SECTION IX
DAMAGE TO AIRCRAFT

9.1 General
Aircraft are relatively vulnerable to the blast and thermal effects of nuclear detonations. Since aircraft are designed within narrow limits for flight and landing loads, the structure can withstand only small additional loads imposed by weapon effects. Blast overpressure on striking an aircraft surface may cause dishing of panels and buckling of stiffeners and stringers. On the side struck by the blast wave, the pressure is increased above the incident intensity by reflection and a diffractive force of short duration is generated. As the wings, empennage, and fuselage are completely enveloped by the blast, further dishing and buckling of skins and structure may result from the crushing effect of the differential pressure between the outside and inside of the aircraft components. Additional damaging loads are also developed by the particle velocity accompanying the blast wave. This particle velocity results in drag loading, which is usually termed “gust loading” with reference to aircraft. The duration of the gust loading is many times that of the diffractive loading, and it develops bending, shear, and torsion stresses in the airfoil and fuselage structures. For aircraft in flight, these stresses are usually the major effect on the aircraft.

The weapon thermal energy which is absorbed by aircraft components can also produce damaging effects. Very thin skins are rapidly heated to damaging temperatures by exposure to the short period thermal flux, because the energy is absorbed by the skin so much more rapidly than it can be dissipated by conduction and convective cooling. Exposed fabric, rubber, and similar materials with low ignition and charring temperatures are vulnerable items which may also initiate extensive fire damage at very low levels of radiant exposure. In recent years, designers of military aircraft have reduced aircraft vulnerability to thermal effects by coating thin skinned materials with low absorptivity paints, by eliminating ignitable materials from exposed surfaces, and by substitution of thicker skins for very thin skins. With these protective measures and design modifications, aircraft can be safely exposed at radiant exposure levels several times those which formerly caused serious damage.

9.2 Parked Aircraft
a. Air Blast. The diffraction phase loading and the drag phase loading have varying relative importance in producing damage to parked aircraft. In general, the diffraction phase is of primary importance in the zones of light and moderate damage. In the zone of severe damage the drag phase assumes more importance. Orientation of the aircraft with respect to the point of burst affects vulnerability considerably. With the nose of the aircraft directed toward the burst, higher weapon effects inputs can be absorbed without damage than for any other orientation. The longer duration of the positive phase of the blast from a large yield weapon may result in some increase in damage over that expected from small yields at the same overpressure level. This increase is likely to be significant at input levels producing severe damage but is not likely to be important at the levels of moderate and light damage. Experiments have shown that revetments provide only slight shielding against blast overpressure and under some conditions reflected pressures within the revetment are higher than corresponding incident pressures. Revetments do provide significant shielding from damage due to flying debris borne by the blast wave. Damage to various types of parked aircraft may be estimated from the curves of figures 9–1, 9–2 and 9–3. Distances to which a given level of damage from a subsurface burst occurs may be derived from figure 7–18 in conjunction with these figures. Quantitative data with respect to high yield influence on damage is not
available. Therefore this influence has not been reflected in the damage curves.

b. Thermal Radiation. A military weapon delivery aircraft properly prepared for its delivery mission with reflective paint and all vulnerable materials shielded from direct thermal radiation will not be damaged by thermal inputs at distances where damage from blast inputs is severe. Other aircraft not so prepared may sustain serious damage at very low thermal levels as a result of ignition of items such as fabric covered control surfaces, rubber and fabric seals, cushions and headrest covers. The radiant exposure levels at which damage to these materials may be expected can be estimated from the data of table 12–2. Aircraft painted with dark paint are especially vulnerable to thermal radiation damage because the dark painted surfaces absorb three to four times the thermal energy that is absorbed by polished aluminum surfaces or surfaces protected with reflective paint. Temporary emergency shielding as provided by trees, buildings, embankments, or similar barriers may be useful for thermal protection of unprepared aircraft, but any of these may increase the blast damage by adding to the flying debris or by multiple reflection of incident overpressures.

