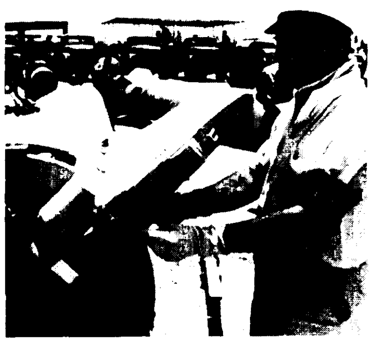
The Proliferation of Delivery Systems 5

A country seeking to acquire weapons of mass destruction will probably desire some means to deliver them. Delivery vehicles may be based on very simple or very complex technologies. Under the appropriate circumstances, for instance, trucks, small boats, civil aircraft, larger cargo planes, or ships could be used to deliver or threaten to deliver at least a few weapons to nearby or more distant targets. Any organization that can smuggle large quantities of illegal drugs could probably also deliver weapons of mass destruction via similar means, and the source of the delivery might not be known. Such low technology means might be chosen even if higher technology alternatives existed. If the weapons are intended for close-in battlefield use, delivery vehicles with ranges well under 100 km may suffice. Strategic targets in some regional conflicts are only a few hundred kilometers from a nation's borders. (A fixed-direction launch system, such as the Supergun being developed in Iraq, might also be used in these circumstances.) Deterrence or retaliation against more distant countries, however, might require delivery ranges of many thousands of kilometers.

This chapter focuses on "high end" delivery systems—ballistic missiles, cruise missiles, and combat aircraft-for the following reasons:

- simpler systems, such as cars and trucks, boats, civil aircraft, and artillery systems are not amenable to international control. No nonproliferation policy could possibly prevent countries with weapons of mass destruction from utilizing such vehicles;
- there is a high degree of overlap among the countries pursuing weapons of mass destruction and those possessing, developing or seeking to acquire missiles and highly capable combat aircraft; and



modem delivery systems enable a country to do more damage to a greater number and variety of targets, with greater reliability, and potentially at longer range, than do low technology alternatives. Ballistic and cruise missiles in particular may have added psychological effects, since they can be harder to defend against, or even to detect, than manned aircraft.

Combat aircraft are already widely distributed around the world. Every country currently suspected of having or seeking weapons of mass destruction also has military aircraft that could be adapted to deliver such weapons. This chapter nevertheless examinesthes the proliferation of advanced aircraft for three reasons:

- such a review indicates how and why combat aircraft are already so widespread and what capabilities they offer;
- states seeking ballistic and cruise missiles do so in the context of widespread aircraft proliferation; and
- since advanced aircraft have proliferated more by transfers than by indigenous production, there is the possibility of limiting the proliferation of still more advanced systems.[1]

Even though owners of weapons of mass destruction may possess combat aircraft, there are reasons outlined below why they might prefer to use missiles. Unlike aircraft, however, ballistic and cruise missiles are subject to international supplier controls through the Missile Technology Control Regime.

This chapter begins with a comparison of the utilities of these three types of system for delivering weapons of mass destruction. Subsequent sections discuss the technological factors affecting the relative ease or difficulty of acquiring each type of capability, either through purchase, co-development, or indigenous design and production. These sections also indicate the types of observable indicators, or signatures, that if detected might reveal attempts to develop, build, or deploy each system.

SUMMARY

Effectiveness of Advanced Delivery Systems

Although combat aircraft, ballistic missiles, and cruise missiles are not necessary to deliver weapons of mass destruction, each type of vehicle is capable of doing so and each has particular strengths. A state with the resources, ability, and inclination to acquire delivery systems specifically for use with weapons of mass destruction has to consider the availability of candidate systems, the type of weapon to be delivered, the targets to be struck, and the purposes of planned attacks or threats of attack. Characteristics affecting the suitability of delivery vehicles to particular missions include range, payload amount and type, ability to evade or penetrate defenses, vulnerability to preemptive attack (pre-launch survivability), cost, and infrastructure requirements.

For delivering a nuclear warhead, the likelihood of successful delivery somewhere in the vicinity of the target (the combination of pre-launch survivability, reliability, and defense penetration) is more important than factors such as accuracy, cost, or excess payload capacity. By this measure, even though missiles are more likely to penetrate defenses, the reliability of piloted aircraft may sometimes count for more. Given their destructive potential, nuclear weapons need not be delivered with great accuracy (even a demonstration explosion on the proliferant nation's own territory or in the ocean could have great effect in some situations); neither would a nuclear delivery system have to carry

[1] Competition in advanced weaponry is part of the context in which some countries seek weapons of mass destruction some analysts believe that limiting the spread of advanced combat aircraft is an important goal whether they would play a direct role in the delivery of weapons of mass destruction or not.

payloads much beyond the weight of a single nuclear weapon.

To the extent that cost matters in delivering a nuclear weapon, it is probably the total cost of acquiring a delivery capability-not the cost per ton of payload—that is relevant. Here, missiles (ballistic or cruise) have a strong advantage, since they are generally considerably cheaper than advanced aircraft.

Aircraft and cruise missiles are better suited than ballistic missiles to deliver chemical and biological agents over an extended area. Size of payload matters in chemical and in typical large-area biological attacks, since the damage that can be inflicted depends directly on the amount of agent that can be delivered.[2] In this respect, the typically larger payload capacity of manned aircraft would give them a strong advantage over both cruise and ballistic missiles.

Since known biological and chemical weapons are cheaper to develop than are nuclear weapons, the cost of their delivery system is a much larger fraction of the total cost, and hence a more important criterion, than in the nuclear case. To attack military targets with chemical weapons, the cost per ton of delivered payload would probably be important to the attacker. With their larger payloads and their reusability, aircraft are typically cheaper than missiles by this measure. Depending on how biological weapons were used (e.g., once for shock value, or repeatedly for genocide) either the cost of one sortie or the cost per ton of payload could be more important. Aircraft have a strong advantage for attacks against military targets, if the targets are mobile or located in unknown positions. Ballistic missiles, on the other hand, would have an advantage if the targets were particularly well defended.

Availability of Delivery Systems

Unlike weapons of mass destruction, whose trade is heavily constrained by treaties and international norms, delivery systems such as aircraft and short range antiship cruise missiles are widely traded internationally. The United States and other Western industrialized countries have tried to delegitimize the sale of longer range ballistic and cruise missiles by creating the Missile Technology Control Regime (MTCR). When formed in 1987, the MTCR was intended to limit the risks of nuclear proliferation by controlling technology transfers relevant to nuclear weapon delivery other than by manned aircraft. To this end, the MTCR established export guidelines that, when adopted by complying nations, would prohibit them from selling ballistic or cruise missiles with ranges over 300 km and payloads over 500 kg to nonmembers.[3]

The Persian Gulf War and the recent emergence of potential secondary suppliers of missiles have helped convince a number of additional countries to participate in the MTCR. Beginning with seven original members in 1987, the MTCR has grown to 23 full members, with Argentina and Hungary now in the process of becoming full members. Another four countries (China, Israel, South Africa, and Russia) have agreed to abide by the MTCR's export restrictions (see table 5-l). On January 7, 1993, MTCR member states further tightened up the export restrictions, agreeing to a "strong presumption to deny' transfers of 300-km ballistic or cruise missiles regardless of their payload, and of any missiles-regardless of range

[2] For attacks on cities, optimally distributed biological agents measuring in the tens of kilograms could theoretically inflict casualties comparable to a nuclear weapon. If contagious biological agents were used, damage would be less directly related to amount of agent distributed; however, contagious agents have serious operational drawbacks (see ch. 3). For comparisons of nuclear, chemical, and biological weapon effects, see ch. 2 of U.S. Congress, Office of Technology Assessment, *Proliferation of Weapons of Mass Destruction: Assessing the Risks*, OTA-ISC-559 (Washington, DC: U.S. Government Printing Office, August 1993).

[3] As applied to missiles or unmanned aerial vehicles, the MTCR prohibits the transfer of *complete systems*, *components* that could be used to make complete systems, and *technology involved in the production* of components or of complete systems. Each participating nation controls export of these items through its own national system of export controls, and the controls are coordinated among MTCR members.

Table 5-1—MTCR Countries

7 original members (1987):
Canada, France, Federal Republic of Germany, Italy, Japan, United Kingdom, United States

16 additional full members (as of Mar. 25, 1993):
Australia, Austria, Belgium, Denmark, Finland, Greece, Iceland, Ireland, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland

Countries that have pledged to abide by MTCR provisions, but are not full members:
Argentina (pledged May 1991; in process of becoming full member, March 1993)
China (pledged November 1991)
Hungary (in process of becoming full member, March 1 993)
Israel (agreed October 3, 1991 to abide with MTCR provisions by the end of 1992; applying for membership, March 1993)
Romania (applying for membership, as of March 1993)
South Africa (has pledged to join, but date unspecified)
Soviet Union/Russia (pledged 1990/June 1991, respectively)

SOURCE: Adapted from Australian Department of Foreign Affairs and Trade, press release, Mar. 11, 1993; and *Arms Control Reporter, 1993* (Cambridge, MA: Institute for Defense and Disarmament Studies, 1993), section 706.

or payload—if the seller has reason to believe they would be destined to carry weapons of mass destruction.

Technological Barriers to Delivery-System Proliferation

According to published sources, ballistic missiles with ranges from 300 to 600 km are already possessed or being developed by over a dozen countries outside of the five declared nuclear powers. In general, the acquisition by additional countries of more advanced missile technologies-those allowing ranges in excess of 1,000 km or accuracies much better than roughly 0.3 per cent of range-cm be slowed but not stopped by multilateral export controlls. It is unlikely that any country (other than China and the former Soviet republics that already possess intercontinental ballistic missiles) would pose a direct ballistic missile threat to the United States within the next 10 years. However, as the Persian Gulf War and the ongoing nuclear tensions involving North Korea have emphasized, important U.S. allies and overseas interests can already be put at risk by existing missiles in a number of countries.

Cruise missiles or other unmanned aerial vehicles that exceed the MTCR thresholds are not widespread outside of the United States and the former Soviet Union, but a number of systems with ranges of 50 to 200 km are available for purchase. In addition, technologies for guidance, propulsion, and airframes have recently made major advances and are becoming considerably more accessible to many Third World countries—particularly with the export of more advanced short range systems and the spread of aircraft production technology and co-licensing arrangements. Since very few countries have been able to develop *indigenous* aircraft industries capable of manufacturing jet engines, it should be possible in principle to control the spread of the most sophisticated engines and propulsion systems. However, the highest performance engines are not required for simple cruise missiles, and engines with lesser capabilities are becoming increasingly available on international markets.

The availability of satellite navigation services, such as the U.S. Global Positioning System (GPS), the Russian Glonass system, and possible future commercial equivalents, essentially eliminates guidance as a hurdle for weapon delivery by manned or unmanned aircraft. GPS receivers are inexpensive and commercially available. Although exportable models do not operate at sufficiently high altitudes and speeds to provide much help for guiding ballistic missiles (and even custom-made receivers operating during the entire boost phase would have very limited utility for improving ballistic missile accuracy), such receivers could be used with manned or unmanned aircraft to provide unprecedented navigational accuracy anywhere in the world. Even the least accurate form of GPS broadcasts would be sufficiently accurate for aircraft delivery of weapons of mass destruction.

Delivery System Signatures and Monitoring

Most long range delivery system programs are hard to hide. Test launches of ballistic missiles can be readily detected, and intermediate and long range missiles require a lengthy development period and extensive flight testing at each phase, making an overall program particularly difficult to keep secret. Far from being hidden, civil space-launch programs-which inherently can provide knowledge useful to a military program—are usually considered a source of national prestige and are proudly advertised. In particular, the two most important aspects of missile capability for weapons of mass destruction-range and payload-can usually be inferred from monitoring such a space-launch program. (Guidance technology and accuracy would be more difficult to determine, but are less important for weapons of mass destruction.) Nevertheless, once deployed on camouflaged mobile launchers, missiles can be exceedingly difficult to track and account for.

Since combat aircraft are widely accepted as integral to the military forces of a great number of countries, there is no reason to hide their existence. But the act of modifying aircraft to carry weapons of mass destruction, or training pilots to deliver such weapons, might be very difficult to detect without intrusive inspections.

Of the three types of delivery system discussed in this chapter, development and testing of cruise missiles will be the hardest to detect. Several types of civilian-use unmanned aerial vehicles are also being developed and marketed, and without actual inspections it will be very difficult to discern whether such vehicles have been converted to have military capability. Monitoring delivery systems capable of carrying weapons of mass destruction will have the most success with ballistic missiles and highly capable aircraft.

EFFECTIVENESS OF DELIVERY SYSTEMS

The delivery capability required to use weapons of mass destruction varies enormously, depending on the weapon and the mission. A simple, covert means of delivery, such as smuggling, could be sufficient for a single nuclear or biological weapon, whereas a great many aircraft would be required to deliver hundreds of tons of chemical munitions in a coordinated attack against defended sites.

The following discussion examines the characteristics that affect the ability of combat aircraft, cruise missiles, and ballistic missiles to deliver weapons of mass destruction against relatively inaccessible targets.[4] These characteristics include range, payload, accuracy, cost, defense penetration, and reliability. Although a wide variety of systems have been or could be developed to deliver weapons of mass destruction (see table 5-2), the delivery systems discussed in this chapter have unique capabilities and thus pose particular dangers to potential victims. Unlike mines or clandestinely placed bombs, they do not require that the attacker be able to gain direct access to the target, and they can deliver weapons in far less time than would be required to smuggle them to a target. Unlike artillery shells, rockets, or mortars, they can reach distant military targets and population centers as well as tactical or battlefield targets. Unlike torpedoes, they are suitable for use against land as well as sea targets. Unlike civil vehicles such as commercial aircraft or ships, they have some ability to penetrate defenses.

The choice of delivery system will depend on the political or military circumstances envisioned as well as on the systems' individual capabilities. In at least one instance of known nuclear proliferation, for instance, delivery-system capabilities may have been all but irrelevant. In a speech to the South African parliament in which it was revealed that South Africa had assembled six nuclear

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[4] Much of the following discussion draws on Stanford University, Center for International Security and Arms Control, Assessing *Ballistic Missile Proliferation and Its Control* (Stanford, CA: Stanford University, November 1991), pp. 25-56.

Table 5-2—Actual and Possible Methods of Delivery

Weapon	Nuclear	Biological	Chemical
Aerial bomb	√	√	√
Bomb submunitions		√	√
Aerial spray tank		√	√
Ballistic missile, nonseparating reentry vehicle	√	√	√
Ballistic missile, separating reentry vehicle	√	(poss.)	(poss,)
Artillery shell	√	√	√
Rocket shell	√	√	√
Mortar shell	√		√
Cruise missile warhead	√	(poss)	(poss,)
Mine (land)	√		√
Mine (sea)	√		
Antialrcraft missile warhead	√		
Torpedo	√		
Transportable clandestine bomb	√	(poss,)	(poss)

Actual cases √

Theoretical possibility: (Poss)

SOURCE: U.S. Congress, Office of Technology Assessment, *Prolieration of Weapons of Mass Destruction:* Assessing the Risks, OTA-ISC-559 (Washington, DC: U.S. Government Printing Office, August 1993), p. 50.

weapons in the 1980s, President F.W. de Klerk said that

> The strategy was that if the situation in Southern Africa were to deteriorate seriously, a confidential indication of the deterrent capability would be given to one or more of the major powers, for example the United States, in an attempt to persuade them to intervene. It was never the intention to use the devices, and from the outset the emphasis was on deterrences

Perhaps most importantly, however, choice of delivery systems will depend on a state's ability to develop or acquire, adapt, and maintain them. These factors are discussed in detail later in this chapter.

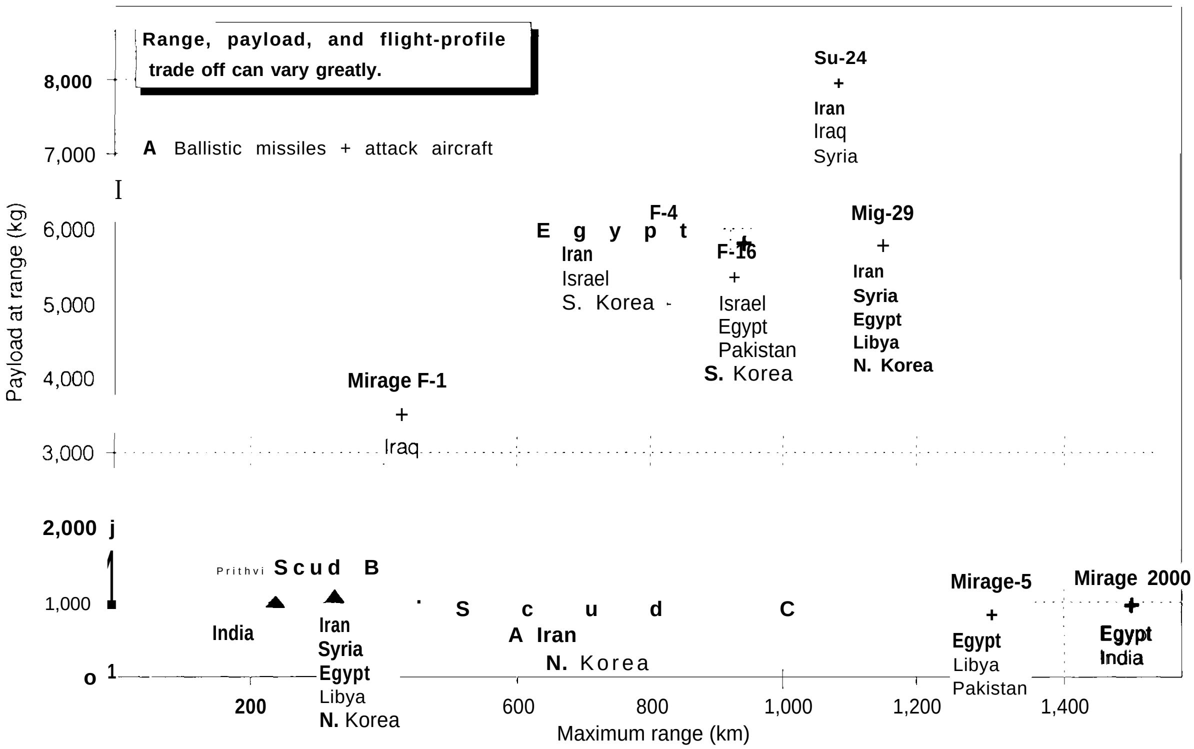
Range

The importance of a delivery system's range is highly specific to the regional context. Seoul, South Korea, for example, is less than 50 km from the North Korean border. Major cities and military installations in Israel, Syria, and Jordan are located within a few hundred kilometers of each other, putting them within reach not only of each other's strike aircraft but also short range ballistic missiles.[6] Distances between key points in other pairs of Middle Eastern countries are somewhat larger; Jerusalem, Israel is about 350 km from the closest point inside Iraq, with Baghdad, Iraq the same distance from Saudi Arabian territory. Tehran, Iran is at least 525 km from the Iraqi border, which was one of the principal motiva-

[5] President F.W. de Klerk, speech on the Nuclear Nonproliferation Treaty to a joint session of the South African Parliament, March 24, 1993, as quoted in ***Arms Control*** *Today, vol. 23, No. 3,* Aprit 1993, p. 28.

[6] The widely proliferated Scud missile, for instance, has a range of 300 km with a payload of about 1,000 kg.

Figure 5-l—Range and **Payload of Selected Aircraft and Missiles Operated by Potential Proliferants**



SOURCE: U.S. Congress, Office of Technology Assessment, *Proliferation of Weapons of* Mass *Destruction: Assessing the Risks, OTA-ISC-559* (Washington, DC: U.S. Government Printing Office, August 1993), p. 68

tions for Iraq to extend the range of its Scud-B missiles to about 600 km during the Iran-Iraq war.[7] Distances between the Korean peninsula and Japan, and between the nearest major cities in India and Pakistan, fall into the 600 to 1,200 km range. At ranges of a few thousand kilometers, U.S. allies and out-of-theater powers in Europe and Asia could be targeted from the Middle East, South Asia, or elsewhere.

As figure 5-1 shows, most combat aircraft in countries of proliferation concern have ranges far exceeding those of most ballistic and cruise missiles in those same countries. Moreover, the ranges of some aircraft can be extended by in-flight refueling. The need for greater geographical reach may also motivate the development or acquisition of longer range missiles, or the adaptation of cruise missiles for use from air or sea-based platforms. (The effective reach of such cruise missiles would be extended by the range of their carrier.) A full assessment of the military utility of cruise missiles must consider their use in conjunction with aircraft, surface ships, or submarines.

I Payload Amount and Type

Combat aircraft generally can carry much greater payload than can either ballistic or cruise missiles. Combat aircraft available to proliferant states typically have payload capacities from

[7] The Iraqi extended-range Scuds were subsequently able to reach cities in Israel and Saudi Arabia during the Persian Gulf War of 1991.

2,000 to 4,000 kg, ranging all the way to 10,000 kg, whereas missile payloads tend to run from 500 to 1,000 kg (see fig. 5-l.). Cruise missiles available to proliferant nations typically carry much smaller warheads than do large ballistic missiles, although there is no reason why larger cruise missiles could not be developed. Indeed, large cruise missiles are in some ways easier to build than smaller ones, albeit also easier to intercept.

Without very sophisticated technology, ballistic missiles are not well suited for delivering chemical or biological weapons to broad-area targets. Such targets are most effectively covered with an aerosol spray delivered at slow speeds and low altitudes upwind from the target, a delivery profile much better suited to cruise missiles or aircraft. Nevertheless, by the 1960s the United States had developed submunitions for ballistic missiles that would spread chemical and biological agents more efficiently than would release at a single impact point.

For nuclear weapon delivery, both ballistic and cruise missiles have the advantage of not needing to provide an escape route for the pilot. In general, high-flying aircraft are more vulnerable to air defense than low-flying ones. However, delivering nuclear weapons with low-flying aircraft requires either a pilot willing to sacrifice himself with his plane, a time-delay fuse, or a lofted delivery profile in which the bomb is released on a high, arcing trajectory that provides enough time for the pilot to fly out of the area.

I Accuracy

Like range and payload, the accuracy with which a weapon of mass destruction must be delivered depends on the type of weapon and the target. Most of the ballistic missiles so far deployed in countries of proliferation concern have ranges less than 1,000 km and are unable to deliver weapons with accuracies much better than 1,000 meters. In the absence of weapons of mass destruction or large numbers of missiles, ballistic missiles this inaccurate have little military utility; they are better suited to wage terror campaigns against civilian populations or perhaps to badger large military installations.

It is not yet clear what accuracies will be achieved by the several countries developing or having already deployed missiles of greater than 1,000-km range. Depending on the level of technology, inaccuracies could range from hundreds of meters to many kilometers. Inaccuracies at the upper end of this range could be enough to limit the *military* effectiveness of even some types of weapons of mass destruction (though probably not their political impact).

Combat aircraft with sophisticated weapon-delivery systems and well trained pilots, on the other hand, can deliver munitions with accuracies of 5 to 15 meters, far better than is needed to deliver weapons of mass destruction to wide-area targets. Cruise missiles that are guided to their target on command from a remote operator can also attain accuracies much better than crude ballistic missiles. New guidance technologies make it possible even for autonomously operated cruise missiles to attain about 100-meter accuracies.

I Costs and Infrastructure Requirements

Since the total expense of producing nuclear materials and developing and building a nuclear weapon far exceeds that of any delivery system described here, it is not likely that cost considerations will play a very important role in selection of a nuclear delivery system.

Nevertheless, the cost of maintaining a modern air force could affect a state's ability to deliver large-scale chemical attacks, for instance. A typical estimate for the cost of a single advanced strike aircraft, including pilot training and several years of operations and support, but excluding the infrastructure investment, is $40 million. (The marginal cost of a Scud or SS-21 ballistic missile, similarly including operations and support but excluding launcher and other infrastructure expenses, costs only on the order of $1 million.[8]) In addition to their high unit cost, however, advanced strike aircraft require an extensive support infrastructure including maintenance facilities, spare parts, and highly trained personnel.

