ment, hydraulic pumps, actuators, electrical generators, environmental control system, auxiliary power unit, and gun bay.

The worst feature an aircraft can have for maintainability is a requirement for major structural disassembly to access or remove a component. For example, the V/STOL AV-8B Harrier requires that the entire wing be removed before removing the engine. Several aircraft require removal of a part of the longeron to remove the wing.

Similarly, the designer should avoid placing internal components such that one must be removed to get to another. In the F-4 Phantom, an ejection seat must be removed to get to the radio (a high-break-rate item). It is not uncommon for the ejection seat to be damaged during this process. "One-deep" design will avoid such problems.

9 CREW STATION, PASSENGERS, AND PAYLOAD

9.1 INTRODUCTION

At the conceptual design level it is not necessary to go into the details of crew-station design, such as the actual design and location of controls and instruments, or the details of passenger and payload provisions. However, the basic geometry of the crew station and payload/passenger compartment must be considered so that the subsequent detailed cockpit design and payload integration efforts will not require revision of the overall aircraft.

This chapter presents dimensions and "rule-of-thumb" design guidance for conceptual layout of aircraft crew stations, passenger compartments, payload compartments, and weapons installations. Information for more detailed design efforts is contained in the various civilian and military specifications and in subsystem vendors' design data packages.

9.2 CREW STATION

The crew station will affect the conceptual design primarily in the vision requirements. Requirements for unobstructed outside vision for the pilot can determine both the location of the cockpit and the fuselage shape in the vicinity of the cockpit.

For example, the pilot must be able to see the runway while on final approach, so the nose of the aircraft must slope away from the pilot's eye at some specified angle. While this may produce greater drag than a more-streamlined nose, the need for safety overrides drag considerations. Similarly, the need for over-side vision may prevent locating the cockpit directly above the wing.

When laying out an aircraft's cockpit, it is first necessary to decide what range of pilot sizes to accommodate. For most military aircraft, the design requirements include accommodation of the 5th to the 95th percentile of male pilots, (i.e., a pilot height range of 65.2–73.1 in.). Due to the expense of designing aircraft that will accommodate smaller or larger pilots, the services exclude such people from pilot training.

Women are only now entering the military flying profession in substantial numbers, and a standard percentile range for the accommodation of female pilots had not yet been established as this was written. Future military aircraft might require the accommodation of approximately the 20th percentile female and larger. This may affect the detailed layout of cockpit controls and displays, but should have little impact upon conceptual cockpit layout.

General-aviation cockpits are designed to whatever range of pilot sizes the marketing department feels is needed for customer appeal, but typically are comfortable only for those under about 72 in. Commercial-airliner cockpits are designed to accommodate pilot sizes similar to those of military aircraft.

Figure 9.1 shows a typical pilot figure useful for conceptual design layout. This 95th percentile pilot, based upon dimensions from Ref. 22, includes allowances for boots and a helmet. A cockpit designed for this size of pilot will usually provide sufficient cockpit space for adjustable seats and controls to accommodate down to the 5th percentile of pilots.

Designers sometimes copy such a figure onto cardboard in a standard design scale such as twenty-to-one, cut out the pieces, and connect them with pins to produce a movable manikin. This is placed on the drawing, positioned as desired, and traced onto the layout. A computer-aided aircraft design system can incorporate a built-in pilot manikin (see Ref. 14).

Dimensions for a typical cockpit sized to fit the 95th-percentile pilot are shown in Fig. 9.2. The two key reference points for cockpit layout are shown. The seat reference point, where the seat pan meets the back, is the reference for the floor height and the legroom requirement. The pilot's eye point is used for defining the overnose angle, transparency grazing angle, and pilot's head clearance (10-in. radius).

