

Osirak Redux?

Whitney Raas and
Austin Long

Assessing Israeli Capabilities to Destroy Iranian Nuclear Facilities

The use of military force to halt or reverse nuclear proliferation is an option that has been much discussed and occasionally exercised. In the 1960s, for example, the United States considered destroying China's nuclear program at an early stage but ultimately decided against it.¹ More recently, the key rationale for the invasion of Iraq in 2003 was the threat posed by Iraq's suspected inventory of weapons of mass destruction (WMD). Although significant evidence of WMD was not found in the Iraq case, the potential utility of military force for counterproliferation remains, particularly in the case of Iran. The possibility of military action against Iranian nuclear facilities has gained prominence in the public discourse, drawing comments from journalists, former military officers, and defense analysts.² This makes the Iranian nuclear program a potential test case for military counterproliferation.

Iran's nuclear ambitions have been the subject of serious debate within the international community for more than four years.³ Media reports have repeatedly discussed the possibility that the United States might attempt a preventive strike against Iran. The United States' ongoing involvement in Iraq, however, may limit U.S. willingness to do so. Israel, in contrast, has more to

Whitney Raas is a Research Analyst at the Center for Naval Analyses in Alexandria, Virginia. She conducted this work while completing graduate studies in nuclear engineering and political science at the Massachusetts Institute of Technology. Austin Long is a doctoral candidate in political science at the Massachusetts Institute of Technology, a member of the MIT Security Studies Program, and Adjunct Researcher at the RAND Corporation.

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1. See William Burr and Jeffrey T. Richelson, "Whether to 'Strangle the Baby in the Cradle': The United States and the Chinese Nuclear Program, 1960-64," *International Security*, Vol. 25, No. 3 (Winter 2000/01), pp. 54-99.

2. One widely cited example is Seymour M. Hersh, "The Iran Plans," *New Yorker*, April 17, 2006, pp. 30-37.

3. In 2002 the National Council of Resistance of Iran exposed Tehran's secret nuclear sites at a press conference. "Mullahs' Top Secret Nuclear Sites and WMD Projects Exposed at NCRI Press Conference," *Iran Liberation*, August 19, 2002, pp. 1-4. Since then, repeated International Atomic Energy Agency (IAEA) reports have detailed Iran's nuclear activities. In his 2006 address to the United Nations General Assembly, IAEA Director-General Mohamed ElBaradei stated, "The IAEA continues therefore to be unable to confirm the peaceful nature of Iran's nuclear programme." Quoted in "Statement to the Sixty-first Regular Session of the United Nations General Assembly," New York, October 30, 2006.

fear from a nuclear Iran than the United States and may see no choice but to resort to force to curtail Iran's capabilities if diplomacy fails.⁴

Israel has repeatedly stated its unequivocal opposition to a nuclear-armed Iran, and much speculation exists about what action the Israelis might take to prevent Iran from developing nuclear weapons.⁵ Indeed, multiple reports suggest that Israeli leaders are contemplating a preventive military strike to remove the threat of an Iranian nuclear capability. Such action would not be without precedent: on June 7, 1981, Israel launched one of the most ambitious preventive attacks in modern history. Israeli Air Force (IAF) F-16 and F-15 fighter jets destroyed the Iraqi reactor at Osirak in one of the earliest displays of what has become known as "precision strike." No IAF planes were lost, and despite the political repercussions, the raid was considered a great success.⁶

As Iran's nuclear program moves forward, arguments for preventive action may seem increasingly compelling to the government of Israel. Yet no unclassified net assessment of Israel's current capability to destroy Iranian nuclear facilities exists.⁷ The capabilities of the IAF have grown dramatically in the past two decades, but the Iranian facilities are a significantly more challenging target than Osirak.

As an unclassified assessment of military options, this analysis contains a number of assumptions and omissions. First, it relies on public reports regarding Iran's nuclear program, specifically the International Atomic Energy Agency (IAEA) safeguard reports that describe Iran's documented nuclear ac-

4. Diplomatic overtures by France, Germany, and the United Kingdom have focused on providing incentives to Iran in exchange for a halt in nuclear conversion and enrichment. These efforts have failed, however, and the UN voted unanimously to impose sanctions on Iran at the end of 2006. Nasser Karimi, "Iran Rebuffs U.N., Vows to Speed Up Uranium Enrichment," *Washington Post*, December 25, 2006.

5. See, for example, Uzi Mahnaimi and Sarah Baxter, "Israel Readies Forces for Strike on Nuclear Iran," *Sunday Times* (London), December 11, 2005, <http://www.timesonline.co.uk/article/0,,2089-1920074,00.html>; Ian Bruce, "Israelis Plan Pre-emptive Strike on Iran," *Herald* (London), January 10, 2006, <http://www.theherald.co.uk/news/53948.html>; and Josef Federman, "Israeli Hints at Preparation to Stop Iran," *Washington Post*, January 22, 2006.

6. For details on the 1981 raid, see Rodger W. Claire, *Raid on the Sun: Inside Israel's Secret Campaign That Denied Saddam the Bomb* (New York: Broadway Books, 2004); and Shelomoh Nakdimon, *First Strike: The Exclusive Story of How Israel Foiled Iraq's Attempt to Get the Bomb* (New York: Summit Books, 1987).

7. Some recent works have addressed the possibility of a preventive attack and the potential consequences, but have not presented any actual net assessment of Israeli capabilities against Iranian defenses. Instead, they have simply stated that attacking Iranian facilities would be more difficult than attacking Osirak. See Sammy Salama and Karen Ruster, "A Preemptive Attack on Iranian Nuclear Facilities: Possible Consequences," Center for Nonproliferation Studies Research Story, August 12, 2004, <http://cns.miis.edu/pubs/week/040812.htm>; and Yiftah Shapir, "Iranian Missiles: The Nature of the Threat," Tel Aviv Note, No. 83 (Tel Aviv: Jaffee Center for Strategic Studies, Tel Aviv University, 2003), <http://www.tau.ac.il/jcss/tanotes/TAUnotes83.doc>.

tivities. Some observers argue, however, that Iran is likely to have a parallel, covert nuclear program that is as advanced—or possibly more advanced—than the known program monitored by the IAEA. If this is true, a strike against Iran’s known facilities would not significantly delay its development of nuclear weapons.⁸

In our view, however, the likelihood that Iran is engaged in a “covert” nuclear program is slim. Given that the known program was not exposed until 2002, a parallel program would, in essence, mean that Iran was developing two covert programs, with all the attendant expense, secrecy, and manpower.⁹ Iran probably deliberately concealed its “overt” program with the hope that it would not be discovered. Thus, its large, industrialized facilities, especially those for uranium conversion and enrichment, are likely the primary and most advanced nuclear sites. A disruption of these activities would deal a significant blow to Iran’s nuclear ambitions.

Second, this article does not attempt to address all the military scenarios. There are three broad forms that military action could take: a directed strike against Iranian nuclear facilities, a larger strike that included general military targets, or a full-scale invasion with the intent to overthrow the Iranian regime. Because the latter two scenarios are probably not realistic options for Israel, this article concentrates on a military strike directed at Iran’s nuclear sites only. In particular, we focus on air power, as the Israelis have purchased significant parts of their air force structure with long-range strikes in mind.

Finally, this article does not take a position as to whether Israel should attempt to destroy Iran’s nuclear facilities. The repercussions of such an attack would be significant in terms of diplomatic condemnation and a variety of potential Iranian military responses. The final outcome of diplomatic negotiations over Iran’s nuclear program is uncertain, and an attack might only harden Iran’s resolve to continue its nuclear program. This article is intended to address the more limited but vitally important question of whether such an attack is even possible, regardless of whether it is a good idea or not.

In addition to providing an assessment of the Iran-Israel scenario, this article provides insight into the more general phenomenon of military counterproliferation, particularly with regard to the use of air power as a counterproliferation tool. As concern over WMD proliferation grows, the use of air power for

8. One widely cited example is Graham Allison, “How Good Is American Intelligence on Iran’s Bomb?” *YaleGlobal Online*, June 13, 2006, <http://yaleglobal.yale.edu/display.article?id=7553>.

9. An analogy would be if the United States had simultaneously developed two Manhattan Projects during the early 1940s.

strikes on individual targets may become even more appealing. Indeed, the George W. Bush administration has already made military counterproliferation part of its national strategy.¹⁰ The case of Iran provides a template for the prospects and problems of using air power against targets of interest, especially nuclear-related, hardened, and well-defended targets.

This article seeks to fill this gap in the existing literature by providing a rough net assessment of an Israeli strike on known Iranian nuclear facilities. It does so by updating the Osirak scenario to account for both the improved IAF capabilities and the much tougher Iranian targets. The first section presents an overview of the Osirak raid. The second section describes the nature and location of Iran's nuclear facilities in the context of targeting for the IAF. The third section offers a rough estimate of the "weaponizing" necessary to destroy the target set. The fourth section discusses the forces the IAF and Iran possess relevant to this planned strike. The fifth section evaluates potential attack routes and the likely interaction of Israeli and Iranian forces. The sixth section offers a brief discussion of the likely outcome of an Israeli attack and the implications for military counterproliferation.