Given that a country has sufficient technical capability, it could build and maintain cruise missiles much more cheaply than piloted aircraft. Cruise missiles need only fly once, and they do not incur the expense of training pilots, nor the structural requirements of carrying them along, keeping them alive, and ensuring their safe return. Not counting sunk development and production costs, each additional U.S. *Tomahawk* sea-launched cruise missile costs about $1.5 million.[9] U.S. defense engineers estimate that it should be possible to build an equivalent missile for less than $250,000 by substituting low-cost satellite navigation receivers for the *Tomahawk's* sophisticated radar and optical pattern-recognition guidance systems.[10]

In general, however, cost comparisons of delivery systems for weapons of mass destruction are likely to be only marginally important. A proliferant country will probably make do with the delivery systems it already has or can most easily acquire or modify. Prices of delivery-system acquisition are also difficult to estimate, since they could vary drastically if systems are dumped on world markets by hard-currency-starved counties or if effective embargoes are implemented on sales, so as to drive up prices on the black market.

Defense Penetration

The high speed and steep angle at which ballistic missiles strike a target make them considerably harder to defend against than either piloted or unpiloted aircraft. The Patriot system, originally designed as an antiaircraft weapon, showed only a limited capability to intercept Scud missiles during the Persian Gulf War of 1991.[11] Furthermore, defending against missile attack would be considerably harder if missile warheads were fused to detonate on interception, or if each warhead dispersed many submunitions before coming into range of the defense.

Many developing countries possess air-defense systems capable of destroying traditional (non-stealthy) strike aircraft that attempt to attack defended sites. The effectiveness of such defenses would depend strongly on the sophistication and scale of the attack. Evidence from recent air engagements indicates that properly equipped and maintained strike aircraft-operated in conjunction with defense-suppression techniques (e.g., electronic countermeasures and attacks on air defense batteries)-can penetrate sophisticated defenses with losses of at most a few percent over the course of a campaign.[12] Although many Third World air forces would not be able to mount such a sophisticated and sustained air campaign, those pursuing weapons of mass destruction, with few exceptions, each have relatively advanced combat aircraft that might be used with sufficient effectiveness even against defended areas.

Whether an extensive air campaign would be necessary would depend on the context. A single nuclear weapon can destroy a city, and a relatively

8 Stanford, *Assessing Ballistic Missile Proliferation,* op. cit., footnote 4, p. 45.

9 Steve Fetter, ''Ballistic Missiles and Weapons of Mass Destruction: What is the Threat? What Should be Done?" *International Security,* vol. 16, No, 1, Summer 1991,p. 11.

10 As cited in ibid.

11 Although early claims of Patriot success rates were clearly too Optimistic, the system's Overall performance against Scud attacks may never be known exactly. See, for example, Theodore A. Postol, ''Lessons of the Gulf War Experience with Patriot,'' *International Security,* vol. 16, No. 3, Winter 1991/92, pp. 161-171; and Robert M. Stein and Theodore A. Postol, "Correspondence: Patriot Experience in the Gulf War, " *International Security,* vol. 17, No. 1, Summer 1992, pp. 199-240.

12 See, for example, John R. Harvey, "Regional Ballistic Missiles and Advanced Strike Aircraft,'' *International Security,* vol. 17, No. 2, Fall 1992, p. 59.

small amount of properly delivered biological agent could kill tens of thousands of people. Therefore, if a state is willing to tolerate higher losses of airplanes, pilots, and weapons—and if it is able to persuade its pilots to fly in spite of those risks-it may well be able to deliver weapons of mass destruction by air even against well-defended sites. Of course, this option was apparently not available to Iraq in the 1991 Persian Gulf War, since its air force was so mismatched with that of the coalition forces that its leaders decided not even to mount a serious aerial counterattack.

Cruise missiles can be effective at attacking defended targets, relying on their ability to execute low-altitude, circuitous approaches. They may also be air-launched and accompanied by aircraft in a defense-suppression role, making even short range cruise missiles particularly suited to attacking defended targets. Even if cruise missiles were detected, they can fly at altitudes below the reach of many medium or long range surface-to-air missiles, leaving only antiaircraft artillery or short range surface-to-air missiles to shoot them down,

Reliability and Survivability

Since they are single-shot systems, ballistic and cruise missiles are generally less reliable than manned aircraft, which are designed with pilot safety and multiple sorties in mind.[13] The types of redundant systems used to provide safety on aircraft are harder to provide for ballistic or cruise missiles, since a missile's range is more sensitive to changes in payload. Moreover, aircraft are generally tested in the design process more thoroughly than ballistic or cruise missiles, and more mission-critical systems in an airplane can be tested prior to use than in a ballistic missile. (For example, a solid rocket motor cannot be tested without being used up, and most liquid-fueled motors are only designed for a single fining.) Aircraft also tend! to fail gracefully and can usually return to base if problems are encountered.

Nevertheless, a state with a nuclear arsenal of only a few very expensive weapons may well pay the price-in cost and performance-of making its missiles more reliable. (This would likely involve a substantial engineering effort, precluding use of an "off-the-shelf' missile designed to less demanding requirements.) But even a reliable missile would likely be less forgiving of failure when it did happen than would an airplane. In the event an airplane fails to take off successfully, its weapon and its mission can usually be recovered—an important consideration in the case of a nuclear weapon whose completion may have cost a state a noticeable fraction of its gross national product for many years. Warheads are less likely to survive launch failures when mounted on cruise or ballistic missiles.

The *pre-launch* survivability of ballistic and cruise missiles is likely to be higher than that of airplanes, however, since they are smaller, can more readily be hidden, and do not need to be located near runways or landing strips. During Operation Desert Storm the coalition air forces pinned down or destroyed much of the Iraqi air force, but they may not have actually destroyed a single Scud missile or mobile launcher. Once located, however, missiles are more vulnerable than aircraft, which can flee or protect themselves.

Command and Control

Political leaders may find missiles (certainly ballistic missiles, but perhaps cruise missiles as well) to be more ''controllable" than piloted aircraft in that the infrastructure required to launch missiles is significantly smaller than that needed to sustain air operations. Launch orders need pass through fewer levels of command, and fewer people are in a position to block them. Perhaps most fundamentally, an unpiloted missile

13 Reliability here is defined as the probability of successful flight given that pre-flight or pre-launch checks have been passed.

cannot question its launch order. Ground-launched cruise missiles could have infrastructures more the size of those for ballistic missiles than those for piloted aircraft. Although deploying air- or sea-launched cruise missiles would require the participation of an air force or navy, with its attendant logistical and command structures, the launching platform could remain out of range of enemy forces. Thus, its logistical infrastructure might still be considerably less than that required to penetrate enemy airspace using manned aircraft.

| Achieving Tactical Surprise

Intercontinental ballistic missiles (ICBMs) can reach targets a quarter of the way around the globe in about 30 minutes. Tactical missiles complete their flight in even less time. Even though missiles traveling over ranges of a few hundred kilometers can be detected by early-warning radars or space-based infrared sensors early in their flight, they travel so fast that there is still very little warning of their arrival. Iraqi Scuds took about seven minutes to reach Israel, traveling at up to eight times the speed of sound, and the Israelis had about five minutes' warning of their arrival.[14] Combat aircraft could cover the same distance in about a half-hour. However, when hugging the ground over routes that mask their approach, they could hide from search radars and arrive on target with about as little warning as ballistic missiles.[15] Cruise missiles in general are harder to detect than aircraft because they are smaller, quieter, and operate at lower skin and engine temperatures. However, to take as much advantage from terrain masking as some aircraft can, they would require advanced guidance systems and accurate geographical information for planning flight routes.

| Target Acquisition

In *the* absence of remote, near-real-time reconnaissance capabilities, which are beyond the capabilities of most states, neither ballistic nor cruise missiles are suitable for use against mobile targets. Piloted aircraft would be the only available choice for such missions-and even then, only for some of them. As noted above, for example, even a determined coalition air-campaign had great difficulty locating and attacking Iraqi Scud launchers. Delivering chemical or biological weapons against moving military formations would call for pilot judgment, as might tactical uses of nuclear weapons. Attacking cities or fixed military bases with any of these weapons, however, would not demand precise target-acquisition capabilities.

Piloted aircraft have a clear advantage for military missions in which it is important to ascertain quickly that the weapon has been delivered to a target and detonated. Ballistic missiles do not provide any such indication, nor do autonomously guided cruise missiles. A cruise missile that was guided to its target via data link to a remote operator could send information (e.g., video imagery) indicating whether or not it arrived at its intended target. But this information would not necessarily indicate whether the warhead detonated, much less whether the target was destroyed.[16]

BALLISTIC MISSILES

| Classification of Missiles

A "ballistic missile" is a rocket-powered delivery vehicle that has some form of guidance system, that is primarily intended for use against ground targets, and that travels a large portion of its flight in a ballistic (free-fall) trajectory. Ballistic missile flight profiles are usually de-

14 Postol, "Lessons of the Gulf War Experience with Patriot," op. cit., footnote 11, pp. 161-171.

15 Stanford, *Assessing* Ballistic *Missile Proliferation,* op. Cit., footnote 4, p. 43.

16 Aircraft pilots, too, can have difficulty making accurate bomb damage assessments. Despite its sophisticated reconnaissance systems, U.S. bomb damage assessments during the Persian Gulf War were still incomplete and delayed.

Table 5-3-Space-Launch Vehicles and Ballistic Missiles With Ranges Over 100 km in Non-MTCR Countries

Producing country[a]	Missile designation	Status[b]	Range [km]	Payload [kg]	Accuracy CEP [m]	Fuel/ stages	Comment[c]	imported missiies[d]
Countries with indigenous missile programs:								
Former	SS-21 (Scarab)	s	120	450	240-300	solid/1	1976 IOC	
Soviet Union[d]	Scud-B (SS-1)	s	300	1,000	500-900	liquid/1	1962 Ioc	
China[d]	M-1 1	s?	300	500	300?"	solid/2	1990 Ioc?	
	M-9	D	600	500	300-600	solid/l	—	
	DF-3A (CSS-2)	s	2,500-3,000	2,000	2,500	liquicVl	1971 Ioc	
Israel	Jericho 1	s	480-650	250-500	smali?	solid/2?	w/France; 1973 IOC	Lance[f]
	Jericho ii	s	1,500	650-I,000?	?	solid/2	w/France; 1990 IOC	
	Jericho IIB	T	2,500	700?	?	solid/2	—	
	Shavit	s	2,500/7,500	750/150	NA	solid/3	SLV; w/France; 1988 IOC	
India	Prithvi	T	150/250	1 ,ooo/5oo	250?	liquid	1992 IOC?	
	Agni	T	2,500	1,000	2,500?	solid-liq/2	w/France, FRG; 1989 test	
	"ICBM"	P	5,000	?	Smaii?	NA	—	
	SLV-3	s	800	100	NA	solid/4?	SLV; 1980 IOC	
	ASLV	T	4,000	150-500?	NA	solid/4	SLV; w/France, FRG	
	PSLV	T	8,000	1,000	NA	liq-solid/4	SLV	
	GSLV	P	14,000	2,500	NA	cryo/solid	SLV	
Taiwan	Ching Feng	s-?	100-130	275-400?	?	liquid/1	like Lance; w/Israel; 1983 IOC	
	hen Ma	D-?	950	500?	?	solid	"Sky Horse"; canceled?	
	name unknown	D?	[950]?	?	NA	solid?/3?	SLV	
North Korea (DPRK)	Scud-B	s	340	1,000	≲1,000	liquid/1	w/USSR, Egypt?	FROG-P;
	Scud-C	s?	600	500-700	?	liquid/1	w/China	Scud-B (via Egypt)
	Nodong-1	T?	1,000	1 ,Ooo?	?	liquid/1 ?	w/China	
South Korea	NHK-1	s-?	180	500	?	solid	w/U. S.; 1978 IOC	
	Korean SSM	T	260	?	?	solid/2	.	
	name unknown	D-	[4,000]	?	NA		SLV; development began 1987	

(Continued on next page)

Table 5-3-Space-Launch Vehicles and Ballistic **Missiles** With Ranges Over 100 **km in** Non-MTCR Countries—(Continued)

Producing country.	Missile designation	Status[b]	Range [km]	Payload [kg]	Accuracy CEP [m]	Fuel/ stages	Comment[c]	Imported missiles[d]
Brazil	Orbita MB/EE	D?	150	500	?	solid/1	1991 IOC?	
	Avibras SS-300	T-	300	1,000	?	liquid/1	suspended; 1991 IOC?;	
	MB/EE-350	D.?	350	500	?	solid	MB/EE's in abeyance	
	(MB/EE)?-600	D-?	600	500	?	solid	—	
	MB/EE-1000	D-7	1,000	?	?	solid	—	
	SS-looo	D-?	1,200	?	?	solid	SS-series in abeyance	
	IRBM	P?	3,000	?	?	solid	—	
	Sonda 3	s	80	135	NA	solid	SR; w/FRG	
	Sonda 4	S?	950	500	NA	solid	SR; w/FRG, France	
	VLS (Avibras)	D?	[10,000]	160-500?	NA	solid?/4	SLV; w/FRG	
Argentina	Alacran	D	200	100-500?	?	Solid/1	consortium; 1989 test	
	Condor II	D-	900	500	900?	solid/2	canceled 1991; SLV plans?	
South Africa	Arniston	T	500-1,500	500-1,000?	?	solid	w/Israel (Jericho 11?); '89	
	RSA-4	D	[10,000]	500	NA	solid/3	test SLV; test planned 1996	
Iraq (before Gulf War)	Fahd 300/600	D	300/600	?	?	solid/1	—	FROG-7; Scud-B
	A1-Husayn	s	600	150-500?	3,000	liquid/1	modified Scud-B; 1988 IOC	
	A1-Hijarah/Abbas	s?	750-900	1 00-300?	3,000	liquid/1	modified Scud-B; 1990 IOC?	
	Tammuz-1 (A1-Abid)	D	2,000	750?	?	liquid/3?	SLV?; w/USSR; December 1989test;clustered booster?	
Iran	Mushak-120	s	120	500	?	solid/1	w/China; 1990 IOC?	Scud-B&C (from DPRK);
	Mushak-200	D	200	500?	?	solid/1	w/China	M-9 (negotiations);
	Scud-B	S?	300	1,000	1,000	liquid?/1	w/DPRK; 1984 IOC?	Nodong-1 (negotiations)
	"Iran-700"	D?	700	?	600?	?	—	
	Tondar-68	D	1,000	400?	?	solid	w/China	

(Continued on next page)

Table 5-3-Space-Launch Vehicles and Ballistic Missiles With Ranges Over 100 km in Non-MTCR Countries-(Continued)

Producing country[a]	Missile designation	Status[b]	Range [km]	Payload [kg]	Accuracy CEP [m]	Fuel/ stages	Comment[c]	Imported missiles[d]
Pakistan	Hatf II	T	300	500	?	solici/2?	w/France, China; 1988 test	M-1 1 (under negotiation)
	Hatf III	D?	600	500-1,000	?	solid/1 ?	w/China; staiied?	
	Suparco	s	[300]	?	NA	soiid/2?	SR; w/France; China?	
	name unknown	P	[1 ,200]	?	NA	soiid/3?	SLV	
Egypt	Scud-B	D7	300	1,000	1,000	liquid/1	—	FROG-7; Scud-B
	Scud-100	D	600	500	?	iiquid/1	w/DPRK	
	Vector (Badr-2000/Condor II)	D-?	<1 ,200"	450	750-900?	solid/2	w/Argentina Iraq	
Libya	Ai-Fatah (also "Otrag/ittisalt")	D?	450-900	500?	?	liquid	w/FRG?, Brazil?; possibly in abeyance	FROG-7; Scud-B; SS-217; M-9 (negotiations)

Countries that have only imported missiles:

Saudi Arabia:	DF-3A (from China, 1987-1988)
Syria	FROG-7, SS-21, Scud-B (from USSR); Scud-C (from DPRK); M-9 (negotiations with China)
Yemen:	FROG-7; SS-21 ; Scud-B
Afghanistan:	Scud-B
Algeria:	FROG-7; Scud-B?
Cuba:	FROG-7

a Countries listed were not full members of the MTCR as of March 1993. (At that time, however, Argentina was becoming a full member.)

b S: in service. T: testing. D: under development. S-/T-/D-: in abeyance/suspended/abandoned. P: planned.

c IOC: initial operational capability. SLV: space-launch vehicle. SR: sounding rocket. NA: not applicable/available.

d All Scud-Bs listed as *imported* were obtained from the former Soviet Union except Iran's, which were obtained from North Korea.

e The missiles listed for China and the former Soviet Union (which have both pledged to abide by the MTCR export provisions but are not full members) include only those known or suspected to have been exported to other countries.

f U.S. Lance (1972 IOC): liquid-fueled, 133-km range, 275-kg payload, 150- m CEP, and can carry cluster munitions. Soviet FROG-7 (1965 IOC): *unguided,* solid-fueled, 6&km range, 450-kg paytoad (perhaps 100 km with lighter payload), 400-m CEP.

The following countries are also able to or have already produced the following short-range missiles (under 100 km):

Argentina (Condor 1-95 km/365 kg, SR?, abandoned?); Brazil (Astros-II/SS-60 artillery rocket); Egypt (Sakr-80—solid, unguided, copy of FROG-7); India (MBRS); Indonesia (RX-250-2-stage sounding rocket, with France; MAR); Iran (Oghab—solid, unguided, 40 km; Nazeat—90 km/150 kg, solid, with China); Iraq (Ababil 50/100; Sajil-60 or Brazil's Astros-II/SS-60 artillery rocket; Laith-90); Israel (MAR-290/350-solid artillery rockets, up to 90 km/330 kg); South Korea (U.S. Honest John—solid, unguided, 40 km); Pakistan (Hatf-I, with France); Taiwan (U.S. Honest John).

SOURCES: W. Seth Carus, *Ballistic Missiles in Modern Conflict* (New York: Praeger, 1991), pp. 85-90; *Arms Control Today,* April 1992, pp. 28-29; U.S. Dept. of Defense, *Conduct of the Persian Gulf War: Final Report to Congress,* Pursuant to Title V of the Persian Gulf Conflict Supplemental Authorization and Personnel Benefits Act of 1991 (Public Law 102-25), April 1992, p. 16; John W. Lewis and Hua Di, "China's Ballistic Missile Programs," *International Security,* vol. 17, *No.* 2, fall 1992, p. 11; Janne Nolan, Testimony before the Subcommittee on Arms Control, International Security and science, House Foreign Affairs Committee, Mar. 3, 1992; Duncan Lennox, ad., Jane's *Strategic Weapons Systems* (Surrey, U. K.: Jane's Information Group, 1990), Issues O-7, 1990-Jan. 7, 1992, and Jane's *Defense Weekly,* Jan. 11, 1992, p. 50, June 6, 1992, p. 996, and Jan. 23, 1993, p. 18; Aaron Karp, "Ballistic Missile Proliferation," *World Armaments and Disarmament: SIPRI Yearbook 1991* (New York: Oxford University Press, 1991); and U.S. Arms Control and Disarmament Agency, *World Military Expenditures and Arms Transfers, 1988/89,* pp. 18-19.

scribed in terms of three phases: the boost phase, in which the propulsion system generates thrust; the midcourse phase, in which the missile coasts in an arc under the influence of gravity; and the terminal phase, in which the missile experiences strong decelerating forces during its descent into the atmosphere. Missiles with ranges under 300 km remain in the atmosphere for their entire trajectory (and travel slower than longer range missiles), thus reducing the abruptness of the reentry transition.[17] In this chapter, all ranges refer 'minimum-energy trajectories, ' which maximize the range available to a given missile.[18]

Although *unguided rockets,* such as the Soviet FROG-5, the U.S. *Honest John,* and the Iranian *Oghab* rockets, maybe useful in some battlefield situations, they will not be considered here, primarily because their ranges are generally much less than 100 km even with small payloads. Similarly, rocket-assisted artillery, surface-to-air, air-to-air, and air-to-surface missiles are not included in this analysis.

A functional ballistic missile must (i) employ a propulsion system to provide thrust (ii) have a guidance and control system to direct its thrust (iii) carry a useful payload, and (iv) be supported by some sort of launcher, e.g., a freed gantry, a mobile truck-mounted erector-launcher, or a silo. The missile and its payload must be designed to withstand the mechanical and thermal stresses involved in launch and final approach to a target. For missiles with ranges substantially greater than about 400 km, the final approach involves reentering the atmosphere from space at very high speeds, causing intense heating, deceleration, and the possibility of strong lateral forces. The difficulty of designing missiles for a given payload therefore increases dramatically with range and level of accuracy.

Missiles are characterized in terms of several key parameters. The most fundamental of these are the missile's range and payload, Payload is defined as the mass of the warhead(s) or other useful material (not counting the empty booster canister, for instance) that the missile can deliver at a given range. Within certain limits, payload can be traded off against range. (The same is true for aircraft and cruise missiles.) Accuracy refers to the likelihood that the payload will be delivered to within a certain distance of an intended target. There are both systematic and random contributions to inaccuracy, but in many cases the random errors are more important. Random errors are quantified by the Circular Error Probable (CEP), which defines the radius of a circle on the ground into which half of a large number of identical missiles launched along the same intended trajectory would fall.[19] Missiles are also characterized in terms of their number of propulsion stages, or sequentially firing boosters.

I Status of Missile Proliferation

Table 5-3 illustrates the existing or developing missile programs in countries that were not full members of the MTCR as of March 1993, as reported in public sources. (For China and the former Soviet Union, only missiles known or suspected to have been exported to other countries are included.) Since the sources for this table contain substantial variance and uncer-

17 The limit of the tangible atmosphere occurs at approximately 100 km altitude (below which the lighter and heavier air molecules are nearly uniformly mixed). At 100 km altitude, air density and pressure are roughly one millionth of their values at the Earth's surface.

18 Shorter ranges result when missiles are launched at angles either closer to the horizontal or closer to the vertical than the minimum-energy launch angle. Such trajectories are called ''depressed' or "lofted."

19 CEP does not take into account either launch failures or the systematic errors associated with mis-aiming the missile in the first place, called the ''bias. ' The CEP is also a median, rather than a mean; it does not predict how@ outside the circle the other half of the missiles will land. (For instance, some of Iraqi Scuds fired toward Israel during the Persian Gulf War landed quite far from intended targets or in the Mediterranean Sea.) Furthermore, in practice the expected miss-distance is usually elongated in the downrange direction, leading to an elliptical rather than circular error pattern. Therefore, even ignoring the bias, the CEP gives only a rough indication of the likelihood that a missile will hit an intended target.

Table 5-4-Ballistic Missile Production Capabilities

Category	Description	Countries
Advanced	Able to design and produce missiles comparable to those produced in the United States in the mid-1960s (e.g., ICBM-range ballistic missiles and space-launch vehicles)[a]	India Israei, and possibly Taiwan
Intermediate	Able to reverse-engineer, introduce changes to, and manufacture Scud-ilke missiles, and to make solid-propellant short-range missiles	Brazil, North Korea South Korea, and possibly Argentina and South Africa
Incipient	*some* capability to modify existing Scuds, but little else	Egypt, Iran, Iraq (before the Persian Gulf War), and Pakistan
No *indigenous capability*	*No* missile design or manufacturing capability, but have imported missiles with ranges above 100 km	Afghanistan, Libya, Saudi Arabia, Syria, Yemen, and possibly Algeria and Cuba

a Comparable *capability*, however, refers primarily to the design and assembly capability of large solid-propellant motors, and does not imply U.S. levels of manufacturing *capacity*.

SOURCE: Stanford University, Center for International Security and Arms Control, *Assessing Ballistic Missile Proliferation and Its Control* (Stanford, CA: Stanford University, November 1991), p. 153.

tainties in reporting the status or specifications of some missile programs, a range of estimates is indicated where appropriate.

