094)
Terrorist attack	3.06e-05***	3.14e-05***	–1.33e-05	–3.50e-05	–3.89e-05
	(3.296)	(3.407)	(0.659)	(1.097)	(1.213)
State-based conflict	–0.00612	–0.00626	–0.0186	0.0185*	0.0191*
	(1.483)	(1.519)	(1.304)	(1.835)	(1.906)
Major state-based conflict	–0.0557**	–0.0564**	–0.0596***	–0.0791***	–0.0768***
	(2.323)	(2.340)	(3.082)	(3.168)	(2.982)
Nonstate conflict	–0.00160	–0.00156	–0.00355	–0.00626	–0.00638
	(0.723)	(0.704)	(0.815)	(1.310)	(1.329)
Major nonstate conflict	–0.00938	–0.00884	0.000925	–0.0296	–0.0316
	(0.551)	(0.527)	(0.0126)	(0.894)	(0.929)
One-sided violence conflict	0.000587	0.000728	0.00392	0.00339	0.00289
	(0.140)	(0.171)	(0.477)	(0.324)	(0.279)
Major one-sided violence conflict	–0.00534	–0.00642	–0.0144	–0.0399	–0.0360
	(0.322)	(0.380)	(0.177)	(1.302)	(1.171)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

state-based conflicts on all economic outcomes holds in the model that only controls for these types of conflicts.

Alternative Imputation of 1993 Terrorist Attack Target Data

As noted in the body of the report, the GTD lacks details on terrorist attacks carried out in 1993. It has the total number of attacks, and the total number of deaths, for each country in that year, but does not include information on the target type that would allow us to generate

Table C.3
Results Including Only State-Based Conflict Indicators

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	−0.0146			0.0475	
	(1.035)			(1.416)	
Aircraft attack	−0.0124*	−0.0155***	0.00154	0.0398	0.0497**
	(1.869)	(2.905)	(0.123)	(1.393)	(2.054)
Airport/aircraft attack	0.00488*	0.00505*	−0.000997	−0.00611	−0.00664
	(1.856)	(1.906)	(0.173)	(0.826)	(0.922)
Terrorist attack	2.64e-05***	2.71e-05***	−1.71e-05	−4.54e-05	−4.86e-05
	(3.025)	(3.172)	(0.823)	(1.451)	(1.556)
State-based conflict	−0.00893	−0.00906	−0.0122	0.0332*	0.0336*
	(1.515)	(1.546)	(0.678)	(1.788)	(1.818)
Major state-based conflict	−0.0497***	−0.0506***	−0.0638***	−0.0863***	−0.0835***
	(2.913)	(2.963)	(2.995)	(3.264)	(3.058)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

the airport and aircraft attacks (general) and attacks on aircraft in flight (specific) variables. We imputed these values by taking the share of all terrorist attacks in a given country over the 1989–2017 period (excluding 1993) that were attacks on these target types and applying this share to the number of attacks in that country in 1993. In our core model, we allowed these values to be non-integers. For example, if for a given country 1 percent of all terrorist attacks over the period for which we had data were on aircraft, and the country had ten total attacks in 1993, we imputed a value of 0.1 for aircraft attacks.

We ran an alternative version of the model that restricted these values to integers, rounding off to the nearest whole number, but that otherwise included the same variables as the core model. Given that any values below 0.5 would round down to zero, we expect that this specification understates the prevalence of attacks on air infrastructure generally as well as aircraft in flight in 1993. Table C.6 includes our results for this specification. Descriptive statistics that include the alternative construction of these variables for 1993 is included in a table at the back of this appendix. The alternative method of imputation has little effect on our results.