The Osirak Strike

The Israeli raid on the Osirak reactor was a calculated risk with no guarantee of success. The government of Prime Minister Menachem Begin was divided on the wisdom of the raid in discussions that began almost immediately after Begin's election in 1977. Begin decided to wait as long as possible before acting. In the meantime, the Mossad, Israel's intelligence agency, took steps to buy additional time. These steps included allegedly sabotaging the reactor cores for Osirak before the French companies that built them could deliver them to Iraq, as well as assassinating Iraqi nuclear officials. At the same time, the IAF began contingency planning for a strike on Osirak.¹¹ The plan to buy time worked to some degree, but it could not stop the Iraqi nuclear program. In October 1980, the Mossad reported to Prime Minister Begin that the Osirak reactor would be fueled and operational by June 1981. Following an intense debate, the order to strike was given.

10. See George W. Bush, *The National Security Strategy of the United States of America* (Washington, D.C.: White House, September 2002), sec. 5, <http://www.whitehouse.gov/nsc/nss.html>. The 2006 version does not differ on this point. See George W. Bush, *National Security Strategy of the United States of America* (Washington, D.C.: White House, March 2006), <http://www.whitehouse.gov/nsc/nss/2006>.

11. This summary is drawn principally from Claire, *Raid on the Sun*.

After months of careful preparations, a sixteen-plane strike package of eight F-15s and eight F-16s took off from Etzion air base in the Sinai. The flight profile was low altitude, across the Gulf of Aqaba, southern Jordan, and then across northern Saudi Arabia. The F-16s each carried two Mk-84 2,000 lb. bombs with delayed fuses. These bombs were “dumb,” meaning they had no guidance other than that provided by the aircraft dropping them. The F-16s did have onboard targeting systems that would make the dumb bombs fairly accurate, but such accuracy would require that the plane get close to the target.

The strike package arrived near Osirak undetected and at low altitude. The F-16s formed up on predetermined points to begin their bombing runs, while the F-15s set up barrier combat air patrols to intercept Iraqi fighters. At 4 miles from the target, the F-16s climbed to 5,000 feet in order to dive at Osirak and release their bombs. Despite some navigation problems and Iraq air defenses, at least eight of the sixteen bombs released struck the containment dome of the reactor.

The strike package then turned and climbed to high altitude, returning much the way it had come. All sixteen planes successfully returned to Israel after recrossing Jordan. The results of the raid were spectacular. The reactor was totally destroyed, leaving much of the surrounding area undamaged.

Iranian Nuclear Facilities

The Iranians have learned important lessons from the Osirak raid: Iran’s nuclear complex is large, carefully concealed, and spread extensively throughout the country, with multiple pathways to a nuclear weapons capability. The Nuclear Nonproliferation Treaty, to which Iran is a signatory, allows states access to peaceful nuclear technologies within certain safeguards and guidelines.¹² Iranian officials have claimed that by 2020, the country’s growing population and the expected global demand for oil will require the extensive use of nuclear power to meet Iran’s increasing energy needs while still enabling significant petroleum exports.¹³ To meet these energy goals, Iran has developed a nuclear power program over the last few decades, including full front-end and back-end nuclear fuel cycle technology.¹⁴

12. *Treaty on the Nonproliferation of Nuclear Weapons*, <http://www.un.org/events/npt2005/npttreaty.html>, especially art. 4.

13. Reza Aghazadeh, “Iran’s Nuclear Policy: Peaceful, Transparent, Independent,” presentation by the vice president of Iran, IAEA headquarters, Vienna, Austria, May 6, 2003.

14. The “front end” of the nuclear fuel cycle refers to all activities engaged in prior to placing fuel in a reactor; the “back end” refers to post-irradiation activities. Front-end technology includes ura-

Iran is developing both indigenous uranium enrichment capabilities to produce weapons-grade uranium and a heavy-water plutonium production reactor and associated facilities for reprocessing spent fuel for plutonium separation.¹⁵ Both developments pose proliferation risks, although at present Iran's progress toward enriching uranium appears significantly more advanced than its plutonium production ability. Declared industrial-scale facilities include a light water reactor at Bushehr, uranium mines, uranium conversion and enrichment plants, a fuel fabrication plant, and a heavy-water production facility. Iran is also building heavy water reactors.¹⁶ Smaller, laboratory-scale projects include clandestine plutonium reprocessing and laser enrichment, as well as experiments involving uranium metal.¹⁷ For this study, it is important to distinguish between activities that are low risk for proliferation and those that pose the most serious threat of proliferation. Iran has distributed its many nuclear facilities around the country, which would make it impossible for Israel to destroy the country's entire nuclear infrastructure.¹⁸ To have a reasonable chance of significantly delaying Iranian nuclear efforts, Israel would have to limit the target set to the infrastructure's most critical nodes—that is, those directly involved in the production of fissile material, because without fissile material, no bomb can be produced.

Iran's nuclear complex has three critical nodes for the production of fissile material: a uranium conversion facility in Isfahan, a large uranium enrichment

mium mining, milling, conversion, enrichment, and fuel fabrication, while back-end technology consists of fuel reprocessing and waste management procedures. For more details on the nuclear fuel cycle, see Ronald Allen Knief, *Nuclear Engineering: Theory and Technology of Commercial Nuclear Power*, 2d ed. (New York: Hemisphere, 1992).

15. Weapons-grade uranium is generally quoted as above 93 percent U²³⁵. See Owen R. Coté Jr., "A Primer on Fissile Materials and Nuclear Weapon Design," in Graham T. Allison, Coté, Richard A. Falkenrath, and Steven E. Miller, *Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Material* (Cambridge, Mass.: MIT Press, 1996). For information on Iran's plutonium production, see Iran Watch, "Latest Developments in the Nuclear Program in Iran, In Particular on the Plutonium Way," presentation by France, Nuclear Suppliers Group 2003 plenary meeting, Pusan, Republic of Korea, May 19–23, 2003.

16. Unless otherwise noted, the following summary of Iran's nuclear activities has been taken from the following sources: Director-General, IAEA, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran," GOV/2004/11 (Vienna: IAEA, February 24, 2004); Director-General, IAEA, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran," GOV/2003/63 (Vienna: IAEA, August 26, 2003); and Director-General, IAEA, "Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran," GOV/2003/75 (Vienna: IAEA, November 10, 2003).

17. Andrew Koch and Jeanette Wolf, "Iran's Nuclear Facilities: A Profile" (Monterey, Calif.: Center for International Studies, Monterey Institute of International Studies, 1998), <http://cns.miiis.edu/pubs/reports/pdfs/iranrpt.pdf>.

18. One analyst has identified "more than 400" military targets of interest, although not all are identified as nuclear sites. See Hersh, "The Iran Plans"; and James Fallows, "Will Iran Be Next?" *Atlantic Monthly*, December 2004, pp. 99–110.

facility at Natanz, and a heavy water plant and plutonium production reactors under construction at Arak.¹⁹ In the past, international concerns over Iran's nuclear weapons program centered on Tehran's agreement with Russia to build a light-water civilian reactor complex at Bushehr.²⁰ But because the Bushehr reactor is not considered crucial to Iran's development of a nuclear weapons capability, we do not include it in the target set.²¹ Moreover, even if Israel decided the reactor would be worth attacking, Bushehr is not a hardened target and is on the Persian Gulf coast; thus, submarine-launched cruise missiles could be used rather than an air strike.²²

Iran's uranium conversion facility (UCF) is the primary chemical facility for Iran's nuclear program. The facility produces uranium hexafluoride (UF₆, the feed gas for uranium centrifuges), uranium dioxide (UO₂) for reactor fuel, and uranium metal.²³ The loss of a domestic supply of UF₆ for enrichment activities, as well as the loss of lines for the conversion of UF₆ back to uranium metal, would greatly reduce Iran's ability to produce enriched uranium for a nuclear weapon in the future. Because the agreement with Russia for fueling the Bushehr reactor requires Russia to provide fuel for the reactor, destruction of the UCF would not immediately affect Iran's ability to supply electric power. It would, however, severely reduce Iran's enrichment and fuel fabrication capabilities by eliminating the primary means of producing UF₆ and UO₂.

Destruction of Iran's UCF would be complicated, however, by activities that have already taken place. Many tons of uranium exist at the UCF in various

19. For a more detailed analysis of Iran's nuclear infrastructure in the context of nuclear weapons development, see Whitney Raas and Austin Long, "Osirak Redux? Assessing Israeli Capabilities to Destroy Iranian Nuclear Facilities" (Cambridge, Mass.: Security Studies Program, Massachusetts Institute of Technology, April 2006).