Table 5-3 shows that 13 non-MTCR countries (not counting China and the former Soviet Union) may have indigenous missile-development programs for ballistic missiles exceeding 100 km in range. Only two of these, however—Israel and India-have demonstrated capability sufficient for indigenous design and production of multi-stage missiles.[20] Another six countries have imported missiles but have virtually no capability to develop or manufacture them. Most of the imported missiles have come from the former Soviet Union-Scud-Bs, FROG-7s, and some SS-21s—and many of them were obtained more than a decade ago. More recently, however, China has exported 2,500-km range DF-3s and possibly M-9s and M-lls, and North Korea has exported Scud-Cs. According to one analysis, the 19 countries mentioned above fall roughly into four categories, which are described in table 5-4.[21]

Indigenous capability is only one factor affecting missile proliferation. In the past, countries have been able to enhance their missile capabilities substantially from what they could have done

20 Taiwan also has relatively advanced aerospace industrial *capability,* but its ballistic-missile and space-launch programs (other than work on satellite vehicles themselves) have largely been on hold for many years.

21 These categorizations, as well as the framework for evaluating indigenous capability, were developed in the Stanford report, *Assessing Ballistic Missile Proliferation,* op. cit., footnote 4, p. 153. Study methodology for that report included preparing detailed profiles for 17 subject proliferant countries that surveyed national, geographical, economic, and regime parameters, current conflicts and recent history, military posture, and the record of ballistic: missile acquisition. See *Ballistic Missile Proliferation Study Country Profiles,* Center for International Security and Arms Control (CISAC), Stanford University, July 1990 (unpublished). The study participants also examined technical features of missiles deployed or under development in the subject countries, along with key technologies needed for indigenous production. Many of the study participants have close ties to missile and aircraft development and production in both private industry and government. Principal authors (affiliated with CISAC unless indicated otherwise) were John Barker (Graham& James), Michael Elleman (CISAC and Lockheed), John Harvey, and Uzi Rubin. Other study participants were: Ronald Beaver, David Bernstein, Hua Di, Phil Farley, Lewis Franklin (CISAC and TRW, Inc.), Susan Lindheim, Michael McFaul, and William Perry.

on their own by importing missiles or advanced components, or by participating in joint ventures (e.g., between Argentina, Egypt, and Iraq to develop the *Condor* II *missile).* However, since the MTCR has restricted many of the outside sources of cooperation and assistance on missile development, indigenous capability has become more important for most countries of proliferation concern.

To understand the problem of missile proliferation more fully, trends in these capabilities must also be taken into account. According to at least two estimates, most of the countries in the top three categories of capability *could* advance upward in the list by about one category during the next decade, placing Israel, India, Taiwan, South Korea, Brazil, and possibly North Korea and South Africa in the "Advanced" category, and Pakistan, Iran, Argentina, and Egypt in the "Intermediate" category.[22] Assuming continuation of constraints imposed by U.N. Resolution 687 on Iraq's weapon programs, Iraq would be the only country remaining in the ''Incipient' category.

If countries are willing to dedicate sufficient resources to their missile programs, most of these advances in capability could occur even under a well-functioning MTCR. MTCR constraints, however, can significantly increase development costs, helping to convince leaders that the benefits are not worth the expense. The ballistic-missile programs in Brazil and South Africa for instance, may well *not* advance significantly, in part because of increased costs. (Brazil's diminishing export market and the decline in the threat that South Africa perceives itself to face may also be playing a large role.) Furthermore, largely because of diplomatic efforts by the United States since the 1970s, Taiwan and South Korea do not appear to be aggressively pursuing either ballistic-missile or space-launch programs at the present time, although they would have the technological *capability* to do so if they chose.

Even if such advances did take place, a large gap would remain between the capabilities of most of these nations and what would be needed to strike the United States. According to then-CIA Director Robert Gates, "Only China and the Commonwealth of Independent States have the missile capability to reach U.S. territory directly. We do not expect increased risk to U.S. territory from the special weapons of other countries-in a conventional military sense-for at least another decade. . . .' '[23] Among the handful of countries with both the technological capability and the resources to develop long range ballistic missiles over the next decade, few if any would likely have the intent to target the United States.

Missile Propulsion Technologies

The engineering fundamentals of rocket propulsion systems are well documented in standard texts.[24] In theory, there are few secrets involved in basic missile design. In practice, however, considerable expertise is required to integrate the various aspects of a ballistic missile into a militarily useful device.

Two kinds of chemical propulsion technologies—solid and liquid fuel-are widely used in ballistic missiles. Both rely on burning a fuel at high temperatures and expelling the hot combustion gases out the back of the engine. Whereas aircraft and many cruise missiles use oxygen in the atmosphere to burn the fuel they carry, ballistic missiles are unable to do so and must

22 Stanford, Assessing *Ballistic Missile Proliferation*, op. cit., footnote 4, p. 154; and *Ballistic Missile Proliferation: An Emerging Threat* (Arlington, VA: System Planning Corp., 1992) p. 28, Some reports indicate that Iran may have already moved into the "intermediate" category with indigenous production or assembly of Scud-B missiles. See, for example, Joseph S. Bermudez, Jr., ' 'Ballistic Missiles in the Third World—Iran's Medium Range Missiles, ' *Jane's Intelligence Review,* April 1992, pp. 147-152.

23 Testimony of then CIA director Robert Gates, before the Senate Committee on Governmental Affairs, Jan. 15, 1992, p. 3.

24 See, for example, George P. Sutton and Donald M. Ross, *Rocket Propulsion Elements: An Introduction to the Engineering of Rockets, 6th edition (New York:* John Wiley and Sons, 1992).

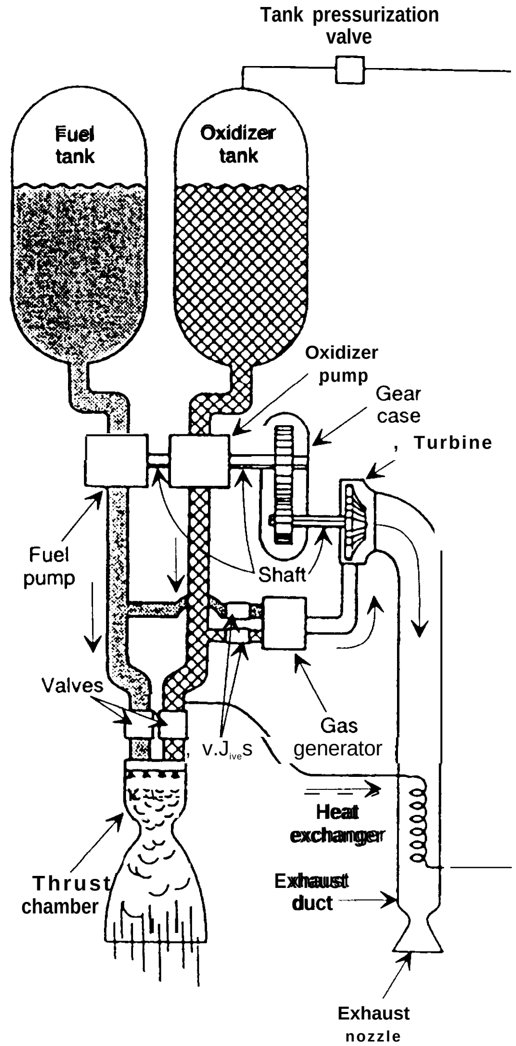
carry their own oxidizer.[25] In liquid-fueled boosters, the oxidizer is usually kept separate fromthe fuel and mixed with it only in the final combustion chamber. In solid 'boosters, the oxidizer is contained in the propellant mixture. Regardless of the fuel type, however, ballistic missiles generally reach much higher speeds than other kinds of delivery vehicles with comparable payloads. Even 100-km range missiles, which remain in the atmosphere, typically strike their targets at approximately the speed of sound (330 rn/see, or 740 mph), and 1,000-km missile warheads are only slowed by the atmosphere from 3 km/see to about 1 km/sec (2,200 mph).[26]

LIQUID-FUELED PROPULSION

A country that operates chemical processing facilities would likely also be able to manufacture fuel and at least crude components for short range liquid-fueled missiles such as Scuds. Although many liquid fuels are physically hazardous due to their corrosive, explosive, carcinogenic, and toxic properties, several types are already in use by about a dozen developing countries.[27]

Liquid-fueled engines more powerful than those found in Scuds, however, are correspondingly harder to build (figure 5-2 shows a schematic diagram of a liquid-fueled engine). Substantially greater experience is required in the design and manufacture of their components, including precision valves, injectors, pumps, turbines, and combustion chambers-many of which would call for numerically controlled machine tools or highly skilled machinists to fabricate. The added difficulties include: the design and fabrication of larger components with

Figure 5-2-Schematic Diagram of a Liquid-Propellant Rocket Engine



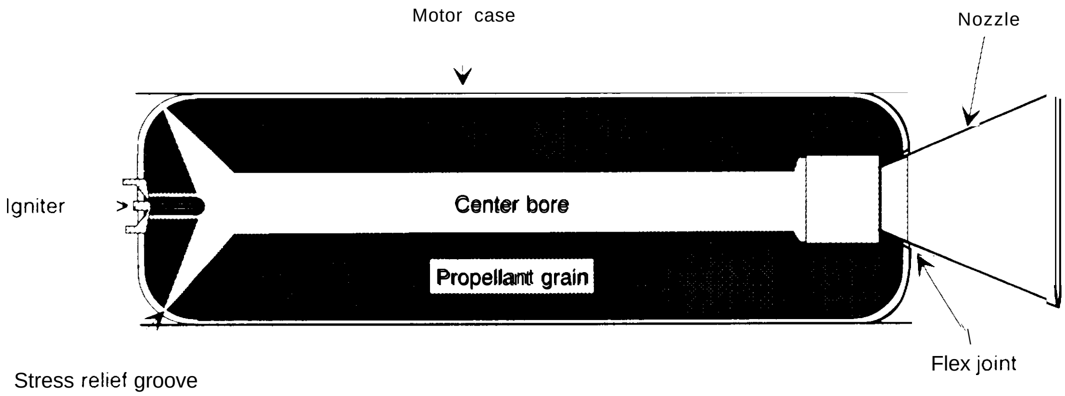
SOURCE: George P. Sutton and Donald M. Ross, *Rocket Propulsion Elements,* 5th edition (New York, NY: John Wiley and Sons, 1986). Copyright @ 1986 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.

25 Ballistic missiles carry their own oxidizers both to help reach the speeds needed for long range ballistic trajectories and because oxygen becomes too scarce at high altitudes. Propulsion systems that scoop up external air (called "air breathers' ')-except for more sophisticated technologies, such as high-speed ramjets and scramjets—are much more limited in the speeds they can achieve. Note, however, that short range air-launched cruise missiles, for example, can also be rocket-powered and can be designed to achieve supersonic speeds as well.

26 See Juergen Altmann, *SDI for Europe? Technical Aspects of Anti-Tactical Ballistic Missile Defenses,* Peace Research Institute Frankfurt, Research Report 3/1988, September 1988, pp. 27-28.

27 Commonly used fuels include hydrazine and unsymmetrical dimethyl hydrazine (UDMH), which are burned using the oxidizers nitrogen tetroxide or inhibited red fuming nitric acid (IRFNA). Scuds, for instance, use UDMH and IRFNA. Readily available liquid fuels that can also be used in rockets include gasoline, kerosene, ethyl alcohol, and liquid ammonia.

Figure 5-3—Schematic Diagram of a Solid-Propellant Rocket Engine



SOURCE: Center for International Security and Arms Control, Stanford University, ***Assessing Ballistic Missile Proliferation and Its*** Corrfro/(Stanford, CA: Stanford University, November 1991), p. 136. Reprinted by permission of Stanford University.

tighter tolerances; greater cooling requirements for engine parts exposed to high-temperature combustion gases; and more rigorous requirements for combustion stability, in order to avoid dangerous flow oscillations during thrust.

Moreover, to avoid gross inaccuracies, liquid-fueled engines capable of delivering sufficient thrust to deliver a 500 kg payload more than 1,000 to 1,500 km must employ a much more complex system of valves, pressurizers, flow-control meters, and actuators than are needed for less powerful engines, to control and terminate the thrust precisely. If lesser quality components are substituted, for example, from (dual-use) chemical-manufacturing or petrochemical-industry equipment, their poor performance might require development of a post-boost vehicle—a final stage capable of course corrections-to achieve even modest (several-kilometer) accuracies.[28] This would present an entirely new set of design problems.

In order to design these larger engines, many well-trained and experienced combustion scientists, chemical engineers, heat transfer specialists, and experts in fluid mechanics and mechanical design would be required, along with a well-funded, multiyear research and development program. Because of the similarity between some aircraft and missile components and the types of machining required to produce or maintain them, experience with aircraft maintenance facilities and especially with production, assembly, and rebuilding of jet engines might be very helpful in this regard.[29]

SOLID-FUELED PROPULSION

Although conceptually simpler than liquid-fueled missiles and involving almost no moving parts, solid-fueled missiles require years of practical experience to design and develop successfully, to learn how to manufacture safely, and to make accurate (figure 5-3 shows a schematic diagram of a solid-fueled booster). In addition to the advantage many proliferant countries have by already possessing liquid-fueled Scuds or their variants, the technology behind liquid-fueled engines can more easily be ‘‘reverse engineered’ than can solid-fueled boosters. Taking apart

28 For example, a valve that shut off 0.25 seconds too late at bum-out (when a 1,000-km range missile might be accelerating at 100 m/sec^2) would lead to a velocity error of 25 m/see and about a 17-km overshoot at the target. (Range is roughly proportional to the bum-out velocity squared, and bum-out velocity is about 3 Ian/see at 1,000-km range.)

29 Stanford, *Assessing Ballistic Missile Proliferation,* op. Cit., footnote 4, p. 135.

someone else's solid missiles reveals little about the processes by which they were put together. The performance of liquid engines can be studied in detail by refueling and retesting them on static test stands, including partial throttle or early termination of thrust if problems develop during a test. The performance of solid motors, on the other hand, is heavily dependent on the way the solid fuel is cast into the particular missile, and once fired, it is almost impossible to stop the burning fuel in the middle of the test. If a solid motor fails on the test stand, there may be no recoverable data from which to try and correct the problem, and it might not even be clear if the problem was generic to the design or specific to the missile being tested. Even replicating the failure mode of such a test can be exceedingly difficult.[30] When launched, solid-fueled motors also require sophisticated thrust-termination mechanisms or computer-controlled maneuvers to use up excess propellant while remaining fixed on a given target; their burning fuel cannot be shut off simply by closing a valve.[31]

Since solid-fueled motors can be transported and stored with the propellant intact, and readied for launch much more quickly than their liquid-fueled counterparts, they offer operational and tactical advantages over liquid-fueled missiles. Many solid propellants from the 1950s and 1960s are well understood both theoretically and practically, and enough has been published about them to make this information easily available. Once the practical aspects of manufacturing solid-fueled missiles are mastered, far fewer components need be assembled, and production is consequently more straightforward. Hence, about a half dozen countries appear to be focusing their missile development programs primarily on solid-fueled technology.

Indigenous manufacture of steel motor *cases,* while requiring well-trained metallurgists and a moderately sophisticated steel treatment facility for rolling, forming, and welding chambers, would not present much difficulty for countries with metallurgical experience from manufacturing ships, oil pipelines, or oil-drilling equipment.[32] Very large chambers for intermediate-or long range missiles would require more sophisticated metal-working capabilities than typically found in these industries, however, because of the high temperatures and pressures they would have to withstand.[33]

The most challenging aspect of manufacturing solid-propellant motors involves safely preparing, ing, and casting the entire propellant—called the "grain"—into the missile case. For small motors and short range missiles, this is relatively simple. But as the motor size increases, preparing and casting a uniformly structured, well-bonded propellant grain can become problematic.

Preparing the mixture itself is not significantly harder than other chemical processes involving explosives. The oxidizer crystals must be ground to the proper size in a controlled environment and then carefully analyzed for impurities that could upset subsequent manufacturing steps or burning characteristics. The propellant ingredients consist of relatively dense solid particles suspended in a much-less dense liquid plastic material called a "matrix." To improve their structural, manufacturing, and burning properties, solid-propellant grains employ mixtures of crystalline oxidizers and powdered metal fuel in a plastic matrix that

30 C. Robert Dietz, senior missile designer (retired), Lockheed Missiles and Space Co., private communication, Dec. 8, 1992.

31 The forward thrust of solid-fueled boosters can be cutoff by blowing out thrust-termina tion ports at the top of the booster, but this technique is relatively sensitive to error. Some missiles, such as the Indian Agni missile and certain space-launch vehicles, employ a combination of solid and liquid boosters to exploit the relative advantages of each.

32 Stanford, Assessing *Ballistic Missile Proliferation,* op. Cit., footnote 4, p. 135.

33 Some motor cases are fabricated out of fiber-reinforced composite materials, a technology currently available to moderately advanced industrial countries. The United States was employing woven spun fiberglass in the third stage of the Minuteman II missiles by the early 1%0s.

usually contains precise amounts of curing agents, catalysts, plasticizers, burn-rate modifiers, and processing aids. These ingredients must be combined in a specially designed large batch mixer to achieve uniformity of the propellant, a task that can be likened to producing a uniform mixture of sand and honey. Mixing is inherently dangerous, however, since accidents can cause large fries or explosions; a mixing blade that scrapes any surface can cause sparks that would ignite the fuel.

The mixture must then quickly be cast into the missile case and allowed to harden and cure. Extreme care must be taken during casting to ensure proper bonding of the propellant grain to the case wall and to avoid the formation of cracks or voids. Such imperfections can expose additional surface areas within the propellant, causing it to burn erratically or reach the wall prematurely, resulting in catastrophic failure of the motor. In addition, the larger the motor, the more susceptible solid propellants are to the formation of cracks due to repeated changes in temperature.

Proper grain design is also important. Its hollow cross-sectional shape determines the amount of surface area burning at any time, thus influencing the rate of burn, the internal pressure, and thus the motor's thrust. Design trade-offs must be made between minimizing the change in chamber pressure during the burn, on the one hand, and avoiding excessively rapid acceleration at the end of the bum when the missile is lightest, on the other; too much of one or the other would put undue stress on the missile casing. During boost, the grain must also withstand extremely high temperatures, pressures, and stresses of acceleration. As solid motors become larger, their engineering and fabrication therefore become increasingly more difficult.

To verify their integrity and proper structure, solid motors are inspected after their manufacture by nondestructive methods such as x-rays, ultra-

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Blades of a highly specialized Iraqi solid-fuel rocket propellant mixer being destroyed under the authority of U.N. Security Council Resolution 687 during an inspection in 1992. Such mixers are used to prepare the fuel before casting it into the missile housing.

sound, and thermal imaging. (The equipment required for manufacturing a typical advanced solid motor is given in table 5-5.) Skipping these inspections would exact a price in terms of lower reliability.

Obtaining Missile Technology

PURCHASE

Until the 1980s, the majority of ballistic missiles sold or traded were related to the original liquid-fueled Soviet Scud-B, with at least eight developing countries obtaining Soviet Scuds directly-Afghanistan, Egypt, Iraq, Libya, North Korea, Syria, and North and South Yemen (which have since united) .34 Notably, all of the indigenous missile programs in the developing world that did *not* receive Scud missiles from the Soviet Union appear to have primarily (though not exclusively) pursued solid-fuel technology for their more advanced programs. These include Argentina, Brazil, India, Iran, Israel, South Korea

[34] Several of these—Syria, Yemen, and possibly Libya—also obtained the more accurate (but shorter range) solid-fueled SS-21. See table 5-3 and sources therein.

Table 5-5-Typical Equipment for Processing Composite Solid Propellants

Process	Typical equipment
Reducing oxidizer crystal size and blending	Hammer mills; micropulverizers; fluid energy mills; sieves, screens, rotary dryers
Mixing	Automatic 2-or 3-bladed rotary vertical mixers
Casting	Coated mandrels; bells; spouts
Fabricating fiber-reinforced cases or nozzles	Automatic filament-winding machine
Inspecting to detect voids or unbended areas	X-ray or ultrasound equipment; thermal imaging; manipulators
Transferring components within the plant	Special vehicles or trailers for semi-finished motors and mixed-propellant slurry

SOURCE: Adapted from Tom Morgan, former group leader for counter-proliferation and delivery vehicle systems, Lawrence Livermore National Laboratory, presentation at SDIO Missile Proliferation Conference, System Planning Corporation, Rosslyn, VA, Apr. 4-10, 1992.

Pakistan, South Africa, and Taiwan. No Soviet Scud recipients appear to have successfully developed solid-fueled missiles with anywhere near comparable range to their liquid-fueled missiles, except possibly Egypt.[35]

Although the Soviet Union was the main supplier of ballistic missiles to the Third World, some secondary suppliers and traders of missiles and missile technology have emerged.[36] These include: North Korea, which received Soviet-built Scuds from Egypt, sold indigenously built Scud-Bs and Scud-Cs to Iran and Syria, and appears to be in the process of selling 1,000-km *Nodong I missiles* to Iran as well; Libya, which trans-shipped Soviet-built Scud-Bs to Iran and North Korea; Israel, which reportedly transferred Lance missiles to Taiwan and Jericho missile technology to South Africa; Argentina, Egypt, and Iraq, who banded together in an unsuccessful effort to develop the *Condor II missile;* Brazil, which in the past has engaged in attempts to develop and sell missiles to a number of countries, including Libya and Iraq; and China.[37]

North Korean and Chinese behavior regarding missile sales have been particularly troubling to the West, since both have long resisted calls to exercise restraint. China has maintained that the sale of missiles does not qualitatively differ from sales by the West of high-technology jet fighters to countries in the same regions. Nevertheless, by the end of 1991 China had agreed in principle to abide by the provisions of the MTCR and largely accepted the West's judgment that both its M-9 and M- 11 missiles exceeded the MTCR's 300-km/500-kg threshold.[38]

Before this apparent change in policy, Chinese missile sales and technical assistance had added noticeably to missile capabilities in the Middle East and elsewhere. In 1988, China sold to Saudi Arabia about 30 to 50 liquid-fueled 3,000-km DF-3A missiles (called CSS-2 by the United States). These missiles have the longest range by far of any sold to a Third World country.

35 In addition to producing the solid-fueled Sakr-80 (a copy of the Soviet FROG-7, an unguided missile with range less than 100 km), Egypt participated in the now-abandoned consortium with Argentina and Iraq to develop the two-stage solid-fueled *Condor II* missile with approximately 1,000-km range.

36 In the past, the United States supplied *Lance* and *Honest John* missiles to Israel and South Korea, respectively, but since the 1970s has transferred missiles only to NATO allies, and even these have had significant restrictions attached. The 1987 INF Treaty further constrained both U.S. and Soviet missile transfers. In 1991, Russia pledged to abide by the MTCR guidelines.

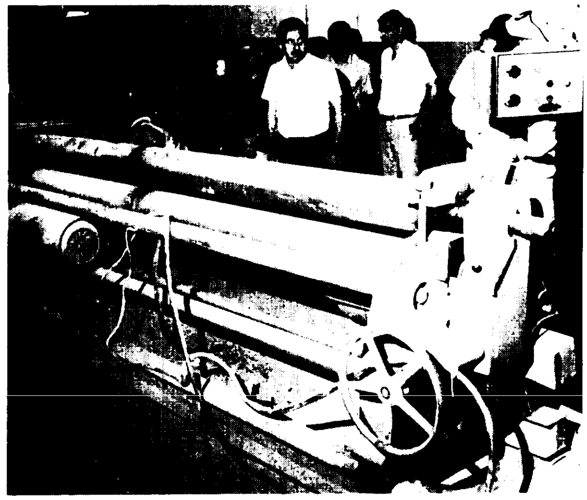
37 -Pies in this paragraph taken from W. Seth Carus, *Ballistic Missiles in Modern Conflict* (New York: Praeger, 1991), PP. 14.18, and 21; and Douglas Jehl, "Iran is Reported Acquiring Missiles,' New *York Times,* April 8, 1993, p. A9.

