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Introduction to basic offensive fighter manoeuvres

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£8

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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.

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

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LIST OF SYMBOLS

C_D	Drag coefficient
E_t	Total Energy
E_k	Kinetic Energy
E_p	Potential Energy
E_r	Rotational Energy
E_s	Specific Energy
P_s	Specific Power

GREEK

Δ	Change in parameter

SUBSCRIPTS

sus	Sustain
ins	Instantaneous

ABBREVIATIONS

AB	Afterburner
ASAP	As Soon As Possible.
BFM	Basic Fighter Manoeuvers
ECM	Electronic Counter Measures
IR	Infrared
R/I	Radar and/or Infrared
R/IWR	Radar and/or Infrared Warning Receiver.

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 involves 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 manoeuvers 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.

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.
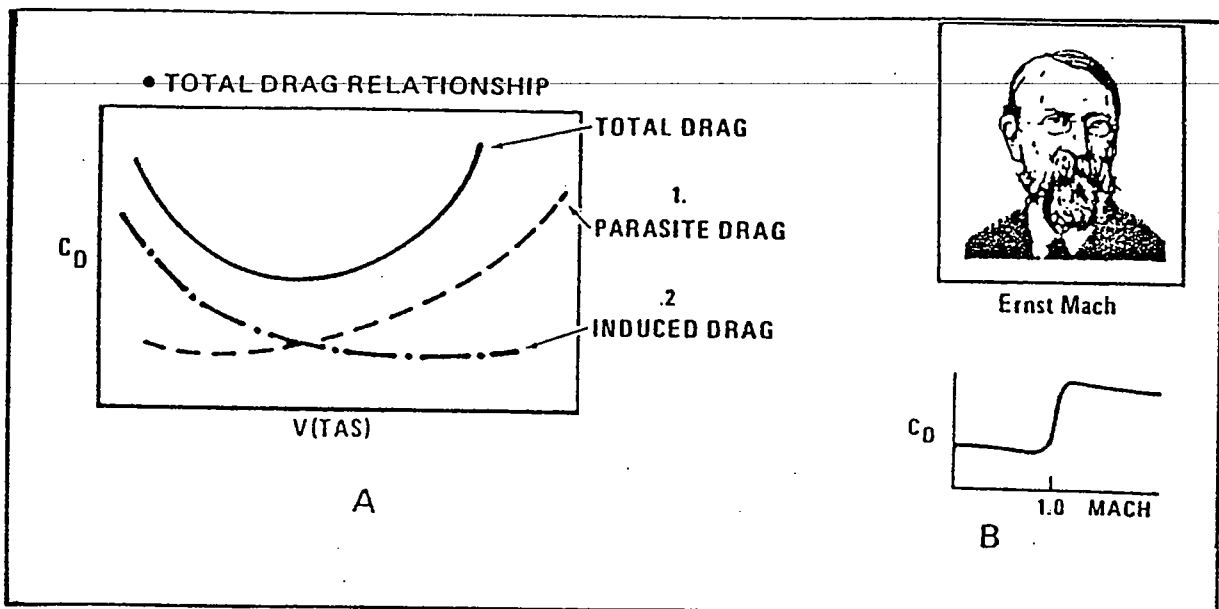
Figure 1: Drag

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

PHASE OF ENGAGEMENT	TASK	THE EXAMINED PARAMETER	THE EXAMINED VELOCITY
Pre-engagement	To increase the energy level	ΔP_s in 1 g	Corner Velocity
Conversion	To decrease the angle-off and aspect angle (get the tail of the enemy)	ΔTR_{sus}	The velocity that gives the maximum TR_{sus}
Terminal			
Offensive position	To achieve and maintain good shooting position	ΔTR_{ins}	Corner Velocity
Defensive position	i. To avoid the enemy's shot (gunshot mainly)	ΔTR_{ins}	Corner Velocity
	ii. To force the enemy to perform an overshoot	ΔP_s min (no energy left)	Corner Velocity
Separation	To avoid the enemy's missiles	ΔP_s in 0 g's or ΔP_s in 0.65 TR_{sus} (trying to have visual contact with the enemy by performing a slight turn)	The velocity that gives the maximum TR_{sus}

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Where :

$$E_s = H + V^2/2g_o \quad \text{(Specific Energy)}$$

$$\dot{E_s} = P_s = dEs/dt = dH/dt + [(V/g_o)(dV/dt)] \quad \text{(Specific Excess Power)}$$

ΔP_s : The difference between the P_s of the two aircraft in the specific velocities

TR_{sus} : Maximum turn rate without loosing velocity and /or height (maintain energy level)

TR_{ins} : Instantaneous Turn Rate with the maximum g's available (energy loss)

ΔTR_{sus} : The difference between the TR_{sus} of the two examined aircraft in a specific speed.