Table C.4
Results Including Only Nonstate Conflict Indicators

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0241			0.0366	
	(1.652)			(1.086)	
Aircraft attack	–0.0123*	–0.0176***	0.00126	0.0413	0.0490**
	(1.720)	(2.774)	(0.0930)	(1.471)	(2.072)
Airport/aircraft attack	0.00259	0.00279	–0.00309	–0.00850	–0.00880
	(1.183)	(1.259)	(0.492)	(1.130)	(1.190)
Terrorist attack	9.86e-06	1.05e-05	–3.44e-05*	–5.46e-05**	–5.63e-05**
	(1.364)	(1.456)	(1.672)	(1.979)	(2.052)
Nonstate conflict	–0.0119*	–0.0116*	–0.0409***	–0.0241	–0.0245
	(1.850)	(1.823)	(2.767)	(1.240)	(1.252)
Major nonstate conflict	–0.00773	–0.00689	0.0126	–0.0352	–0.0365
	(0.388)	(0.352)	(0.178)	(0.805)	(0.826)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.980	0.980	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

Alternative Specifications of Terrorist Attack Variables

Our core specification includes count versions of all four terrorist attack variables, which allows us to estimate the additional effect on economic outcomes for each attack, as well as to control more granularly for the extent of terrorist activity in the country. However, we ran an alternative specification that includes dichotomous versions of the terrorist attack variables in the models. The interpretation, then, is of the effect on economic outcomes of having had a MANPADS attack (or an aircraft attack generally) in the country year, whether one such attack or more than one. We draw on our alternate imputation of 1993 values for aircraft in flight attacks and airport and aircraft attacks in constructing the dichotomous versions of these variables (i.e., a country will not flag as having had an aircraft attack if its non-integer imputed value is 0.1 but will flag as having had such an attack if its noninteger imputed value is 0.6 and its integer imputed value is 1).

Table C.7 presents the results of the model with dichotomous versions of all terrorism variables. Notably, in this specification, the MANPADS attack indicator is negative, statistically significant, and economically meaningful. We are skeptical of these findings for several reasons. First, the general caveat that the results derive from a very small sample size bears repeating—just 11 country years with a MANPADS attack are included in the regression model. Second, we find that the statistical significance of the MANPADS result is not robust

Table C.5
Results Including Only One-Sided Violence Conflict Indicators

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0205			0.0425	
	(1.432)			(1.312)	
Aircraft attack	–0.0113	–0.0157**	0.00136	0.0419	0.0505**
	(1.606)	(2.518)	(0.106)	(1.516)	(2.176)
Airport/aircraft attack	0.00207	0.00221	–0.00395	–0.00949	–0.00978
	(0.850)	(0.901)	(0.663)	(1.329)	(1.392)
Terrorist attack	2.03e-05*	2.15e-05*	–3.78e-05	–4.66e-05	–4.97e-05*
	(1.825)	(1.894)	(1.540)	(1.588)	(1.680)
One-sided violence conflict	–0.0111*	–0.0112*	–0.00560	–0.00229	–0.00191
	(1.917)	(1.948)	(0.644)	(0.126)	(0.105)
Major one-sided violence conflict	–0.0332	–0.0356	–0.0203	–0.0571	–0.0520
	(1.407)	(1.506)	(0.270)	(1.280)	(1.171)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.952	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

to the exclusion of *either* the country year of Angola in 1993 (when there were two MANPADS attacks and GDP fell by about one quarter) or Iraq in 2003 (when there was a MANPADS attack and GDP fell by about one third). Table C.8 presents the results using dichotomous versions of the terrorism variables and excluding Angola 1993, and Table C.9 presents the results using the dichotomous terrorism variables (excluding Iraq in 2003).

Considering these findings, we re-ran our core model excluding *both* of these country years to determine whether our core findings of a negative and statistically effect on GDP of aircraft attacks is robust to their exclusion. They are, although the absolute value of the effect falls to closer to 1 percent (down from 1.4 percent). We present these results in Table C.10.

