Introduction to basic offensive fighter manoeuvres

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"The views expressed herein are those of the author/s alone and do not necessarily represent those of the University"

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To my newborn son Christopher
About the author

Dimitri Pantelatos is a serving officer in the Hellenic Airforce. He has more than two thousand hours of flight experience, one thousand eight hundred of which are in combat aircraft. He has a class B flight instructor licence and was an Hellenic Aircraft Industry test pilot involved in the maintenance of the F-4E aircraft and weapon systems in the period 1987 to 1994. He was a lecturer in the Hellenic Airforce Instructors School and has also given specialist lectures on Electronic Warfare in the Airforce Academy during the academic year 1994-95. He was a student in the College of Aeronautics in the period 1995-97 during which time he studied for the MSc in Flight Dynamics.

The opinions expressed in this report are those of the author alone and do not necessarily represent those of the College of Aeronautics or of the University.
ABSTRACT

The contents of this report were presented during a talk to the Flight Dynamics and Aerodynamics MSc and PhD students, arranged and supported by the Flight Dynamics Group of the College of Aeronautics. This talk took place on 17th March 1997 in lecture room C of the College of Aeronautics.

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The aim of this report is, by gathering essential information from the air combat literature and relating this information with personal experience, to provide knowledge about the practical application of some aspects of the Flight Dynamics lecture course material.
ACKNOWLEDGEMENTS

I would like to extend sincere gratitude and appreciation to the Flight Dynamics group.

In particular I would like to thank Mr. P.G. Thomasson for having the idea of this presentation, Dr S. Fairs for making all the necessary arrangements that made this presentation possible, Mr. M.V. Cook for his supervision and corrections made in the resultant report and finally Mr. D.J.G. Lewis for his constant support and guidance.

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<tr>
<td>$C_D$</td>
<td>Drag coefficient</td>
</tr>
<tr>
<td>$E_t$</td>
<td>Total Energy</td>
</tr>
<tr>
<td>$E_k$</td>
<td>Kinetic Energy</td>
</tr>
<tr>
<td>$E_p$</td>
<td>Potential Energy</td>
</tr>
<tr>
<td>$E_r$</td>
<td>Rotational Energy</td>
</tr>
<tr>
<td>$E_s$</td>
<td>Specific Energy</td>
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<tr>
<td>$P_s$</td>
<td>Specific Power</td>
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GREEK

$\Delta$ Change in parameter

SUBSCRIPTS

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<th>Description</th>
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<tr>
<td>sus</td>
<td>Sustain</td>
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<tr>
<td>ins</td>
<td>Instantaneous</td>
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ABBREVIATIONS

<table>
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<th>Description</th>
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<tr>
<td>AB</td>
<td>Afterburner</td>
</tr>
<tr>
<td>ASAP</td>
<td>As Soon As Possible.</td>
</tr>
<tr>
<td>BFM</td>
<td>Basic Fighter Manoeuvres</td>
</tr>
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<td>ECM</td>
<td>Electronic Counter Measures</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>R/I</td>
<td>Radar and/or Infrared</td>
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<td>R/IWR</td>
<td>Radar and/or Infrared Warning Receiver.</td>
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INTRODUCTION

Aerial combat is by far the most difficult aspect of flight for the fighter pilot to understand and master. The skills used in aerial combat are learned over time and the interest, desire and personal discipline of a pilot are important factors in this learning process.

The first step in building pilot's skills, toward the end objective of achieving a first look, first kill capability, is to train in an environment which begins with the basics of a close-in encounter by using Basic Fighter Manoeuvres (BFM).

This environment does not involve tactics, it is mainly a gladiators contest, where the two opponents are allowed to concentrate on each-other (the presence of one or more aircraft will change the scene dramatically), but on the other hand, because of this, pilots and aircraft are also allowed to reach the limits of their performance.

Both the energy states and their rates of change, are of primary importance in the pilot's attempt to achieve a position within the firing parameters of his weapons and as a result to accomplish the ultimate objective in aerial combat, means effective weapons employment.