20. For U.S. concerns over the Bushehr reactor, see Central Intelligence Agency, "Unclassified Report to Congress on the Acquisition of Technology Relating to Weapons of Mass Destruction and Advanced Conventional Munitions, January 1 through June 30, 2002," http://www.cia.gov/cia/reports/archive/reports_2002.html.

21. Bushehr is not considered essential to Iran's nuclear weapons program for four reasons: the plutonium produced by the reactor is of extremely poor quality for nuclear weapons; fears of unauthorized technology transfer are diminishing as the Bushehr complex nears completion; Iran has signed an agreement to repatriate spent fuel to Russia; and the reactor is heavily monitored by the IAEA with minimal (if any) protest from Iranian officials. For more information, see Harmon W. Hubbard, "Plutonium from Light Water Reactors as Nuclear Weapon Material" (Washington, D.C.: Nonproliferation Policy Education Center, April 2003), <http://www.npec-web.org/Essays/2003-04-01Hubbard.pdf>.

22. Israel has several Dolphin-class diesel submarines capable of firing Sub Harpoon cruise missiles and potentially Gabriel or Popeye cruise missiles as well. See *Jane's Underwater Warfare Systems* electronic database entry for Dolphin, March 2006.

23. The production of uranium metal actually occurs after the UF₆ has been enriched. The gas, enriched in U²³⁵, is returned to the UCF for conversion back to uranium metal.

chemical forms. Destruction of the facility could result in the release of tons of UF_6 , UF_4 , and other fluorine and uranium products into the atmosphere. In addition to the contamination due to the release of uranium, the presence of fluorine in the atmosphere would almost certainly result in significant production of hydrofluoric acid, a highly corrosive chemical. Presuming that the Israelis are willing to assume the risks inherent in attacking a chemical facility close to a major city like Isfahan, the destruction of the UCF would interrupt the production of UF_6 feed gas for uranium enrichment at Natanz, as well as the preparation of UO_2 fuel for future heavy-water reactors at Arak.

The Natanz facility is the next critical link in the production of enriched uranium. The facility is composed of a pilot fuel enrichment plant and a much larger commercial plant underground, which is awaiting the arrival of thousands of centrifuges. The site is located approximately 200 miles south of Tehran and about 40 miles from the nearest city. To ensure maximum delay of the Iranian nuclear program, Israel would have to wait until the majority of the centrifuges intended for the commercial plant are in place. These thousands of centrifuges represent a massive capital investment that could not easily be replaced. Thus, the optimal time for launching a military strike would be after the centrifuges have been installed but before a large quantity of UF_6 has been introduced. Bombing the empty halls prior to centrifuge emplacement would not significantly damage Iran's nuclear program, as the Iranians could simply place centrifuges in another, potentially unknown facility.

The final fissile material production facility that Israel could target is the heavy water plant and plutonium production reactors under construction at Arak. The heavy water plant is a large facility located in central Iran approximately 150 miles southwest of Tehran. The site itself is about 20 miles from the nearest town.

Iran has only one small research reactor that uses heavy water as coolant, but the Arak heavy water facility will be able to produce more than 16 tons of heavy water per year—much more than is required by this reactor and more than is needed for virtually all civilian applications. Iranian officials have declared their intentions to build heavy water reactors—and, in fact, construction has begun on two such reactors at Arak—that will utilize much of the heavy water produced at this facility.²⁴ These reactors are scheduled to be completed in 2014.

24. It is possible, though not likely, that Iran has built a larger plutonium production reactor that has not been discovered. We judge it unlikely, as reactors are difficult to hide and difficult for Tehran to build without outside assistance.

Heavy water reactors of the kind Iran intends to build pose the greatest plutonium proliferation risk because the plutonium produced by these reactors would be weapons grade.²⁵ Iranian officials have told the IAEA that they also intend to build reprocessing facilities at Arak in order to separate “long-lived isotopes” from spent fuel burned in future plutonium production reactors at the site.²⁶ It is highly likely that the Arak facility could instead be used for the production of weapons-grade plutonium—the same hot cells could be used to recover plutonium from spent fuel. Even though construction of the reactor is only in the initial stages, the Arak facility remains a serious concern, and eliminating the heavy water plant would significantly slow Iran’s future ability to produce plutonium.

Iran’s nuclear program contains many more elements, but the three facilities discussed above are critical for nuclear weapons development. Destruction of these facilities would have the greatest impact on Tehran’s ability to manufacture nuclear weapons—the UCF by denying Iran the ability to make UF₆ for enrichment, the Natanz facility for enriching uranium, and the Arak heavy water plant for use in plutonium production system. Of the three, the Arak heavy water facility is the least important—the plutonium production reactors at the site are not scheduled for completion for years, and thus the heavy water produced by the Arak facility will not be necessary until the reactors are completed—while Natanz is the most important site for Iranian production of fissile material.²⁷ The destruction of the Natanz facility is critical to impeding Iran’s progress toward nuclearization.

Weaponizing: What Kind of Bombs and How Many?

The IAF has developed substantially better munitions for attacking hardened targets, such as reactor containment facilities or buried centrifuge plants, than it used against Osirak in 1981. These improvements come in two forms: enhanced accuracy and enhanced penetration. This makes current munitions both easier to deliver and more likely to destroy the target.

The acquisition of precision-guided munitions in the 1980s and 1990s changed the dynamics of IAF bombing. Accurate delivery no longer required

25. Plutonium is produced in all uranium-fueled reactors as a natural reaction in the fuel. In other types of reactors, however, the plutonium produced is non-weapons-grade.

26. Director-General, IAEA, “Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran,” GOV/2003/63.

27. This of course assumes that there are no other large-scale reactors in the country that could use heavy water as a moderator to obtain plutonium from spent fuel.

approaching at low altitude and then “popping up” to dive directly at the target as at Osirak. Instead, using both the Global Positioning System (GPS) and laser-guided bombs (LGBs), the IAF can deliver munitions from high altitude with longer standoff range.²⁸

For example, the F-16s used against Osirak had a computerized aiming system, which, if the aircraft could make a reasonably steady approach, would give the unguided bombs a circular error probable (CEP) of roughly 8 to 12 meters.²⁹ In contrast, GPS munitions such as the Joint Direct Attack Munition (JDAM) have a roughly comparable (if not better) accuracy dropped from high altitude and long standoff range (at least 15 kilometers). LGBs have substantially better accuracy, with modern LGBs having a CEP of about 3 meters or less with roughly the same standoff range. Both GPS and LGB munitions have less restrictive “envelopes” than computer-aided bombing, as they can maneuver themselves on target after launch.³⁰

Similarly, munitions for attacking hardened targets have been significantly improved since the Osirak raid. These weapons, known as penetrating warheads or “bunker busters,” have seen extensive use by the U.S. Air Force. Delivered from high altitude and arriving at steep angles, these munitions can penetrate tens of feet of earth, and even several feet of reinforced concrete.³¹

The IAF arsenal includes a 1,000 lb.-class penetrating bomb known as the PB 500A1.³² Additionally, Israel has sought to acquire two heavier penetrating warheads from the United States. In September 2004, Israel announced that it would purchase approximately 5,000 precision-guided munitions from the United States, including about 500 equipped with the 2,000 lb.-class BLU-109 penetrating warhead.³³ More recently, Israel has received approval to purchase

28. On the benefits of operating at high altitude, see Barry R. Posen, “Command of the Commons: The Military Foundation of U.S. Hegemony,” *International Security*, Vol. 28, No. 1 (Summer 2003), pp. 5–46.

29. CEP is the standard measure of accuracy for munitions and is the radius of a circle around the aim point that 50 percent of weapons fired at a target will land within. Computer-aided bombing accuracy is dependent on a number of factors that can generate error. Further, because the bomb is unguided, error propagates with range. The 8 to 12-meter CEP given can be considered near optimal at 2 kilometers. For the theory behind error calculation in computer-aided bombing, see Morris Drells, *Weaponizing: Conventional Weapons System Effectiveness* (Reston, Va.: American Institute for Aeronautics and Astronautics, 2004), pp. 70–93.

30. See *Jane's Air-Launched Weapons* electronic database entries for JDAM and Paveway III penetration bombs, November 2006. The envelope is the three dimensional point or area a plane must occupy when the weapon is released in order for it to strike the target.

31. For an overview of penetrating munitions, see Clifford Beal and Bill Sweetman, “Striking Deep: Hardened-Target Attack Options Grow,” *Jane's International Defense Review*, Vol. 27, No. 7 (July 1994), pp. 41–44.