A final reason we are skeptical of the finding of a significant MANPADS effect, as presented in Table C.7, is that it is not robust to the inclusion of controls for the level of terrorism in the country in the year. Any country with a MANPADS attack necessarily will flag as having had an aircraft attack, an airport/aircraft attack, and a terrorist attack, per dichotomous versions of those variables, but this does not control for whether this was an isolated incident or one that occurred in a country with numerous terrorist attacks in the year. Table C.11 displays the results of a model that includes a binary MANPADS indicator (if there was a MANPADS attack in the country year) but that controls more granularly for other types of terrorism by including the counts versions of the aircraft, airport/aircraft, and terrorist attack variables. While the MANPADS effect on GDP appears large in magnitude (though it does include

Table C.6
Results with 1993 Imputed Values as Integers

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0146			0.0483	
	(1.077)			(1.496)	
Aircraft attack	–0.0109	–0.0139**	0.000527	0.0421	0.0519**
	(1.599)	(2.516)	(0.0425)	(1.513)	(2.210)
Airport/aircraft attack	0.00457*	0.00470*	0.000299	–0.00694	–0.00736
	(1.716)	(1.755)	(0.0537)	(0.985)	(1.073)
Terrorist attack	3.06e-05***	3.16e-05***	–1.25e-05	–3.50e-05	–3.90e-05
	(2.787)	(2.906)	(0.529)	(1.144)	(1.265)
State-based conflict	–0.00730	–0.00745	–0.0124	0.0367*	0.0371*
	(1.253)	(1.283)	(0.593)	(1.935)	(1.965)
Major state-based conflict	–0.0474***	–0.0482***	–0.0606***	–0.0811***	–0.0785***
	(2.653)	(2.696)	(3.060)	(3.155)	(2.959)
Nonstate conflict	–0.00829	–0.00807	–0.0371**	–0.0217	–0.0225
	(1.135)	(1.117)	(2.556)	(1.090)	(1.117)
Major nonstate conflict	–0.00540	–0.00478	0.0135	–0.0286	–0.0307
	(0.312)	(0.281)	(0.190)	(0.788)	(0.824)
One-sided violence conflict	–0.00245	–0.00243	0.00727	–0.00488	–0.00477
	(0.473)	(0.465)	(0.597)	(0.262)	(0.254)
Major one-sided violence conflict	–0.0212	–0.0227	–0.0102	–0.0418	–0.0363
	(0.775)	(0.826)	(0.133)	(1.146)	(1.008)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

Angola in 1993 and Iraq in 2003), it is not statistically significant. Table C.11 does not report results for regressions without the MANPADS indicator since they would be identical to the core model (the aircraft attack variable is a count variable).

In addition, we have estimated these models, dropping each of the countries individually to test for outlier countries, rather than country years. There is little variation in the aircraft attack coefficient, with the exception of Libya, which is still statistically significant but not statistically different from all other estimates for the GDP without MANPADS estimation.

Table C.7
Results with Dichotomous Versions of Terrorism Variables

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	−0.0648*			0.104	
	(1.780)			(1.061)	
Aircraft attack	−0.0133	−0.0188*	−0.00195	0.0295	0.0373
	(1.265)	(1.656)	(0.105)	(1.036)	(1.334)
Airport/aircraft attack	0.00692	0.00709	0.00378	−0.0111	−0.0112
	(1.134)	(1.100)	(0.312)	(0.754)	(0.765)
Terrorist attack	−0.00199	−0.00219	−0.00857	−0.0192	−0.0190
	(1.066)	(1.166)	(1.008)	(1.216)	(1.203)
State-based conflict	−0.00605	−0.00637	−0.0119	0.0394**	0.0397**
	(1.054)	(1.106)	(0.578)	(2.037)	(2.062)
Major state-based conflict	−0.0400***	−0.0419***	−0.0636***	−0.0830***	−0.0803***
	(2.606)	(2.616)	(3.377)	(3.340)	(3.073)
Nonstate conflict	−0.00851	−0.00824	−0.0373**	−0.0210	−0.0218
	(1.176)	(1.155)	(2.563)	(1.031)	(1.062)
Major nonstate conflict	−0.00781	−0.00613	0.0144	−0.0240	−0.0266
	(0.423)	(0.352)	(0.203)	(0.654)	(0.702)
One-sided violence conflict	−0.000924	−0.000807	0.00780	−0.00340	−0.00309
	(0.183)	(0.153)	(0.625)	(0.187)	(0.168)
Major one-sided violence conflict	−0.00511	−0.00942	−0.0134	−0.0445	−0.0361
	(0.174)	(0.336)	(0.179)	(1.062)	(0.855)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