38 The pledge by China to abide by the MTCR was made at the end of 1991 during a trip by then-Secretary of State James A. Baker, III. During congressional testimony in February 1992, Baker said tbat China's pledge was "a very substantial and significant step forward, if they will adhere to their commitment. If they don't. . sanctions [on high-sped computers and satellite parts] will go right back on. " In August, 1993, the United States found that China had in fact violated its commitment to observe MTCR constraints, and announced that sanctions-yet to be determined—would be imposed. (See Stephen A. Holmes, ''U.S. Determines China Violated Pact on Missiles,' New *York Times,* Aug. 2s, 1993, p. 1).

Although the DF-3's accuracy is among the worst in the Middle East (CEP of over 2 km), these missiles have placed the entire Middle East and parts of the former Soviet Union within reach of Saudi Arabia. Chinese technical assistance has also played a significant role in the missile programs of North Korea, Iran, Brazil, and Pakistan.

According to various reports, certain German firms in the past have also provided technical assistance to missile programs in Argentina, Brazil, Egypt, India, Iraq, and Libya, and French and Italian firms have helped with aspects of programs in Argentina, Egypt, India, and Paki-Stan.[39]

More recently, however, several countries that had exported missile technology have been curtailing their assistance to foreign missile programs, and some are even becoming members of the MTCR. For instance, with the demise of its *Condor* || missile program, Argentina agreed to abide by the provisions of the MTCR in May, 1991, as did the Soviet Union one month later. As of March 1993, Argentina was in the process of becoming a full member of the MTCR, and Brazil may be considering joining. Each of these countries has had a history of either supplying missiles to developing countries or collaborating in missile programs with them. The only state said by the United States to be exporting MTCR-covered missiles today is North Korea. However, in light of China's reported export of M-11 missile launchers to Pakistan in 1991 and the more recent U.S. finding that China has violated its MTCR commitments, it remains to be seen whether or how well China will uphold the export constraints dictated by the MTCR.[40]



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A metal-rolling mill+me example of the type of multipurpose equipment that can be associated with ballistic missile production. This and other missile-related equipment in Iraq were destroyed under U.N. auspices in 1992.

EXPERTISE REQUIRED FOR INDIGENOUS DEVELOPMENT

Short range missiles

Reproducing, reverse engineering, modifying, and launching short range missiles does not require a particularly complex or expensive infrastructure. Many countries that would have great difficulty assembling a well-trained group of technical, operational, and tactical specialists needed to field an effective air force could still deploy a significant missile force.[41] (See box 5-A.)

The V-2 missile, designed and used extensively by the Germans during World War II, provides a baseline against which more sophisticated ballistic missiles can be compared. The V-2 was the frost operational version of a class of ballistic missiles that led to the Soviet-designed

39 See, for example, Carus, *Ballistic Missiles in Modern Conflict* op. cit., footnote 37, pp. 22-23.

40 See, for example, Jim Mann, ''Ctia Said to Sell Pakistan Dangerous New Missiles, ' *Los Angeles Times,* Dec. 4, 1992, p. Al; and Ann Devroy and R. Jeffrey Smith, "U.S. Evidence 'Suggests' China Breaks with Arms Pact,'' ***Washington Post, May 18, 1993,*** p. A9.

41 Edward N. Luttwak, foreword to Carus, *Ballistic Missiles in Modern Conflict,* Op. cit., footnote 37, p. vii.

Box 5-A-Iraq's Missile Programs

Of those countries that have imported Scud missiles in the past, only North Korea and Iraq appear to have been successful at modifying and extending their range. North Korea has reportedly done so by a process called "reverse engineering": disassembling the missiles, learning how to manufacture or modify their parts, and manufacturing new missiles.[1] Iraq extended the range of its Scuds by taking sections from one missile's fuel and oxidizer tanks and splicing them into other missiles. In this way, three missiles were cannibalized to make two longer range ones.[2]

By mid-1990, Iraq possessed the Soviet-supplied *d-B missile (300-km range, 1-km CEP) @us two indigenous variants-the Al-Husayn(600-km range, 3-km CEP) and the Al-Hijarah(75O-km range, unknown CEP, also called Al-Abbas-ali capable of carrying conventional or chemical warheads. *Al-Husayn* and Al-Hijarah missiles, each about two meters longer than the original 1 l-meter Scud-Bs, were launched toward targets in Israel and Saudi Arabia during the PersianGulf War. From their launcher complexes, these missiles were capable of reaching Tel Aviv, Haifa, and Israel's nuclear facility at Dimona in the Negev desert.[3]

Despite the existence of a missile manufacturing center, however, it is likely that Iraq would still have required foreign assistance to fabricate precision missile components such as fuel-injector plates, turbo pumps, and guidance systems.[4] Since Iraq is known to have been importing many components and receiving foreign technical assistance for its missile (as well as other weapon) programs, it is uncertain whether it could have manufactured even a Scud-type missile completely on its own at the time of the Persian Gulf War.

1 Joseph S. Bermudez, Jr., "Ballistic Ambitions Ascendant: North Korea's Ballistic Missile Programme is a Threat to be Reckoned With," *Jane's Defence Weekly*, Apr. 10,1993, p. 20-22. Although Egypt and Libya have also both worked on developing 300 to 700 km one-stage liquid-fueled missiles, and Egypt was involved in the *Condor* //program, nothing isknowntohavebeen fietded so farfromtheseprograms. See, for example, Bermudez, "Ballistic Missile Development in Egypt," *Jane's Intelligence Review*, October 1992, pp. 452-458.

2 W. Seth Carus and Joseph S. Bermudez Jr., "Iraq's 'Al-Husayn' Missile Programmed," *Jane's Soviet Intelligence Review, vol.* 2, No. 5, May, 1980, p. 205. Liquid-fueled missiles lend themselves to this technique, since the engines do not haveto change appreciably to accommodate larger amounts of propellant and longerburn-times.

3 U.S. Dept. of Defense, *Conduct of the Persian Gulf War: Final Report to Congress,* Pursuant to Title V of the Persian Gulf Conflict Supplemental Authorization and Personnel Benefits Act of 1991 (Pub! lc Law 102-25), April 1992, p. 16. Note that many sources call the second modification of the Scud-B the *Al-Abbas*, and claim a range of 900 km. Such a discrepancy could easily be explained by a difference in payload.

4 Tom Morgan, former group leader for counterproliferation and delivery vehicle systems, Lawrence Livermore National Laboratory, private communication, Dec. 20,1992.

Scud. Its characteristics are summarized in table 5-6.

As missile range increases from under 1,000 km to 2,500 to 5,000 km, there are generally at least two principal hurdles: manufacturing the larger propulsion systems needed to achieve the higher velocities required for longer range, and designing missiles with more than one stage.[42] Ensuring stable fuel combustion and flight characteristics while in the atmosphere also become more complex. *Expertise* is therefore a key ingredient in developing long range missiles—especially having access to engineers and technicians skilled in the areas of subsystem integration, testing, and production methods (see table 5-7 for one estimate of the personnel and time required) According to one experienced U.S. missile designer, a considerable amount of 'art" is always involved, especially for more sophisticated designs. Specifications and documentation can-

42 Additional design problems are caused by heating of the missile skin, the internal components, the propellant, and the reentry vehicle as a result of air friction at higher velocities.

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View from the ***muzzle end (top)*** *of the Iraqi ''supergun,''* ***which Iraq installed and tested at Jabal Harmayn, some 200 kilometers north*** *of Baghdad.*

Using the experience gained from modifying Scuds, Iraq had also built and launched a prototype of a crude space-launch vehicle named the Al-Abid, and claimed that it had developed a 2,000-km range ballistic missile named ***Tammuz*** using similar technology.[5] Iraq's "Project Babylon"-not a missile itself, but a program to develop a specialized 1,000 mm-bore launcher or "Supergun"-was partially impeded by a British customs seizure of parts and by the murder of Gerald Bull, its principal designer. The supergun was being designed to fire guided rockets with conventional, chemical, or possibly nuclear warheads hundreds of miles.[6] A 350-mm research prototype had been completed and test- fired from a site about 120 miles north of Baghdad?

5 The prototype missile appeared to have three stages. The first consisted of engines in an indigenously built airframe (e.g., possibly dustered boosters). The second and third stages used for testing were inert, but were included for their weight and aerodynamic effects. See, for example, U.S. Dept. of Defense, *Conduct of the Persian Gulf War,* op. cit., footnote *3,* p. 20.

6 U.S. Dept. of Defense, *Conduct of the Persian Gulf War,* op. cit., footnote 3, p, 20. Note, however, that if such a missile launcher was intended to use *guided* rockets, much of its advantage would be lost (since the projectile's ultimate accuracy would still depend onits onboard guidance system), while it would subject the entire projectile to extreme accelerations not experienced innormat missile trajectories. The" Super Gun" may have Indeed been better suited for placing small payloads into orbit, a task requiring less accuracy than attacking ground targets. C. Robert Dietz, senior missile designer (retired), Lockheed Missiles and Space Co., private communication, Dec. 8, 1992. See also, Brigadier K.A. Timbers, "Iraq: Supergun—A Complex Matter," *Army Quarterly and Defense Journal, vol. 22, April 1992,* p. 149.

7 U.S. Dept. of Defense, *Conduct of the Persian Gulf War,* op. Cit., footnote 3, p. 20.

not **substitute** for first-hand experience in ballistic-missile design and manufacture.[43]

Nevertheless, foreign expertise in missile development has been widely available in the past. Countries such as Germany and Italy, even though members of the MTCR, had not sought until recently to restrict individual citizens from assisting with missile projects in developing countries.[44] Germany had not applied its export regulations to weapon systems co-produced with a foreign firm, or to *dual-use* components, technologies, or manufacturing capabilities. Although recent changes in German export control law now forbid this type of assistance, the breakup of the Soviet Union may lead to additional new sources of expertise.[45]

Before the advent of the MTCR, other major powers also engaged in a variety of cooperative

43 C. Robert Dietz, senior missile designer (retired), Lockheed Missiles and Space CO., private communication, Dec. 8, 1992.

44 U.S. General Accounting Office, *U.S. Efforts* t. *Control the Transfer of Nuclear-Capable Missile Technology,* Report to Sen. DeConcini (NSIAD-90-176, June 1, 1990), p. 17.

45 One incident in October 1992 illustrating these potential risks involved Russian authorities stopping 60 Russian engineers and technicians from departing to North Korea, reportedly to help with the latter's missile programs.

Table 5-6-Characteristics of the German V-2 Missile

Range	240-300 km
Warhead	1,000 kg high-explosive (conventional) warhead
Weight	12,900 kg fully fueled (twice that of the Scud); 4,000 kg empty
Maximum altitude	80 km
Impact velocity	0.8 km/sec
Propellant	Bi-propellant liquid-alcohol and hydrogen peroxide
Guidance and control	Gyroscopes for determining direction and velocity;a rotating vanes at ends of missile fins and rotating heat-resistant vanes in exhaust jet
First tested	1942, by Germany
World War II usage	2,000 missiles against Britain, resulting in 1,500 deaths 3,500 total missiles against cities in England and on the continent

a Experiments were also carried out, but no operational missiles produced, using radio-controlled guidance.

SOURCE: Gregory Kennedy, *Vengeance Weapon 2: The V-2 Guided Missile* (Washington, DC: The Smithsonian Institute, 1983), pp. 70-73.

efforts to develop Third World missile technology, including:[46]

- In the late 1960s and early 1970s, France provided sounding-rocket technologies and granted licensed production rights to India and Pakistan, in part to subsidize France's own space-launch development costs; the French also assisted with missile-development programs in Argentina, Brazil, and Indonesia.
- In the 1970s, the United States assisted South Korea in the construction of a Nike-Hercules surface-to-air missile manufacturing facility, whose product was later modified by the Koreans for surface-to-surface use. The United States also assisted India and Brazil in developing their sounding rocket programs.
- In the 1980s, Chinese missile experts travelled to Argentina and Brazil to provide technical assistance for their missile programs, as well as to promote sales of Chinese intermediate range missile technologies.

In the past, missile technology has also been transferred through sales and technical assistance among secondary suppliers themselves. Examples of such transfers were provided in the previous section. The foreign training of key individuals, too, has played a key role in missile programs. For example, according to William H. Webster, then Director of the CIA, "In the mid-1960s, the United States accepted a young Indian scientist, Dr. Kalam, into a training program at the Wallops Island Rocketry Center. This scientist returned to India, and, with the knowledge gained from his work on the civilian space program, Dr. Kalam became the chief designer of India's Prithvi and Agni ballistic missiles. "[47]

Hence, the proliferation of missile expertise and technology for at least short range systems was advanced by a variety of paths during the 1980s, helping facilitate its acquisition by several emerging missile powers. However, with the advent of the MTCR, many of the mechanisms by which this technology transfer had occurred have been constrained. (See box 5-B.)

Reentry vehicles

As ranges increase beyond 1,000 to 2,000 km, a ballistic-missile warhead must be afforded greater thermal protection to survive the heat

46 See, for example, Stanford, *Assessing Ballistic Missile Proliferation*, *Op. Cit.*, footnote 4, pp. 94-99.

47 Testimony of William H. Webster, Director of Central Intelligence, in U.S. Senate, Committee on Governmental Affairs, *Nuclear and Missile Proliferation*, 101st Congress, 1st Session, May 18, 1989, S. Hrg. 101-562 (Washington DC: U.S. Government Printing Office, 1990), p. 12.

Table 5-7—Notional Personnel Requirements for Ballistic Missile Development

Design task	Personnel/time requirement
Design first-generation liquid-fueled missiles (similar to Scuds)	5 to 10 well-trained and experienced combustion scientists, chemical engineers, heat transfer specialists, and experts in fluid mechanics and mechanical design, in a well-funded, multiyear research and development program
Develop simple flight-control systems tailored to a particular missile (for instance, rotating vanes mounted in the path of the exhaust gas)	About 20 mechanical, electrical, and manufacturing engineers and technicians, and about 5 to 10 specialists to develop the guidance computer and software
Manufacture Scud-like or longer range liquid-fueled missiles	30 to 50 experienced machinists and technicians
Indigenously design, develop, and produce first-generation (Scud-like) ballistic missiles from scratch, starting from only a rudimentary industrial infrastructure	Total of 300 to 600 well-coordinated and experienced engineers, technicians, and manufacturing personnel
Learn how to manufacture solid-fueled rocket motors of 1,500-km range or more	A team of at least 5 to 10 specialists with many years of propellant-processing experience, to master the largely empirical mixing and casting techniques
Carry out a thorough program of flight testing	Roughly 100 or more experienced personnel and up to a dozen or more tests, plus specialized instrumentation, radars, data acquisition systems, and test ranges
Develop and produce a longer range, more advanced ballistic missile—if a relatively sophisticated industrial infrastructure were already in place	As few as 3 to 10 missile designers with hands-on experience could train local specialists within about 5 to 10 years

SOURCE: Adapted from Stanford University, Center for International Security and Arms Control, *Assessing Ballistic Missile Proliferation and Its* Control (Stanford, CA: Stanford University, November 1991), pp. 135,138, 140-141, 145, 147.

generated by reentry into the atmosphere.[48] In general, such protective packaging-called a reentry vehicle (RV)-is coated with material that gradually burns off and carries away heat in a process called ablation, thereby protecting the warhead inside. However, asymmetric ablation can cause an RV to steer itself far off course. Developing ablatively coated RVs that erode smoothly and predictably would be very difficult for most developing nations and, in any case, would require extensive flight testing.[49]

To protect a warhead during its passage through the atmosphere, it is also possible to use a blunt reentry vehicle. Manned space capsules are examples of blunt RVs designed to dissipate reentry heat and protect astronauts. Blunt RVs

48 There is one application using a nuclear weapon that requires neither accurate delivery nor a reentry vehicle. A nuclear weapon detonated at high altitude can generate a powerful pulse of radio waves (called ‘‘electromagnetic pulse’ ‘), which can wreak havoc on some types of electronic equipment. However, this would not pose the kind of direct human health risk normally associated with weapons of mass destruction.

49 Stanford, *Assessing Ballistic Missile Proliferation*, op. cit., footnote 4, p. 143. Typical materials used in ablative nosetips include fiberglass, carbon-phenolic, and carbon-carbon composites.

Box 5-B-Technology Transfer and the Condor II Program

Although ballistic missiles rely on a number of multiuse technologies, some key technologies have characteristics uniquely identifiable with missile or space-launch-vehicie development programs. Such items include the hardware and software used in missile guidance systems,[1] special composite materials, largs specially designed soiid-propellant mixers and casting apparatus, and rocket-motor static test stands. Restricting trade in the suite of technologies most useful to developing missiles therefore provides some measure of control over missile proliferation. Nevertheless, control of missile proliferation by restricting trade in certain materials and technologies is Inherently more difficult than similarly controlling nuclear proliferation, since there are more potential suppliers of missile technologies and fewer of the relevant technologies are uniquely military in nature.

The cancellation in 1991 of the Argentina-based Condor ll program, heralded as one of the successes of the MTCR regime, points broadly to the inherent difficulties involved in developing missiles with longer rangethanthe Scud. The 1,000-km -stage, solid-fueled Condor // missile, whose development may have been partly motivated by Argentina's defeat in the Falklands War, was to have been the product of a consortium between Argentina and Egypt, with financial assistance from Iraq. Each of the three states had previously developed or improved the performance of short range missiles such as the Scud, with varying degrees of success. However, despite attempts to recruit technical assistance and to import goods from a number of firms in Europe and the United States, the Condor II project ultimately proved unable to acquire many of the technologies needed for a complete system. in 1988, under pressure from the United States and constrained by the MTCR's newly imposed export restrictions, the consortium began to dissolve. By 1990 the program had ground to a standstill in all three countries.

Egypt's involvement in the project sheds light on the extent of foreign assistance that was sought.[2] Before the Condor II project, Egypt had advanced little beyond modifying Scuds and making the 80-km unguided missile called the Sakr-80. However, in gearing up for the more ambitious Condor //, an organization known as the CONSEN Group[3] arranged on behalf of Egypt for a number of well established European firms to provide key components:

- Messerschmitt-Boeikow-Biohm (MBB) of Germany-guidance systems and general missile technology
- MAN of West Germany--wheeled transporter-erector-launchers
- Sagem of France -inertial navigation systems
- SNIA-BPD of Italy-rocket motors and solid-fuel technology
- Additional contractors, such as Bofors of Sweden, and Wegmann of West Germany.

The long list of companies and technologies that Egypt and Argentina attempted to involve in efforts to advance the levelofthe Coondor II missile in the l980s attests to the complexity of such an undertaking. From 1963 to 1988, an Egyptian by the name of Abdel Kader Helmy (who became a naturalized American citizen in October 1987) conducted on behalf of Egypt an ambitious program to acquire missile-related technology and components

1 For instance, missile guidance and control requirements are much more stringent than the simple position and velocity information available from widely used airline and shipping navigation systems.

2 Much of the following is taken from Joseph S. Bermudez, Jr., "Ballistic Missile Development in Egypt," *Jane's Intelligence Review*, October 1992, pp. 456-45S. See also James Adams, *Engines of War: Merchants of Death and the* New Arms *Race (New* York, *NY:* Atlantic Monthly Press, 1990), pp. 257-267.

3 The two most important companies in the CONSEN Group for Egypt% participation in the *Condor* project were iFAT Corp. Ltd., of Zug, Switzerland (responsive for the financial aspects) and CONSEN S.A.M., located in Monaco (responsible for contracting). Underthe direction of Egypt% Minister of Defense, an office tooordinatethe *Condor* //project was established in Salzburg, Austria, co-located with the offices of the CONSEN Group.

illegally from the United States. Helmy and his co-conspirators either exported or intended to export a wide variety of missile-related items to assist Egypt's programs for both the Scud and Condor//, including'!

- , A fully instrumented test-stand for analyzing rocket motors of up to **20 tons thrust**
- **Strap-down inertial** guidance systems for the Con&//, and software for their optimization
- Fuel-air explosive warheads for the Condor //[5]
- Carbon-carbon and ceramic-composite materials to be used **in** *Condor //* nose cones
- Various chemicals for composite solkf-propellant rocket motors:
  - 18,000 lbs. of militarygrade aluminum powder
  - 11,000 lbs. of the synthetic rubber HTPB (hydroxyl-terminated polybutadiene)
  - 500 lbs. of EPON from the Miller-Stephenson Co., used in the aerospace industry for gluing composite fabrics to surfaces
  - Epoxy-hardeners from the Hemkel Co.
  - 40 lbs. of MAPO (tris-2-methyl aziridinyl phophine oxide), a soiid-propellant additive, from Arsynco co.
  - HMDI (hexamethylene diisocyanate), a curing agent for HTPB
- 21,200 lbs. of maraging steel intended for the motor casing of the first stage and connecting segments
- 185 yds. of Rayon-based ablative carbon fabric from the HITCO Co. for heat-shiefds to protect Condor //payload covers
- 436 lbs. of MX-4926, an ablative carbon-phenolic fabric from the Fiberite Co., essential for manufacturing the flexible nozzles the Condor // was to use for maneuverability
- Microwave rocket telemetry antennas from Vega Precision Laboratories

The majority of these efforts failed, however, and Helmy and a number of his collaborators were eventually arrested in June 1986. The loss of a U.S. conduit for missile technology imposed a staggering blow to the Egyptian component of the Condor //projct. Within months, both Egypt and Iraq had ended their involvementwith project.

4 Bermudez, "Ballistic Missile Development in Egypt," op. cit., footnote 2, p. 457.

5 A prior attempt in 1984 by the Egyptian Ministry of Defense to import components for fuel-air explosives 'ad been blocked by the U.S. State Department and Customs Service because the parts were on the Munitions Control List.

were also used with early U.S. ICBMs such as the Atlas. Exotic ablative materials are not nearly so important for blunt RVs, since air resistance quickly decelerates them to speeds slow enough for ordinary materials to withstand the heat generated during reentry. However, in employing blunt RVs, accuracy is lost both from self-steering and from atmospheric winds having a relatively larger effect on a slower moving RV. Their use could easily result in a loss of several kilometers or more in accuracy.

Long range missiles and ICBMs

Although several systems have been developed for categorizing ballistic missiles with ranges greater than 300 km, the U.S. Department of Defense classification system provides a useful reference:

- Short range ballistic missiles (SRBMs) have ranges up to 1,100 km, or 600 nautical miles (nmi),
- Medium range missiles (MRBMs) have ranges from 1,100 to 2,750 km (600 to 1,500 nmi),
- Intermediate range ballistic missiles (IRBMs) travel from 2,750 to 5,550 km (1,500 to 3,000 nmi),[50] and
- Intercontinental range ballistic missiles (ICBMs) can reach from 5,550 to 14,800km (3,000 to 8,000 nmi).

50 The Intermediate range Nuclear Forces (INF) Treaty categorized all surface-to-surface ballistic and cruise missiles with ranges between 500 and 5,500 km as "Intermediate Range".

With nominal payloads of roughly 500 to 1,000 kg, SRBMs are generally single-stage, meaning that they have a single set of (possibly clustered) rocket motors that is carried throughout the flight, even after its fuel is expended.[51] Multistage rockets, in contrast, are powered by successive sets of rocket motors, each of which is jettisoned when its fuel burns out. IRBMs and ICBMS are almost always multistage.[52] MRBMs are an intermediate case, typically consisting of either one or two stages.

Making the transition from a short range ballistic missile capability to being able to design and produce ICBMs involves a number of substantial technological hurdles. Iraq increased the range of imported Scuds from 300 km to between 600 and 900 km by cannibalizing and rejoining sections from different missiles to create longer ones, while simultaneously reducing the payload. But such methods would not work to create ICBMs.[53]

Developing accurate and reliable ICBMs—which would almost always be multistage-presents inherently new and drastically more complex difficulties than simply extending the range of Scuds. The following factors make the engineering and design of long range missiles difficult.[54]

Staging. Proper mating of the stages and getting them to detach and fire at precisely the right moment adds considerable complexity to the design. (Once the missile leaves the atmosphere, the missile can easily begin to tumble at the stage transition, because aerodynamic forces cannot be utilized to stabilize it.) Staging also increases the difficulty in designing the missile's flight control systems, while it generally decreases reliability, accuracy, and mobility.