32. See *Jane's Air-Launched Weapons* electronic database entry for PB 500A1, February 2007.

33. “American Sale of New Bombs to Israel Sends Message to Iran,” *Times* (London), September

100 precision-guided munitions equipped with the 5,000 lb.-class BLU-113 penetrating warhead.³⁴ After the July 2006 conflict with Hezbollah, delivery of these bombs has apparently been expedited, and they could be rapidly integrated into the IAF.³⁵

In addition to precision-guided munitions and bunker busters, Israel maintains two elite special forces units dedicated to assisting with air strikes: one specialized in laser target designation (Sayeret Shaldag/Unit 5101), the other in real-time bomb damage assessment (Unit 5707).³⁶ These could potentially infiltrate the target zone prior to attack. The presence of one or both units would enable target designation in bad weather. These units could also assess the damage from those weapons that hit their targets and then direct additional munitions to compensate for misses.

Having presented the general outline of IAF capabilities, we now turn to the application of those capabilities to specific targets. Natanz is both the most difficult and most important target to destroy. The main enrichment facility apparently has two large (25,000 to 32,000 square meter) halls located 8 to 23 meters underground and protected by multiple layers of concrete.³⁷ The combination of large size and hardening makes this a very challenging target.

One method for defeating hardened facilities is to use LGBs targeted on the same aim point but separated slightly in release time to “burrow” into the target, a technique contemplated by the U.S. Air Force in the 1990–91 Persian Gulf War.³⁸ This takes advantage of the extremely high accuracy of LGBs in combination with a penetrating warhead. The IAF appears to have purchased penetrating LGBs with this technique in mind. Gen. Eitan Ben-Elyahu, former

22, 2004. For details, see *Jane's Air-Launched Weapons* electronic database entry for BLU-109. The penetration capability is given as 1.8 to 2.4 meters of concrete, depending on angle of impact.

34. “Pentagon Notifies Congress of Potential ‘Bunker Buster’ Sale to Israel,” *Defense Daily*, April 29, 2005. For details, see *Jane's Air-Launched Weapons* electronic database entry for Paveway III penetration bombs, February 2007. The penetration capability is credited as at least 6 meters of concrete (presumably reinforced concrete) and 30 meters of earth.

35. Tim McGirk, “Israel and the Bombs,” *Time*, August 14, 2006.

36. See *Jane's Sentinel Eastern Mediterranean* electronic database entry for IAF, August 2005.

37. See “Natanz,” in “Weapons of Mass Destruction,” <http://www.globalsecurity.org/wmd/world/iran/natanz.htm>; and David Albright and Corey Hinderstein, “The Iranian Gas Centrifuge Uranium Enrichment Plant at Natanz: Drawing from Commercial Satellite Images” (Washington, D.C.: Institute for Science and International Security, March 14, 2003, http://www.isis-online.org/publications/iran/natanz03_02.html).

38. See Eliot Cohen, *Gulf War Air Power Survey* (Washington, D.C.: Office of the Secretary of the Air Force, 1993), Vol. 2, pt. 1, pp. 240–241. The U.S. Air Force considered using up to four weapons targeted on each aim point to dig into buried targets. It has been reported to the authors that the technique was successfully used against an underground aircraft storage facility at Podgorica Airfield in Montenegro during Operation Allied Force in 1999, but this cannot be confirmed from unclassified sources.

commander of the IAF and a participant in the Osirak strike, commented on this method of attacking hardened facilities in *Jane's Defence Weekly*: "Even if one bomb would not suffice to penetrate, we could guide other bombs directly to the hole created by the previous ones and eventually destroy any target."³⁹

For a heavily hardened target such as Natanz, the BLU-113 would be the most likely weapon to use. One BLU-113 might be sufficient to penetrate the protective earth and concrete over the Natanz facility, but two properly sequenced almost certainly would. The probability of two LGBs aimed at the same point hitting essentially one on top of the other is likely to be about 0.45.⁴⁰ Sequencing of the BLU-113s would be necessary for only the upper end of the estimated hardness of the Natanz centrifuge halls. For example, if the facility is protected by 23 meters of concrete and earth, sequencing would be needed only if roughly 2 meters or more of the 23-meter total are concrete. For the lower estimate of 8 meters of concrete and earth cover, one BLU-113 could easily penetrate.

The question then is: How many BLU-113s able to penetrate the centrifuge halls would be needed to ensure destruction? We estimate that the confined blast from three BLU-113s, combined with collapsing ceiling, shrapnel, and incendiary effect, would likely be sufficient to ruin most if not all of the centrifuges present.⁴¹ According to some analysts' estimates, even this might be overkill, as centrifuges in operation are inherently vulnerable to a destructive series of failures from disruptions in the power supply.⁴²

The delivery of six pairs of BLU-113s on each hall, for a total of twelve pairs or twenty-four weapons, would give fairly high confidence of achieving this level of damage. With each pair having a 0.45 probability of success, six pairs

39. Quoted in Alon Ben-David, "Paveway III Sale to Bolster Israeli Strike Capability," *Jane's Defence Weekly*, May 4, 2005. Note that unlike earlier LGBs, many modern LGBs incorporate inertial navigation and GPS systems; thus, if the laser designation is lost due to dust or smoke from the first bomb, the second bomb will continue toward the designated target with high precision.

40. See appendix for calculations; 0.45 is the midpoint of our estimates, which range from about 0.1 to 0.7 depending on assumptions.

41. Each BLU-113 contains 306 kilograms of Tritonal. Using known TNT blast curves, TNT equivalence value of 1.07 for Tritonal, and the formula for scaled distance $Z = D/W^{1/3}$, we calculate that each BLU-113 detonation would generate 3 pounds per square inch (psi) overpressure at a distance of about 41 meters in a free airburst. Three detonations would cover 50 to 65 percent of the centrifuge hall with this level of peak overpressure, which is sufficient to cause moderate structural damage to wood frame buildings. Vulnerability data are from Department of Defense, *Physical Vulnerability Handbook* (Washington, D.C.: Defense Intelligence Agency, 1974), declassified.

42. Terrence Henry quotes nonproliferation analyst Jon Wolfstahl: "If the [electrical] current powering the magnet fluctuates . . . you can send the centrifuge flying out of its case, careening across the room like a bowling pin, and knocking out the rest of the centrifuge cascades." Henry, "The Covert Option: Can Sabotage and Assassination Stop Iran from Going Nuclear?" *Atlantic Monthly*, December 2005, p. 56.

would give a total probability of about 0.31 of achieving at least three successful penetrations in both halls and a 0.71 probability of at least two penetrations in each hall.⁴³ In addition to the weapons that actually penetrated the centrifuge halls, all but one or two of the other BLU-113s would be expected to detonate over each hall, possibly collapsing the entire structure. This gives further confidence in the successful destruction of the facility. For greater confidence, the BLU-113 impact points could be targeted by additional BLU-109s, as discussed below. Finally, the above-ground pilot plant at Natanz would have to be destroyed as well. It does not appear to be hardened, so two 2,000 lb. bombs would likely be sufficient. These need not be penetrating warheads.

The next target, the Isfahan UCF, is not buried, though some evidence of tunneling is visible near the complex.⁴⁴ Based on photographs and commercial satellite imagery, the facility appears to be rectangular, roughly 180 meters in length with a varying width of 40 meters up to 80 meters.⁴⁵ The facility does not appear to be heavily hardened, so penetrating weapons would probably not be required to destroy it. The IAF could choose to use penetrating weapons, however, to pierce the walls and ensure detonation near critical components.

In this case, the smaller BLU-109 would be useful. BLU-109s could easily penetrate, so extremely high accuracy is less important. The facility appears to be roughly 10,000 square meters, so nine BLU-109s would be sufficient to expose the entire facility to sufficient overpressure to rupture chemical storage tanks.⁴⁶ The accuracy of LGBs is such that there is a much greater than 0.9 probability of the weapon falling within 10 meters of the aim point. Combined with a reliability of 0.9 for the weapons themselves, targeting the facility with twelve BLU-109s would be more than sufficient to guarantee its destruction.⁴⁷

43. By summing the results of the binomial formula for a k of 0, a k of 1, and a k of 2 where $p = 0.45$ and $n = 6$, we can show that the total probability of achieving 0, 1, or 2 successes is 0.44. By subtracting this probability from 1, we arrive at the probability of achieving three or more successes, which is 0.56 per hall. Squaring this probability gives the chance for getting three or more successes in each hall, or 0.44. The same process can be used to determine the probability of at least two successes, which yields 0.84. Squaring this yields a probability for at least two successes in each hall of 0.71.

44. See "Esfahan/Isfahan Technology Center," in "Weapons of Mass Destruction," <http://www.globalsecurity.org/wmd/world/iran/esfahan-imagery-tunnel2.htm>.

45. This description is based on the imagery at *ibid.*, http://www.globalsecurity.org/wmd/world/iran/esfahan_comp-zonea.htm, as well as photographs in *Jane's Sentinel Eastern Mediterranean* electronic database entry for Israel, October 2005.

46. In a free airburst, the BLU-109's 240 kilograms of Tritonal explosive would produce 10 psi of overpressure, roughly sufficient to rupture storage tanks, at a distance of about 20 meters.