The range of point estimates for the aircraft attack coefficient is [–0.0156, –0.0100]. For other models, the results are similar, with little variation in the coefficients.[1]

Alternative Specification Using Deaths in Attacks and Conflicts

A final specification of the model includes a variable that tallies the number of deaths in terrorist attacks of all types in the country year instead of the count of all terrorist attacks; it includes counts of deaths by conflict type for the three types of conflict (state-based, nonstate, and one-sided) in lieu of the binary indicators for these types of conflict included in our core model (one indicator for any conflict, one for any major conflict). We continue to include count versions of terrorist attacks by target type and how the attack was carried out (i.e., the MANPADS, aircraft, airport/aircraft variables).

Note that in a small number of cases in the GTD (about 5 percent across all types of attacks across all years in the data set), data on the number of deaths in the attack are missing. We assume that there were zero deaths in these attacks (this is the median value across all attacks for which there are deaths data), meaning that our death tallies for all terrorist attacks understate the total number of deaths in attacks in the country year. We do include in the terrorist attack death count those deaths occurring in MANPADS attacks that were in our separate dataset described in Chapter One but that were not in the GTD. The death counts by conflict type also might be underestimates because they are restricted to deaths in conflicts that rose to the threshold of 25 deaths in the country in the year.

The results for this model specification are in Table C.12 (Table C.13 includes the descriptive statistics for variables). The negative relationship between aircraft attacks and GDP is larger in absolute value and more statistically significant in this iteration than in the core model. Many of the variables we constructed that tally deaths in terrorist attacks and by conflict type have a negative and statistically significant relationship with the economic outcome measures we consider, although not all of these variables achieve statistical significance for all outcome measures. On balance, the core findings of an insignificant relationship between MANPADS attacks and outcome measures and a negative and significant relationship between aircraft attacks (regardless of how they are carried out) and GDP hold in this specification.

[1] These results are available from the authors, by request, as there are too many models to report them in this report.

Table C.8
Results with Dichotomous Versions of Terrorism Variables (Dropping Angola, 1993)

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0462			0.101	
	(1.029)			(0.977)	
Aircraft attack	–0.0134	–0.0171	–0.00195	0.0295	0.0367
	(1.274)	(1.494)	(0.105)	(1.036)	(1.314)
Airport/aircraft attack	0.00692	0.00703	0.00378	–0.0111	–0.0112
	(1.124)	(1.094)	(0.312)	(0.753)	(0.764)
Terrorist attack	–0.00198	–0.00212	–0.00857	–0.0192	–0.0190
	(1.061)	(1.135)	(1.008)	(1.216)	(1.204)
State-based conflict	–0.00615	–0.00638	–0.0119	0.0394**	0.0397**
	(1.074)	(1.111)	(0.578)	(2.037)	(2.065)
Major state-based conflict	–0.0385**	–0.0397**	–0.0636***	–0.0832***	–0.0812***
	(2.527)	(2.518)	(3.377)	(3.327)	(3.124)
Nonstate conflict	–0.00866	–0.00849	–0.0373**	–0.0210	–0.0217
	(1.203)	(1.192)	(2.563)	(1.030)	(1.057)
Major nonstate conflict	–0.00774	–0.00659	0.0144	–0.0240	–0.0264
	(0.426)	(0.380)	(0.203)	(0.654)	(0.698)
One-sided violence conflict	–0.000540	–0.000410	0.00780	–0.00344	–0.00322
	(0.107)	(0.0781)	(0.625)	(0.189)	(0.176)
Major one-sided violence conflict	–0.00776	–0.0110	–0.0134	–0.0441	–0.0355
	(0.264)	(0.396)	(0.179)	(1.052)	(0.837)
Number of observations	4,314	4,314	3,088	4,099	4,099
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