Thus the ability to achieve the latter not only depend on pilot's skills but also on the pilot's understanding of his aircraft's manoeuvrability (particularly in dissimilar type of aircraft engagements).

The time available for the pilot to perform these manoeuvres is also limited and is becoming more and more critical as the aircraft's performances improved.

In this report, before the description of some "popular" offensive fighter manoeuvres, an introduction to the salient parameters in aircraft comparison and energy manoeuvrability will be made, in relation with the air combat requirements.
Aircraft Comparisons and Energy Manoeuvrability.

The aim of this section is to provide a general feel for specific aerodynamic relationships and terms used in approaching the subject of aircraft manoeuvrability.

I.1. Wing Loading

The turn performance of two aircraft may be analyzed by comparing the ratio of combat gross weight to wing surface area. This ratio is called wing loading. Wing loading is inversely proportional to the load factor and also to the turn rate. That is, the smaller the wing loading, the greater the turn rate. Wing loading is considered as the primary factor which affects the instantaneous turn performance.

Prior to the early 1970s the method of comparing aircraft by comparing the wing loading, was fairly accurate and described turning performance pretty well. Lower wing loading could generally be considered a sign of a more manoeuvrable aircraft. But in many recent aircraft, engineers have designed aircraft that can increase $C_L$ in flight by sweeping their wings, blowing air across the wing or, changing the camber of the wing with manoeuvring flaps and adding leading edge extensions to the wings. Wing loading, therefore, is no longer the only significant factor in the turn equation. Furthermore, there are devices which improves turn performance and do not depend on wings at all, such as vectored thrust. Although wing loading may still be used to provide a clue to comparative performance, it can be deceptive when applied to modern aircraft.

I.2. Thrust to Weight Ratio

A useful parameter for comparing an aircraft's ability to accelerate and sustain turn rates is derived by dividing the aircraft's combat gross weight into total installed thrust. This is called the Thrust to Weight Ratio. Almost always, a larger Thrust to Weight Ratio indicates better acceleration and sustained turning capability.

There are some problems in using Thrust to Weight Ratio in comparing aircraft. For one thing, the ratio takes no account of airframe aerodynamic efficiency or drag reduction. Installed thrust varies considerably with altitude and airspeed. Thrust to Weight Ratio makes no allowances for variable geometry inlets and other refinements in intake design which permit some aircraft to produce a large proportion of installed sea level thrust at altitude. So like wing loading, Thrust to Weight Ratio may be deceptive and care must be taken when applying to modern aircraft.
I.3. Total Energy

The total mechanical energy of the aircraft is the algebraic sum of three particular types of energy, kinetic, potential and rotational:
\[ E_t = E_k + E_p + E_r \]
where \( E_k \) results from the linear motion of the aircraft
\( E_p \) is the energy needed to raise the aircraft to its particular altitude above the ground
\( E_r \) is a function of angular velocity as the aircraft rotates around any or all of the three axes. However, the value of rotational energy is negligible and for practical purposes, is considered to be zero.

I.4. Specific Energy

Total energy by itself, however, is not an accurate measure of manoeuvrability because of the inertia associated with weight. In order to get a more accurate indication of manoeuvrability, total energy is divided by gross weight to determine the energy per pound of weight of the aircraft. This is called “Specific Energy” or \( E_s \), and is expressed in units of length.

I.5. Specific Power

In order to achieve a better understanding of aircraft performance during a manoeuvring engagement, the rate of change of specific energy is considered. This is because in manoeuvring, energy is “lost” from the aircraft system (transferred to the surrounding air as heat and turbulence) and “added” to the system by the engines. Thus, the change in energy and more important, the rate of change in energy, determines which aircraft will have the energy advantage.

The rate of change of energy with respect to time, is called “power”. For the same reason we are interested in specific energy (energy per unit of weight), we are also primarily interested in specific power (power divided by weight). This power may also be considered “excess thrust”, and the descriptive term “specific power” is normally used (symbolized as “\( P_s \)”, in most American Handbooks). \( P_s \) refers to the ability of the aircraft to change its energy state by accelerating/decelerating, climbing/diving, or increasing/decreasing normal load factor \( g \). \( P_s \), in any condition (climbing, diving, accelerating, or decelerating) is a function of thrust, drag and velocity.