As a partial alternative to staging, strap-on clusters of boosters can be and have been used to increase the range, possibly at considerably less expense than developing larger boosters. However, in addition to stability and reliability problems caused by using boosters not originally designed to be clustered, the potential increase in range would remain quite limited. In most cases, staging would still be required to reach ICBM ranges.[55]

Structure and Materials. To withstand the large forces caused by their greater launch-weight and stresses in the atmosphere, longer range missiles must incorporate stronger materials than

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51 To generate enough thrust to lift a heavy missile, the (fret) stage must expel propellant gases at a tremendously high rate, requiring a large and thus heavy motor. But since the motor must be accelerated along with the rest of the missile, its own mass limits the speed it can achieve. (The same limits apply to strap-on boosters.) Only by abandoning a fret-stage spent motor and then firing a subsequent stage can a missile easily achieve the velocities necessary for ranges in excess of a few thousand kilometers.

52 One exception is the U.S. Atlas missile, first tested in the early 1950s and deployed in the late 1950s, which achieved 10,000-km range with essentially one stage. Although it generated additional thrust by burning fuel after the first-stage-firing was complete, it did not release the first stage motor or housing. Fueled by kerosene and liquid oxygen, the Atlas used such a thin walled canister on its main stage that it could not reliably support its own weight in launch position until it had been properly loaded with fuel and pressurized.

53 Increasing the size of the fuel tanks on a given stage can only go so far toward increasing a missile's range, since the overall missile weight, including the additional fuel, would at some point become greater than the missile's thrust, thus inhibiting liftoff. Moreover, adding length or weight can cause undesirable and sometimes unstable flight characteristics by altering the aerodynamic stresses, causing the missile to bend and flex, and changing the moment of inertia.

54 See also, Lora Lumpe, Lisbeth Gronlund, and David C. Wright, 'Third World Missiles Fall Short,'' *Bulletin of the Atomic Scientists*, vol. 48, No. 2, March 1992, p. 36.

55 Potential problems with strapped-together boosters include stability of the flight-control system, interference between the exhaust plumes, excess heat generation, and thrust cut-off errors that can lead to large inaccuracies, One analyst has estimated that by strapping together *Al-Abbas* extended range Scud missiles to carry a single 350-kg payload, one could achieve the following ranges: 1 booster—700 km; 3 boosters, dropping first two at burn out—1,500 km; 5 boosters, dropping first four at bum out—2,200 km; 7 boosters, dropping first four, then two, at respective bum outs-5,100 km. James R. Howe, Rockwell International, Space Systems Division, "Emerging Long Range Threat to CONUS," briefing packet, December 1992. Note that this last example is essentially a three-stage missile, but still does not achieve ICBM ranges.

those used in the Scud, usually requiring advanced composites or alloys.

Fuel-fraction. Only about 75 per cent of a rocket engine's weight can be propellant if materials and technologies comparable to those used in the Soviet Scud missile are employed. The greater the fuel fraction, the greater the range; therefore, a low fuel-fraction puts limits on the range a missile can achieve even if multistage. (Modern ICBMs achieve up to about 90 per cent propellant in each stage.)

Reentry vehicles. ICBMs reenter the atmosphere at higher speeds than shorter range missiles, making it considerably more difficult to protect their warheads from atmospheric heating.

Accuracy. Longer range missiles typically have correspondingly longer boost times which, for the same guidance system, would result in larger errors in bum-out velocity. These guidance errors then accumulate over longer flight times, increasing a missile's miss-distance. More accurate guidance and control systems are therefore required.

SPACE-LAUNCH CAPABILITIES AS A ROUTE TO BALLISTIC MISSILES

Instead of developing ballistic missiles directly or reverse-engineering short range missiles, a country might also try to attract foreign assistance in developing a space-launch capability.[56] At least five nations besides the United States and the former Soviet Union now have indigenous space-launch capabilities: China, France (whose Ariane launchers have been developed and operated in conjunction with the European Space Agency), Japan, India, and Israel. Brazil and Pakistan are also developing space-launch or sounding-rocket programs. Much of the technology used in sounding rockets and space-launch vehicles is directly applicable to surface-to-surface missiles. Hence, countries such as Brazil, India, and Pakistan have used civilian programs and foreign assistance to build expertise needed to design and build their own military systems. Israel's civilian and military programs are also undoubtable linked; the Shavit space-launch vehicle is widely reported to be a version of the *Jericho II* missile.[57] Although the space-launch or sounding-rocket programs of South Korea, Taiwan, and Indonesia do not appear to have progressed significantly in recent years, these programs have also received foreign technology assistance.

Some analysts have concluded that there are no longer any valid economic reasons for new countries to develop space-launch vehicles, and hence that the United States should not provide technical assistance to these programs.[58] However, this argument may give too little weight to the possible prestige value or hopes of technology transfer that could result from developing a space-launch capability. It also minimizes the reluctance nations may have to depend on other nations for space-launch services. Countries may also be motivated to develop the capability to launch satellites for military communications or reconnaissance-goals that are not civilian but fall short of developing offensive weapon-delivery systems.

Space-launch vehicles differ substantially from ballistic missiles intended for ground targets in their requirements for accurate guidance and reentry technology. Space payloads do not require reentry vehicles and rarely require extremely precise orbits, meaning that space-launch vehicles need not have as sophisticated guidance systems as long range ballistic missiles. Boost-

56 The material in this paragraph is primarily taken from Carus, *Ballistic Missiles in Modern Conflict, Op. cit.,* footnote 37, pp. 13, 24-25.

57 Some analysts believe that the Shavit space-launch vehicle incorporates technology that the Israelis could use to build an ICBM (with useful weapon payloads and accuracy) with range in excess of 5,000 km. See, for example, Steven E. Gray, "Israeli Missile Capabilities: A Few Numbers to Think About," Lawrence Livermore National Laboratory, unpublished memorandum, Oct. 7, 1988.

58 See, for example, Brian G. Chow, Emerging *National Space-Launch Programs: Economics and Safeguards,* RAND Report No. R-4179-USDP, January, 1993.

phase inaccuracies resulting in errors of tens of kilometers at apogee may be easily tolerable when placing a satellite in orbit, but they can be significant for surface targets even with weapons of mass destruction. Moreover, space-launch vehicles are usually launched from specific locations and can take weeks or months, if needed, to prepare for launch. Ballistic missiles, on the other hand, are much more useful *militarily if they can* be launched on short notice and are not restricted to freed launch-sites.

Still, ballistic missile technologies such as large boosters and high-quality guidance systems could be tested and developed under the guise of a well-developed space-launch program. A country that has demonstrated the capability to develop space-launch vehicles should therefore be considered capable of developing ballistic missiles as well.

COSTS OF MISSILE PROGRAMS

Short range missiles, such as Scud-Bs or SS-21s originally from the former Soviet Union, cost as little as $1 million apiece to produce.[59] At the other extreme is the Saudi purchase of DF-3 missiles from China, which reportedly cost $2 billion for 30 to 50 missiles and their associated launchers.[60] Even if the missiles in this purchase accounted for only half of the total cost, they would still cost over $20 million apiece. Together with launchers, this begins to approach the unit cost of acquiring advanced strike aircraft.

Producing missiles *indigenously can also* be extremely expensive. Press reports have indicated that the Saad-16 missile-development complex being built in northern Iraq (reportedly with the help of several West German companies) may have cost Iraq **$200 million.**[61] **Estimates suggest that it would have cost Argentina $3.2** billion to develop and produce 400 *Condor II missiles,* and development costs alone may have been destined to exceed $1 billion.[62] Without financial assistance from other states, such costs would remain prohibitive for many of the countries of proliferation concern.

I Weaponization and Deployment

NAVIGATION, GUIDANCE, AND CONTROL SYSTEMS

As missile range is extended beyond a few thousand kilometers, the inaccuracies of less-sophisticated missile systems could begin to exceed several-kilometer CEPs,[63] which could affect targeting plans even for weapons of mass destruction. However, for most scenarios involving a proliferant country using or threatening to use a nuclear weapon, or even a terror attack with chemical weapons against another country's territory, it would matter little whether its missiles' CEPs were measured in meters or kilometers.

Guiding a missile to its target requires knowing precisely its orientation, position, and velocity—at least throughout its boost phase-and the ability to control its thrust to compensate for unexpected deviations in trajectory. (It also requires knowing precisely the locations of the launcher and target.) Guidance systems used by most ballistic missiles rely on *inertial* navigation systems to provide boost-phase information. Standard designs consist of gyroscopes, whose spinning components resist change in their orientation and thus provide a freed reference frame, and accelerometers, which in principle utilize weights

59 Stanford, *Assessing Ballistic Missile proliferation, Op.* Cit., footnote 4, P. 45.

60 Ibid., p. 95.

61 See Carus, *Ballistic Missiles in Modern Conflict,* op. cit., footnote 37, p. 22.

62 Ibid., p. 64.

63 For example, the 2,500-km range Chinese CSS-2 (DF-3) missile has a CEP of about 2.5 km, and the Iraqi *Al-Hijarah/Abbas* missile, an extended range Scud with a range of only 900 km has been estimated to have a CEP of over 3 km (2 to 3 miles). See, for example, *World Military Expenditures and Arms Transfers, 1988 (Washington DC: Arms* Control and Disarmament Agency, 1989), pp. 18-19.

attached to precisely calibrated springs. Well before the advent of computers, Germany devised an inertial guidance system for the V-2 missile that combined gyroscopes with electrical capacitors and electro-mechanical actuators to send flight-controI information to the missile fins. Compact computers, however, are now used in essentially all modern inertial guidance systems.[64]

Adapting inertial navigation systems originally intended for aircraft or ships for use in missiles is problematic for several reasons. First, they may be too heavy or too large. Second, their performance may be degraded by a missile's high acceleration. And third, it may be impossible to align their orientation precisely enough to achieve the accuracy needed for missile guidance. Similarly, straightforward application of NAVSTAR Global Positioning System (GPS) information would be inadequate for keeping a missile oriented precisely enough during boost-phase for good flight control, and would only be useful if late boost-phase corrections or a post-boost vehicle were used to correct for any trajectory errors measured by GPS. (GPS is discussed in more detail in the cruise missile section below.)

Furthermore, in order to make use of navigation information, the guidance system (which computes the missile's position and orientation) must be connected to the missile's flight-control system, which adjusts the missile's trajectory during the boost-phase. Accuracies (due to boost-phase errors alone) better than about 0.3 per cent of range[65] can only be achieved with modem computer-controlled guidance packages that incorporate precise knowledge of the missile's response-times and steering forces. Precise understanding of the behavior of flight-control systems is required to avoid unstable flight maneuvers and over- or under-steering the missile. Slight flexing of the missile during boost can also be difficult to compensate for, even with sophisticated control systems.


U.N. PHOTO, H. ARVIDSSON

United Nations Special Commission inspector examining the tail section of an Iraqi modified Scud *missile, showing its heat-resistant vanes mounted in the exhaust path and its rotating tail fins.*

Advanced computer algorithms coupled with extensive flight testing can be very helpful in understanding and overcoming the biases of guidance system hardware. Coupling the guidance and flight control systems, however, has proven to be a major problem for many missile programs in developing countries, including those in Argentina and Brazil.[66] More advanced flight control systems relying on gimballed engines for liquid-fueled motors, or high-temperature flexible joints at the nozzle exit-cones of solid boosters, would also be difficult for developing countries to master in the short run.

64 In addition, the United States and other countries with advanced avionics industries have developed ring-laser gyroscopes for use as guidance systems in both missiles and advanced combat aircraft such as the F-16. These not only provide greater accuracy, but, since they have far fewer moving parts, can be readied for launch much more quickly than traditional gyroscopes.

65 Expressing accuracy as a percentage of range is only a very approximate description of the effects Of error factors. Since these errors contribute indifferent and often nonlinear ways to miss-distances at the target, such percentages are used only for convenience and are not meant to imply a direct proportional relationship between accuracy and range.

66 See, for example, Andrew Slade, "Condor Project in Disarray, " *Jane's Defense Weekly,* Feb. 17, 1990, p. 295.

Moreover, boost-phase guidance errors are only one contribution to the inaccuracy of ballistic missiles. For all but the shortest range missiles, the midcourse and reentry phases can contribute significant and sometimes unpredictable errors, resulting from:

- reentry vehicles steering off course, in much the same way that skydivers steer with their arms and legs (steering and lift forces can be caused by the RV's oscillating or tumbling when it first encounters the atmosphere, or by unexpected rates of RV ablation);[67]
- barometric pressure and weather over the target; and
- unmodeled anomalies in the earth's gravitational field.

In sum, accurate and reliable guidance, control, and reentry-vehicle systems for large, multistage ballistic missiles require integrating a set of critical technologies that would appear to be particularly difficult for developing countries to master. To the extent that reliable delivery of a weapon within several kilometers of its target matters, these difficulties provide an important barrier to the proliferation of long range missiles in developing countries. Barring direct purchase, progress toward long range missiles will come in measured steps at best, and sudden breakthroughs are unlikely.

MOBILITY AND SURVIVABILITY

Most missiles deployed in Third World countries can be launched from mobile wheeled or tracked vehicles known as transporter-erector-launchers (TELs). (Even ICBMs, such as the Russian single-warhead SS-25 and the U.S. Peacekeeper, can be put on mobile launchers and hidden.) Such launchers can be very difficult to locate and track and can be stored in secure locations, making them less vulnerable to preemptive attack. Syria reportedly stores its TELs in specially constructed, fortified tunnels, and Saudi Arabia may protect its DF-3 missiles by storing them in a chosen group of bunkers that are based on a design China uses to protect its strategic missiles.[68] In the Persian Gulf War, the mobility of the Scud launchers proved to be much more of a problem for the allied forces than had been anticipated. Even with the combined benefits of massive air superiority, the most advanced reconnaissance and targeting systems available, and hundreds of sorties flown each night, an extensive air-power survey carried out for the U.S. Air Force has found that although a few mobile Scud launchers may have been destroyed by coalition aircraft or by special operations forces during the war, there is no hard evidence that coalition air attacks destroyed ***any*** Iraqi Scud missiles or mobile launchers.[69]

Mobility comes at some cost, however. While it adds flexibility in choosing a launch site, it could require developing a reprogrammable flight-control system to adjust missile trajectories.[70] Long range missiles are significantly harder to make mobile than shorter range ones; many roads, bridges, and tunnels may not be capable of handling the weight and size of a long range missile, and off-road transportation would proba-

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67 Reentry errors have been reduced in the United States and other countries with advanced missile programs, however, by extensive testing, computer modeling, use of techniques such as spinning the RV after properly aligning its axis, and using exotic materials to optimize nose-tip ablation.

68 Carus, *Ballistic Missiles in Modern Conflict,* op. cit., footnote 37, p. 42.

69 Eliot A. Cohen, *Gulf War Air Power Survey* (Washington, DC: School of Advanced International Studies, Johns Hopkins Univ., draft April 28, 1993), ch. 3, pp. 23,31-32. See also, Julie Bird, "Gulf Airstrikes Left Scuds Intact," *Defense News,* vol. 8, No. 19, May 17-23, 1993, p. 26.

70 Reprogrammable flight-control systems would not be essential, however, since one could always keep a missile's range fixed by restricting its launch to an arc centered on a fixed target; for liquid-fueled missiles, one could compensate for the differences in range by adjusting the propellant level before launch.

bly be quite slow.[71] Nevertheless, any country with experience in manufacturing large heavy-duty vehicles, railroad cars, and construction equipment such as cranes, should be able to construct at least primitive mobile launchers for short range missiles. Therefore, mobile launchers would not present a major hurdle for an emerging missile power.

OVERCOMING DEFENSES

To date, the only use of ballistic missile defenses in wartime occurred during the Persian Gulf War, in which Patriot defense batteries were rapidly deployed to Israel and Saudi Arabia to counter Iraqi Scuds.[72] Over the six weeks of the war, 81 Scuds were reportedly launched by Iraq, 43 of which were targeted on military facilities and populated areas in Saudi Arabia, with the remainder against Israeli cities, About 47 Scuds were engaged by Patriot missiles. Claims made by the U.S. Army and Raytheon, the manufacturer of Patriot, over Patriot's success rate were initially quite optimistic. However, these claims generated much controversy and have since been revised downward several times .73

Few if any lessons from the Patriot-Scud engagements can be applied to the problem of missile defense in general, since both offensive and defensive systems will continue to evolve. Nevertheless, it was instructive that one of the simplest and indeed lowest technology forms of "penetration aid" probably played a role in reducing the effectiveness of Patriot. The Scud rocket casing, which remained with the warhead until late in reentry, tended to break up in the lower atmosphere, creating a much more difficult target for the Patriot to intercept. According to an engineer from the Raytheon Company who has had nearly two decades of involvement with the Patriot system,

> Due to design changes and poor workmanship when the Scuds were modified, they broke apart in midair and created the combined effects of stealth, maneuvering reentry vehicles (RVs), decoys and fragments, and reduced warhead vulnerability. All were unanticipated and added to the difficulty of defeating these TBMs [tactical ballistic missiles]. The inference of those who claim that because these TBMs were crude they were easy to defeat is incorrect.[74]

Simple measures might therefore be adequate against a defense system not designed to discriminate decoys, To protect against mid-course interceptors or associated radars, decoys could be rather primitive; dispersing bundles of radar-reflecting wire known as chaff might suffice. However, penetrating advanced terminal defenses might require more realistic decoys having aerodynamic properties similar to those of the warhead. Deploying such decoys would impose significant weight penalties.

Development work is now vigorously being carried out in the United States and in Israel on a variety of improved antitactical ballistic missile systems (ATBMs), including, for example, next-generation Patriots (called the PAC-3), a theater

71 Unless great care is taken to dampen shocks and vibrations, transporting medium- and long range *solid-propellant* missiles may also *damage the* fuel grain, resulting in loss of reliability.

72 Several missile-defense systems had previously been developed by the United States and Soviet Union (and deployed, in the latter case), but all of these had used nuclear warheads, and none had been used in wartime.

73 See, for example, U.S. Congress, House Committee on Government Operations, Subcommittee on Legislation and National Security, *Performance of the Patriot Missile in the Persian Gulf War,* 102nd Congress, 2nd Session, Apr. 7, 1992; and U.S. Congress, General Accounting Office, *Operation Desert Storm: Data Does Not Exist to Conclusively Say How Well Patriot Performed,* NSIAD-92-340 (Washington, D. C.: U.S. General Accounting Office, Sept. 22, 1992). See also Representative John Conyers, Jr., "The Patriot *Myth:* Caveat Emptor,'' *Arms Control Today,* vol. 22, No. 9, November 1992, pp. 3-10; Theodore A. Postol, ''Lessons of the Gulf War Experience with Patriot, " *International Security,* vol. 16, No. 3, Winter 1991/92, pp. 119-171; and Robert M. Stein and Theodore A. Postol, "Correspondence: Patriot Experience in the Gulf War, " *International Security,* vol. 17, No. 1, Summer 1992, pp. 199-240.

74 Robert M. Stein, Manager of Advanced Air Defense Programs for the Raytheon Company, ''Patriot ATBM Experience in the Gulf War, ' article sent to subscribers of *International Security,* Jan. 9, 1992.

high-altitude area defense interceptor (called THAAD), and Israeli *Arrow* interceptors. Although one or more of these systems or others may eventually provide some level of regional defense against ballistic missiles carrying *conventional* weapons, even very small leakage rates against missiles carrying weapons of mass destruction could have devastating consequences. The potential effectiveness of defenses against the latter type of threat is therefore highly speculative at the present time.

COMMAND, CONTROL, HANDLING, AND SAFETY REQUIREMENTS

As was stated earlier, the infrastructure required to support a missile capability is smaller than that needed to sustain an effective air force. During the Iran-Iraq war, for instance, Iran was unable to acquire manned combat aircraft, but did manage to obtain and launch missiles under the control of the Islamic Revolutionary Guard, a force without a particularly high level of technical expertise.[75] Furthermore, targeting requirements at least for weapons of mass destruction would not present much of a problem, since published maps or commercially available satellite imagery would probably suffice in most cases.

Without its own reconnaissance aircraft or satellites, however, a country using missiles to deliver weapons of mass destruction may not know whether they landed anywhere near their intended targets, and might have to rely on news reports or spies to know the extent of the destruction it had caused. (For this reason, Israeli military censors restricted reporting during the Persian Gulf War about Iraqi Scud strikes in Israel.)[76]

Great care must be taken in transporting liquid rocket fuel or fielding mobile missiles to avoid accidents that could lead to explosions. However, transporting weapons of mass destruction would also warrant strict safety and security measures, so that the incremental safety requirements for handling the missiles would probably not add significant additional obstacles.

TESTING REQUIREMENTS

Ensuring the reliability of the complex thermodynamic, aerodynamic, and electro-mechanical systems involved in ballistic missiles requires extensive testing, both at the subsystem level and in full-scale tests. The engines can be tested in specialized static test stands on the ground, but missile guidance, control, and overall reliability assessments require flight tests. For instance, it is reported that after the initial flight test of China's frost medium range missile (the 1,200-km, single-stage, liquid-fueled CSS-1) failed in 1962, seventeen ground tests were performed before a series of three more flight tests (all successful) were carried out in 1964.[77] A thorough program of flight testing would involve specialized instrumentation, radars, data acquisition systems, and test ranges. If the intended payload were very expensive, such as a nuclear weapon, a high level of reliability would probably be desired, making short-cuts in missile flight-testing unwise and unlikely. Still, even well-developed and thoroughly tested missile systems are often still considered to be only about 80 to 90 per cent reliable .78

If a missile is to carry and disperse decoys and other penetration aids to help it overcome defenses, an additional development and testing

75 Carus, *Ballistic Missiles in Modern Conflict, op. Cit.,* footnote 37, p. 30.

76 See, for example, "Missile Fired at Israel, ''New *York Times*, Feb. 1, 1991, p. 11. Also, during World War II, the British used double agents to carry false information to the Germans about the impact points of V-1 and V-2 missile attacks on London. See David Irving, *The Mare's Nest* (Boston: Little, Brown and Company, 1964), pp. 250-251.

77 Phillip S. Clark, "Chinese Launch Vehicles-' Chang Zheng l', " *Jane's Intelligence Review,* November 1991, p. 508.

78 See U.S. Congress, Office of Technology Assessment, *Access to Space: The Future of U.S. Space Transportation Systems*, OTA-ISC-415 (Washington DC: U.S. Government Printing Office, April 1990), p. 22.

program might be needed to develop them. Depending on the sophistication of the defenses, however, such a program to develop penetration aids would probably not be nearly as complex as developing the missiles and reentry vehicles themselves.

IMPLICATIONS OF GPS AND NEW GUIDANCE TECHNOLOGIES

One way a country might try to improve navigational accuracy is through incorporating Global Positioning System (GPS) data into a missile's guidance system (see section on Cruise Missiles, below, for a discussion of GPS capabilities). However, this presents two inherent difficulties. First, to comply with MTCR guidelines, GPS receivers for commercial or export sales must shut themselves down if they compute that they are traveling faster than 515 m/see or are at an altitude above 18 km. Since even 300-km-range Scud missiles reach speeds of more than 1,500 m/see and altitudes around 30 km before burnout, commercial GPS receivers would be of little use either in boost-phase or beyond. Nevertheless, if a country could manufacture its own GPS receivers, or obtain the underlying electronic processor chips from elsewhere, this part of the problem could be avoided.

The other problem with using GPS systems for missile guidance, however, is common to all missile systems: accurate navigational information must be translated into effective flight control. GPS could be of great help with rapid and accurate initialization of the missile's position before launch, and to some extent with determining true north, both of which could be important contributions. But GPS information alone would probably not help reduce the remaining uncertainty from inertial guidance-system measurements in the missile's *orientation* **at the** moment of thrust termination, when the missile is moving and accelerating most rapidly. Even during the boost phase itself, it is would be technically complex to transform GPS position and velocity information via the flight control system into useful adjustments in the missile trajectory, especially given the slow rate at which most GPS receivers update their readings. During boost phase, therefore, employing GPS data would probably not be of much help in producing more accurate missiles.