ΔTR_{ins} : The difference between the TR_{ins} 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.
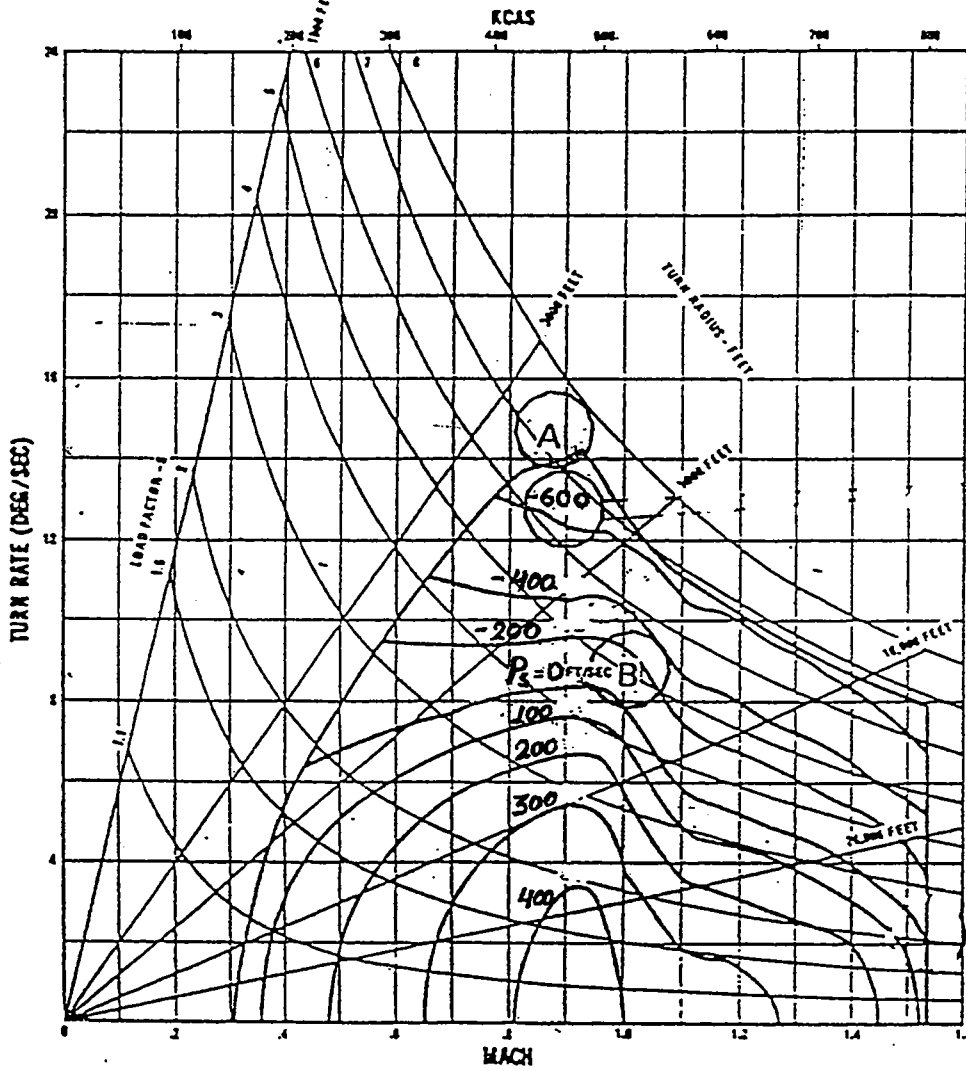
Figure 2: F-4E Corner Velocity and Sustained Corner Velocity

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.
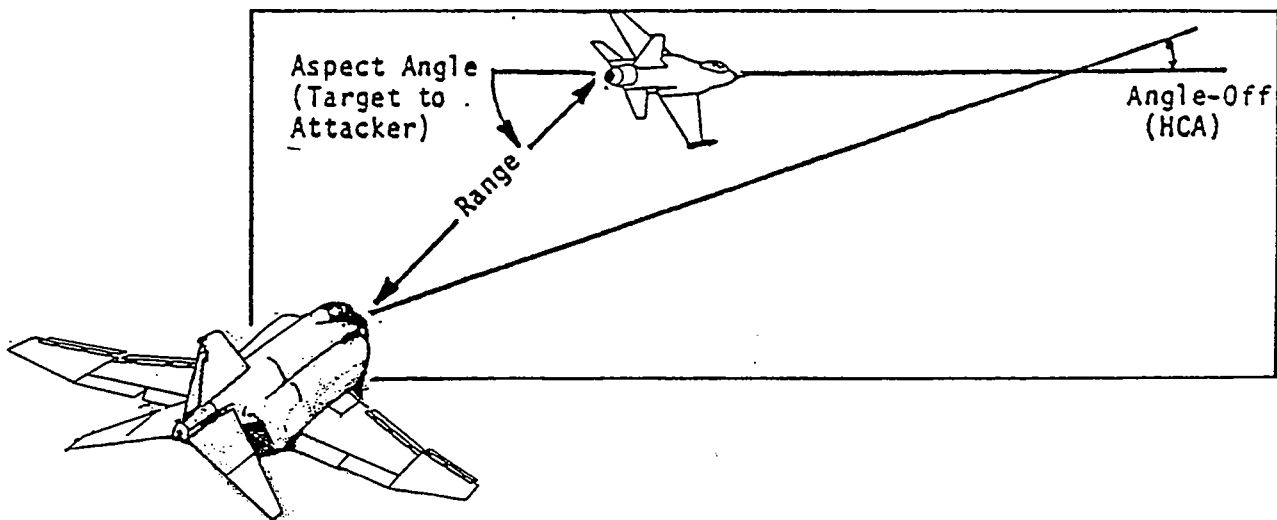
Figure 3: Attacker/Target Geometric Relationship