9.3 Aircraft in Flight

a. Air Blast. The response of an in-flight aircraft to blast loading is very complex. Factors which influence the response are—

1. Velocity and altitude of the aircraft.
2. Orientation of the aircraft with respect to the burst.
3. Intensity and duration of the overpressure and particle velocity accompanying the blast wave.
5. Natural frequency of the aircraft structural components.
6. Weight and weight distribution at the time of shock arrival.

For weapon delivery aircraft, analytical methods have been developed for predicting response under a variety of flight conditions and for kiloton and megaton yields. These methods require a detailed analysis for each aircraft type. Such analyses have been verified for several aircraft types by observing response at weapon effects tests.

For prediction of weapon effects required to destroy an enemy aircraft in flight, the response problem becomes even more complex. The knowledge of structural behavior and load carrying capacity of aircraft structures in regions above design limit, through ultimate strength to failure, is very limited. Estimates of lethal envelopes for various types of aircraft have been made on the basis of approximate analysis and limited experimental data. Three of these typical envelopes are presented in figure 9–4 to illustrate the general shape and size of regions about a nuclear antiaircraft burst within which an enemy aircraft may be expected to be destroyed by the weapon blast.

b. Thermal Radiation. The radiant exposure of an aircraft in flight varies widely with atmospheric conditions, orientation of the aircraft with respect to the burst, the ground reflecting surfaces, and clouds. Scatter and reflection add to the direct radiation and under some circumstances the thermal energy incident on an aircraft in space may be two to three times that computed at a given slant range from figure 3–6. Conversely, when a heavy cloud layer is between the burst and the aircraft the radiant exposure may be only a fraction of the predicted value for a given range. In other situations, reflected radiation from clouds may contribute significant thermal energy to areas of the aircraft shaded from direct radiation. During weapon effects tests of an aircraft flying in a cloud above the burst, the radiant exposure at the top of the aircraft and its cockpit area was observed to be as much as one-fourth of the direct radiation on the lower surfaces. This experiment demonstrated the need for protection of weapon delivery aircraft from radiant exposure from any direction. For subsonic weapon delivery aircraft which are adequately protected from thermal radiation, the blast loading is usually the limiting effect. However, supersonic aircraft can outrun the shock wave from a delivered weapon, so that thermal inputs determine the minimum safe separation distance of the aircraft and detonation.
Lethal thermal effects are not well defined. It has been estimated that 100 to 135 cal/cm² applied normal to a typical aircraft skin surface would destroy the protective coating and heat the skin to melting temperatures; however, this would not necessarily destroy the aircraft or prevent it from completing its mission. In general, the lethal blast effects extend well beyond the 100 to 135 cal/cm² thermal level from a detonation at operating altitudes for air-breathing-engine aircraft. The thermal envelope representing an expected thermal input of 135 cal/cm² normal to the lifting surfaces is also illustrated on each of the diagrams of figure 9-4 for comparison purposes only.
Figure 9–1 presents height of burst vs. ground range curves for light, moderate and severe damage to randomly oriented parked transport airplanes, light liaison airplanes, and helicopters. These curves are drawn for 1 KT and are based on the following definitions of damage and corresponding peak overpressure criteria:

**Light Damage**—That damage which does not prevent flight of the aircraft, though performance may be restricted thereby. Transport airplanes, 1 psi; light liaison airplanes, \( \frac{1}{2} \) psi; helicopters, \( \frac{1}{4} \) psi.

**Moderate Damage**—That damage which requires field maintenance to restore the aircraft to operational status. Transport airplanes, 2 psi; light liaison airplanes, 1 psi; helicopters, 1\( \frac{1}{2} \) psi.

**Severe Damage**—That damage which requires depot level maintenance to restore the aircraft to operational status. Transport airplanes, 3 psi; light liaison airplanes, 2 psi; helicopters, 3 psi.

**Scaling.** Height of burst and ground range for a given degree of damage scale as the cube root of the yield:

\[
\frac{h_i}{h_2} = \left( \frac{d_i}{d_2} \right) \left( \frac{W_i}{W_2} \right)^{1/3},
\]

where \( h_i \) and \( d_i \) are height of burst and ground distance for yield \( W_i \), and \( h_2 \) and \( d_2 \) are the corresponding height of burst and distance for yield \( W_2 \).