In theory, a post-boost vehicle could use GPS navigational data to greater advantage in making leisurely mid-course corrections outside the atmosphere. But a post-boost vehicle represents an additional missile stage with its own propellant, thrusters, and computational power; and it would pose an additional obstacle for emerging missile powers.

Terminal guidance, or steering a warhead to a precise aim point after it has reentered the atmosphere, has been employed on some advanced U.S. missiles (the *Pershing II*, for instance), but it would be exceptionally challenging for an emerging missile power to develop.

In sum, designing and producing reliable and reasonably accurate ballistic missiles of over 1,000-km range would be difficult but not impossible for many developing states. There may be increasing numbers of scientists from the former Soviet Union and elsewhere willing to assist in these efforts. Without dedicated resources and some outside technical assistance, however, a program would be lengthened substantially and likely encounter frequent setbacks. As missile range and size are increased, almost all aspects of missile development (e.g., combustion chambers, casting of solid propellants, multiple staging, guidance and control systems, reentry vehicles, and even transporters) become increasingly complex and technologically demanding. Consequently, achieving accuracy and reliability for such systems requires more time and expense and cannot be assumed to follow on the heels of first-generation missile deployment.

| Monitoring Ballistic Missile Programs

Intelligence capabilities for discovering or tracking missile transfers have been far from perfect. It was reportedly largely by accident that U.S. intelligence sources discovered the Saudi purchase of Chinese DF-3 missiles, and then at least two years after the fact.[79] It has also been reported that the United States was unaware of the extent to which Iraq had successfully extended the range of its Scud missiles during the 1988 Iran-Iraq ''War of the Cities.''[80]

Missile development programs also draw on many dual-use goods that have legitimate industrial applications, making them difficult to control and monitor. These include forging, rolling, and other large metal-working equipment that could be used in manufacturing large motor cases, as well as computers and certain types of precision computer-controlled equipment.[81]

Nevertheless, production facilities for large missiles and especially for solid-fueled boosters might have distinctive characteristics that could facilitate their identification and monitoring. These features might be associated with their size or their capability to withstand accidental detonations.[82] Accidental explosions themselves might also be possible to monitor. Furthermore, for the vast majority of developing countries, development of longer range missiles would require that significant amounts of specialized hardware, materials, or technical assistance be imported, thus providing other governments a possible means to monitor the program's progress. It is therefore much more difficult to develop longer range missiles in secret than it is to secretly import medium range missiles or extend the range of short range missiles.

FLIGHT TESTING OF BALLISTIC MISSILES

By their bright exhaust plumes and unique flight profiles, flight tests of missile systems will continue to be easily monitored remotely. Static ground tests might also be visible. Static tests of individual missile stages and flight-tests at reduced range can partially disguise capabilities and make it difficult in the early stages of a program to determine its intent. But the step-wise progress and extensive test programs required to develop *long range* systems provide a lengthy window for observation.

MISSILE DEPLOYMENT

If a country wanted to convince its neighbors that it was indeed pursuing space-launch capabilities and not developing ballistic missiles, it might suggest that other countries inspect its missile production facilities. A plant that had the manufacturing capacity to turn out only one or two boosters per year would be less likely to be used for offensive missile production than one capable of mass-producing boosters by the dozen. Such a country might also allow others to inspect its payloads or observe its space launches at close range. However, not all countries would allow such transparency in their space-launch programs. Furthermore, such inspections could only verify that a given production facility, launch, or series of launches had a nonthreatening objective; they could not prove that the *capability* for developing a ballistic-missile delivery system was absent.

Like other delivery systems and weapons of mass destruction themselves, monitoring ballistic missiles can be more problematic once they are deployed than during their development and production. The best opportunity for monitoring

79 See David Ottaway, ''Saudis Hid Acquisition of Missiles,'' *Washington Post*, March 29, 1988, p. A13; and Jim_ "U.S. Caught Napping by Sine-Saudi Missile Deal," Los Angeles Times, May 4, 1988.

80 Carus, *Ballistic* Missiles *in Modern Conflict,* op. cit., footnote 37, P. 62.

81 Stanford, Assessing Ballistic Missile *Proliferation,* op. cit., footnote 4, p. 6.

82 For example, the one-stage Chinese DF-3A missile (range of about 3,000 km with a 1,100-kg payload) weighs 65,000 kg; the U.S. MX ICBM (1 1,000 km with 3,800 kg) weighs 90,000 kg. See, for example, *The Military Balance 1988-1989,* (London: International Institute for Strategic Studies, 1988).

the status of missile programs (other than openly displayed space-launch systems) is clearly afforded by the development and testing phase.

Summary—Ballistic Missile Proliferation

According to published sources, ballistic missiles with ranges from 300 to 600 km are already possessed or being developed by well over a dozen countries outside of the five declared nuclear powers. Their spread was greatly facilitated by the export in the 1970s and 1980s of Scud-B missiles from the Soviet Union. With the advent of the MTCR and an increasing number of countries abiding by its constraints on missile trade, the potential number of non-Third World suppliers of missiles has declined markedly. However, at the same time, additional countries have learned to copy, modify, extend the range of, and produce their own missiles, and a small number have developed long range systems—often in conjunction with space-launch programs and foreign technical assistance.

In general, the acquisition by developing countries of more advanced missile technologies-those allowing ranges in excess of 1,000 km or accuracies much better than roughly 0.3 per cent of range-can be slowed but not stopped by multilateral export controls. Those emerging missile powers that might have the intent to strike at the United States (e.g., Iran, Iraq, North Korea, Libya) will not be able to field long range missiles or ICBMs over the next 10 years, and those that could develop the capability (e.g., Israel, India, Taiwan) are not likely to have the intent. It is therefore unlikely that any country (other than China and the former Soviet republics that already possess intercontinental ballistic missiles or ICBMs) would pose a direct ballistic missile threat to the United States within the next 10 years.

Nevertheless, given the continuing export behavior of North Korea and possibly China, the potential for collaboration between emerging missile powers, and the possibility of missile experts becoming available from the former Soviet Union or from financially troubled companies in other non-MTCR countries, expertise in both short-and long range missile systems may continue to spread. Countries may continue to seek ballistic missiles for a number of reasons, including their prestige, their psychological value as terror weapons, the opportunities they provide for generating hard currency, technology transfer from space-launch programs, or even a shortage of trained pilots and infrastructure to support an air force. These motivations, combined with the fact that designing and manufacturing ballistic missiles in general requires considerably less sophistication than does producing jet engines for modem combat aircraft, will continue to make missile technology attractive for a number of countries of proliferation concern.

COMBAT AIRCRAFT

The potential use of combat aircraft for delivering weapons of mass destruction poses a number of complex issues. Advanced fighters and strike aircraft can carry out a wide variety of missions—e.g., air defense, close air support of ground troops, and striking targets inside enemy territory—and are widely accepted as legitimate military instruments.[83] However, some also provide the capability to deliver weapons of mass destruction, a mission not viewed with the same degree of acceptance. It is difficult or impossible to allow the former set of capabilities while preventing the latter, since almost any combat aircraft with an attachment point for ordnance or for other equipment can be modified to accommodate and deliver nonconventional weapons. Moreover, many potential proliferant states either possess or can buy combat aircraft far superior to available missiles in terms of payload, accuracy, range, and other characteristics. In most cases, the range,

83 The U.N. Charter explicitly recognizes the right of a nation to self-defense. Possession of combat aircraft fOr that purpose is thus not illegal under international law.

accuracy, and payload capabilities of combat aircraft already possessed by developing countries far exceed those of' their ballistic or cruise missiles, and many more countries have aircraft than have missiles.[84]

The relative numbers and capability of military aircraft in countries of proliferation concern vary greatly (see table 5-8). For example, the Israeli air force, which includes 63 F-15, 209 F-16,95 Kfir C2/C7, and 112 F-4E aircraft,[85] has a vastly greater capability in wartime for large-scale ordnance delivery at long range, and in the presence of hostile defenses, than is possessed by most developing countries. For some countries, however, capability is determined more by the availability of pilots, technicians, or even spare parts, than it is by numbers of aircraft. The training given pilots and the doctrine they employ is also very significant. Although variations in air-force size, readiness, and even pilot skill might not matter much for delivering a single nuclear weapon to an undefended target or a large city, the overall capability of a proliferant's air force could affect its ability to deliver large quantities of chemical weapons by air, or to engage in a protracted conventional air war that might eventually escalate to use of weapons of mass destruction.

Outside NATO and the former Warsaw Pact, most nations with large air forces and advanced combat aircraft also tend to have, or are thought to have, programs for the development of nuclear, chemical or biological weapons.[86] As can be seen from table 5-8, 7 of the top 10 non-NATO nonformer Soviet Bloc countries with the largest air forces are thought to have active programs in weapons of mass destruction (those not believed to have such programs are Japan, Sweden, and Yugoslavia); of those with the top 25 air forces, 11 have active programs and another four are thought to have had programs in the 1980s that are now being reversed. Furthermore, of all the developing nations believed to be engaged in the development of weapons of mass destruction, only one, Myanmar (formerly Burma), has less than 150 combat aircraft. (Figure 5-4 illustrates the overlapping nature of programs for the development of weapons of mass destruction in various counties.)

Trade in Weapon-Capable Aircraft

The proliferation of combat aircraft is already more widespread and intractable than that of ballistic missiles. Although some ***dual-use*** technologies useful in the development of ballistic missiles are still actively traded, trade in missiles themselves has always caused concern and has been subject to multilateral export controls since the MTCR was established in 1987. Nations are increasingly willing to take diplomatic or economic measures to contain the spread of ballistic missiles, forcing commerce in missiles-when it has taken place-to be carried out clandestinely.

In sharp contrast, most nations with advanced arms industries actively support the efforts of their aerospace companies to make international sales. The international market for fighters, interceptors, and strike aircraft is extremely competitive. In the middle 1980s, for example, when the U.S. Congress blocked the sale of F-15 fighter aircraft to Saudi Arabia, the Saudis turned to a U.K. firm, British Aerospace, and bought more

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84 This analysis focuses on combat aircraft in countries believed to have *programs* for developing weapons Of mass destruction (other than the five acknowledged nuclear powers in the case of nuclear weapons) or that have ballistic missile programs but are not full members of the MTCR. These countries are almost exclusively in the developing world. (See ch. 2 of U.S. Congress, Office of Technology Assessment *Proliferation of Weapons of Mass Destruction: Assessing the Risks,* op. cit., footnote *2,* for the methodology used in identifying mass-destruction weapon programs in these countries.)

85 International Institute for Strategic Studies, *The Military Balance 1992-1993* (London: Massey's, 1992).

86 During the period over which most of the aircraft discussed in this section were acquired, NATO and former Warsaw Pact states were covered by a nuclear umbrella and other security guarantees resulting from their NATO and Soviet Bloc alliances. The close ties these states had to superpower allies armed with weapons of mass destruction lessened their own motivations to develop such weapons.

Table 5-8-Combat Aircraft and Mass-Destruction Weapon Programs in Non-NATO and Non-former Warsaw Pact Countries

Country[a]	FGA[b]	Fighter[b]	Bomber	Total[b]	WMD/M[c]	Example
China	600	4600	630	5830	(N)BCM	Q-5(MiG-19)
North Korea	346	376-387	81?	814?	NBCM	MiG-29
India	400	327	9	736	NM	Mirage-2000
Israel	169	479	0	648	NBCM	F-15/16
Syria	170	302-463	0	633	BCM	MiG-29
Taiwan	512	0	0	512	BC	F-5
Japan	94-198	280	0	478	none	F-15
Egypt	113-149	295-323	0	472	CM	F-16
Sweden	97-237	214	0	451	none	JA-37
Yugoslavia	213-283	126	0	409	none	MiG-29
South Korea	265	128	0	393	M?	F-16
Libya	128	238	5	371	BCM	Mirage F-l
Pakistan	126-150	214	0	364		F-16
Iraq	130	180	6	316	[NBCM]	MiG-29
Saudi Arabia	97-152	102-132	0	284	M	F-15C/D
Iran	130	132	0	262	NBCM	F-14
South Africa	116-245	14	0	259	[N]M?	Mirage F-l
Algeria	57	185	0	242	N?M?	MiG-23
Afghanistan	110	80-123	0	233	M	MiG-23
Switzerland	87	137	0	224	none	Mirage III
Brazil	200	18	0	218	[N]M	F-5
Singapore	107-149	38	0	187	none	F-16
Vietnam	60	125	0	185	c	Su-17
Cuba	20	140	0	160	none	MiG-29
Argentina	16-89	66	0	155	[NM]	SuperEntendard

Key: FGA = fighter/ground-attack aircraft
Fighter -combat aircraft optimized for air-to-air mission
Bomber = aircraft optimized for delivering large payloads of bombs at relatively long range, possibly with internal bomb bay, and lacking air-combat capability

a Countries with less than 150 combat aircraft are not listed. The only such country that is frequently reported to have a mass-destruction weapon program is Myanmar (Burma), which is suspected of having chemical warfare capability and is reported to have 12 fighter aircraft.

b Higher numbers include combat-capable trainer aircraft, which are also included in totals.

c WMD/M - weapon of mass destruction or missile program:

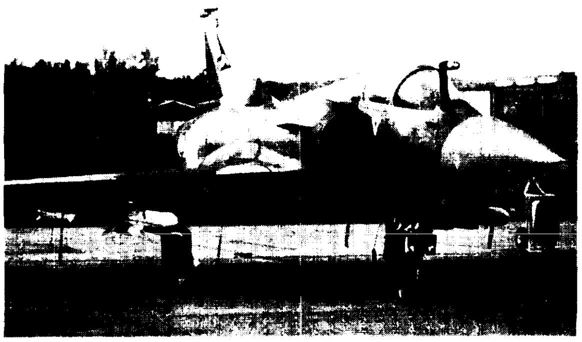
N = frequently reported as having or trying to acquire nuclear weapons
B = frequently reported as having offensive biological warfare program
C = frequently reported as having offensive chemical warfare capability
M = suspected of having or developing ballistic missiles with range of at least 300 km, and not full member of the MTCR as of March 1993
[ ] = program in reversal or no longer considered a proliferant threat

States are listed here as having nuclear, chemical, and biological weapon programs if they are commonly cited in the public literature as having such programs, as reviewed in ch. 2 of U.S. Congress, Office of Technology Assessment, *Proliferation of Weapons of Mass Destruction: Assessing the Risks*, OTA-ISC-559 (Washington, DC: U.S. Government Printing Office, August 1993). See also figure 5-4, drawn from the same source. (Since China is a nuclear-weapon state under the Nuclear Non-Proliferation Treaty, it is not considered a "nuclear proliferant" here.) States are listed as having missiles if they are listed in table 5-3 as having indigenous missile programs or imported missiles.

d Federal Republic of Yugoslavia (Serbia-Montenegro)

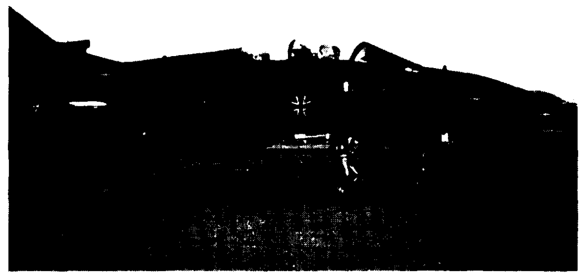
SOURCE: Office of Technology Assessment. Based on information drawn from International Institute for strategic Studies, *The Military Balance 1992-1993* (London: International Institute for Strategic Studies, 1992).

U.S. DEPARTMENT OF DEFENSE



(a) Mirage-2000

C.S. DEPARTMENT OF DEFENSE



(b) Tornado

U.S. NAVY

(c) *Kfir*

GENERAL DYNAMICS CORP.

(d) F-16

Advanced combat aircraft such as (a) the French Mirage-2000, (b) the Gerrnan/British/Italian Tornado, (c) *the Israeli Kfir, and (d) the U.S. F-16 are operated by a number of countries around the world, some of which are thought to have programs to develop weapons of mass destruction.*

than 100 comparable Tornado IDS aircraft.[87] In a few instances, political or regional considerations have made it difficult for countries to obtain advanced combat aircraft, but most have been able to do so.[88]

Moreover, as developing nations have continued to purchase advanced combat aircraft, they have increasingly demanded transfer or licensing of underlying production technologies as part of

87 The Tornado aircraft includes technology and components developed and manufactured in Britain, Germany, and Italy. It has considerably less air-combat capability than the F-15.

88 For example, Iranian F-14 aircraft played only a small role in delivering conventional ordnance during the Iran-Iraq war, largely because the United States had cut off spare parts, training, and maintenance support following the Islamic revolution in 1979. On the other hand, even under the Pressler Amendment, which cut off aid (including military aid) to Pakistan after the President could no longer certify that it did not possess a nuclear weapon, commercial sales of military equipment supporting that country's air force appear to have continued. See, for example, "Shipments to Pakistan Under Investigation," *Washington Post, Mar.* 7, 1992, p. Al.

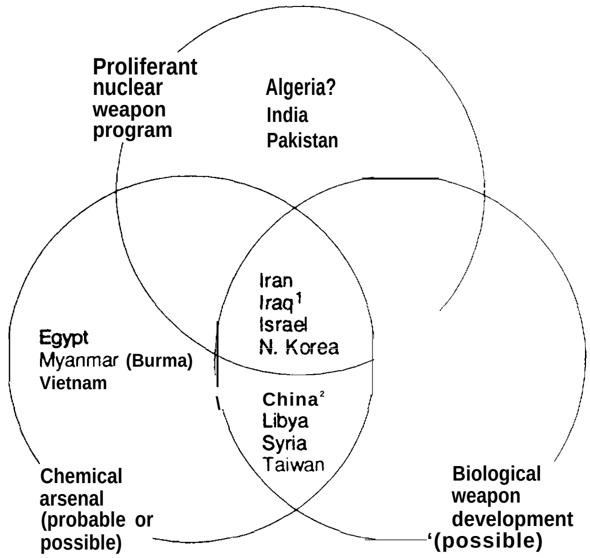
GENERAL DYNAMICS CORP.

The General Dynamics F-16 fighter, here being assembled at the U.S. Fort Worth facility, is flown by 17 air forces around the world. Licensed co-production facilities have been built in Belgium, Turkey, and the Netherlands.

the transaction.[89] These licensed production arrangements help build up and extend the defense industrial infrastructure of recipient nations. Such transfers are often accomplished through complicated sales agreements, for example, in which the recipient nation buys a few copies of an advanced fighter off-the-shelf, assembles a second batch under license, and-to the extent that its industrial base can absorb and produce the technologies and components in question—manufactures the rest indigenously. In such transfers, highly sophisticated and classified subsystems are often withheld by the seller or provided in a downgraded version as an assembled component.

Over the past several years, trade in advanced combat aircraft has been brisk. During 1987-1992, the 20 developing countries having the largest air forces ordered a total of over 1,600 aircraft (see table 5-9). Of those aircraft, over

Figure 5-4-Suspected Weapon of Mass Destruction Programs



Shaded area: also has Scud-type or longer range ballistic missile

1 Iraqi programs reversed by U.N.

2 China is an acknowledged nuclear-weapon state.

SOURCE: U.S. Congress, Office of Technology Assessment, *Proliferation of Weapons of Mass Destruction: Assessing the Risks,* OTA-ISC-559 (Wash., DC: U.S. Government Printing Office, August 1993), p. 66.

two-thirds were ordered by proliferant nations that either now possess or are thought to be developing weapons of mass destruction (WMD), or were thought to be developing them at the time of the orders.

As these data suggest, proliferation of WMD-capable aircraft is embedded in the economic competition among firms of several different nations. The most common reasons cited in Europe and the United States to export advanced combat aircraft are that foreign military sales are necessary both to maintain existing production facilities and to fund R&D within the firm for

89 On the subject of licensed production of major weapon systems, see U.S. Congress, Office of Technology Assessment, *Global Arms Trade*, OTA-ISC-460 (Washington, DC: U.S. Government Printing Office, June 1991), pp. 6-9. Selected licensed production agreements in the 1980s include: U.S. F-16 fighter (to Turkey and to South Korea); French-German Alpha Jet (to Egypt); Brazilian EMB-312 Tucano trainer (to Egypt); Anglo-French Jaguar fighter (to India); Soviet MiG-27 fighter (to India); and U.S. F-5E Tiger-2 fighter (to Taiwan). Selected licensed production agreements in the 1970s included: French Mirage F- 1 fighter (to South Africa); Soviet MiG-21 fighter (to India); and Soviet MiG-19 fighter (to North Korea). See, for example, *SIPRI* Yearbook (New York: Oxford University Press, various years).

Table 5-9-Combat Aircraft Ordered 1987-1992 by Countries of Proliferation Concern[a]

Country[a]	Total	WMD/M[b]	No.	Type of Aircraft	Supplier[c]	Year
China	76	(N)BCM	12	SU-24 Fencer	USSR	1990
			24	SU-27 Flanker	"	1991
			40	MiG-29	"	1991
North Korea	195	NBCM	20	SU-25 Frogfoot	USSR	1987
			25	MiG-29	"	1987
			150	MiG-21 MF	USSR	1988
India	40	NM	15	MiG-29	"	1988
			15	Jaguar	France/U.K.	1988
			10	Sea Harrier	U.K.	1989
Israel	90	NBCM	5	F-15D Eagle[d]	Us.	1988
			30	F-16C	"	1988
			30	F-16D	"	1988
			15	F-1 5A Eagle	"	1990
			10	F-1 5A Eagle	"	1991
Syria	8+	BCM	7	SU-24 Fencer	USSR	1988
			8	MiG-25 Foxhound	"	1989
Taiwan	250	BC	34	Kfir-C7	Israel	1991
			6	Kfir-TC7	Israel	1991
			150	F-1 6	Us.	1992
			60	Mirage 2000-5	France	1992
Egypt	123	CM	42	F-16C	Us.	1987
			4	F-16D	"	1987
			1	F-1 6D	"	1988
			20	Mirage-2000	France	1988
			10	L-39 Albatros[d]	*Libya*	1980
			46	F-16C	Us.	1991
South Korea	357	M?	24	F-4D Phantom	Us.	1987
			4	F-1 6D	"	1988
			24	F-4E Phantom	"	1988
			12	RF-4C Phantom	"	1988
			24	F-4E Phantom	"	1989
			120	F/A-18 Hornet	"	1989
			20	Hawk[d]	U.K.	1990
			9	RF-4C Phantom	Us.	1990
			120	F-1 6C	"	1991
Libya	15	BCM	15	Su-24 Fencer	USSR	1988
Pakistan	196	NM	11	F-1 6A	Us.	1988
			75	F-7	China	1989
			60	F-1 6A	Us.	1989
			50	Mirage-30	*Australia*	1990
Iraq	52	[NBCM]	36	Mirage F-1 C	France	1987
			16	Mirage F-1 C	France	1989
Saudi Arabia	176	M	12	F-15C Eagle	Us.	1987
			420	Hawk-200	U.K.	1988
			60	Hawk-1 00	U.K.	1990
			12	F-15D Eagle	U.S.	1990
			72	F-15XP	Us.	1992
Iran	1 30+	NBCM	?	MiG-21 F	*E. Germany*	1988
			15	EMB-312 Tucano[d]	*Egypt*	1988
			?	MiG-29	USSR	1990

Country[a]	Total	WMD/M[b]	No.	Type of Aircraft	Supplier[c]	Year
South Africa	7	[N]M?	7	PC-7[d]	Switzerland	1989
Algeria	?	N?M?	?	MiG-29	USSR	1988
Afghanistan	0	M				
Brazil	43	[N]M	11	S2F-1	Canada	1987
			23	F-5E Tiger II	Us.	1988
			3	F-5F Tiger II[d]	Us.	1988
			6	Mirage-3E	France	1988
Vietnam	0	c				
Argentina	0	[NM]				

a See notes to Table 5-8 for explanation of countries listed.
b See key to Table 5-8.
c Supplier countries in italics are not the original producers of the aircraft.
d Trainer

SOURCE: Office of Technology Assessment. Based on information from *SIPRI Yearbooks,* 1988-92 (New York, NY: Oxford University Press, various years) and selected newspaper reports.

future production. Proponents of combat aircraft exports also assert that in the absence of exports, the balance-of-payments deficit would rise and tens of thousands of domestic aerospace workers would lose their jobs. Incentives for former Soviet republics to export military hardware, in the face of severe economic hardship and shortages of hard currency, are even stronger.