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.
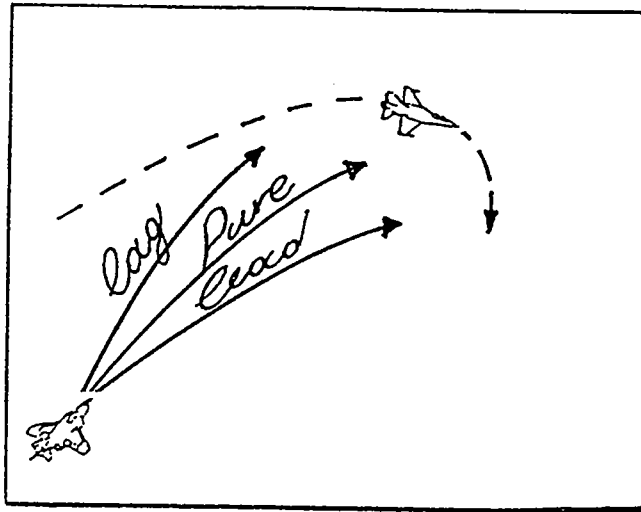
Figure 4: Attack Pursuit Courses

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.
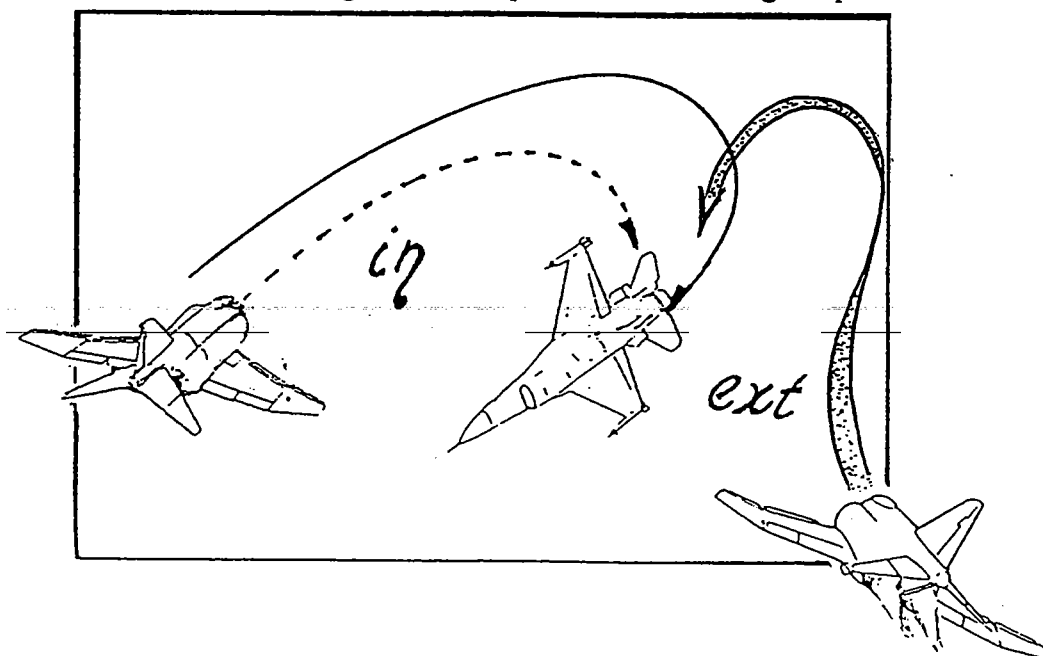
Figure 5: Turning Room

OFFENSIVE FIGHTER MANOEUVRES SEQUENCE
FOR SHORT RANGE AIR TO AIR WEAPONS

Threat Alert

Is there Visual or Radar contact ?

NO → Other information
i. Distance
ii. Threat heading
iii. R/IWR

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

YES
Engage AB
CUT OFF Approach
Adjust Pitch Attitude

Line A

Line B

21

Line A

Line B

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

IF

High Aspect
Distance D
1NM>D>4000ft
High Energy

THEN
Perform
Hi Yo-Yo

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

THEN
Perform
Immelman
Attack

ELSIF
High Aspect
Distance D
D<3000ft
High Energy

THEN
Perform
Quarter
Plane

Perform
Separation
ASAP

NO

Energy
$V_e > 300$ Kts

YES

NO

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

Perform Separation
ASAP

YES

NO

Energy
$V_e < 300$ Kts

YES

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<1500ft
High Energy

THEN
Perform
Lag Roll

(*) Depends on Fire Control
System

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

THEN
**Aim
the Target
Engage
Missiles**

D. Pantelatos: Medium to Short Range
Offensive manoeuvres

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