47. As with the centrifuges of Natanz, some analysts believe that the damage threshold for the Isfahan UCF is actually much lower. Henry notes that former CIA officer Reuel Marc Gerech

The final target, the Arak facility, has two target sets. The first is the heavy-water production plant, and the second is the heavy-water reactor construction site. Neither target is hardened, so they would be relatively simple to destroy.

The central element of the production plant is a set of towers used to manufacture heavy water. There are three main and nine smaller towers in the complex. They are located in two clusters that are approximately 80 meters long and 30 meters wide. Three nonpenetrating 2,000 lb. LGBs, such as the GBU-10 targeted on each cluster, would likely be sufficient to ensure destruction.⁴⁸

The heavy-water reactor construction site consists of an unfinished containment dome and cooling facility. Assuming this incomplete site is worth targeting, four 2,000 lb. weapons should be more than sufficient to destroy it. This brings the total number of weapons needed to have reasonable confidence in destroying all three target sets to twenty-four 5,000 lb. weapons and twenty-four 2,000 lb. weapons.

Israeli and Iranian Forces

In the more than two decades since the Osirak strike, the IAF's deep-strike capability has improved dramatically. An early display of this growing capability was the 1985 IAF strike on the Palestinian Liberation Organization's headquarters in Tunis. This strike required aerial refueling of F-15s and total travel of more than 4,000 kilometers.⁴⁹

The IAF's deep-strike capability remains centered on its F-15s and F-16s. Israel, however, now fields twenty-five of the F-15I Raam and twenty-five or more of the F-16I Soufa, both of which are specially configured for deep strike.⁵⁰ The F-15I is the Israeli version of the U.S. F-15E Strike Eagle, an F-15

claims that a backpack full of explosives would be sufficient to severely damage the Isfahan facility. Henry, "The Covert Option."

48. The GBU-10's warhead of 428 kilograms of Tritonal would generate 15 psi peak overpressure (sufficient to destroy petroleum fractionating towers, which we use as a proxy) at a distance of about 21 meters; three weapons would ensure that the entire cluster would be covered with this level of overpressure.

49. See Associated Press, "Israel Calls Bombing a Warning to Terrorists," *New York Times*, October 2, 1985.

50. This estimate is based on Israeli acquisitions from Boeing and Lockheed Martin. The first two F-16Is were delivered in February 2004, and the rate of delivery has been roughly two per month since then. Estimates for the total number of F-16Is delivered at the end of 2004 were eighteen to twenty. *Jane's Sentinel Eastern Mediterranean* lists the IAF as having initiated a fifty-aircraft buy in November 2003, which should have been completed by the end of 2005. See "F-16I Suva (Storm)," *Global Security*, <http://www.globalsecurity.org/military/world/israel/f-16i.htm>; *Jane's Sentinel*

modified to optimize its air-to-ground capability. The F-15I is equipped with conformal fuel tanks (CFTs), which when combined with external drop tanks could likely give it an unrefueled combat radius of roughly 1,700 kilometers with a full weapons load.⁵¹ In addition to its bombing capabilities, the F-15I has a built-in electronic countermeasures suite and is very capable in air-to-air combat.

The F-16I is an F-16 Block 52/60 variant produced specifically for Israeli deep-strike requirements. Like the F-15I, it has CFTs to extend its radius of action. The F-16I's exact combat radius is unknown, but is likely to be on the order of 1,700 kilometers with external fuel tanks.⁵² Given the Israeli decision to forgo additional F-15I procurement in favor of increased F-16I procurement, its range is presumably not significantly less than the F-15I. The F-16I could deliver two 2,000 lb. bombs while carrying external fuel tanks, and like the F-15I it carries an advanced electronic countermeasures suite while remaining capable in air-to-air combat.

In contrast to the modern systems of the IAF, the Iranian military possesses an odd amalgamation of technologies. Prior to the fall of the shah in 1979, Iran was the United States' premier client state, and as such was well armed with the best technology the United States could provide. Yet following the revolution, much of the Iranian military's technical competence disappeared, as technicians and skilled officers were killed or fled the country. Spare parts for U.S. systems also became difficult to obtain. Subsequently, Iran has sought to upgrade its military technology with purchases from Russia, China, and elsewhere.⁵³

This mixture of various systems is readily apparent in Iran's air defense capabilities. While this defense does not appear incredibly effective, it cannot be entirely discounted. The defense comprises three elements: aircraft, surface-to-air missiles (SAMs), and anti-aircraft artillery (AAA).

The inventory and capability of the Islamic Republic of Iran Air Force (IRIAF) are qualitatively poor. IRIAF maintenance and training are insufficient to produce an air force capable of competing with a first-class air force such as

Eastern Mediterranean electronic database entry for IAF, August 2005; and "Transfers and Licensed Production of Major Conventional Weapons: Imports Sorted by Recipient. Deals with Deliveries or Orders Made in 1994-2004," Stockholm International Peace Research Institute, http://www.sipri.org/contents/armstrad/REG_IMP_ISR_94-04.pdf.

51. For detailed calculations, see appendix.

52. For detailed calculations, see *ibid.*

53. For a recent overview of Iran's military organization, see Anthony H. Cordesman, "Iran's Developing Military Capabilities," draft paper (Washington, D.C.: Center for Strategic and International Studies, 2004).

the IAF. The IRIAF fields only forty modern MiG-29s; the remainder of its inventory is of 1970s' or earlier vintage. Further, most of the air-to-air missiles that arm the IRIAF fleet are old and of low quality.⁵⁴

The IRIAF, however, would have two substantial advantages against an IAF strike package in Iranian airspace. First, IRIAF aircraft would be operating near their bases and therefore would be less concerned with fuel usage, which is often important in air-to-air combat. Second, the Iranian aircraft could rely heavily on Ground Control Intercept radar to guide them to IAF aircraft. This advantage could allow IRIAF aircraft to begin an engagement from a favorable position (e.g., attacking from behind the IAF aircraft).⁵⁵

Iran's SAM inventory is similar in quality to its aircraft inventory, with the further complication that this inventory is divided between the IRIAF, the Iranian Revolutionary Guards Corps, and the army. The centerpiece of the inventory is the MIM-23B Improved HAWK, which is of early 1970s' vintage. The combination of age and lack of spare parts probably reduces the utility of the Iranian I-HAWKs. Further, Israel also uses the HAWK system and is thus likely to have developed a significant electronic-countermeasures-suite capability against it. Iran's other SAMs are of similar vintage and would have limited utility against first-class air forces.⁵⁶ Iran has tried to purchase the advanced Soviet/Russian SA-10 Grumble SAM, but there are no confirmed reports of delivery.⁵⁷

Recent reports indicate that Iran is taking delivery of Soviet/Russian SA-15 Gauntlet SAM systems.⁵⁸ This would add a modern low-/medium-altitude mobile SAM with a phased array tracking radar to Iran's arsenal. The maximum engagement range for the system, however, is believed to be 12 kilometers, with a maximum target altitude of 6,000 meters.⁵⁹ Because the IAF strike package would likely be flying more than 5,000 meters aboveground and could drop precision-guided munitions from more than 10 kilometers away, it is unlikely that these weapons would present a major risk to the aircraft. In

54. This assessment is derived primarily from *ibid.*, pp. 25–28; *Jane's World Air Forces* electronic database entry for IRIAF, November 2006; *Jane's World Armies* electronic database entry for Iran, October 2006; and "Air Force," in "Military," <http://www.globalsecurity.org/military/world/iran/airforce.htm>.

55. For an idea of the advantage this type of radar confers, see Marshall Michel III, *Clashes: Air Combat over North Vietnam, 1965–1972* (Annapolis: Naval Institute Press, 1997).

56. See *Jane's Land-based Air Defense* electronic database entry for HAWK, October 2006.

57. See *Jane's Sentinel Gulf States* electronic database entry for Iran, October 2005.

58. See "U.S. Criticizes Russian Sale of Anti-missile Systems to Iran," *Haaretz*, January 16, 2007; and "Tor-M1s to Go to Iran by Year-End," *Jane's Defence Weekly*, October 18, 2006.

59. See *Jane's Land-based Air Defence* electronic database entry for SA-15, October 2006.

contrast, the older I-HAWK is reported to be able to engage targets at an altitude of more than 17,000 meters at a range of 40 kilometers.⁶⁰ The SA-15 could potentially engage the incoming bombs themselves, but even a modest IAF defense suppression effort would likely minimize this effect.

Finally, Iran possesses a large quantity of AAA. In general, AAA is ineffective at higher altitudes, though it has some advantages over SAM systems. Most notably, AAA can compensate for electronic jamming to some degree by relying on a high volume of fire.

Iran's combined SAM and AAA inventory could provide some defense of key points. Nonetheless, a major weakness remains tying all of these systems together in an effective Integrated Air Defense System (IADS). Without an effective IADS, the Iranian systems would not be fully mutually supporting, which would further limit their capabilities during an aerial attack. Fear of fratricide could also limit the ability of the Iranian air defense to use interceptors and SAMs in the same area.