In addition to reasons of economics and alliance politics, however, trade in combat aircraft is driven by their utility in a wide range of military roles, including air defense, close-air support, reconnaissance, antiship, and tactical missions. Arms exporters assert that friendly states require combat aircraft to defend themselves. Such trade is also facilitated by the lack of any legal restrictions. Since military aerospace is a multibillion dollar sector in international trade, it will be extremely difficult to slow proliferation of combat aircraft. Establishing meaningful limits would require that major exporting nations adopt a strict multilateral control regime that did not recognize the right of participating nations to make unilateral sales or transfer production technology. Given these economic, political, and military realities, most analysts believe that a regime significantly curtailing trade in aircraft is unlikely to develop anytime soon.[90]

Capabilities of Aircraft for Delivering Weapons of Mass Destruction

Existing aircraft inventories in both advanced and developing nations, and the diffusion of production capacity, indicate that most countries pursuing weapons of mass destruction already have relatively modem combat aircraft capable-after suitable modification-of delivering them to a variety of targets. While these states may be less able to carry out sustained *conventional air* combat, their current aircraft inventories are probably able to deliver weapons of mass destruction, with the possible exceptions of large-scale chemical weapon delivery (which would require a large number of missions) or penetrating the most heavily defended targets. Table 5-10 illustrates some of the capabilities of combat aircraft that have been exported to or are currently possessed by proliferant states.

In considering the requirements for effective delivery of multiple strikes (e.g., for waging

90 Nevertheless, antagonistic nations or alliances of nations could eventually agree among themselves to reduce inventories of combat aircraft, as was done through the Conventional Armed Forces in Europe (CFE) Treaty.

Table 5-10-Capabilities of Selected Combat Aircraft

Aircraft designation and country of origin	Payload [kg]	Combat Radius~ [km]	Generation[b]	Speed[c]
Brazil				
T-27	500	460 (est.)	3.5	low
China				
J-8 (Soviet derivative)	300?	400 (est.)	2	high
J-7 (MiG-21 derivative)	300	600	2	high
J-6 (MiG-19 derivative)	500	350 (est.)	1.5	reed-hi
J-5 (MiG-17 derivative)	200 (est.)	250 (est.)	1	medium
H-5 (Il-28 derivative)	1,000	600 (est.)	1	medium
	3,000	275 (est.)		
H-6 (Tu-16 derivative)	9,000	1,200 (est.)	1	medium
Q-5 (MiG-19 derivative)	1,000	600	1.5	high
France				
Mirage-2000	1,000	370 (est.)	4	high
Mirage F-1	3,500	425	3	high
	500	1,390		
Mirage-5	907	1,300	2.5	high
Mirage III	907	1,200	2	high
Super Etendard	1,500	850 (est.)	3	high
France/Germany				
Alpha Jet	1,100	1,075	2.5	medium
France/U.K. Jaguar	4,000	1,408	3	high
India				
Ajeet (British Gnat derivative)	1,000	204	2	medium
Israel				
Kfir C2/C7	1,200	1,186	3	high
Dagger	(see French Mirage-5)			
South Africa				
Impala I/n (Italian Aermacchi MB-326 derivative)	1,800	130	2.5	low
	90	648		
Chettah	(see French Mirage-5)			
Taiwan				
AT-3	1,900	900 (est.)	2.5	medium
U.K.				
Buccaneer	3,000	900	2	medium
Sea Harrier	1,000	370	3	medium
U.K./Germany/Italy				
Tornado IDS	6,500	1,390	4	high
Us.				
F-16 Falcon	1,400	1,200	4	high
F-15 Eagle	11,000	1,270 (F-15E)	4	high
F-1 4 Tomcat	5,000	805 (est.)	4	high
F-4 Phantom	7,250	1,100	3	high
F-5 Tiger	730	890	2.5	high
F-104 Starfighter	1,500	312 (est.)	2	high
A-4 Skyhawk	4,600	600 (est.)	2	medium

Aircraft designation and country of origin	Payload [kg]	Combat Radius[a] [km]	Generation[b]	Speed[c]
USSR				
MiG-29 Fulcrum	1,400	475	4	high
	1,000	370		
MiG-27 Flogger D	2,000	700 (est.)	3	high
MiG-23 Flogger	2,000	700	3	high
MiG-21 Fishbed	500	740	2	high
SU-25 Frogfoot	4,400	250 (est.)	3.5	medium
SU-24 Fencer	3,000	1,050	3	high
Su-1 7/20/22	1,000	630	2.5	high
SU-7 Fitter	1,000	300 (est.)	2	medium
Tu-22/26 Blinder	12,000	4,000	3	high
Tu-16 Badger	3,790	3,100	1	medium

a Assumes un-refueled high-low-high flight profile carrying specified payload. However, since fuel, payload, range, and speed can be traded against one another, range and payload figures are subject to considerable variability.

b *Generation* designates the following approximate levels of technology: 1 = 1950s; 2 = 1960s; 3 = 1970s; 4 = 1980s. U.S. aircraft of the mid-1970s, however, receive a rating of generation 4.

c *Speed*: low- subsonic, generally propeller driven; medium - near transonic, to barely supersonic in ideal conditions; high = supersonic capability, e.g., roughly Mach 1.2 and above

SOURCE: Office of Technology Assessment. Based, in part, on information drawn from Jane's *All the World's Aircraft, 1978-1991* (Surrey, U. K.: Jane's Information Group Limited, various years).

large-scale chemical warfare), however, additional factors must be taken into account. First, a significant number of aircraft possessed by most developing countries would probably not be combat-ready. Some may have been disassembled to supply spare parts. Others may be in warehouses or in need of repair, and some will likely have crashed,

Second, combat aircraft vary widely in performance and quality in terms of such factors as reliability, serviceability, logistics, pilot ergonomics, thrust-to-weight ratio, turning radius and transient maneuver performance, and electronic countermeasures, Quality factors could affect the ability of aircraft to carry out certain types of missions, especially when facing opposing fighter-interceptors or other significant air defenses.[91] Moreover, as was demonstrated in Iraq, a superior air power might quickly become involved and effectively suppress even one of the larger air forces deployed in the developing world.

Third, few developing countries have expertise in mission planning, rapid turn-around, or accurate weapon delivery. Many developing countries would have difficulty maintaining a skilled core of pilots who are both able and willing to fly missions to deliver weapons of mass destruction. Capabilities for aircraft delivery of weapons at ranges more than 1,000 to 2,000 km are also very limited outside the major industrial powers. Long range delivery might be facilitated by long range bombers, aerial refueling, aircraft carriers, or forward bases. But few proliferant countries, if any, are expected to be able to incorporate these technologies into their air forces anytime soon.

In sum, any of the countries listed in table 5-8 could probably use their air forces to deliver at least a single nuclear weapon (if they possessed one) in a regional context, at ranges between 500 and 1,500 km, and under a wide variety of conditions. Many could mount a small-scale, but nevertheless effective biological or perhaps even

91 Air defense capability can also be supplied by other countries. For example, the United States supplied Israel with AWACS coverage and the Patriot system during the Persian Gulf War.

a chemical strike.[92] If additional nations embark on programs for the development of weapons of mass destruction, it is likely that many of them would already have the capability to deliver such weapons using aircraft. Nevertheless, the ability of several of these countries' air forces—like those of existing proliferants-may be questionable in terms of conducting sustained warfare, delivering large quantities of chemical weapons, or maintaining an attack in the event of third-party intervention.

Summary–Proliferation of WMD-Capable Aircraft

Combat aircraft with the range and payload sufficient to deliver nuclear, chemical, and biological weapons, though possibly requiring some modification, are possessed by almost all countries of proliferation concern. In terms of payloads deliverable at specified ranges, the capabilities of air forces of virtually all of these countries far surpass those of their missiles. Furthermore, there are no internationally binding restrictions on aircraft trade, which, in many cases, continues to be motivated by economic and foreign policy concerns.

Although the complex set of required technologies and expertise make it extremely difficult for countries of proliferation concern to design and manufacture advanced aircraft without external assistance, licensed production arrangements have increasingly spread manufacturing technologies to many parts of the world. Licensed co-production or assembly of Western or former Soviet supersonic aircraft is taking place in China, India, Israel, South Africa, South Korea, and Taiwan. Developing countries that have manufactured components or complete subsonic aircraft with some ground-attack capability include Argentina, Brazil, Chile, and an Arab consortium based in Egypt with the participation of Saudi Arabia, Qatar, and the United Arab Emirates.[93]

Because aircraft and missiles have different relative strengths-particularly in their ability to penetrate defenses—the two systems are not fully interchangeable.[94] Piloted aircraft have significant advantages over other delivery systems in terms of range, payload, accuracy, reliability, damage-assessment capability, and dispersal of chemical or biological agents. They can be used effectively under most circumstances, usually even in the presence of significant air defenses.[95] On the other hand, the unit price of a ballistic or cruise missile is considerably less than that of a piloted airplane, and missile delivery offers both military and psychological advantages, especially for a country wishing to deliver a single nuclear weapon to a heavily defended area.

CRUISE MISSILES AND UNMANNED AERIAL VEHICLES

The Intermediate Range Nuclear Forces (INF) Treaty defines a cruise missile as "an unmanned, self-propelled vehicle that sustains flight through the use of aerodynamic lift over most of its flight path,' and that is intended as a ''weapon-delivery" vehicle. Very short range cruise missiles can be rocket-powered, but longer range ones generally use small jet engines. Unmanned aerial vehicles (UAV) are usually slower moving air-breathing platforms (e.g., using jet or propel-

92 Lack of spare parts can degrade air-force combat *readiness,* but such degradation would not be as important for scenarios involving delivery of a very small number of nuclear or biological weapons.

93 See, for example, Mark Lambert, ed., *Jane's All the World' s Aircraft: 1990-1991* (Surrey, U.K.: Jane' sInformation Group Limited, 1990); and James G. Roche, Northrop Corp., ''Tactical Aircraft, Ballistic and Cruise Missile Proliferation in the Developing World, " paper presented at the AAAS conference Advanced< *Weaponry in the Developing World,* Washington, DC, June 12, 1992.

94 See John R. Harvey, ''Regional Ballistic Missiles and Advanced Strike Aircraft: Comparing Military Effectiveness," *International Security, vol. 17, No. 2.,* Fall 1992, pp. 41-83.

95 For a more detailed analysis of air defense, see Arthur Charo, *Continental Air Defense: A Neglected Dimension of Strategic Defense* (Cambridge, MA: Center for Science and International Affairs, Harvard University, 1990).

ler engines) that are associated with reconnaissance, surveillance, target, or harassment missions rather than weapon delivery. (Any aircraft can theoretically be made into a UAV by incorporating an autopilot, but the term usually refers to systems initially designed for unmanned operation.) Both cruise missiles and UAVs are treated here as having potential for delivering weapons of mass destruction. Although cruise-missile payloads are generally less than those of ballistic missiles and much less than aircraft, the ability of some modern cruise missiles to fly at very low altitudes and slow speeds makes them particularly well suited for delivering chemical and biological weapons.

Indigenous Development

In the past, indigenous development of guidance and propulsion systems for long range cruise missiles presented almost insurmountable barriers for developing countries, In recent years, however, near-revolutionary advances in satellite navigation, long-distance communications, composite materials, and light-weight turbojet and turbofan engines have greatly facilitated cruise-missile development in a growing number of countries. Developing sophisticated, light-weight jet-engine technology remains a significant obstacle for most Third World countries, Nevertheless, crude pulse-jet technology was successfully employed by the Germans in the V-1 "BuzzBomb" as early as World War II, achieving ranges and payloads comparable to the V-2 and Scud missiles.[96] Furthermore, although the MTCR guidelines have restricted export since 1987 of complete systems and dedicated components for systems exceeding the 300 km/500 kg threshold, relatively sophisticated ready-made components from (unrestricted) short range antiship cruise missiles (ASCMs) and UAVs have been readily available for some time.[97] Trade in these components-m any of which have civilian utility—is making the manufacture of longer range systems considerably easier than in the past. Indigenous cruise-missile design and production has therefore become far more difficult to control. Moreover, cruise missiles and UAVs can be much smaller than other aircraft, and many of them can fly at low altitudes and evade radar, thus making them exceedingly difficult to detect.

As of the beginning of 1993, there were only 11 known cruise missile systems in service that exceeded the 1987 threshold of 300 km/500 kg, three in the United States and eight in Russia.[98] The U.S. Air Launched Cruise Missile (ALCM), *Tomahawk*, and Advanced Cruise Missile (ACM) have ranges of 2,500 to 3,000 km when nuclear-armed and over 1,000 km when armed with a conventional payload of 450 kg. Some Russian cruise missiles have 400 to 600-km ranges with 1,000-kg payload; others have about 3,000 km range with 300-kg payload. China and India are believed to have active development programs for cruise missile with ranges of about 600 km, but unknown payloads.

A growing number of countries already have development programs or the ability to manufacture cruise missiles with shorter range than those described above. The five acknowledged nuclear powers have all designed and built advanced jet-powered missiles capable of being further developed to give ranges in excess of 300 km *at supersonic speeds.* Israel, Italy, Japan, Sweden, and Taiwan have all developed subsonic turbojet-

96 See Anthony L. Kay, *Buzz Bomb* (Boylston, MA: Monogram Aviation Publications, 1977).

97 The new MTCR guidelines adopted on January 7, 1993 prohibit the transfer of any ballistic or cruise missiles with range over 300 km, regardless of payload, and any such missiles—regardless of range or payload-if the supplier has reason to believe they may be destined to carry weapons of mass destruction. This would presumably restrict sales by MTCR members of any cruise missiles to suspected proliferant countries (see figure 5-4).

98 Data in this and the following paragraph is from Duncan Lennox, ''Missile Race Continues, ' *Jane's Defence Weekly,* Jan. 23, 1993, p. 20.

powered missiles capable of flying well beyond 300 km. Brazil, Germany, Iraq, and North Korea also appear to have potential cruise missile programs developing a variety of systems, most of shorter range. In addition, Russia exhibited several cruise missile designs in 1992 that could be developed for export, or even remanufactured by other countries to begin programs of their own.[99]

GUIDANCE SYSTEMS

Command guidance

Short range, radio-controlled command guidance systems are relatively simple to design. The Soviets have used command guidance from airplanes, and the United States has developed several such systems. (The Germans also experimented with radio-controlled command guidance in the V-2 ballistic missile.) Several short range ASCMs have also been equipped with TV terminal guidance. Such systems include Israel's Gabriel II, Taiwan's version of the same, called the Hsiung Feng I, and the U.S. Standoff Land Attack Missile (SLAM). However, the range of a command-guided system. is limited by that of the communication link. If a radio link is used, it is susceptible to jamming. And while launch from aircraft can extend the effective range of command-guided missiles, an escort aircraft must then remain within communication range of the missile.

Inertial guidance

Inertial guidance systems are one of the most mature navigation technologies used in ballistic and cruise missiles. They use gyroscopes and accelerometers to determine the missile's orientation and its motion along a particular heading. All gyroscopes are subject to drift error, however, which accumulates guidance inaccuracy over time. Standard high-quality commercial aircraft systems, for example, have errors leading to CEPs on the order of 2 km per hour of flight.[100] (The MTCR prohibits exporting cruise-missile navigation systems that have accuracies better than 10 km on a 300-km course, unless part of manned aircraft.) To compensate for the drift error, systems can utilize externally supplied information to update inertial navigation systems.

TERCOM

Since the 1970s, the United States has been using an advanced guidance system known as TERCOM (Terrain Contour Matching) for guidance of long range cruise missiles. It operates by comparing the altitude profile of the ground under portions of the missile's flight path with terrain maps stored in its computer database. TERCOM's guidance computer makes course corrections based on differences between measured and expected altitude data. Between updates, the missile's flight is usually controlled by an inertial guidance system.[101] However, since TERCOM relies on terrain variation, it is useless for guidance over water, and ill-suited to flat plains or deserts. Furthermore, because TERCOM requires accurate pre-determined terrain maps along the approach to a target-usually requiring advanced satellite techniques to produce—

99 Ibid., pp. 19, 21. Note that U.N. Security Council Resolution 687 prohibits Iraq from maintaining or developing missiles with ranges exceeding 150 km.

'00 See, for example, ''Sagem Shifting to Systems Integration to Expand Role as Avionics Supplier,' *Aviation Week & Space Technology,* May 11, 1992, p. 50. Ring-laser and fiber-optic gyroscopes (the latter still under development) are capable of substantially greater accuracy, but their manufacture is limited to countries with the most advanced electronics industries.

101 Details of the TERCOM *system are* given in John Toomay, '"lkchrdcal characteristics, '' in Richard Betts, cd., *Cruise Missiles: Technology, Strategy, Politics* (Washington, DC: The Brookings Institution, 1981), pp. 36-9. Conventionally-armed versions of the U.S. cruise missiles have a supplementary terminal guidance system known as Digital Scene Matching Area Correlation (DSMAC), which compares a visual image of the target with onc stored in the missile's computer memory.

developing nations have had little means by which to exploit this technology.[102]

NAVSTAR Global Positioning System

Provided a target's coordinates are known in advance, cruise missiles could use satellite navigation such as GPS (see box 5-C) to fly to a target by any route desired. Circuitous routes using a series of waypoints might be chosen, for instance, to avoid heavily defended areas.

Although the MTCR guidelines prohibit export of any GPS receivers that operate above 18 km altitude and 515 rn/see, or those *designed or modified for use in* ballistic missiles or cruise missile with ranges beyond 300 km, many exportable GPS receivers would still be cruise-missile *capable.* Moreover, export restrictions do not apply to GPS receivers for use in aircraft, and the electronic circuitry required to process GPS signals would not be difficult for many countries to duplicate or otherwise obtain.

A number of methods (e.g., differential GPS) have been developed to improve on the accuracy of the GPS signal available to civilian users, but these methods would not be necessary for delivering weapons of mass destruction.[103] For attacks with weapons of mass destruction against second-echelon forces massing behind front lines, or against ''soft' civilian targets or population centers, even the worst-case 100-m accuracy provided by the degraded commercial signal would be sufficient to result essentially in a direct hit.

U.S. DEPARTMENT OF DEFENSE

The air- or ship-launched U.S. Harpoon *antiship cruise missile was first produced in 1977 and has been sold to 19 U.S. allies including Egypt, Iran, Pakistan, South Korea, and Saudi Arabia.*

PROPULSION AND AIRFRAME TECHNOLOGY

Cruise-missile propulsion systems, like guidance systems, are also much more widely available than in the past. Unlike combat aircraft, whose weight and expense mandates large reusable engines, cruise missiles can use much smaller turbojet or turbofan engines. Such engines are now manufactured in over 20 countries.[104] Despite Russia's agreeing to abide by the Missile Technology Control Regime, the former Soviet Union may be a particularly good source of this technology, since the republics have yet to setup

102 Even if high-quality Stereographic images could be purchased from commercial satellite photographic services such as the French SPOT or U.S. Landsat, it is unlikely that sufficient altitude resolution could be obtained for use with TERCOM systems. At most, this imagery might help with terminal guidance if there were distinctive terrain features in the neighborhood of the target and if the cruise missile could be equipped with a radar altimeter.

103 The GPS signal available to commercial users, known as the "Course Acquisition (C/A)" code, contains errors that have been intentionally introduced to degrade accuracy. Differential GPS uses a receiver whose location is accurately known to calculate these errors. This information can then be used to correct the positions of other receivers viewing the same GPS satellites. This method can be used to obtain dramatic improvements even relative to the accuracy available to military users, called the "P-code." Lee Alexander, "Differential GPS in Operation Desert Storm, " *GPS World, vol.* 3, No. 6, June 1992, p. 37. As such, it could be particularly useful in aiming ballistic missiles accurately toward their targets prior to launch, if other methods of doing so were not available. Other techniques for improving on the C/A code have also been developed.

104 See Mark Lambert, cd., *Jane's All the World's Aircraft, 1990-91,* op. cit., footnote *93.* Although small Jet engines are becoming more widely available, they are not required; even old propeller-piston engines could be used in some applications.

Box 5-C-Satellite Navigation Systems and GPS

Space-based navigation systems began their development in the United States and former Soviet Union in the early 1970s, and for a variety of applications can now offer precise navigation services at low cost. The most developed system is the U.S. NAVSTAR Global Positioning System (GPS), which will soon provide accurate position (latitude, longitude, and altitude)and velocity information to receivers anywhere in thewotid.lhefull GPS constellation will include 21 satellites plus three spares, and is scheduled to be operational by 1995.[1]

Using four atomic clocks, each GPS satellite continuously broadcasts its position relative to the center of the Earth along with the precise time. Using this data a receiver can compute its distance from each of the GPS satellites it can observe, and therefore its own position by triangulation. Receivers must have access to a minimum of three simultaneous satellite broadcasts to obtain latitude and longitude information; a fourth satellite is needed to add altitude information.[2]GPS offers the advantages of being unlimitedly range, cheaper than TERCOM, and more accurate than inertial navigation systems by themselves (GPS would normally be combined with an inertial navigation system).[3]

To deny use of GPS's full capabilities to adversaries, GPS satellites broadcast two signals-one intended for use only by authorized U.S. military receivers, known as P-code (Precision Service), and the other for civilian users, known as C/A-code (Coarse/Acquisition). P-code offers position information accurate to within approximately 10 to 15 meters. The accuracy of C/A-code varies depending on how the United States operates the system, but can be in the neighborhood of 30 to 40 meters. Since even 40 meter accuracy is more than the United States wants to provide adversaries during a crisis, the C/A signal can be degraded by a technique known as "Selective Availability," which introduces intentional errors into the code limiting it to 100-m accuracy.[4]Even so, this would be sufficiently accurate for most purposes involving weapons of mass destruction.

Since navigational data of the quality delivered by GPS has very high commercial value, an extensive market in GPS receivers has grown to meet commercial demand. Off-the-shelf GPS receivers are available for less than

1 As of December 1992, 19 satellites were deployed.

2 Artur Knoth, "GPS Technology and Third World Missiles," *International Defense Review*, vol. 25, May 1992, p. 413. One more satellite signal is required than the number of coordinates sought, since the receiver must also calculate and remove the effects of its own clock error.

3 For example, the U.S. Defense Department, which has developed and maintains GPS, will use the satellite system to supplement missile guidance in the new U.S. Standoff Land Attack Missile (SLAM), a variant of the Harpoon anti-ship cruise missile, and in planned upgrades to the land-attack version of the Tomahawk sea-launched wise missiles. See Eric Arnett, "The Most Serious Challenge of the 1990s? Cruise Missiles in the Developing World," in W. Thomas Wander and Eric Arnett, eds., *The Proliferation of Advanced Weaponry: Technology, Motivations, and Responses* (Washington, DC: American Association for the Advancement of Science, 1992). The French company Sagem will offer a plug-in upgrade to its inertial navigation systems to provide navigational updates from a 12-channel GPS receiver. It will also offer the Integrated GPS/Inertial system for sale. See "Sagem Shifting to Systems Integration to Expand Role as Avionics Supplier," *Aviation Week & Space Technology*, May 11,1992, p. 50; and Clifford Bed, "World In a Box: Air Navigation Leaps Forward," *International Defense Review*, vol. 25, May 1992, pp. 417-418.

4 Note, however, that the quoted GPS accuracies pertain to the 95% confidence level, so that 1OO-m "accuracy" here could translate roughly into a 40 to 50-m CEP (50% confidence level). Sources on empirical GPS signal accuracy include Philip Klass, "Inmarsat Decision Pushes GPS to Forefront of Civil Nav-Sat Field," *Aviation Week & Space Technology*, Jan. 14, 1991, p. 34; Bruce D. Nordwall, "Flight Tests Highlight New GPS Uses, Emphasize Need for GPS/Glonass System," *Aviation Week & Space Technology*, Dec. 2,1991, pp. 71-73; and Paul M. Eng, "Who Knows Where You Are? The Satellite Knows," Business Week, Feb. 10, 1992, pp. 120-121. To prevent unauthorized access to the P-code, the GPS system is capable of encrypting it, producing what is called the Y-code.

