THE INFLUENCE OF FIGHTER AGILITY ON AIR COMBAT EFFECTIVENESS

Gao Hao, Gao Xiao-Guang, Zhang Shu-Guang

Aircraft Engineering Department
Northwestern Polytechnical University
Xi'an, P.R. China

Abstract

This paper presents some advance of research on the relationship between fighter's agility and air combat effectiveness. The objects of research have been to furtherly demonstrate the necessity of recent stress on fighter agility,and determine some essence- revealing and practical metrics of agility, and of equal importance, to acquire suitable research ways to such type of problems. Having been comprehensively considered, two parameters, roll rate and normal load facter rate , were first taken into computation and analysis. With them changed, typical missile firing envelopes against target were computed. An one vs. one air combat computer simulateion model was then employed to qualitatively and quantitatively compare the effect of various parameters on the survival probability of fighters in engagement.

The results show that improving fighter aircarft's agility can greatly strengthening its combat capability at a reasonable cost, though other elements may also be important. And for fighters of the conventional concepts, agility metrics can be divided by roll, roll and axial directions.The data also illustrate that roll ability seems to stretch out from pitch ability within a reasonable extent . But it's more important to strengthen them at a trade- off manner than separately stress one of them.Lastly, both firing envelopes and air combat simulation can provide important qualitative and quantitative information for agility research.

I. Introduction

As one element of air combat effectiveness assessment, agility is the most recent discussion topic of designers of current and future generation fighters . In recent years, the advances in weapons and avionics technologies, especially the emerge of all-aspect and off-boresight short range air to air missiles provide fighter aircraft with integrated weapon system capability, which may dramatically affect tactics and maneuvering. From the viewpoint of fighter air combat effectiveness,the traditional measures of merit, or metrics,have several inadequacies as follows [1]:

- Point performance is not a valid indicator of a fighter's dynamic capability.
- Sustained performance metric does not fully charaterize maneuvers used by fighters equipped with all-aspect short range missiles.
- Unsymmetrically maneuvering capability , especially rolling while turning, is not evaluated by any former metric.

According to some AFFTC pilots, five elements that influence the outcome of an air combat engagement were hightlighted[2]. They are: 1) the aircraft's thrust to weight ratio; 2)the ability to change the aircraft's nose position (attitude) relative to the adversary; 3) the ability to change the aircraft's flight path relative to the adversary; 4) the quickness of these changes; and 5) the preciseness of these changes. Except for the first one, the other four elements comprise the definition of aircraft agility, i. e. , the ability to change aircraft's attitude and flight path with quickness and precision.

Nowadays, many agility metrics have been proposed to define and measure aircraft agility. This paper is not to show the "best" or "most correct" agility metrcs, but to present some relationship between agility and air combat effectiveness. That is a complicated topic, concerning about aircraft flight dynamics, flight control system design , missile dynamics and operations analysis, in other words, it is a multi-discipline integrated dynamic topic.

II. The Measurement of Air Combat Merit

As mentioned above, agility has recently been proposed as an important assessment of air combat outcome. But other parameters are also needed to get the complete picture of a fighter's air combat ability. For conventionally designed fighters, i.e., flying mainly under the stall angle-of-attack and controlled through moment variations, a relatively comprehensive set of mearsures can be listed as[3-6]:

- Point performance
  - Wing loading
  - Thrust to weight ratio
  - Corner speed
  - Max. instantaneous turn rate
  - Max. constant turn rate
  - Max. level flight Mach number
  - Max. sea level rate of climb
- Energy maneuverability (E-M)

Classical E-M is generally presented through Specific Excess Power (SEP) vs. turn rate plots.

- Agility

Its measurement is to be settled. Here, three assessment metrics are recommended for a prior post. Respectively, they are:

1.Torsional Agility (TA) It expresses the difference in rolling capability between defensive and offensive aircraft in high angle turning maneuvers. The TA parameter can be defined as

$$TA = \frac{\text{Turn Rate}}{\text{Time to roll and capture } 90^\circ \text{ bank}} = \frac{TR}{\Delta t_{RC90^\circ}}.$$

For the case where the pilot's objective is weapon pointing, other than normal force vector's reorientation, an appropriate metric could be

$$LA = \frac{1}{\Delta t_{RC90^\circ}},$$

so-called lateral agility.

2.Axial Agility (AA) It can be measured by Power Onset Rate (POR):

$$POR = \frac{\Delta P_s}{\Delta t} = \frac{P_{s1} - P_{s2}}{t_1 - t_2},$$

where subscripts 1,2 express

1 min thrust max drag state,

and 2 max thrust min drag state.

respectively

3.Pitch Agility (PA) The PA parameter can be defined as

$$PA = \frac{1}{\text{Time to pitch and capture 9g from 1g}} = \frac{1}{\Delta t_{PC9g}}.$$

III. The Analysis of Air Combat Effectiveness

In this section, two approaches are used to inspect air combat effectiveness: computing the missile firing envelopes under various target aircraft agility parameters; and, estimating the exchange ratio in engagement of two fighters with the same performance but different agilty parameters from an one vs.one air combat computer simulation model.