**Example.**

Given: A 100 KT weapon is to be burst at optimum height to obtain moderate damage to parked transport airplanes.

Find: The ground range at which moderate damage may be expected and the optimum height of burst.

**Solution:** From figure 9–1, the optimum height of burst for 1 KT is 1,300 feet. The optimum height of burst for 100 KT is \((100)^{1/3} \times 1300 = 6,000\) feet. **Answer.**

Also from figure 9–1, the ground range for moderate damage from a 1 KT burst at a height of burst of 1,300 feet is 1,380 yards. The corresponding ground range for 100 KT is \((100)^{1/3} \times 1,380 = 6,400\) yards. **Answer.**

**Reliability.** These curves are based on full scale test data for military bomber and fighter aircraft and detailed analysis of weapons effects on basic structural components. It is considered that they represent the best available estimates, for the aircraft types specified, of distances at which 50 percent of the aircraft parked at that range may be expected to be damaged to the degree specified.

**Related Material.**

See paragraph 9.2.

See also figures 9–2 and 9–3.
DAMAGE TO PARKED NON-COMBAT AIRCRAFT IN RANDOM ORIENTATION
BY A 1 KT BURST AS A FUNCTION OF
HEIGHT OF BURST AND GROUND RANGE

Damage to Transport Airplanes
- Light
- Moderate
- Severe

Damage to Light Liaison Airplanes
- Light
- Moderate
- Severe

Damage to Helicopters
- Light
- Moderate
- Severe

Ground Range (yards)
DAMAGE TO PARKED COMBAT AIRCRAFT, RANDOM ORIENTATION

Figure 9–2 presents height vs. ground range curves for light, moderate and severe damage to bomber and fighter aircraft for random orientation. These curves are drawn for 1 KT and are based on the following definitions of damage and corresponding peak overpressure criteria.

**Light Damage**—That damage which does not prevent flight of the aircraft, though performance may be restricted thereby. Jet bombers, 1½ psi; propeller fighters, 2 psi; jet fighters, 2 psi.

**Moderate Damage**—That damage which requires field maintenance to restore the aircraft to operational status. Jet bombers, 2½ psi; propeller fighters, 4 psi; jet fighters, 5 psi.

**Severe Damage**—That damage which requires depot level maintenance to restore the aircraft to operational status. Jet bombers, 4 psi; propeller fighters, 5 psi; jet fighters, 8 psi.

**Scaling.** Height of burst and ground range for a given degree of damage scale as the cube root of the yield:

\[
\frac{h_1}{h_2} = \frac{d_1}{d_2} = \frac{W_1^{1/3}}{W_2^{1/3}}
\]

where \(h_1\) and \(d_1\) are height of burst and ground distance for yield \(W_1\), and \(h_2\) and \(d_2\) are the corresponding height of burst and distance for yield \(W_2\).

**Example.**

**Given:** A 50 KT burst at ground level.

**Find:** At what range from ground zero must a jet fighter be parked in order to be no more than lightly damaged.

**Solution:** From figure 9–2, the distance from ground zero for light damage to jet fighters for a 1 KT burst is 900 yards. The corresponding distance for a 50 KT burst is \(900 \times (50)^{1/3} = 3,300\) yards. Answer.

**Reliability.** These curves are based on full scale test data for military bomber and fighter aircraft and detailed analysis of weapons effects on basic structural components. It is considered that they represent the best available estimates, for the aircraft types specified, of distances at which 50 percent of the aircraft parked at that range may be expected to be damaged to the degree specified.

**Related Material.**

See paragraph 9.2.