This cockpit layout uses a typical 13-deg seatback angle, but seatback angles of 30 deg are in use (F-16), and angles of up to 70 deg have been considered for advanced fighter studies. This entails a substantial penalty in

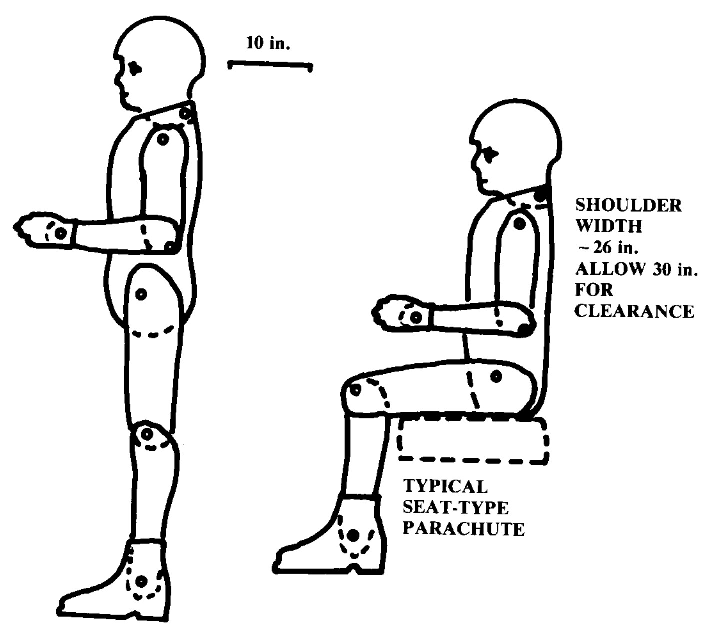

Fig. 9.1 Average 95th percentile pilot.

outside vision for the pilot, but can improve his ability to withstand high-*g* turns and also can reduce drag because of a reduction in the cockpit height.

When designing a reclined-seat cockpit, rotate both the seat and the pilot's eye point about the seat reference point, and then use the new position of the pilot's eye to check overnose vision.

Overnose vision is critical for safety especially during landing, and is also important for air-to-air combat. Military specifications typically require 17-deg overnose vision for transports and bombers, and 11–15 deg for fighter and attack aircraft. Military trainer aircraft in which the instructor pilot sits behind the student require 5-deg vision from the back seat over the top of the front seat.

Various military specifications and design handbooks provide detailed requirements for the layout of the cockpit of fighters, transports, bombers, and other military aircraft.

General-aviation aircraft land in a fairly level attitude, and so have overnose vision angles of only about 5–10 deg. Many of the older designs have such a small overnose vision angle that the pilot loses sight of the runway from the time of flare until the aircraft is on the ground and the nose is lowered.

Civilian transports frequently have a much greater overnose vision angle, such as the Lockheed L-1011 with an overnose vision angle of 21 deg. Civilian overnose vision angles must be calculated for each aircraft based upon the ability of the pilot to see and react to the approach lights at decision height (100 ft) during minimum weather conditions (1200-ft runway visual range). The higher the approach speed, the greater the overnose vision angle must be.

Reference 23 details a graphical technique for determining the required overnose angle, but it can only be applied after the initial aircraft layout is complete and the exact location of the pilot's eye and the main landing gear is known. For initial layout, Eq. (9.1) is a close approximation, based upon the aircraft angle of attack during approach and the approach speed.

$$\alpha_{\text{overnose}} \cong \alpha_{\text{approach}} + 0.07\, V_{\text{approach}} \tag{9.1}$$

where V_{approach} is in knots.

Figure 9.2 shows an over-the-side vision requirement of 40 deg, measured from the pilot's eye location on centerline. This is typical for fighters and attack aircraft. For bombers and transports, it is desirable that the pilot be able to look down at a 35-deg angle without head movement, and at a 70-deg angle when the pilot's head is pressed against the cockpit glass. This would also be reasonable for general-aviation aircraft, but many general-aviation aircraft have a low wing blocking the downward view.

The vision angle looking upward is also important. Transport and bomber aircraft should have unobstructed vision forwards and upwards to at least 20 deg above the horizon. Fighters should have completely unobstructed vision above and all the way to the tail of the aircraft. Any canopy structure should be no more that 2 in. wide to avoid blocking vision.