$500, and relatively expensive, multichannel sets that provide more frequent updates sell for less than $5,000.[5] Receiver prices are likely to continue to drop.

The U.S. Government recognizing the system's civil application, has promised to provide the C/A-code signal free of charge for a period of at least 10 years. Commercial users are also exerting considerable pressure on the U.S. Department of Defense to cease degrading the C/A signal. This pressure is likely to mount, particularly if GPS is widely adopted for use in international air-traffic control.[6]

Two other systems may offer navigational data in the future that can supplement that provided by GPS. The Soviet Union has begun to deploy a system somewhat comparable to GPS called Glonass (Global Navigation Satellite System), and the international satellite agency Inmarsat plans to add GPS-like signals to its third generation of satellites.[7] Combining data received from the three systems would allow increased accuracy and reliability y, including the capability for real-time verification of the integrity of individual satellite signals.[8]

The Glonass system, which would provide the same accuracy to all users, advertises plus-or-minus 17-m accuracy 50 per cent of the time, comparable to P-code GPS accuracy.[9] However, only about 8 of the first 32 *Glonass* satellites deployed are still in operation, and given the political situation in Russia, the system's fate is uncertain.[10]

5 Inexpensive single-channel receivers, more appropriate for boaters than for aircraft, must switch sequentially among four GPS satellites in order to compute position; multichannel receivers allow reception from more than one satellite at a time, which improves accuracy and update-speed. Receivers with 6 channels are widely available, and 12 channels can aiso be obtained. See Gordon West, "Navigation," *Motor Boating & Sailing*, voi. 168, No. 4, October 1991, pp. 65-77; and Jeff Hum, *GPS: A Guide to the Next Utility* (Sunnyvale, CA: Trimble Navigation, 1989).

6 See Philip J. Klass, "FAA Steps Up Program to introduce GPS as instrument Approach Aid," *Aviation Week & Space Technology*, Aug. 17, 1992, p. 38.

7 See, for example, Klass, "Inmarsat Decision. . .", op. dt., footnote 4, p. 34. One reason for Inmarsat's decision to provide satellite navigation is concern that the United States may not continue to provide GPS services.

8 Simultaneous access to five broadcasting satellites is sufficient to detect whether one of the satellites is malfunctioning, but six signals are needed to identify which one is in error. When the GPS constellation is complete, however, there should be enough satellites at any time in one's line-of-sight that this should not present a problem. See Bruce D. Nordwall, "Flight Tests Highlight New GPS Uses, Emphasize Need for GPS/Glonass System," *Aviation Week & Space Technology, Dec. 2, 1991,* p. 71.

9 Artur Knoth, "GPS Technology and Third World Missiles," Op. dt, footnote 2, P. 414.

10 Klass, "Inmarsat Decision. . .", op. cit., footnote 4, p. 35.

an effective system of export controls.[105] Moreover, Ukraine, which holds a substantial fraction of the former Soviet Union's military aerospace industry,[106] has not yet agreed to abide by MTCR constraints, Antiship cruise missiles (ASCMs) purchased from Russia or elsewhere could also provide a proliferant country with engines suitable to power its own airframes up to perhaps a few hundred kilometers. ASCMs are widely available and, due to their short range, are generally exempt even from the new MTCR restrictions.

Nevertheless, very small, lightweight, and fuel-efficient engines, which are particularly important for longer range or stealthy cruise missiles, are still very difficult for proliferant countries to acquire.

105 See, for example, William C. Potter, "Exports and Experts: Proliferation Risks from the New Commonwealth,'' *Arms Control To&y*, vol. 22, No. 1, July/August 1992, pp. 32-37; and Jeffrey M, Lenorovitz, ''Russian Engine Firms Strive to Realign, ' *Aviation Week & Space Technology*, March 30, 1992, pp. 38-9.

106 See, for example, Central Intelligence Agency, Directorate of Intelligence, "The Defense Industries of the Newly Independent States of Eurasia, " OSE 93-10001, January 1993, p. 7.

Airframes are probably the easiest part of cruise missiles to produce indigenously. Unlike combat aircraft, cruise missiles need only fly once, lessening the requirements for fatigue-resistant materials. They are also smaller, mostly subsonic, and need only accelerate modestly, thus avoiding the need for the type of high-strength or specialized materials typically found in ballistic missiles and reentry vehicles.[107] Unless high-speed maneuvers are required, cruise missiles and UAVs can more easily use light-weight or even radar-absorbent materials that would not ordinarily stand up to great aerodynamic stresses.[108] And since they require no cockpit or features to protect a pilot, they can be built much more cheaply and with smaller radar cross-sections than can piloted aircraft.

In sum, any country that supports an aerospace industry or has a modest industrial infrastructure should be able to integrate commercially available GPS receivers, turbojet engines taken from imported ASCMs, and indigenously built composite airframes to build its own cruise missiles. If launched from manned aircraft, the effective range of such cruise missiles could be increased substantially. Harder, though, would be to build cruise missiles with ranges far exceeding 300 km (carrying 500 to 1,000-kg payloads) or long range cruise missiles with low-observable (stealthy) technology.

OPERATIONAL FACTORS

To remain undetected by air defenses, cruise missiles can be made to fly at very low altitudes, exploiting the natural radar cover offered by reflections off trees, buildings, hills and other features of the terrain.[109] (Other techniques for increasing the probability of penetrating defenses include stealth technologies, supersonic speeds, or high-altitude approaches that might be detected but not easily engaged by air defense systems. U.S. and Soviet systems have incorporated a number of these techniques.) Low flight, however, increases the risks of crashing and sacrifices fuel efficiency.[110] Look-ahead radars and maneuverability can lessen the risk of crashes, but their weight will decrease a cruise missile's range, and their signal may help defenses locate them. These also require fairly sophisticated guidance and control technologies.

Early generation land-attack cruise missiles were particularly vulnerable to defenses, as demonstrated by the largely unsuccessful attempt by Egypt to use them against Israel in the Yom Kippur War of 1973. To saturate air defenses and increase the probability of key weapons getting through, a state may therefore wish to accompany a few cruise missiles carrying weapons of mass destruction with a large number of decoys. But such tactics would only be needed when attacking defended areas. The number of cruise missiles needed for guaranteed penetration would thus be highly scenario-dependent.[111]

The GPS system was designed to operate with completely passive receivers, obviating the need to send any signal back to the satellites. Receivers can therefore operate undetected. However, since GPS radio signals can be weak even compared with background noise levels, in theory they can

107 This advantage is less salient in cruise missiles designed for underwater launch from submarines, because the stresses inherent in changing pressure environments during flight require stronger materials.

108 Sir Michael Armitage, *Unmanned Aircraft, Brassey's Air Power, Volume 3* (London: Brassey's Defense Publishers, 1988), p. 121.

109 See William E. Dean, *How Low Can an Unmanned Aerial Vehicle Fly?*, RAND Paper P-7680-RGS (Santa Monica, CA: RAND Graduate School, October, 1990).

110 The air-breathing engines used in most cruise missiles function more efficiently at higher altitudes, where the less dense air reduces both the drag on the airframe and the quantity of fuel necessary for efficient combustion.

111 See, for example, Charo, *Continental Air Defense*, op. cit., footnote 95.

be jammed, at least for short periods of time.[112] (Between GPS updates, or if jammed, a cruise missile would have to fly using an inertial system.) Although all GPS satellites broadcast on the same frequency, each Glonass satellite broadcasts at its own frequency, and Inmarsat satellites will provide still more frequencies,[113] thus making it difficult to jam the entire future suite of satellite navigation signals. Furthermore, an incoming cruise missile must be detected ahead of time in order for jamming attempts to be activated.

At least for short range missile guidance, fiber-optic technology may also take on an increasing role in the future. The United States and Brazil have developed systems that connect antitank and antihelicopter missiles to controllers at distances up to 15 km. These systems use fiber-optic cables that spin off the end of a reel when the missile is launched.[114] Although optic cables can transmit signals over hundreds of kilometers without serious distortion, in practice these systems would probably be limited to about 100 km or less.[115] At such ranges, much simpler command-guidance systems are also available.

Availability of Cruise Missiles and UAVs

No *land attack* cruise missiles are known to have been exported by the principal exporters of cruise missiles (the five acknowledged nuclear powers and Italy), and there is little reason to believe that these will be exported in the future.[116] Furthermore, no potential proliferant state is publicly known to have developed or acquired cruise missiles for the purpose of delivering weapons of mass destruction. Still, acquisition by such countries cannot be ruled out. Many of the components and technologies for producing cruise missiles fall outside of MTCR constraints, or can be obtained by converting civil systems, cannibalizing readily available ASCMs, or purchasing cruise missiles from non-MTCR suppliers.

ANTISHIP CRUISE MISSILES

The effectiveness of ASCMs frost gained notoriety in 1967, when Soviet-built Styx antiship missiles launched by Egypt sank the Israeli destroyer *Eilat.* More recently, incidents involving ASCMs drew worldwide attention when French-built *Exocet missiles* destroyed the HMS *Sheffield in the 1982* Falklands War and damaged the USS *Stark in 1987 in the* Persian Gulf.

Although only 11 countries have designed and produced ASCMs indigenously, ASCMs can

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112 The ability to jam GPS signals is still the subject of some debate. Directional antennas designed to receive GPS signals from above may be less susceptible to jamming. Edward R. Harshberger, Long Range *Conventional Missiles: Issues for Near-Term Development, RAND* Note N-3328-RGSD (Santa Monica, CA: RAND Graduate School, 1991), p. 105. Furthermore, the nature of the signals broadcast by GPS satellites should make it possible using special signal-processing techniques to distinguish even very weak broadcasts from background noise or from powerful jamming signals, making GPS "a very hardy system." Jeff Hurn, *GPS: A Guide to the Next Utility (Sunnyvale,* CA: Trimble Navigation, 1989), p. 8.

113 Philip Klass, "Inmarsat Decision Pushes GPS to Forefront of Civil Nav-Sat Field," *Aviation Week* & *Space Technology,* January 14,1991, p. 34.

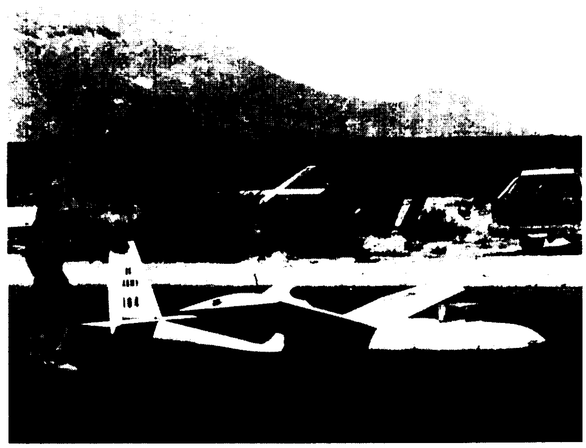
114 The U.S. Navy is also experimenting with air-launched, fiber optically-guided antiship cruise missiles. "U.S. Navy Tests Fiber-Optic Data Links for Air-Launched Weapons," *Aviation Week & Space Technology,* June 12, 1989, pp. 275-8.

115 Hughes representatives indicated in a statement quoted in "U.S. Navy Tests Fiber-Optic Data. . .," ibid., that a 100-km range is near the limit for these systems. See also Carl White, "Light Fantastic: Fiber Optics: The Core of High-Tech Programs," *Sea Power, vol.* 34, *Mar@* 1991, p. 28.

116 W.Seth Carus, *Cruise Missile Proliferation in the 1990s* (Washington, DC: Center for Strategic and International Studies, 1992), p. *32.*

U.S. DEPARTMENT OF DEFENSE

First produced around 1980, the Chinese Silkworm *liquid-fueled rocket-powered antiship cruise missile has been exported to Egypt, Iran, Iraq, and Pakistan, and is coproduced under license in North Korea.*



WARREN WEAVER, U.S. ARMY

A remotely piloted vehicle ready for testing at White Sands Missile Range, NM. This ground-controlled fixed wing vehicle with a cruising speed of 60 knots is designed to carry sensors. It is not a weapon system and is not designed to penetrate defenses. However, similar vehicles might be adaptable for weapon purposes, for example, for biological attacks against undefended targets.

readily be purchased.[117] They have consequently proliferated even more widely than ballistic missiles, with over 40 Third World countries now operating them.[118] Three systems in Particular have been widely exported: the Chinese *Silkworm* (95 km/510 kg); the Soviet Styx (80 km/500 kg); and the French *Exocet* (65 km/165 kg). Other systems exported to Third World countries include the British *Sea Eagle,* Israeli *Gabriel I/II,* Italian *Otomat,* and U.S. *Harpoon* (see table 5-11). Of these, the *Otomat* and *Harpoon* have the longest ranges, at 180 km and 220 km, respectively, but still fall short of the MTCR threshold.

Many ASCMs rely on active radar or infrared homing devices for terminal guidance against ships on the open ocean, which stand out readily from their surroundings. As such, ASCMs would not be very useful for land attacks except against distinctive short range targets. To give ASCMs a true land-attack capability, their homing systems would have to be replaced or supplemented by another type of guidance.[119]

Nevertheless, most ASCMs also use a rudimentary inertial-guidance system to navigate into the vicinity of a target that would be transferable

117 The 11 countries with indigenous cruise-missiles are the five declared nuclear powers plus Germany, Israel, Italy, Japan, Norway, and Sweden. Six other countries either currently manufacture ASCMs based on another country's design or have their own systems under development: Brazil, India, Iraq, North Korea, South Africa, and Taiwan. Cams, *Cruise Missile Proliferation in the 1990s,* ibid., pp. 34, 126-133 (table B-4); and Duncan Lennox and Arthur Rees, eds., *Jane's Air-Launched Weapons (Surrey, UK:* Jane's Information Group, 1990), Issues 8 and 9.

118 Carus, *Cruise Missile Proliferation in the 1990s,* op. cit., footnote 116, p. 34. Even though many ASCMs cost more than a half million dollars apiece, there has been considerable interest among Third World countries in purchasing ASCMs.

119 The United States developed the Standoff Land Attack Missile (SLAM) by replacing the seeker of the Harpoon ASCM with a television terminal guidance system. Other countries that would likely be able to replace a traditional ASCM seeker with TV guidance include Israel, India, South Africa, Taiwan, and possibly South Korea. Carus, *Cruise Missile Proliferation in the 1990s,* op. cit., footnote 116, p. 131.

Table 5-1 I—Selected Cruise Missiles and their Characteristics

Designation	Range [km]	Payload [kg]	Comment
ASCM Systems not exceeding the 1987 MTCR threshold of 300 k&500 kg:			
British Sea Eagle.	110	230	1985; turbojet; exported to Germany, India
Chinese HY-2. . . . . (Soviet SS-N-2 derivative)	95	510	+1980; "Silkworm"; liquid-fuel rocket-powered; exported to Egypt, Iran, Iraq, Pakistan, and co-produced under license in DPRK
Chinese HY-4.	135	500	late 1980s; turbojet
French Exocet.	65	165	1979; solid-rocket powered; widely sold; operated by over 25 countries
German Kormoran 2.	55+	220	1993; air-launched, rocket powered; operated only by Germany and Italy
Israeli Gabriel Mk-II.	40	180	1976; solid-rocket powered; licensed variants produced in Taiwan and South Africa; exported to Chile, Ecuador, Kenya Singapore, Thailand
Israeli Gabriel Mk-IV.	200	1 50+	1993?; turbojet (under development)
Italian Otomat Mk-II.	180	210	1984; turbojet; European consortium; exported to Egypt, Iraq, Kenya, Libya, Nigeria, Peru, Saudi Arabia, and Venezuela
Japanese SSM-1.	150	250	1988; turbojet; land-, ship-, or submarine-launched
Norwegian Penguin Mk-III. . . .	40+	120	1987; solid-rocket powered; exported to Greece, Turkey, Sweden, and United States
Soviet SS-N-2C.	80	500	1962; "Styx"; liquid-rocket powered; exported to Algeria, Angola, Cuba Egypt, Ethiopia, Finland, India, North Korea, Libya, Somalia, Syria, Vietnam, Yemen, Yugoslavia; licensed production in Iraq
Soviet AS-5.	230	1000	1966; liquid-rocket powered; "Kelt"; past exports to Egypt and Iraq; may exceed MTCR limits; land-attack and ASCM capability
Swedish RBS-15.	70-150	250	1989; turbojet; exported to Finland, and possibly to Yugoslavia
Taiwanese Hsiung Feng-2. . .	80-180	75?	1993?; turbofan?; (pre-production development)
U.S. Harpoon.	120-220	220	1977; turbojet; air- and sea-launch platforms; sold to 19 U.S. allies including Egypt, Iran, Pakistan, South Korea, and Saudi Arabia; land-attack version (SLAM) has shorter range and television terminal guidance
Selected longer range cruise missiles (restricted from export by MTCR guidelines):			
Soviet SS-N-3.	460	1000	1963; turbojet; "Shaddock"; strategic/anti-ship; launched from land, surface ships, and surfaced submarines; sold to Syria and Yugoslavia
Soviet AS-6.	560	1000	1973; solid-rocket powered; "Kingfish"; Mach 3.5; land-attack capability; can be nuclear-armed
Soviet SS-N-21.	3000	300	1987; turbofan; "Sampson"; nuclear-armed
U.S. Tomahawk.	480-1250	450	1983; turbofan; HE warhead; 2500-km range with 300-kg payload
U.S. ACM.	3000	?	1992; nuclear-armed; stealthy; air-launched

SOURCE: W.Seth Carus, *Cruise Missile Proliferation in the 1990s* (Washington, DC: Center for Strategic and International Studies, 1992); *Jane's A/rLaunched* Weapons, Issue 09, and *Jane's Strategic Weapons Systems,* Issue 07 (Surrey, U.K.: Jane's Information Group Limited, 1992); and James G. Roche, Northrop Corp., "Tactical Aircraft, Ballistic and Cruise Missile Proliferation in the Developing World, " paper presented at the AAAS conference *Advanced Weaponry in the Developing World,* Washington, DC, June 12, 1992.

to other platforms and missions. Systems such as the Israeli Gabriel II, which has been exported to several Third World countries (see table 5-1 1), use TV-terminal guidance and can therefore be used against land targets. Furthermore, typical ASCM payloads of 100 to 500 kg (sufficient for many types of high-explosive armor-piercing warheads) would be sufficient to carry biological agents or modest amounts of chemical agent. Soviet export models and some ASCMs copied by other countries have payloads of 500 to as much as 1,000 kg, which may be sufficient to carry proliferant nuclear warheads.[120]

UNMANNED AERIAL VEHICLES

An alternative to developing or modifying cruise missiles would be to purchase commercially available unmanned aerial vehicles (UAVs). Modern over-land UAVs are used in a wide variety of roles around the world, and could be purchased under the guise of surveillance for fighting drug trafficking,, forest fires, or illegal immigration. A state could then disassemble them for parts or mod@ them for weapon-delivery .121 UAVs or "target drones" could also be made from expendable auto-piloted aircraft programmed for one-way missions.

UAVs offer many of the characteristics of cruise missiles.[122] However, most of them do not have suitable payload or range to be useful for carrying weapons of mass destruction. For instance, many are intended for short range reconnaissance missions, carrying sensor-payloads of 20 to 40 kg to ranges of less than 100 km.[123] Others are designed as target or harassment drones or for long endurance flight, but with payloads well under 100 kg. Nevertheless, longer range systems able to carry several hundred kilograms to ranges of several hundred kilometers have been designed in recent years by a number of companies.[124]

One example is the Teledyne-Ryan Model 350, built under contract in the United States as a surveillance platform. This UAV has a wingspan and length of only 3.2 m and 5 m, respectively, making it hard for enemy air defenses to detect .[125] Its turbojet engine can achieve speeds of Mach 0.9 and carry a 146-kg payload to a range of 1,500 km and back. It is based on an earlier model (Model 324, or "Scarab") sold to the Egyptian armed forces in 1988 for reconnaissance purposes.[126] Although the Scarab can carry 113 kg to a range of 1,000 km and back, it could not carry payloads exceeding the 500 kg MTCR threshold without substantial redesign and in-field modification. Its

120 Both the United States and the former Soviet Union have produced *nuclear-armed* ASCMs for their own fleets, but each has now committed to removing them.

121 The most successful combat use of UAVs by developing countries was in the 1982 Israeli action against *Syrian* air defenses in the Bekaa Wiley in Lebanon. There, Israeli- and U.S.-designed UAVs were used for both reconnaissance and harassment. UAVs caused Syrian SAM air-defense batteries to trigger their fire control radar, leaving the SAMS open to Israeli anti-radiation missiles without exposing Israeli aircraft to the air defenses. The Syrians lost 19 out of 20 SAM batteries and 86 combat aircraft, while Israel lost one combat aircraft. Sir Michael Armitage, *Unmanned Aircraft, Brassey's Air Power, Volume 3,* op. cit., footnote 108, pp. 85-6.

122 For training, in fact, some UAVs are specifically designed to mimic the characteristics of cruise missiles. Don Flamm, "Defense Technology: Unmanned Aerial Vehicles," *Asian Defense Journal,* August, 1991, p. 27.

123 See, for ~-pie, E.R. Hooton and Kenneth Munson, eds., *Jane's Battlefield Surveillance Systems, 3rd edition, 1991-92* (Surrey, UK: Jane's Information Group, 1991).

124 Stefan Geisenheyner, "Current Developments in Unmanned Aerial Vehicles," *Armada International,* vol. 14, October/November, 1990, pp. 78-80.

125 Technical data for the Model 350 is taken *from Jane' s Battlefield Surveillance Systems,* op. cit., footnote 123, p. 229; and Geisenheyner, "Current Developments in Unmanned Aerial Vehicles," op. cit., footnote 124, pp. 80-3.

126 The Scarab is built almost entirely of low radar-cross-section Kevlar-epoxy composites and can be programmed for long range guidance using a satellite navigation system and up to 100 waypoints. Don Flamm, 'Defense Technology: Unmanned Aerial Vehicles,' op. cit., footnote 122, p. 28.

export to Egypt was only approved by the United States subject to a U.S.-Egypt bilateral agreement *restricting* its use to reconnaissance within Egypt, forbidding modification, and giving the United States the right to inspect the inventory on short notice.[127]

Other examples of UAVs that could be given ground-attack capabilities include indigenously produced target drones or small RPVs built by Argentina, India, Iran, and Iraq.[128] Many of these have payloads well under 100 kg, however.

| Monitoring Cruise Missile Acquisition

Given the number of options available for their acquisition, cruise missiles will be extremely difficult to monitor in the developing world. Some cruise-missile related technologies-for example, GPS receivers—have so many legitimate uses that commercial sales receive little notice. Even UAV systems that require export notification or licensing have both civilian and military uses completely unrelated to the delivery of weapons of mass destruction, and whose promotion may well be in the interest of the exporting nation.

Indigenous production or cannibalization of ASCMs to acquire cruise missiles would be difficult to detect.[129] Although flight tests would certainly be required, cruise missiles have few readily identifiable inflight observables; they expel only modest amounts of heat and remain well within the atmosphere. Low-flying cruise missiles are difficult to detect even in wartime, when airspace is carefully monitored, illustrating the difficulty of detecting covert tests. The proliferation of at least short range cruise missiles could therefore prove to be an intractable problem over the next decade or so. Fortunately, longer range land-attack systems are not yet available to proliferant countries and are still amenable to some measure of control through the MTCR.

127 Major Patrick Michelson, Egypt country director, Office of the Secretary of Defense, private communication, June 2, 1993.

128 Roche, "Tactical Aircraft. . .," op. cit., footnote 93, p. 11.

129 See, fo, example, U.S. Congress, Office of Technology Assessment, *Monitoring Limits on Sea-Launched Cruise Missiles*, OTA-ISC-513 (Washington+ DC: U.S. Government Printing Office, September 1992), pp. 11,21.