Possible Attack Routes

The Israelis have three possible attack routes. The first is to fly north over the Mediterranean, refuel from airborne tankers, and then fly east over Turkey to Iran. The second is to fly southeast, skirt Jordan and Saudi Arabia, and then fly northeast across Iraq (essentially the Osirak route), possibly refueling in the air along the way. Alternatively, the Israelis could fly northeast across Jordan and Iraq. Finally, they could fly southeast and then east along the Saudi-Iraqi border to the Persian Gulf and then north, refueling along the way.

The northern route has three main legs. The first is from Israeli air bases to the Turkish border. The likely bases that aircraft would be launched from are Haterim (near Beersheba), Hatzor (near Ashdod), and Ramat David (near Haifa).⁶¹ To simplify, we calculate the longest distance to the target set, in this case from Haterim. The IAF could reduce this distance by moving planes between bases, though this could provide warning to other countries' intelligence services. The distance from Haterim to the Mediterranean is approximately 80 kilometers, and then north to Turkey is approximately 500 kilometers.

60. See *Jane's Land-based Air Defence* electronic database entry for HAWK.

61. See "Airfields," in "Military," <http://www.globalsecurity.org/military/world/israel/airfield.htm>.

The second leg crosses Turkey from west to east, a short distance north of the Syrian border. The route begins east of Adana, passes south of Diyarbakir, and ends at the Iranian border west of Orumiyeh. This is a total distance of about 840 kilometers.

The final leg is southeast across Iran to Arak, Natanz, and Isfahan. We calculate the end point as the distance to the farthest target, in this case Isfahan. The distance from the border near Orumiyeh to Isfahan is approximately 800 kilometers. The total route length is thus roughly 2,220 kilometers.

This route is longer than the estimated unrefueled combat radius of Israel's strike aircraft, but it carries the advantage of aerial refueling over the Mediterranean. Tankers are vulnerable to attack, so being able to refuel over the international waters of the Mediterranean would be a big advantage. Israeli tanker assets are not well documented, but they appear to consist of five to seven KC-707s and four to five KC-130Hs.⁶² The KC-130, due to its drogue refueling design, would be unable to refuel F-16s and F-15s without some modification or carrying of special refueling probe-equipped external fuel tanks. The KC-707 can probably deliver roughly 120,000 pounds of jet fuel at a range of 1,000 nautical miles, and can transfer this fuel very quickly.⁶³ For a strike package of fifty aircraft, the KC-707 fleet could deliver 12,000 to 16,000 pounds of fuel per aircraft at a range of 1,000 nautical miles. As the actual distance to the refueling point would probably be less than 400 nautical miles, there should be more than this amount of fuel available.

By refueling over the Mediterranean, the strike package could maneuver against Iranian air defenses with less concern about fuel. The refueling on the inbound leg of the flight, however, would take place very early (after flying fewer than 600 kilometers), so only a limited amount of fuel could be offloaded to each aircraft before they would be full again. The total distance from Adana to Isfahan is about 1,640 kilometers, very close to the combat radius predicted for the F-15I. This would mean the strike aircraft would probably have to refuel a second time, after leaving Turkish airspace on the return trip. The IAF tankers could wait near the Turkish border to refuel the strike aircraft as they returned to Israel, potentially protected by other IAF aircraft.

62. See "Israel—IAF Equipment," in "Military," <http://www.globalsecurity.org/military/world/israel/iaf-equipment.htm>; and *Jane's World Air Forces* electronic database entry for Israel, October 2006.

63. See Federation of American Scientists, "KC-135 Stratotanker," <http://www.fas.org/nuke/guide/usa/bomber/kc-135.htm>. The KC 707 has essentially the same airframe as the U.S. KC-135, so we assume they have roughly the same refueling capability.

One disadvantage of this route is that it passes quite close to several Turkish air force bases, including two large ones: Incirlik (near Adana) and Diyarbakir. Turkey's reaction to a potential Israeli incursion is uncertain. Although the Turks would undoubtedly be angry, the central question is whether they would fire on Israeli aircraft. Turkey and Israel have historically enjoyed good military and economic relationships, even if their political rhetoric is sometimes harsh. On the other hand, the current Turkish government of moderate Islamists has to some degree distanced itself from Israel.

Furthermore, this route passes near a number of Iranian air bases: Tabriz, Sharohki (near Hamadan), Kermanshah, Khatami (near Isfahan), and Vahdati (near Dezful).⁶⁴ The major bases near Tehran are slightly farther away. This would put the strike package in range of a number of possible intercept squadrons during both ingress and egress.

If the IAF were reluctant to accept the diplomatic problems of flying over Turkey, it could instead cross Syria for most of the east-west leg of this route. It would then have to cross Turkish airspace only briefly near the Iranian border. Syria would almost undoubtedly fire on Israeli aircraft. This route would thus trade significantly higher operational risk for somewhat lower diplomatic costs.

The second route is the most direct route, but it carries major political difficulties. It has one or two main legs, depending on how it is flown. The first leg of option one would be from Ramat David (the farthest from the target) to the Gulf of Aqaba. This is basically the entire length of Israel, so planes might be relocated farther south before the strike. As noted above, however, we assume for simplicity and operational security that all planes launch from home base. The length of this leg would be roughly 360 kilometers. The second leg of option one is from the northern end of the Gulf of Aqaba to the target zone. This leg is extremely long, with the farthest target, Natanz, roughly 1,800 kilometers away. The total distance traveled, 2,160 kilometers, would be scarcely less than that of the northern route. Refueling would be required at some point. The second option, directly across Jordan and Iraq, is shorter. The distance from Hatzerim to Natanz is roughly 1,750 kilometers, which is just over the estimated combat radius of the strike aircraft.

Both options would require cooperation (or at least acquiescence) from the Jordanians and especially the Americans in Iraq. The flight path of option two

64. See "Airfields and Bases," in "Military," <http://www.globalsecurity.org/military/world/iran/airfield.htm>.

is directly over Jordan and would pass near the capital of Amman and a major air base at Azraq ash Shishan. Each would traverse all of Iraq, and any refueling would likely be over Iraq. It would be all but impossible to accomplish without the notice of the Americans and probably the Jordanians. While any strike against Iran by Israel would be interpreted as having U.S. backing, this option would provide unambiguous evidence of it.

The central route has the advantage of crossing less Iranian airspace than the northern route. It would avoid the base at Tabriz, though the other bases noted above would still be in range. Iranian air defense on the Iraqi border might potentially be on higher alert than along the Turkish border.

The southern route covers perhaps the least well-defended airspace, at least in its initial legs. It is also quite long and poses refueling challenges. It runs west to east across northern Saudi Arabia to the Persian Gulf, then north/northeast into Iran.

The first leg would be the Ramat David to the Gulf of Aqaba route noted above, a distance of 360 kilometers. As with that route, IAF aircraft could be shifted to bases farther south to shorten the distance. From Aqaba the aircraft would cross Saudi Arabia south of the Iraqi border, from the coast near the town of Haql to the Persian Gulf coast near Ras al-Khafji. This is a distance of roughly 1,350 kilometers.

The second leg would cross the Persian Gulf into Iran, and then north to the target zone. The farthest target would be Natanz, a distance of about 700 kilometers. This makes the total route length on the order of 2,410 kilometers, easily the longest route of the three.

The third route poses the same kind of diplomatic challenges as the northern route, as it crosses Saudi airspace and passes near several Saudi air bases. Further, Saudi Arabia has invested significantly in IADS. On paper this appears to be a highly formidable air defense system. Saudi readiness levels are alleged to be very low, however.⁶⁵ In addition, much of Saudi Arabia's northern air defense was intended to protect against Iraq, and presumably readiness levels are much lower now that the threat from Saddam Hussein has been removed. In addition, the question would still remain whether the Saudis would fire on Israeli aircraft or simply launch a massive diplomatic protest.

A more serious issue is refueling. The route would be significantly longer than the estimated combat radius of the strike aircraft. The IAF would thus have two options, both dangerous. It could attempt to refuel the strike package

65. See Anthony H. Cordesman, *The Military Balance in the Gulf: The Dynamics of Force Development* (Washington, D.C.: Center for Strategic and International Studies, 2005), pp. 131–134.

over Saudi territory, which would be subject to disruption by Saudi forces. Alternatively, it could refuel over the Persian Gulf, which might be less subject to disruption. It would still require flying the tankers across Saudi Arabia, and would also put the tankers in a position to possibly be engaged by IRIAF interceptors over the gulf. The route would pass near several IRIAF bases: Bushehr, Vahdati, Isfahan, and Abadan (a nonmilitary but potentially usable airfield). Shiraz is only slightly farther away.⁶⁶

All of the routes pose significant operational and political risks. From a technical perspective, none are impossible. The remainder of this analysis focuses on Iranian air defenses near the target areas, regardless of the route taken by the IAF's strike package.

