## Chapter 1

# ENERGY MANEUVERABILITY

1-1. (U) **INTRODUCTION.** Aircraft maneuverability can be defined as the ability to change direction and/or magnitude of the velocity vector. While this definition describes maneuverability accurately, it provides little feel for the fighter aircrew or engineer on how to acquire best (optimum) maneuverability. However, from experience, we know that the best way to maneuver for position advantage or to deny this same advantage to an opponent depends on the type of ordnance used and the performance of the aircraft. The type of ordnance employed determines the possible delivery conditions needed to effectively deliver this ordnance, whether it be guided missiles, guns, or bombs. Quantitatively, these delivery conditions can be depicted by launch or firing envelopes. Once the initial delivery conditions are known, the problem becomes one of maneuvering into the effective launch envelope. Such maneuverability is dependent upon the ability of the pilot to control turn, altitude, airspeed, and acceleration. The purpose of the following discussion is to show how energy maneuverability is related to operational maneuverability and how this relationship may be exploited by the fighter pilot, commander, planner, or designer in developing valid maneuvering and/or delivery tactics along with better aerial combat weapons systems.

1-2. (U) **BASIS.** Aircraft maneuverability can be considered as the capability to perform changes in altitude, airspeed, and direction; the theory of energy maneuverability was developed in an attempt to describe this capability. Following are the factors considered in establishing diagrams to represent aircraft performance.

a. **Load Factor (G).** The ratio of lift to weight is the G (gravity) load or load factor. For straight and level flight, the lift generated by the aircraft is equal to its weight (1G flight). For turns or direction changes, lift must exceed weight, and G loads greater than 1 are necessary. The higher the load factor, the greater the turn rate and the smaller the turn radius.

b. **Energy.** The total energy, per pound of weight, possessed by an aircraft is an expression of the combination of its altitude and speed. That is:

Energy (feet) = Potential Energy (Altitude MSL) + Kinetic Energy (Airspeed)

or mathematically:

$$E_s = h + (V^2 \div 2G)$$

The rate of change in $E_s$ with respect to time is expressed as specific excess power ($P_s$) where:

$$P_s = \frac{(\text{Thrust} - \text{Drag}) \times \text{Velocity}}{\text{Weight}}$$

If $P_s$ is a positive number ($>0$), the total energy of the aircraft is increasing. Conversely, negative $P_s$ indicates a loss in total energy.

When $E_s$ stays constant, the rate of change in $E_s$ with respect to time ($P_s$) is zero. The terms "sustained maneuver", "sustained G", or "sustained turn rate" are associated with the ability of the airplane to fly without losing airspeed or altitude.

c. **Turn Rate.** Excess lift is necessary to obtain G loads greater than 1.0G and thus obtain a turn rate. This increase in lift results in an increase in drag. Since at a constant power setting, Mach number, altitude, and weight, the $P_s$ value depends on the drag produced, the relationship between $P_s$ and turn rate can be developed. $P_s$ may be traded for turn rate and vice versa; when one is increased, the other decreases. The greater the $P_s$ value, the more the sustained turn rate can be increased within the limits of the envelope. *This is the main idea* *behind the energy maneuverability concept.*

d. **Turn Radius.** Rate and radius of turn are interdependent and are controlled by true airspeed and radial G. Therefore, all aircraft capable of maintaining a given G at a given velocity will, in fact, have the same rates and radii of turn.

e. **Mach – KCAS.** Mach and calibrated airspeed references are used in the diagram plots since both are readily available in the cockpit.

**1–3. (U) MANEUVER DIAGRAMS.** The maneuver diagram represents the performance capabilities of an aircraft, for a given set of flight conditions, in terms of its ability to change altitude, airspeed, and direction of flight. Characteristics of the aircraft considered are the maximum lift capability of the wing, aerodynamic drag, structural limits, thrust of the engine(s), and total weight. Each diagram is applicable to only one altitude, configuration, weight, and power setting. Also, these diagrams consider turning in only a horizontal plane, However, while they are limited in scope, they are still very useful in determining maneuver performance. Refer to Figure 1–1 for the following discussions.