At high altitudes, where thrust is reduced \( P_s \) decreases. In high-g turns where induced drag is high, \( P_s \) will be lower. At high speed \( P_s \) increases but is limited by increasing parasite drag (Figure 1). These are the factors that actually distinguish the performance of one aircraft from another which can be measured. Therefore, \( P_s \) provides a basis for comparing aircraft and for studying individual aircraft performance.
**Figure 1: Drag**

Table 1 shows the parameters involved in the comparison between different types of aircraft in various air combat phases.

**Table 1: Salient Parameters examined in the various air combat phases**

<table>
<thead>
<tr>
<th>PHASE OF ENGAGEMENT</th>
<th>TASK</th>
<th>THE EXAMINED PARAMETER</th>
<th>THE EXAMINED VELOCITY</th>
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<tr>
<td>Pre-engagement</td>
<td>To increase the energy level</td>
<td>$\Delta P_i$ in 1 g</td>
<td>Corner Velocity</td>
</tr>
<tr>
<td>Conversion</td>
<td>To decrease the angle-off and aspect angle (get the tail of the enemy)</td>
<td>$\Delta TR_{\text{max}}$</td>
<td>The velocity that gives the maximum $TR_{\text{max}}$</td>
</tr>
<tr>
<td>Terminal</td>
<td>To achieve and maintain good shooting position</td>
<td>$\Delta TR_{\text{max}}$</td>
<td>Corner Velocity</td>
</tr>
<tr>
<td>Offensive position</td>
<td>To avoid the enemy’s shot (gunshot mainly)</td>
<td>$\Delta TR_{\text{max}}$</td>
<td>Corner Velocity</td>
</tr>
<tr>
<td></td>
<td>ii. To force the enemy to perform an overshoot</td>
<td>$\Delta P_i$ min (no energy left)</td>
<td>Corner Velocity</td>
</tr>
<tr>
<td>Defensive position</td>
<td>To avoid the enemy’s missiles</td>
<td>$\Delta P_i$ in 0 g’s or $\Delta P_i$ in 0.65 $TR_{\text{max}}$ (trying to have visual contact with the enemy by performing a slight turn)</td>
<td>The velocity that gives the maximum $TR_{\text{max}}$</td>
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Where:

\[ E_s = H + \frac{V^2}{2g_o} \quad \text{(Specific Energy)} \]

\[ E_s = P_s = \frac{dE_s}{dt} = \frac{dH}{dt} + \left[ (V/g_o)(dV/dt) \right] \quad \text{(Specific Excess Power)} \]

\( \Delta P_s \): The difference between the \( P_s \) of the two aircraft in the specific velocities

\( \text{TR}_{\text{sus}} \): Maximum turn rate without losing velocity and/or height (maintain energy level)

\( \text{TR}_{\text{im}} \): Instantaneous Turn Rate with the maximum g’s available (energy loss)

\( \Delta \text{TR}_{\text{sus}} \): The difference between the \( \text{TR}_{\text{sus}} \) of the two examined aircraft in a specific speed.

\( \Delta \text{TR}_{\text{im}} \): The difference between the \( \text{TR}_{\text{im}} \) of the two examined aircraft in a specific speed.

Figure 2 showing a typical example of a F-4E aircraft diagram, where the \( P_s \) contours, the V-N envelope and the turn performance of the aircraft at a particular height, combat weight and configuration, are plotted conjointly. This allowing the examination of the parameters described in table 1, according to the phase of engagement and also, the comparison between parameters coming from diagrams of dissimilar aircraft.

Point A corresponds to the corner velocity, i.e. the minimum velocity that gives the maximum available g-load for the specific flight condition.