Table C.9
Results with Dichotomous Versions of Terrorism Variables (Dropping Iraq, 2003)

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0266			0.104	
	(1.583)			(1.061)	
Aircraft attack	–0.0126	–0.0147	–0.00195	0.0295	0.0373
	(1.220)	(1.540)	(0.105)	(1.036)	(1.334)
Airport/aircraft attack	0.00624	0.00626	0.00378	–0.0111	–0.0112
	(1.085)	(1.075)	(0.312)	(0.754)	(0.765)
Terrorist attack	–0.00202	–0.00210	–0.00857	–0.0192	–0.0190
	(1.078)	(1.116)	(1.008)	(1.216)	(1.203)
State-based conflict	–0.00569	–0.00579	–0.0119	0.0394**	0.0397**
	(0.993)	(1.013)	(0.578)	(2.037)	(2.062)
Major state-based conflict	–0.0384***	–0.0391***	–0.0636***	–0.0830***	–0.0803***
	(2.626)	(2.679)	(3.377)	(3.340)	(3.073)
Nonstate conflict	–0.00692	–0.00672	–0.0373**	–0.0210	–0.0218
	(0.906)	(0.892)	(2.563)	(1.031)	(1.062)
Major nonstate conflict	–0.00699	–0.00631	0.0144	–0.0240	–0.0266
	(0.397)	(0.366)	(0.203)	(0.654)	(0.702)
One-sided violence conflict	–0.00311	–0.00319	0.00780	–0.00340	–0.00309
	(0.677)	(0.697)	(0.625)	(0.187)	(0.168)
Major one-sided violence conflict	–0.0130	–0.0151	–0.0134	–0.0445	–0.0361
	(0.494)	(0.581)	(0.179)	(1.062)	(0.855)
Number of observations	4,314	4,314	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively

Table C.10
Core Model Results (Dropping Angola, 1993, and Iraq, 2003)

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	0.00386			0.0475	
	(0.429)			(1.427)	
Aircraft attack	–0.0113	–0.0105*	0.00221	0.0423	0.0516**
	(1.633)	(1.886)	(0.178)	(1.498)	(2.177)
Airport/aircraft attack	0.00405	0.00402	–0.000620	–0.00674	–0.00713
	(1.572)	(1.570)	(0.111)	(0.946)	(1.027)
Terrorist attack	2.58e-05**	2.56e-05**	–1.18e-05	–3.54e-05	–3.92e-05
	(2.462)	(2.513)	(0.501)	(1.151)	(1.265)
State-based conflict	–0.00673	–0.00670	–0.0124	0.0366*	0.0370*
	(1.147)	(1.149)	(0.593)	(1.932)	(1.962)
Major state-based conflict	–0.0421***	–0.0419***	–0.0604***	–0.0811***	–0.0790***
	(2.624)	(2.659)	(3.043)	(3.146)	(2.984)
Nonstate conflict	–0.00685	–0.00691	–0.0371**	–0.0217	–0.0224
	(0.878)	(0.898)	(2.555)	(1.091)	(1.115)
Major nonstate conflict	–0.00541	–0.00557	0.0133	–0.0286	–0.0306
	(0.323)	(0.330)	(0.188)	(0.787)	(0.820)
One-sided violence conflict	–0.00396	–0.00396	0.00722	–0.00506	–0.00505
	(0.843)	(0.843)	(0.594)	(0.271)	(0.270)
Major one-sided violence conflict	–0.0276	–0.0272	–0.0108	–0.0415	–0.0359
	(1.026)	(1.010)	(0.140)	(1.137)	(0.993)
Number of observations	4,313	4,313	3,088	4,099	4,099
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

Table C.11
Results with MANPADS Attack Indicator and Counts for Other Terrorism Variables