a. **Aerodynamic Limits.** For a given Mach number, the lift can be increased (by increasing the angle of attack) to a maximum before stall, control departure, or intolerable buffet occurs. This limit lift capability ($C_{L\ MAX}$) is represented on the maneuver diagram as the left–hand boundary to the airplane envelope. In this region, the load factor capability is *aerodynamically* limited.

b. **Structural Limits.** The available load factor is also limited by the *structural* (or maximum G) capability of the aircraft. This structural limit, as related to total air pressure, is denoted as "max Q" and determines the upper limits of the aircraft envelope.

c. **Corner Velocity.** The minimum velocity at which maximum G can be obtained is defined as "corner velocity" (point A, Figure 1–1). Below this speed, buffet or stall will be encountered; above this speed the structural limit will be encountered first. At the corner

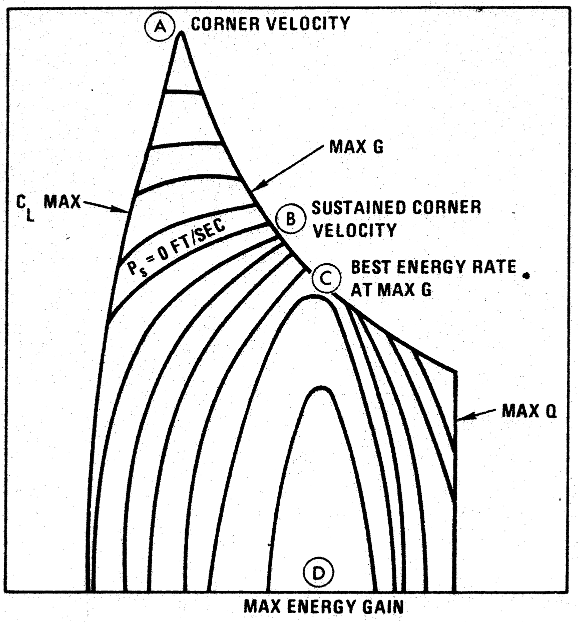

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Figure 1–1 (U). Basic Maneuver Diagram Reference Points velocity, the airplane attains its highest rate of turn which is sometimes referred to as the "Quickest/Tightest Turn", since above this speed turn rate decreases and turn radius increases.

d. **Sustained Corner Velocity.** "Sustained corner velocity" (B, Figure 1-1) is the speed at which a maximum sustained rate of turn can be achieved for a given power setting and is a function of thrust since it occurs where G is the maximum attainable without an accompanying loss of speed and/or altitude ($P_s = 0$)

e. **Best Energy Rate at Maximum G.** If the $P_s$ values are noted all along the maximum load factor line, they will be highest at one point (C, Figure 1-1). This occurs at a higher Mach and lower turn rate than corner velocity but will produce the best energy rate for maneuvers at maximum G.

f. **Maximum Maneuvering Energy Gain Mach.** By noting the average Mach at which the apexes of the energy contours occur, the best maneuvering Mach (D, Figure 1-1) for a given altitude may be determined. Maintaining this Mach will provide approximately the best energy rate for that altitude regardless of G loading.

1–4. (U) **APPLICATIONS.** The format for the energy maneuverability diagrams is that of turn rate–radius charts with $P_s$ contours. This format was selected for the wealth of information supplied in simple and readily useable form. The same scale is used throughout so that any two charts (friendly versus friendly or friendly versus threat) may be overlaid for comparison. Actual comparison charts are provided only for the F–15 and F–4E (LES) versus primary air–to–air threat aircraft. Other comparisons must be made individually.

a. There are several important regions or points on the maneuver diagram to consider when planning engagements. The optimum maneuver for a given situation depends on whether turn rate or energy gain or loss (airspeed, altitude) is more advantageous. Of necessity, this depends on a comparison of the relative energy states of the attacker and defender.

b. If turning is critical and altitude and airspeed losses can be allowed, maneuvering at corner velocity achieves the quickest, tightest turn. When gaining energy for an engagement advantage is important, only the minimum necessary turns should be made and at least maximum energy Mach should be maintained.

c. There are, of course, compromises between the two extremes of maximum turn rate and maximum $P_s$. If the energy level of the aircraft is satisfactory; i.e., the altitude and airspeed are both high enough, then maneuvering should be done where sustained turn rate is highest.

d. To summarize, there is a spectrum of maneuverability between the absolute quickest turn and the absolute maximum energy gain. One can be traded for the other, and the optimum trades can be accomplished by flying the appropriate Mach and G load corresponding to the position on the diagram. It should be emphasized that the maneuver diagrams are good for only one altitude. True optimum maneuverability and energy management should consider variable altitude as well as Mach number and load factor.

e. **Sample Problem.** Conditions: F–4E (LES), 5,000 feet, 500 KCAS, maximum power, 75% internal fuel, and four AIM–7s.