Point B corresponds to the sustained corner velocity, i.e. the velocity that the pilot must choose in order to achieve moderate turn capabilities without losing altitude or slowing his velocity (losing potential or kinetic energy).

The point of \(-600 \ P_s\) corresponds to the flight condition where the aircraft will either lose altitude at a rate of 600 ft/sec maintaining its velocity, or will slowing its velocity with the same rate and maintaining its altitude.
Figure 2: F-4E Corner Velocity and Sustained Corner Velocity
SECTION II

Manoeuvring Principles

II.1. Geometry

(1) Range is nothing more than the distance the two aircraft are separated from each other.

(2) Aspect angle is used to describe the relative position of the attacker to the target without regard to the attacker's heading. Strictly speaking, aspect angle is defined as the angle measured from the tail of the target to the position of the attacker.

(3) Angle-off is primarily concerned with the relative nose position of two aircraft. Angle-off is defined as the angle between the longitudinal axis of the attacker and the longitudinal axis of the defender. Whenever the attacker is pointing at the defender, the aspect angle and angle-off will be equal.

Figure 3 shows the basic geometric relationship between the attacker and his target.

Figure 3: Attacker/Target Geometric Relationship
There are three available attack pursuit courses: lead, lag and pure (Figure 4). Both nose position and lift vector relative to a target contribute to the pursuit course that will be flown.

Figure 4: Attack Pursuit Courses

II.2. Turning Room

Turning room (Figure 5), is the separation between the two aircraft that can be used to accelerate and decrease range or to turn and decrease aspect and angle off. Turning room can be acquired in either the lateral or vertical plane.

- Lateral turning room is in the target's plane of turn
- Vertical turning room is acquired out of the target's plane of turn.

Figure 5: Turning Room
OFFENSIVE FIGHTER MANOEUVRES SEQUENCE
FOR SHORT RANGE AIR TO AIR WEAPONS

Threat Alert

Is there Visual or Radar contact?

YES

IF
Distance > 40 NM
Heading Crossing Angle > 120°
Aspect Angle > or ≤ 90°
No R/I Warning

THEN
Continue the Mission

ELSIF
10 < Distance ≤ 40 NM
Heading Crossing Angle ≤ 120°
Aspect Angle > 90°
R/I Warning

THEN
Abort the Mission
Engage Radar ECM

ELSIF
Distance ≤ 10 NM
Heading Crossing Angle > 120°
Aspect Angle > 90°
(target behind 3/9 o clock)
R/I Warning

THEN
Abort the Mission
Engage IR and RADAR ECM
Engage AB and Separate

Distance > 1 NM

NO

Case Variables
i. Distance
ii. Kinetic Energy
iii. Aspect Angle

Line B

YES

Engage AB
CUT OFF Approach
Adjust Pitch Attitude

Line A

21
OFFENSIVE FIGHTER MANOEUVRES
SEQUENCE (Continued)

Case Variables
(i) Altitude Difference
(ii) Energy Level
(iii) Angle off
(iv) Heading

IF
Altitude
difference > 6000 ft
High Energy (low to
high case)
Aspect Angle and
Angle off > 120°

THEN
Perform
Immelman
Attack

NO
Energy
V > 300 Kts

YES
Aspect angle and
Angle off reduces(*)
Energy Level ≥ Target's

ELSIF
High Aspect
Distance D
D < 3000 ft
High Energy

THEN
Perform
Quarter Plane

NO
Energy
V < 300 Kts

YES
Perform Separation
ASAP

ELSIF
Altitude
difference < 6000 ft
High Energy
Aspect Angle < 40°
Angle off > 40°
Distance > 2 NM

THEN
Perform
Barell-Roll
Attack

ELSIF
High Aspect
Distance D
D < 1500 ft
High Energy

THEN
Perform
Lag Roll

IF
(*) Hi/Low Aspect
Distance D
(*) D < 1 NM
Normal/Low
Energy

THEN
Aim
the Target
Engage
Missiles

D. Pantelatos: Medium to Short Range
Offensive manoeuvres

(*) Depends on Fire Control
System
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