1. The missile firing envelope

The supposed scene is that two fighters engage on a horizontal plane at an altitude of 4500 meters, and both the attacker and the target have the same initial airspeed, 262. 4m/sec. Missiles can be launched off boresight and at all aspects.

Example 1. Target with constant level normal acceleration

Curves 1 and 2 in Fig. 1 show the *minimum* firing range envelops for the attacker to successfully intercept the target at various relative aspect angles. For curve 1 the target's level normal acceleration is kept 2g, and for curve 2, 6g.

Example 2. Target with varying level normal acceleration

Curves 3 and 4 in Fig.1 present the *minimum* firing range envelops when the target maneuvers at varying level normal accelerations. For curve 3, the varying law of acceleration with time is

$$n = 2 + 2t,$$

and for curve 4, the law is

$$n = 2 + 3t.$$

From the above examples, conclusions can be drawn as:

- At the higher acceleration the target maneuvers, the more easily will it escape from the firing region. Here a higher constant level normal acceleration means a greater constant turn rate.
- Escaping from the firing region at varying

accelerations becomes much more easily than at constant accelerations, and the easiness will increase with the varying quickness. For a conventional flight concept, the availability of the varying quickness of the level normal acceleration requires that the fighter can be rapidly and precisely controlled in the roll and pitch axes, and impliedly, can be rapidly deccelerated. Reasonably, that falls into the agility concept and the importance of agility stretches out.

· Firing envelopes can be employed to reveal the elements affecting air combat effectiveness.

2. The exchange ratio of air combat

To furtherly compare the relative contributes of agility and established maneuverability parameters, an one vs. one air combat computer simulation model developed by Chinese Air Force Weapons System Analysis and Research Institute is used. Suppose a red fighter and a blue fighter have the same performance except the specific parameters, and both armed identically with two off-boresight,all-aspect IR short range missiles, two medium range intercepter missiles and a connon and with the same radar. They initially fly at the same altitude of 5000 meters and at a distance of 5000 meters from each other to stress the within-visual-range (WVR) combat capability . The exchange ratio is computed according to each's survival probability averaged from various relative initial postures. Each round lasts 180 seconds. Fig.2 shows a typical engagement scene. And the exchange ratios are as folllows:

Parameters	blue fighter	red fighter	exchange ratio
time to roll & capture 90° bank	1.3sec	1.0sec	1:1.28
time to pitch & capture 9g from 1g	2.6sec	2.0sec	1:1.03
the above two together	1.3sec 2.6sec	1.0sec 2.0sec	1:1.58
propulsion	basic	increase by 30%	1:1.21

The above data show:

· By the same proportion of 30%, the yield from speeding up roll alone is rather notable, while from speeding up loading alone is not evident; but once these two aspects are combined, the composite yield is much greater than the simple sum of their respective yields.

· Increasing propulsion is also very effective in enhancing air combat capabability. But compared with that from agility stated above, the yield ratio is lower because the basic fighter has already sufficient propulsion. At the same time, the cost to yield ratio may be higher than that from agility.

· Air combat simulation can qualitatively and quantitatively provide more details about each parameter's dynamic effect, and it is a very beneficial tool in preliminarily demonstrating the necessity of agility and choosing measures of merit.

IV. Conclusions

— Improving fighter aircarft's agility can greatly strengthening its combat capability at a reasonable cost, though other elements may also be important.

— For fighters of the conventional concepts without fuselage aiming and post-stall maneuvering capabilities , the evalution of agility in three axes, i.e., in the roll, axial and pitch directions is reasonable and practical. In other words, the metrics can be divided by the three axes.

— Roll ability seems to stretch out from pitch ability within a reasonable extent. But it is more important to strengthen them at a trade-off manner than separately stress one of them.

— Both firing envelopes and air combat simulation can provide important qualitative and quantitative information for agility research, but firing envelopes pay more attention on missiles lauching , while the air combat simulation gives a whole dynamic scene.

V. References

[1] Andrew M. Skow: "Advanced Flight Agility Metrics," AIAA 85-211.

[2] Stuart L.Buttls, et al.: "Flight Testing for Aircraft Agility," AIAA 90-1308-CP.

[3] Andrew M.Skow: "Agility as a Contribution to Design Balance," AIAA 90-1305.

[4] R.K.Liefer, et al.: "Assessment of Proposed Fighter Agility Metrics," AIAA 90-2807-CP.

[5] H.Gao, S.Zhang: "Agility and Supermaneuverability of Fighters," Flight Dynamics, Issue 4 , 1991.