The Likely Correlation of Forces

The analysis below assumes that the IAF would attack Iran's nuclear facilities using twenty-five F-15Is and twenty-five F-16Is. The IAF could potentially field a larger strike package, but this would probably tax its refueling capabilities and command and control. This package would probably consist of three smaller packages, one for each of the likely targets.

The interaction of this strike package with Iran's air defenses is highly contingent. In the Osirak strike, IAF aircraft escaped all but the most desultory engagement with AAA around the reactor site. The IAF would probably not be so lucky against Iranian facilities, but Iran's lack of an effective IADS suggests that the level of engagement could potentially be low.

The exact quality and readiness of Iranian equipment is unknown. With moderate reliability and effectiveness in its air defenses, Iran could credibly respond to an IAF incursion. In contrast, if reliability and effectiveness are low, then the IAF could brush aside the Iranian forces with relative ease.

Rather than attempt to map the various contingent outcomes, we look at the number of aircraft that would have to arrive on target to deliver the ordnance noted in the section on weaponing. From that, we can determine the attrition levels the Iranian air defense would have to generate to prevent the Israeli strikes from being fully successful. We can then make some rough guesses about the likelihood of this occurring.

In the case of Natanz, if each F-15I carried only one BLU-113 (along the centerline) in addition to external fuel tanks and air-to-air missiles, then twenty-

66. See "Airfields and Bases," <http://www.globalsecurity.org/military/world/iran/airfield.htm>.

four F-15Is would have to arrive at the target complex. Note that if the F-15Is carried only one BLU-113 centerline, they could potentially carry additional BLU-109s on the CFT hardpoints. Isfahan and Arak would require fewer aircraft to deliver the requisite ordnance. In the case of Isfahan, six F-16Is would have to arrive at the target complex if each carried two BLU-109s. For Arak, only five F-16Is would have to reach the target.

Iran's air defenses would have to impose significant attrition to cause the IAF mission to fail to deliver the ordnance noted above. The IAF could assign two additional F-16Is (out of twenty-five) loaded with 2,000 lb. bombs to both Arak and Isfahan and then have ten left for defending the strike package. The Iranian air defense would have to down three out of seven assigned to Arak and three out of eight assigned to Isfahan, roughly 40 percent attrition. This would be almost unimaginable given Iranian assets, as even the disastrous U.S. raid on Ploesti in World War II sustained only 32 percent attrition (admittedly out of a much larger total number). More comparably, on the third and worst night of the December 1972 Linebacker II raids on Hanoi, U.S. losses from the first and third wave of B-52s were less than 10 percent, while the total loss that night was slightly more than 6 percent.⁶⁷

The major vulnerability would be attrition in the F-15I force, assuming each carried only one BLU-113. Then, Iran's air defenses would have to impose an attrition rate of only 8 percent (downing two out of twenty-five) to cause the mission to fail to deliver the designated ordnance. This is certainly within the realm of possibility. For example, IAF ground attack aircraft sustained massive attrition in the first days of the 1973 Yom Kippur War, including 8 percent of total fighter strength on the first day. The average daily attrition rate of IAF aircraft in that conflict was only about 3 percent, however.⁶⁸

A potentially more relevant example would be the U.S. raid on Libya in 1986. This strike, code-named El Dorado Canyon, was similar to the proposed IAF strike. It used roughly the same number of aircraft (in this case, twenty-four F-111s) flying very long routes (from England and around France to the Mediterranean). The buildup to El Dorado Canyon in the media was such that the Libyans had at least as much warning as the Iranians could expect. In that

67. On Ploesti, see Stephen W. Sears, *Air War against Hitler's Germany* (New York: Harper Row, 1964), p. 74. On Linebacker II, see Alfred Price, *War in the Fourth Dimension: U.S. Electronic Warfare from the Vietnam War to the Present* (Mechanicsburg, Pa.: Stackpole, 2001), p. 120. Both the first and third waves lost three B-52s, out of thirty-three and thirty-nine, respectively. The total sent that night was ninety-nine B-52s, though six were recalled.

68. In a conflict that lasted eighteen days, the IAF lost about 115 fighter-bombers out of a total of 358, for a daily loss rate of 2.5 to 3 percent. See Eliot A. Cohen and John Gooch, *Military Misfortunes: The Anatomy of Failure in War* (New York: Free Press, 1990), pp. 104, 110.

case, only one U.S. aircraft was lost, for an attrition rate of slightly more than 4 percent.⁶⁹

Of course, reliability is an issue with aircraft as well as munitions. If even one F-15I failed to complete the mission due to reliability problems, then the Iranians would have to down only one aircraft. If two failed to function, then the mission would be unable to deliver the designated ordnance without the Iranians even firing a shot. Further, the IRIAF does not have to actually down any IAF aircraft. It must only succeed in engaging the IAF aircraft with sufficient threat to cause them to dump their ordnance in order to maneuver. In Vietnam, this happened with some frequency to U.S. strike aircraft. With the advantage of good Ground Control Intercept radar and SAMs, the IRIAF might achieve similar results.

Yet even if the designated ordnance needed for the total destruction of Natanz were not delivered, the Iranian nuclear program would still be significantly hampered. Even one large bomb detonating in each centrifuge hall would disrupt operations and, if it were operating, would contaminate it with UF₆. Further, to ensure that total destruction is highly likely even with significant attrition in its strike package, the IAF could send additional assets to Natanz, as discussed below.

Finally, Iran's air defense system was only modestly effective against the Iraqi air force during the 1980–88 Iran-Iraq War.⁷⁰ This lack of success against what was at best a very poor air force, compounded by the subsequent aging of systems such as the I-HAWK, makes it unlikely that the Iranians would perform effectively against the IAF. This gives additional confidence in mission success.

The IAF could also supplement the F-15I attack on Natanz by assigning F-16Is armed with BLU-109s to attack the BLU-113 aim points. While the BLU-109 is less certain of penetration than the massive BLU-113s, it is still a very capable weapon. Assuming that six F-16Is were assigned to supplement the F-15Is, each could deliver two BLU-109s on each of six BLU-113 aim points. This would result in a greater than 0.8 probability of at least one weapon, BLU-109 or BLU-113, penetrating the Natanz facility.⁷¹ The actual amount of explosive

69. See Joseph T. Stanik, *El Dorado Canyon: Reagan's Undeclared War with Qaddafi* (Annapolis: Naval Institute Press, 2002).

70. See Efraim Karsh, "The Iran-Iraq War: A Military Analysis," Adelphi Paper, No. 220 (London: International Institute for Strategic Studies, 1987), p. 40; and Anthony H. Cordesman, *The Iran-Iraq War and Western Security, 1984–1987: Strategic Implications and Policy Options* (London: Jane's, 1987), pp. 114–115, 131, 135.

71. The probability of at least two direct hits on the aim point out of four weapons (two BLU-113s and two BLU-109s) is 0.8, assuming the base case of 0.9 reliability and 0.65 probability of a direct

contained in the BLU-109 and BLU-113 is quite similar, so a high confidence of destruction could be obtained in this manner.

Also, as noted earlier, the F-15Is could carry two BLU-109s, adding more firepower. If each carried one BLU-113 and two BLU-109s, the strike package of twenty-five F-15Is would have twenty-five BLU-113s and fifty BLU-109s. Two of these weapons would be used to destroy the pilot plant, but the rest could be aimed at the underground facility. Even if the Iranian air defense imposed 40 percent attrition (ten aircraft downed), fifteen BLU-113s and thirty BLU-109s would arrive on target, even without supplemental F-16Is. This would allow almost four weapons to be targeted for each of the twelve aim points (six per hall), even without additional F-16Is. This would mean that additional F-16Is could be dedicated to defense suppression and air-to-air roles.

Conclusion

The foregoing assessment is far from definitive in its evaluation of Israel's military capability to destroy Iranian nuclear facilities. It does seem to indicate, however, that the IAF, after years of modernization, now possesses the capability to destroy even well-hardened targets in Iran with some degree of confidence. Leaving open the question of whether an attack is worth the resulting diplomatic consequences and Iranian response, it appears that the Israelis have three possible routes for an air strike against three of the critical nodes of the Iranian nuclear program. Although each of these routes presents political and operational difficulties, this article argues that the IAF could nevertheless attempt to use them.

The operation would appear to be no more risky than Israel's 1981 attack on Iraq's Osirak reactor, and it would provide at least as much benefit in terms of delaying Iranian development of nuclear weapons. This benefit might not be worth the operational risk and political cost. Nonetheless, this analysis demonstrates that Israeli leaders have access to the technical capability to carry out the attack with a reasonable chance of success. The question then becomes one of will and individual calculation.