Variable	GDP	FDI Stock
MANPADS attack	–0.0552	0.0314
	(1.590)	(0.387)
Aircraft attack	–0.00982	0.0496*
	(1.490)	(1.937)
Airport/aircraft attack	0.00447*	–0.00710
	(1.675)	(1.014)
Terrorist attack	2.92e-05***	–3.77e-05
	(2.750)	(1.214)
State-based conflict	–0.00712	0.0368*
	(1.224)	(1.944)
Major state-based conflict	–0.0463***	–0.0792***
	(2.690)	(3.071)
Nonstate conflict	–0.00837	–0.0223
	(1.142)	(1.116)
Major nonstate conflict	–0.00620	–0.0299
	(0.347)	(0.806)
One-sided violence conflict	–0.00238	–0.00509
	(0.467)	(0.273)
Major one-sided violence conflict	–0.0186	–0.0388
	(0.670)	(1.067)
Number of observations	4,315	4,100
R-squared	0.981	0.955
Number of countries	176	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively; this table does not include results without the MANPADS indicators because they are identical to those in the core regression model presented in Table 6.2 and Table 6.3.

Table C.12
Results with Controls for Deaths in All Terrorist Attacks and by Conflict Type

Variable	GDP	GDP Without MANPADS	Total Trade Without MANPADS	FDI Stock	FDI Stock Without MANPADS
MANPADS attack	–0.0185			0.0420	
	(1.348)			(1.297)	
Aircraft attack	–0.0136*	–0.0176***	0.000951	0.0436	0.0525**
	(1.963)	(2.993)	(0.0678)	(1.564)	(2.227)
Airport/aircraft attack	0.00312*	0.00333**	–0.00514	–0.0107	–0.0112
	(1.934)	(2.022)	(0.763)	(1.505)	(1.611)
Deaths in terrorist attacks	9.57e-06	9.64e-06	–1.00e-05	–1.95e-05***	–1.98e-05***
	(1.464)	(1.475)	(1.020)	(3.555)	(3.593)
Deaths in state-based conflicts	–8.93e-06	–9.02e-06	–7.35e-06***	–2.53e-06	–2.33e-06
	(1.197)	(1.202)	(4.810)	(1.197)	(1.144)
Deaths in nonstate conflicts	–1.69e-05**	–1.66e-05**	5.71e-06	–3.28e-05*	–3.35e-05*
	(2.217)	(2.212)	(0.246)	(1.845)	(1.852)
Deaths in one-sided violence	–2.99e-06	–3.03e-06	1.04e-05	–7.63e-06***	–7.52e-06***
	(1.161)	(1.167)	(0.327)	(4.458)	(4.276)
Number of observations	4,315	4,315	3,088	4,100	4,100
R-squared	0.981	0.981	0.953	0.955	0.955
Number of countries	176	176	170	177	177

NOTE: t-statistics appear in parentheses; *, **, and *** represent significance at the 10-percent, 5-percent, and 1-percent levels, respectively.

Table C.13
Descriptive Statistics for Variables Used in Sensitivity Analyses, 1989–2017

Variable	*n*	Mean	Standard Deviation	Minimum	Median	Maximum	Source
Terrorist attacks on airports or aircraft (integer imputation)	6,366	0.11	0.63	0	0	20	GTD
Terrorist attacks on aircraft away from airports (integer imputation)	6,366	0.04	0.25	0	0	5	GTD
Deaths in terrorist attacks	6,366	55	416	0	0	13,965	GTD, BICC, Sponsor
Deaths in state-based conflicts	6,366	146	1,116	0	0	48,257	UCDP GED
Deaths in nonstate conflicts	6,366	20	148	0	0	3,485	UCDP GED
Deaths in one-sided violence	6,366	119	6,297	0	0	500,891	UCDP GED

SOURCES: National Consortium for the Study of Terrorism and Responses to Terrorism, 2018; Ashkenazi et al., 2013; UCDP, 2015; sponsor data.
NOTE: A conflict involves 25 or more in-country deaths in the year, and a major conflict involves 1,000 or more in-country deaths in the year; this table does not report descriptive statistics for variables included in the core regression model, which are included in the body of the report.

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