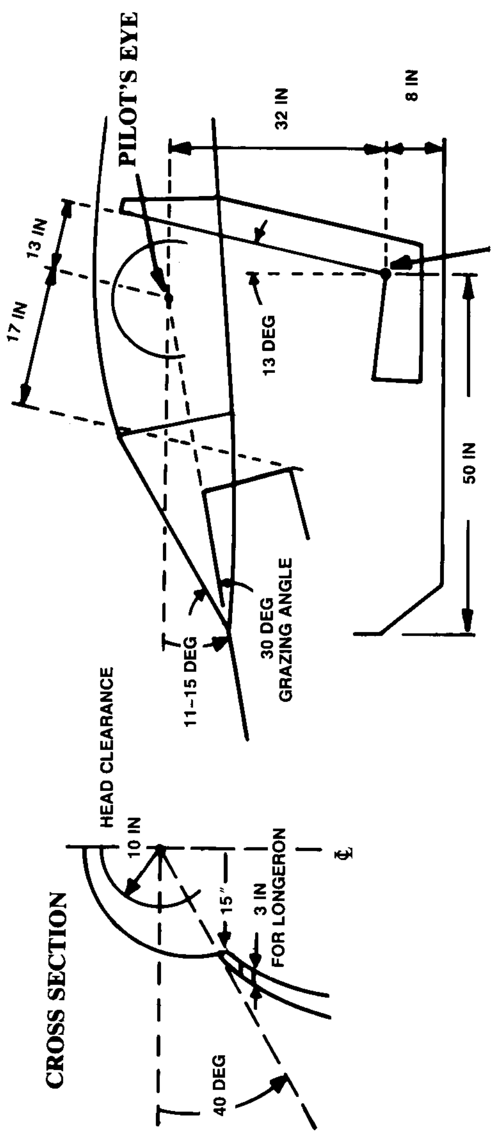

Fig. 9.2 Typical fighter cockpit.

The transparency grazing angle shown in Fig. 9.2 is the smallest angle between the pilot's line of vision and the cockpit windscreen. If this angle becomes too small, the transparency of the glass or plexiglass will become substantially reduced, and under adverse lighting conditions the pilot may only see a reflection of the top of the instrument panel instead of whatever is in front of the aircraft! For this reason, a minimum grazing angle of 30 deg is recommended.

The cockpit of a transport aircraft must contain anywhere from two to four crew members as well as provisions for radios, instruments, and stowage of map cases and overnight bags. Reference 23 suggests an overall length of about 150 in. for a four-crewmember cockpit, 130 in. for three crewmembers, and 100 in. for a two-crewmember cockpit.

The cockpit dimensions shown in Fig. 9.2 will provide enough room for most military ejection seats. An ejection seat is required for safe escape when flying at a speed which gives a dynamic pressure above about 230 psf (equal to 260 knots at sea level).

At speeds approaching Mach 1 at sea level (dynamic pressure above 1200), even an ejection seat is unsafe and an encapsulated seat or separable crew capsule must be used. These are heavy and complex. A separable crew capsule is seen on the FB-111 and the prototype B-1A. The latter, including seats for four crew members, instruments, and some avionics, weighed about 9000 lb.

9.3 PASSENGER COMPARTMENT

The actual cabin arrangement for a commercial aircraft is determined more by marketing than by regulations. Figure 9.3 defines the dimensions of interest. "Pitch" of the seats is defined as the distance from the back of one seat to the back of the next. Pitch includes fore and aft seat length as well as leg room. "Headroom" is the height from the floor to the roof over the seats. For many smaller aircraft the sidewall of the fuselage cuts off a portion of the outer seat's headroom, as shown. In such a case it is important to assure that the outer passenger has a 10-in. clearance radius about the eye position.

Table 9.1 provides typical dimensions and data for passenger compartments with first-class, economy, or high-density seating. This information (based upon Refs. 23, 24, and others) can be used to lay out a cabin floor plan.

There should be no more than three seats accessed from one aisle, so an aircraft with more than six seats abreast will require two aisles. Also, doors and entry aisles are required for approximately every 10–20 rows of seats. These usually include closet space, and occupy 40–60 in. of cabin length each.

Passengers can be assumed to weigh an average of 180 lb (dressed and with carry-on bags), and to bring about 40–60 lb of checked luggage. A current trend towards more carry-on luggage and less checked luggage has been overflowing the current aircrafts' capacity for overhead stowage of bags.