More generally, this assessment illustrates both the utility and limitations of precision-guided weapons for counterproliferation. Assuming that the intelligence is available to identify targets of interest, precision-guided weapons can fill an important role of destroying the target with increased confidence,

hit. Because this does not account for any near misses, it understates the likelihood of success. It also disregards the possibility of the two misses being BLU-113s and the two hits being BLU-109s.

leading to smaller strike packages and lower risk to personnel and equipment. Although limitations still exist, especially in the case of hardened targets, precision-guided weapons have become extremely capable, particularly when strike aircraft are confronted by relatively low-quality air defense. The use of precision strike for counterproliferation should therefore not be discounted lightly.

This analysis, however, highlights the critical nature of target knowledge. In many cases, the means of striking or defending WMD targets may be less important than the ability to locate or hide them. Those seeking to stop proliferation would be advised to invest heavily in intelligence collection and analysis, while proliferators should rely on concealing and dispersing rather than hardening targets.

Additionally, the analysis illustrates that the technical ability to conduct an attack may be overshadowed by the “day after” problem. When Israel struck Osirak, Iraq was involved in a bloody war with Iran that limited its ability to retaliate. With Iraq in chaos, a capable proxy in Lebanon’s Hezbollah, and high oil prices, Iran today has a much greater ability to strike back against both Israel and the United States. Although the IAF may be able to destroy known Iranian nuclear facilities (by extension the U.S. Air Force almost certainly can) and significantly delay Iran’s nuclear program, Iran’s potential responses to such a strike may cause policymakers to reject this option. Despite its potential utility, military counterproliferation must be complemented by political and economic efforts if the spread of nuclear weapons is to be checked.

Appendix: Estimating Aircraft Range and Bomb Sequencing

AIRCRAFT RANGE ESTIMATES

The official ferry range (the range the aircraft can fly one way without refueling) for the F-15E using CFTs and three external fuel tanks is given by the U.S. Air Force as 3,840 kilometers. Other sources suggest that the actual ferry range is in excess of 5,600 kilometers. *Jane’s All the World’s Aircraft* lists it as 4,445 kilometers. In terms of combat radius,

1. For data in the appendix, see John Anderson, *Introduction to Flight*, 5th ed. (Boston: McGraw-Hill, 2005); *Jane’s All the World’s Aircraft* entry for F-15 and F-16; “F-15E Strike Eagle,” <http://www.af.mil/factsheets/factsheet.asp?fsID?102>; “F-15 Eagle,” in “Military,” <http://www.globalsecurity.org/military/systems/aircraft/f-15-specs.htm>; Jaffee Center, “Air Force Equipment,” in “Middle East Military Balance,” <http://www.tau.ac.il/jcss/balance/airf.pdf>; “Air Force Equipment F-15E ‘Strike’ Eagle Long-Range Interdiction Fighter, USA,” <http://www.airforce-technology.com/projects/f15/>; F-15E Strike Eagle, <http://www.f-15estrikeeagle.com/weapons/loadouts/oif/oif.htm>; “F-16 Fighting Falcon,” <http://www.af.mil/factsheets/factsheet.asp?fsID=103>; “F-16 Fighting Falcon,” <http://www.globalsecurity.org/military/systems/aircraft/f-16-specs.htm>; and “F-16 Fighting Falcon Multi-role Fighter Aircraft, USA,” <http://www.airforce-technology.com/projects/f16/>.

the number most often cited for the F-15E is 1,270 kilometers, which appears to be with CFTs and a full weapons load. The combat radius could be extended by replacing two weapons with external fuel tanks. A simple estimate can be derived from comparing the fuel load with CFTs only (approximately 23,000 pounds) with the fuel load of CFTs plus two 610-gallon external tanks (approximately 31,000 pounds). This ratio is about 1.35, which when multiplied by 1,270 kilometers yields a combat radius of roughly 1,700 kilometers. This estimate also appears to roughly conform to the official ferry range, as with three drop tanks and CFTs the F-15E can carry about 35,300 pounds of fuel, or a ratio of about 1.53. This yields a combat radius of about 1,900 kilometers, or a ferry range of 3,800 kilometers. Ferry range assumes no combat maneuvering, but the official estimate, as noted, is probably highly conservative. Some sources list the combat radius of the F-15E as in excess of 1,800 kilometers, so the 1,700-kilometer estimate is probably conservative as well. Breguet calculations based on unclassified estimates of F-15E performance, a specific fuel consumption of 0.9, a constant velocity of 700 miles per hour, constant coefficient of lift, lift-to-drag ratio of 6.193, and a take-off weight of 80,000 pounds with 30,000 pounds of fuel also produce results in this range (approximately 1,800-kilometer radius), not accounting for weapons release.

The F-16D, which the F-16I is based on, has internal fuel storage of almost 5,900 pounds and an estimated combat radius of 540 kilometers. With the addition of CFTs, one 300-gallon centerline and two 600-gallon external fuel tanks, the F-16I could carry about 19,000 pounds of fuel. Using the simple estimation method above, this is a ratio of 3.22, which would give the F-16I a combat radius of about 1,730 kilometers. As the CFTs have much lower drag than the external fuel tanks, the actual combat radius would probably be higher. At least one source, the Jaffee Center, reports a combat radius of 2,100 kilometers, so this estimate is probably conservative. It appears to be roughly in line with other estimates. Jane's *All the World's Aircraft* lists 1,361 kilometers as the combat radius in a hi-lo-lo-hi profile for the F-16C Block 50 with CFTs, a centerline 300-gallon external fuel tank, and two 370-gallon underwing fuel tanks (roughly 17,100 lbs of fuel), while carrying two 2,000 lb. bombs and two Sidewinder missiles. This estimate is also in line with the official U.S. Air Force ferry range in excess of 3,200 kilometers. This ferry range is with two 600-gallon and two 370-gallon fuel tanks for a total of 18,700 pounds of fuel, a ratio of 3.28. This yields a radius of about 1,770 kilometers and a ferry range of at least 3,540 kilometers.

PENETRATING BOMB SEQUENCING

Bomb sequencing is derived from the formula $P_k = 1 - 0.5^{(LR/CEP)}$, where P_k is the probability of successful landing within the lethal radius (LR) of the target. Additionally, the non-Gaussian distribution of LGBs is represented by the fraction of bombs that exhibit no error (i.e., they directly hit the aim point). The lethal radius is crater size, so there is some probability of a near miss still landing in the crater. In the case of two near misses, the lethal radius is reduced by half; in other words, if the first bomb lands within half the LR of the aim point, then the second bomb will definitely hit within the LR if it too lands within half the LR of the aim point. With these assumptions, there are four probability branches: direct hit-direct hit; direct hit-near miss; near miss-direct hit; and near miss-near miss. These branches have a probability of $(0.65)^2 = 0.42$; $0.65 \times (0.35 \times 0.29) = 0.07$; $(0.35 \times 0.29) \times 0.65 = 0.07$; and $(0.4 \times 0.16)^2 = 0.004$. This yields a cumulative

probability of 0.56, which is then multiplied by the cumulative reliability ($0.9 \times 0.9 = 0.81$) to yield a probability of 0.45. The assumption of crater width is based on the 0.37-meter diameter of a GBU-28 combined with the effect of the explosion occurring in the ground, which would rupture the ground surrounding the explosion as well as being vented to some degree out of the entryway of the warhead. This is presumed to create sufficient structural damage to allow the second BLU-113 to penetrate easily if it impacts within a 1.8–3.6 meter radius (10–20 times the diameter of the bomb) of the entry point of the first bomb. This calculation is very sensitive to changes in the parameters, so some variations are presented in Table 1.

Table 1. Variation in Parameters of the BLU-113 Sequenced Penetration

N_{hit}	0.65	0.30	0.50	0.70	0.50	0.15	0.70
N_{nm}	0.35	0.70	0.50	0.30	0.50	0.85	0.30
CEP	6	3	6	2	3	6	3
LR	3	2	3	3	3	3	2
Rel	0.90	0.85	0.90	0.95	0.90	0.90	0.90
Prob	0.45	0.19	0.33	0.70	0.42	0.09	0.53

SOURCES: C.R. Anderegg, *Sierra Hotel: Flying Air Force Fighters in the Decade after Vietnam* (Washington, D.C.: Air Force History and Museums Program, 2001); and Morris Drells, *Weaponeering: Conventional Weapons System Effectiveness* (Reston, Va.: American Institute for Aeronautics and Astronautics, 2004).

N_{hit} = percentage of munitions that directly hit aim point (i.e., non-Gaussian distribution)

N_{nm} = percentage of munitions that exhibit Gaussian distribution of a given CEP

CEP = circular error probable; radius in meters around aim point in which half of Gaussian distributed munitions will fall

LR = lethal radius; in this case, the radius in meters around the impact point of the first BLU-113 that the second must hit within to penetrate the Natanz facility

Rel = reliability; the probability the BLU-113 will function properly

Prob = the cumulative probability of the two BLU-113s functioning and impacting sufficiently close for the second to penetrate the Natanz facility