(1) First determine the basic maneuver speeds as shown in Figure 1–1.
(a) Corner velocity (A) – 405 KCAS
(b) Sustained corner velocity (B) – 560 KCAS
(c) Best energy rate at maximum G (C) – 580 KCAS
(d) Maximum energy gain Mach (D) – 520 KCAS

(2) Determine turn rate and radius for desired conditions (see Figure 1–2).
(a) Maximum G turn at 500 KCAS. Enter at 500 KCAS (E) and read down to maximum G

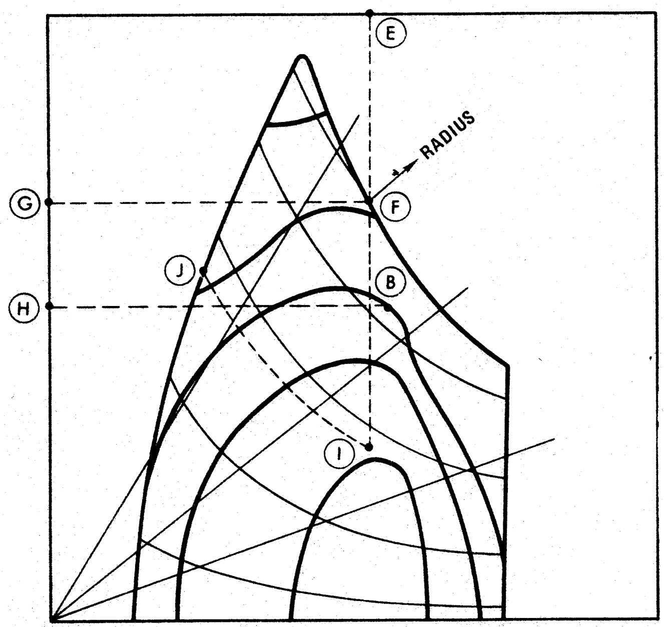

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Figure 1-2 (U). Maneuvering Diagram Sample Problem

line (F). Read turn radius at (F) of 3,200 feet, then left to a turn rate (G) of 16.5° per second.

(b) At sustained corner velocity (B), read turn radius of 5,000 feet, then left to turn rate (H) of 11.5° per second.

(3) Determine stall speed and energy rate for the desired conditions.

(a) 500 KCAS, 3½ G Turn. Enter at 500 KCAS (E) and read down to 3½ G (I); at (I) read $P_s$ of 350 feet per second. Then parallel the G reference lines to the intersection with $C_{L\,MAX}$ (J) for a stall speed of 260 KCAS.

**1-5. (U) SUMMARY.** In the case of an air-to-surface role, the pilot is not as interested in a high energy state as he is in maintaining energy while maneuvering with a wide assortment of stores. If he cannot maintain maneuvering energy, his choice of tactics becomes limited. In addition, if he is attacked by enemy airpower, his ability to evade or nulify the attack becomes questionable. Observing the correlation of energy with maneuverability, it follows that tactical maneuverability is related to the amount of energy possessed and HOW WELL THAT ENERGY IS MANAGED. For best maneuverability, the fighter pilot must know when and how to move to a higher or lower energy level and how to best conserve his internal energy (fuel) when locked in an air-to-air or air-to-ground encounter. Although the cliche that "$P_s$ doesn't kill, only 20mm does" is undoubtedly true, the fighter pilot who arms himself with comprehensive knowledge of the concepts of energy maneuverability, and then becomes thoroughly proficient in the performance of the individual maneuvers has a much greater likelihood of finding himself in a position to deliver that 20mm.