The cabin cross section and cargo bay dimensions (see below) are used to determine the internal diameter of the fuselage. The fuselage external di-

Table 9.1 Typical passenger compartment data

	First class	Economy	High density/ small aircraft
Seat pitch (in.)	38–40	34–36	30–32
Seat width (in.)	20–28	17–22	16–18
Headroom (in.)	>65	>65	–
Aisle width (in.)	20–28	18–20	≥12
Aisle height (in.)	>76	>76	>60
Passengers per cabin staff (international-domestic)	16–20	31–36	≤50
Passengers per lavatory (40″ × 40″)	10–20	40–60	40–60
Galley volume per passenger (ft³/pass)	5–8	1–2	0–1

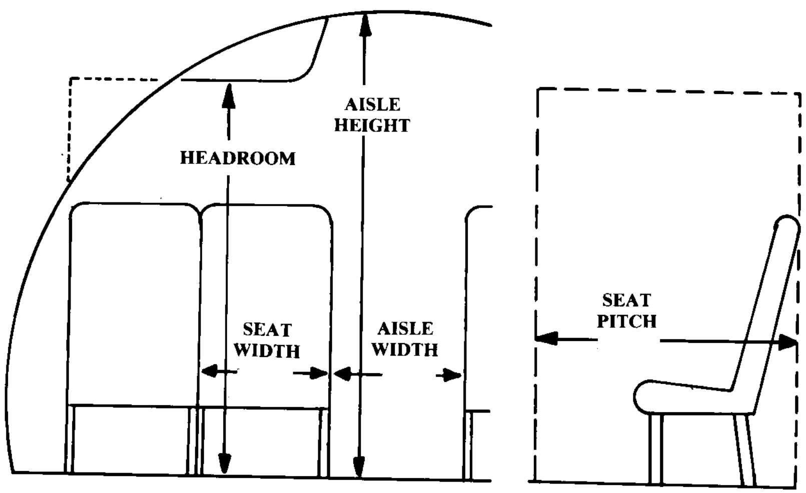

Fig. 9.3 Commercial passenger allowances.

ameter is then determined by estimating the required structural thickness. This ranges from 1 in. for a small business or utility transport to about 4 in. for a jumbo jet.

9.4 CARGO PROVISIONS

Cargo must be carried in a secure fashion to prevent shifting while in flight. Larger civilian transports use standard cargo containers that are pre-loaded with cargo and luggage and then placed into the belly of the aircraft. During conceptual design it is best to attempt to use an existing container rather than requiring purchase of a large inventory of new containers.

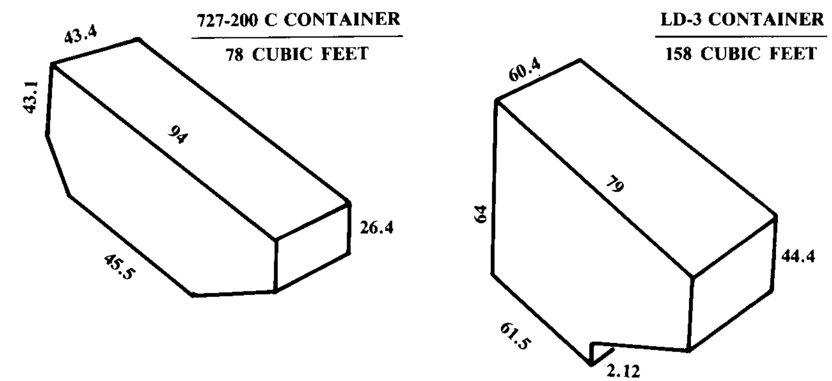

Fig. 9.4 Cargo containers.

Two of the more widely used cargo containers are shown in Fig. 9.4. Of the smaller transports, the Boeing 727 is the most widely used, and the 727 container shown is available at virtually every commercial airport.

The LD-3 container is used by all of the widebody transports. The B-747 carries 30 LD-3's plus 1000 ft^3 of bulk cargo volume (non-containered). The L-1011 carries 16 LD-3's plus 700 ft^3 of bulk cargo volume, and the DC-10 and Airbus each carry 14 LD-3's (plus 805 and 565 ft^3, respectively, of bulk cargo volume).

To accommodate these containers, the belly cargo compartments require doors measuring approximately 70 in. on a side. As was discussed in the section on wing vertical placement, low-wing transports usually have two belly cargo compartments, one forward of the wing box and one aft.