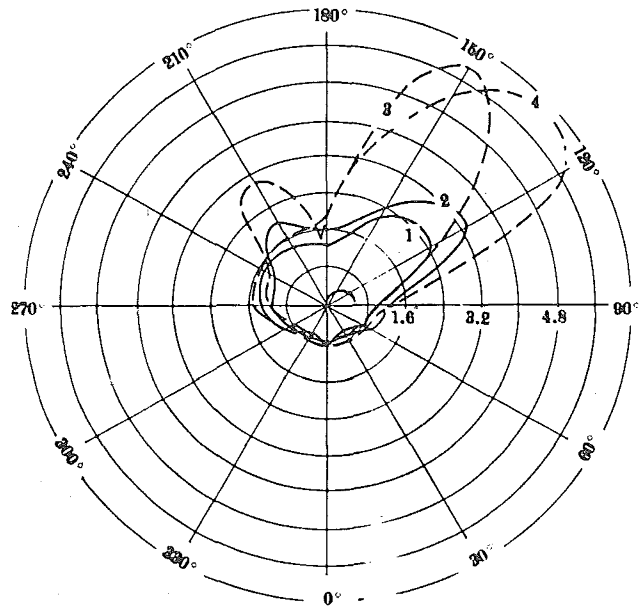

Fig.1 Firing envelopes.

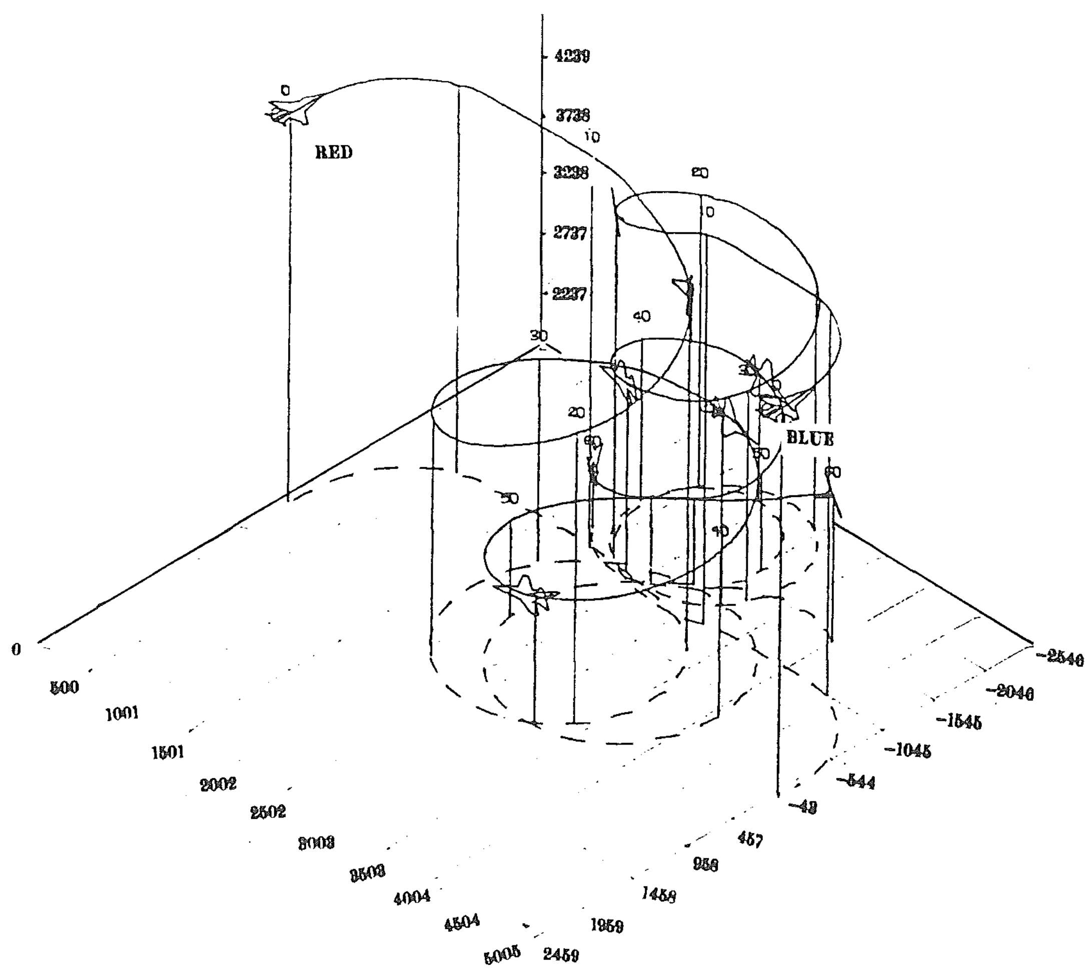

Fig.2 A typical engagement.