See also figures 9–1 and 9–3.
FIGURE 9-2

DAMAGE TO PARKED COMBAT AIRCRAFT IN RANDOM ORIENTATION BY A 1KT BURST AS A FUNCTION OF HEIGHT OF BURST AND GROUND RANGE

Jet Fighter Damage
- Light
- Moderate
- Severe

Propeller Fighter Damage
- Light
- Moderate
- Severe

Jet Bomber Damage
- Light
- Moderate
- Severe

Height of Burst (feet)

Ground Range (yards)

0 200 400 600 800 1,000 1,200 1,400 1,600 1,800
Figure 9-3 presents height of burst vs. ground range curves for light, moderate and severe damage to bomber and fighter aircraft for nose-on orientation. These curves are drawn for 1 KT and are based on the following definitions of damage and corresponding peak overpressure criteria.

Light Damage — That damage which does not prevent flight of the aircraft, though performance may be restricted thereby. Jet bombers, 2 psi; propeller fighters, 2 psi; jet fighters, 3 psi.

Moderate Damage — That damage which requires field maintenance to restore the aircraft to operational status. Jet bombers, 3 psi; propeller fighters, 5 psi; jet fighters, 7 psi.

Severe Damage — That damage which requires depot level maintenance to restore the aircraft to operational status. Jet bombers, 5 psi; propeller fighters, 7 psi; jet fighters, 9 psi.

Scaling. Height of burst and ground range for a given degree of damage scale as the cube root of the yield—

\[ \frac{h_1}{h_2} = \left( \frac{d_1}{d_2} \right)^{1/3} = \left( \frac{W_1}{W_2} \right)^{1/3} \]

where \( h_1 \) and \( d_1 \) are height of burst and ground distance for yield \( W_1 \), and \( h_2 \) and \( d_2 \) are the corresponding height of burst and distance for yield \( W_2 \).

Example.

Given: A 30 KT weapon is burst 4,000 feet above the terrain and a horizontal distance of 2,500 yards from a jet bomber parked nose-on to the burst.

Find: The corresponding 1 KT height of burst and the degree of damage to be expected.

Solution: The corresponding 1 KT height of burst is \( \frac{4,000}{(30)^{1/3}} = 1,290 \) feet.

The corresponding distance from ground zero is \( \frac{2,500}{(30)^{1/3}} = 800 \) yards.

From figure 9-3, moderate to severe damage would be expected at 2,500 yards from ground zero for a 30 KT weapon burst 4,000 feet above the terrain.

Answer.

Reliability. These curves are based on full scale test data for military bomber and fighter aircraft and detailed analysis of weapons effects on basic structural components. It is considered that they represent the best available estimates, for the aircraft types specified, of distances at which 50 percent of the aircraft parked at that range may be expected to be damaged to the degree specified.

Related Material.

See paragraph 9.2.

See also figures 9-1 and 9-2.
ESTIMATES OF GUSTS AND THERMAL ENVELOPES FOR TYPICAL COMBAT AIRCRAFT

Figure 9-4 presents an estimate, for each of three typical combat aircraft types, of the lethal envelope in the vertical plane containing the flight path. For each diagram, the silhouette represents the position of the aircraft at burst time; a 1 KT burst anywhere within the envelope is expected to destroy the aircraft. The corresponding lethal volume is approximately that within the surface of revolution generated by revolving the envelope shown about the flight path axis. Also indicated on the diagrams are the ranges at which the radiant exposure of the aircraft would be 135 cal/cm², an exposure level at which most aircraft would experience some melting of skin panels by thermal radiation from a 1 KT burst.

Scaling and Reliability. Estimates of lethal envelopes for other yields may be made by scaling the ranges to the blast envelopes by the cube root of the yield and the ranges for the 135 cal/cm² envelopes by the square root of the yield. The diagrams are presented to illustrate general shapes and sizes of lethal envelopes for aircraft and it is not intended that the numerical data be applied directly to any specific aircraft models.

Related Material.

See paragraph 9.3.
Figure 9-4

Estimates of Gusts & Thermal Envelopes for Typical Combat Aircraft

1 KT Anti-Aircraft Burst

135 cal. / cm² normal to lifting surfaces

Flight Path

Subsonic Bomber
Altitude 40,000'
Speed, Mach .9

Fighter
Altitude 40,000'
Speed, Mach .95

Supersonic Bomber
Altitude 70,000'
Speed, Mach 2.5