The cargo volume per passenger of a civilian transport ranges from about 8.6–15.6 ft^3 per passenger (Ref. 24). The smaller number represents a small short-haul jet (DC-9). The larger number represents a transcontinental jet (B-747). The DC-10, L-1011, Airbus, and B-767 all have about 11 ft^3 per passenger. Note that these volumes provide room for paid cargo as well as passenger luggage.

Smaller transports don't use cargo containers, but instead rely upon hand-loading of the cargo compartment. For such aircraft a cargo provision of 6–8 ft^3 per passenger is reasonable.

Military transports use flat pallets to pre-load cargo. Cargo is placed upon these pallets, tied down, and covered with a tarp. The most common pallet measures 88 by 108 in.

Military transports must have their cargo compartment floor approximately 4–5 ft off the ground to allow direct loading and unloading of cargo from a truck bed at air bases without cargo-handling facilities. However, the military does use some commercial aircraft for cargo transport and has pallet loaders capable of raising to a floor height of 13 ft at the major Military Airlift Command bases.

The cross section of the cargo compartment is extremely important for a military transport aircraft. The C-5, largest of the U.S. military transports, is sized to carry so-called "outsized" cargo, which includes M-60 tanks, helicopters, and large trucks. The C-5 cargo bay is 19 ft wide, 13½ ft high, and 121 ft long.

The C-130 is used for troop and supply delivery to the front lines, and cannot carry outsized cargo. Its cargo bay measures 10′3″ wide, 9′2″ high, and 41′5″ long.

9.5 WEAPONS CARRIAGE

Carriage of weapons is the purpose of most military aircraft. Traditional weapons include guns, bombs, and missiles. Lasers and other exotic technologies may someday become feasible as airborne weapons, but will not be discussed here.

The weapons are a substantial portion of the aircraft's total weight. This requires that the weapons be located near the aircraft's center of gravity. Otherwise the aircraft would pitch up or down when the weapons are released.

Missiles differ from bombs primarily in that missiles are powered. Today, virtually all missiles are also guided in some fashion. Most bombs are "dumb," or unguided, and are placed upon a target by some bombsight mechanism or computer which releases them at the proper position and velocity so that they free-fall to the desired target. However, "smart-bombs," which have some guidance mechanism, are also in use.

Missiles are launched from the aircraft in one of two ways. Most of the smaller missiles such as the AIM-9 are rail-launched. A rail-launcher is mounted to the aircraft, usually at the wingtip or on a pylon under the wing. Attached to the missile are several mounting lugs, which slide onto the rail as shown on Fig. 9.5. For launch, the missile motor powers the missile down the rail and free of the aircraft.

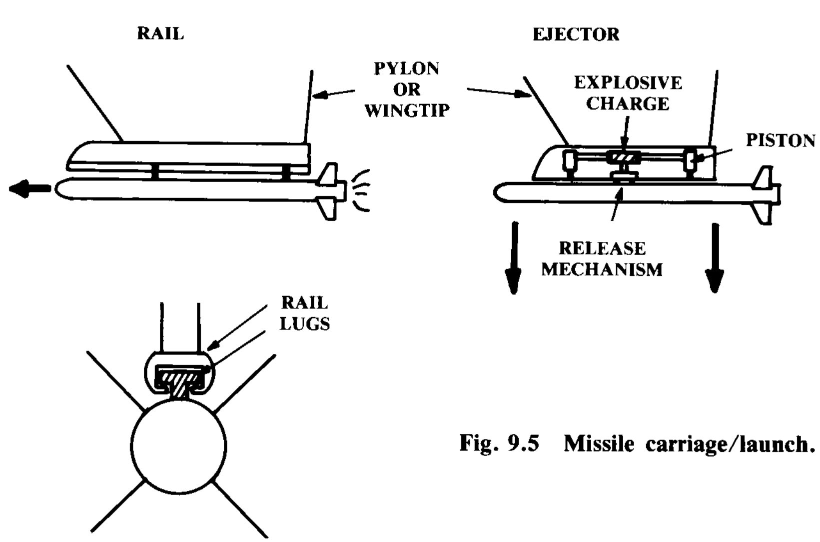

Fig. 9.5 Missile carriage/launch.

Ejection-launch is used mainly for larger missiles. The missile is attached to the aircraft through hooks which are capable of quick-release, powered by an explosive charge. This explosive charge also powers two pistons that shove the missile away from the aircraft at an extremely high acceleration. The missile motor is lit after it clears the aircraft by some specified distance.

Bombs can also be ejected, or can simply be released and allowed to fall free of the aircraft.

There are four options for weapons carriage. Each has pros and cons, depending upon the application. External carriage is the lightest and simplest, and offers the most flexibility for carrying alternate weapon stores.

While most fighter aircraft are designed to an air-to-air role, the ability to perform an additional air-to-ground role is often imposed. To avoid penalizing the aircraft's performance when "clean" (i.e., set up for dogfighting), most fighter aircraft have "hardpoints" under the wing and fuselage to which weapon pylons can be attached, as shown in Fig. 9.6. These are used to carry additional external weapons, and are removed for maximum dogfighting performance.

Most fighter aircraft can also carry external fuel tanks on the weapons pylons. These can be dropped when entering a dogfight, but are not dropped during long overwater ferry flights. Standard external fuel tanks include 150 and 600 gal sizes.

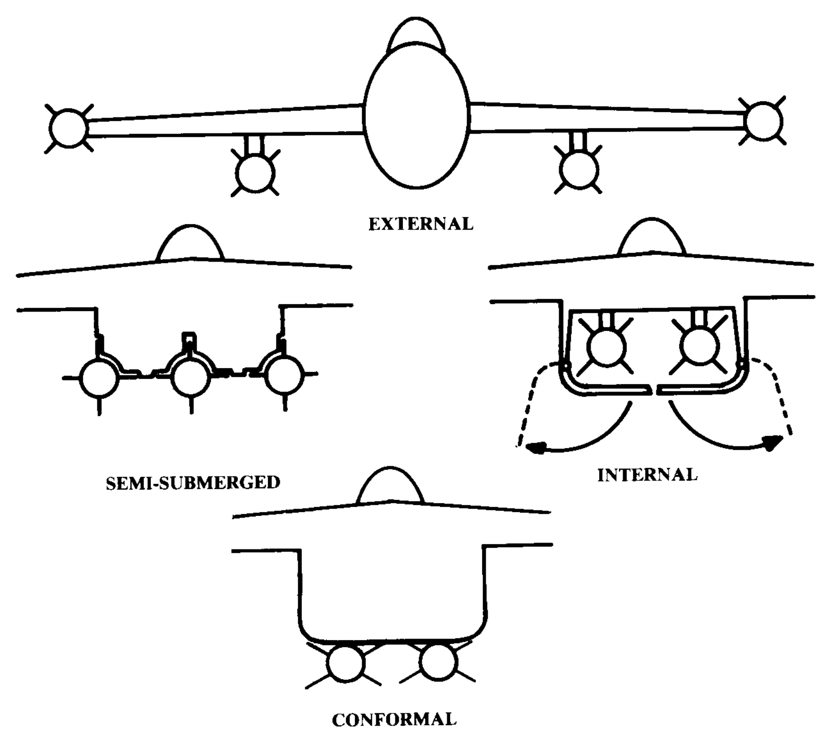

Fig. 9.6 Weapon carriage options.

Externally-carried weapons have extremely high drag. At near-sonic speeds, a load of external bombs can have more drag than the entire rest of the aircraft. Supersonic flight is virtually impossible with pylon-mounted external weapons, due to drag and buffeting. (Wing tip-mounted missiles are small, and have fairly low drag.)

To avoid these problems, semisubmerged or conformally-carried weapons may be used. Conformal weapons mount flush to the bottom of the wing or fuselage. Semisubmerged weapons are half-submerged in an indentation on the aircraft. This is seen on the F-4 for air-to-air missiles.

Semisubmerged carriage offers a substantial reduction in drag, but reduces flexibility for carrying different weapons. Also, the indentations produce a structural weight penalty on the airplane. Conformal carriage doesn't intrude into the aircraft structure, but has slightly higher drag than the semisubmerged carriage.

The lowest-drag option for weapons carriage is internal. An internal weapons bay has been a standard feature of bombers for over fifty years, but has been seen on only a few fighters and fighter-bombers, such as the F-106 and FB-111. This is partly due to the weight penalty imposed by an internal weapons bay and its required doors, but is also due to the prevalent desire to maximize dogfighting performance at the expense of alternate mission performance. However, only an internal weapons bay can completely eliminate the weapons' contribution to radar cross section, so the internal weapons bay may become common for fighters as well as bombers.

During conceptual layout, there are several aspects of weapons carriage that must be considered once the type of carriage is selected. Foremost is the need to remember the loading crew. They will be handling large, heavy, and extremely dangerous missiles and bombs. They may be working at night, in a snowstorm, on a rolling carrier deck, and under attack. Missiles must be physically attached to the mounting hooks or slid down the rail, then secured by a locking mechanism. Electrical connections must be made to the guidance mechanism, and the safety wire must be removed from the fusing mechanism. For an ejector-type launcher, the explosive charge must be inserted. All of this cannot be done if the designer, to reduce drag, has provided only a few inches of clearance around the missile. The loading crew absolutely must have sufficient room in which to work.

Clearance around the missiles and bombs is also important for safety. To insure that the weapons never strike the ground, the designer should provide

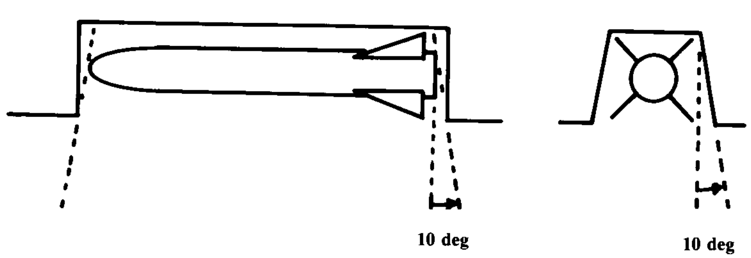

Fig. 9.7 Weapon release clearance.

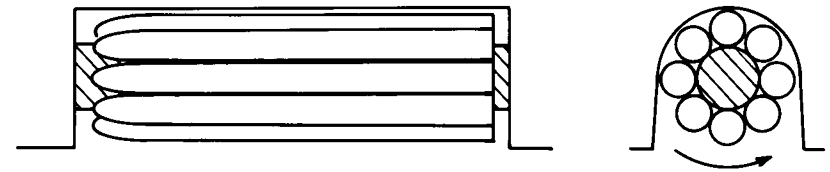

Fig. 9.8 Rotary weapons bay.

at least a 3-in. clearance to the ground in all aircraft attitudes. This includes the worst-case bad landing in which one tire and shock-strut are completely flat, the aircraft is at its maximum tail-down attitude (usually 15 deg or more) and the aircraft is in a 5-deg roll. The minimum clearance should be doubled if the airplane is to operate from rough runways.

If weapons are mounted near each other, there should be a clearance on the order of 3 in. between them. There should also be a foot or more clearance between weapons and a propeller disk.

The path taken by missiles or bombs when launched must be considered. For rail-launched missiles, there should be at least a 10-deg cone of clearance between any part of the aircraft and the launch direction of the missile. Also, the designer must consider the effects of the missile exhaust blast on the aircraft's structure.

For an ejector-launched or free-fall released weapon, there should be a fall line clearance of 10 deg off the vertical down from any part of the missile to any part of the aircraft or other weapons as shown in Fig. 9.7.

A special type of internal weapons carriage is the rotary weapons bay, as shown in Fig. 9.8. This allows launching all of the weapons through a single, smaller door. At supersonic speeds it can be difficult or impossible to launch weapons out of a bay due to buffeting and airloads which tend to push the weapon back into the bay. A single smaller door reduces these tendencies. Also, the rotary launcher simplifies installation of multiple weapons into a single bay. In fact, it is possible to design a rotary launcher that can be pre-loaded with weapons and loaded full into the aircraft.

9.6 GUN INSTALLATION

The gun has been the primary weapon of the air-to-air fighter since the first World War I scout pilot took a shot at an opposing scout pilot with a handgun. For a time during the 1950's it was felt that the then—new air-to-air missiles would replace the gun, and in fact several fighters such as the F-4 and F-104 were originally designed without guns. History proved that missiles cannot be solely relied upon, and all new fighters are being designed with guns.

The standard U.S. air-to-air gun today is the M61A1 "Vulcan" six-barrel gatling gun, shown in Fig. 9.9. This is used in the F-15, F-16, F-18, and others. Note the ammunition container. This must be located near the aft end of the gun. Rounds of ammo are fed out of the container ("drum") through feed chutes and into the gun. Ammo is loaded into the drum by attaching an ammo loading cart to the feed chute shown. The door to this loading chute must be accessible from the ground.

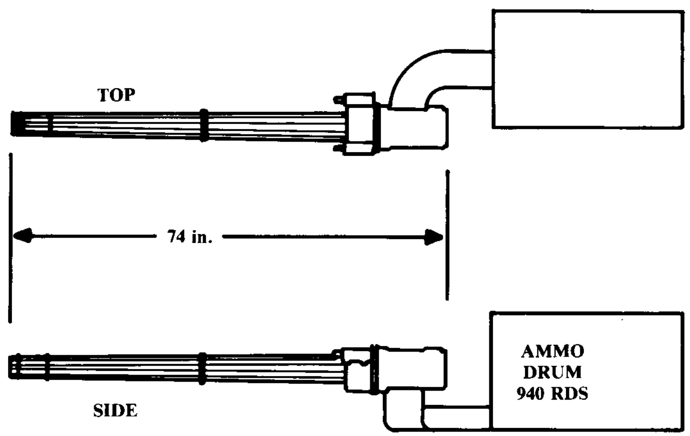

Fig. 9.9 M61 "VULCAN" gun.

An air-to-air gun such as the M61A1 can produce a recoil force on the order of two tons. A large anti-tank gun such as the GAU-8 used in the A-10 can produce a recoil force five times greater. To avoid a sudden yawing motion from firing, guns should be located as near as possible to the centerline of the aircraft. On the A-10, the nose landing gear is offset to one side to allow the gun to be exactly on the centerline. This extreme is not necessary for the smaller air-to-air guns.

When a gun is fired, it produces a bright flash and a large cloud of smoke. The gun muzzle should be located so that these do not obscure the pilot's vision. Also, being very noisy, a gun should be located away from the cockpit.

The cloud of smoke produced by a gun can easily stall a jet engine if sucked into the inlet. This should also be considered when locating a gun.

10 PROPULSION AND FUEL SYSTEM INTEGRATION

10.1 INTRODUCTION

This section treats the integration and layout of the propulsion system into the overall vehicle design, not the calculation of installed propulsion performance. Propulsion analysis methods are covered in Chapter 13.

To develop the propulsion system layout it is necessary to know the actual dimensions and installation requirements of the engine as well as its supporting equipment such as inlet ducts, nozzles, or propellers. Also, the fuel system including the fuel tanks must be defined.

10.2 PROPULSION SELECTION

Figure 10.1 illustrates the major options for aircraft propulsion. All aircraft engines operate by compressing outside air, mixing it with fuel, burning the mixture, and extracting energy from the resulting high-pressure hot gases. In a piston-prop, these steps are done intermittently in the cylinders via the reciprocating pistons. In a turbine engine, these steps are done continuously, but in three distinct parts of the engine.

The piston-prop was the first form of aircraft propulsion. By the dawn of the jet era, a 5500-hp piston-prop engine was in development. Today piston-props are mainly limited to light airplanes and some agricultural aircraft.

Piston-prop engines have two advantages. They are cheap, and they have the lowest fuel consumption. However, they are heavy and produce a lot of noise and vibration. Also, the propeller loses efficiency as the velocity increases.

The turbine engine consists of a "compressor," a "burner," and a "turbine." These separately perform the three functions of the reciprocating piston in a piston engine.

The compressor takes the air delivered by the inlet system and compresses it to many times atmospheric pressure. This compressed air passes to the burner, where fuel is injected and mixed with the air and the resulting mixture ignited.

The hot gases could be immediately expelled out the rear to provide thrust, but are first passed through a turbine to extract enough mechanical power to drive the compressor. It is interesting to note that one early jet engine used a separate piston engine to drive the compressor.

There are two types of compressors. The centrifugal compressor relies upon centrifugal force to "fling" the air into an increasingly narrow chan-