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CONSIDERATION OF OFFENSIVE AND DEFENSIVE METRICS FOR FIGHTER AIRCRAFT AGILITY

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ABSTRACT

The evolution of air-to-air combat has led to the need for criteria used to define and measure aircraft agility. Previously suggested agility definitions and metrics are examined, and the potential for metrics that would be more beneficial to pilots in particular offensive or defensive positions is discussed. Possible follow-up studies to expand the understanding of agility and its contribution to the battle space are presented.

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Introduction

For many decades, fighter aircraft performance was measured predominantly using energy-maneuverability methods[1]. As air combat evolved, specifically in the area of short range, all-aspect air-to-air missiles such as the AIM-9, so did the need for new measures of a fighter jet's performance. Numerous studies[1-7] sought to define a new parameter "agility" and the metrics that would be used to quantify it. These new methods would be used to analyze the abilities of current platforms, as well as in the design of future combat aircraft.

Proposed agility metrics could be categorized by their body axis motion, such as agility in the lateral (roll), longitudinal (pitch), or axial (thrust) directions. These could further be classified by time scale involved as either transient or functional agility. A separate definition of agility focuses less on airplane rotation but instead on manipulating the acceleration rate vector of the aircraft[2].

What was missing from all of these models, however, is the perspective that certain aspects of fighter performance are far more critical in differing scenarios. Agility metrics were categorized by time scale, direction of motion, and other factors, but not by when it would be most useful to exploit that advantage during combat. Few would argue, for example, that having a higher roll rate would make a jet less agile. But in what situations would this enhanced agility make a significant tactical difference? Does it increase the chance of a kill, or the odds of survival? How could one determine whether a characteristic be classified as "offensive" or "defensive" agility?

Traditional Energy-Maneuver Measures

Early measures of an aircraft's maneuverability concentrated on the energy state of an aircraft, namely through airspeed and altitude. Pilots would emphasize holding their corner speed to keep a tighter turning radius so that they could 'get inside' their adversary for a firing solution[1]. This mindset characterizes performance measures such as sustained turn rate, maximum instantaneous turn rate, turning radius, and excess power as vital qualities to determine an aircraft's combat effectiveness. Although these metrics are still useful gauges for maneuverability, advances in weapons technology have made obsolete the need to use energy maneuvering to get onto an opponent's "six" to reach an effective kill shot position. These developments led to a new need to define agility, one more attentive to the rotation rates of the aircraft body.

Body-Axis Agility

In the vein of "angles" flight maneuvering, pilots now had armament that allowed for 'snapshot' firing solutions: just point and shoot. This new ability led to dogfighting tactics that would exchange energy loss to exploit the much larger window for positional advantages and kill shots. To quantify this new definition of agility, many metrics were proposed that fell into two categories based on the duration of the time scale involved.

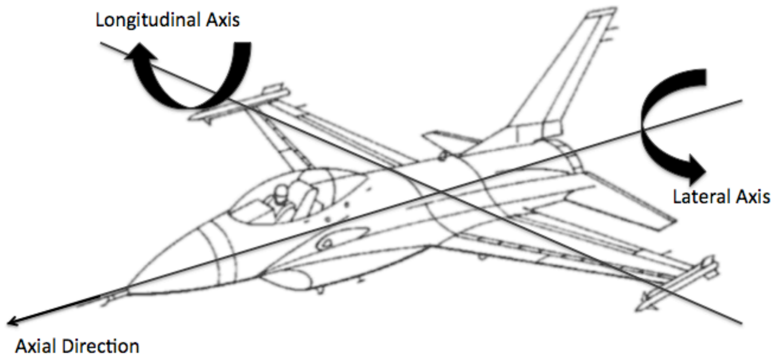

Figure 1: Body Axis Agility Directions

Transient Agility

The rapid-action pace of close quarters air combat dictates that fighters will spend lots of time maneuvering between flight conditions to jockey for position, as opposed to typical performance factors that involve steady-state characteristics of flight. Agility metrics that deal with these 'in-between' states of flight are considered measures of 'transient' agility, and involve motion measured on the order of 1-5 seconds long.[1]

Measures of transient agility include motion in the longitudinal (pitch), lateral (roll), and axial (thrust) directions. Well-accepted metrics include:

- T_{90}, time to roll to and capture a 90 degree bank angle (lateral)[5]
- Positive and negative load factor rate (longitudinal)[1]
- Time to maximum load factor, or time to unload (longitudinal)[1]
- Power onset & power loss parameters (axial)[5]

While these metrics were useful measures of aircraft characteristics, they might not encompass the big picture of aircraft performance during combat. To account for this, other metrics were proposed that account for both transient angular motion and more traditional measures of aircraft performance.

Functional Agility

Functional agility metrics bridge the gap between energy-conscious maneuvers and rapid, transient angular rate motion. The proposed measures of functional agility tend to encompass both the time to change direction and the time needed to make up for energy lost during the first portion of the maneuver[1]. These parameters can still be sorted by direction of primary motion, although often multiple directions are involved. By combining measures of aircraft performance such as turn rate, turn radius, maximum lift, etc., with transient movements, agility metrics could account for more full tactical maneuvers, instead of just a snapshot look. Commonly accepted functional agility metrics include:

- Combat Cycle Time, time required to complete a maximum acceleration turn and regain the lost energy (airspeed & altitude)[6]
- Roll Reversal Parameter, the product of time required to reverse a turn and the displacement that occurs during the turn[7]
- Dynamic Speed Turn, specific power vs. turn rate[4]

These functional agility metrics give a better measure of aircraft performance during flight that closer resembles steady-state maneuvers. These parameters can be approximated well with traditional performance evaluation methods, and greatly reduce the significance of the transient properties of agility.

Acceleration Rate Vector and Lambda Factor

An entirely alternate approach to defining agility is presented by Mazza.[2] The premise is that instead of studying the rotational motion of an aircraft, agility is defined by the acceleration rate vector and the corresponding flight path. This approach derives the axial, curvature, and torsional components of the acceleration rate vector in the Frenet coordinate system. Mazza defines his own 'Lambda metrics,' which encompass the acceleration components and studies how much each measure of agility is affected by a change in flight capabilities, such as vectored thrust or enhanced lift.

This paper presents more than just a new definition for agility, however. Another important contribution is the approach taken during the simulations. Altered flight characteristics were compared against their effects on agility *during specific maneuvers* used in combat scenarios. Using this approach, a pilot could determine whether their aircraft or the opponent's possessed a tactical advantage while performing the double Immelman or various other maneuvers.

While the study sought to show which enhancements to flight characteristics would most enhance a fighter's agility, it also provided the framework for a new consideration: what agility metrics have a larger influence during various maneuver sets dependent on the combat situation.

Determining Combat Effectiveness

Once a potential agility metric is proposed, the natural follow-up question is "how does this metric affect combat performance?" One method to determine this was devised by Hodgkinson.[3] This test simulated a range of scenarios and tracked the exchange ratio between friendly and hostile forces. These models altered one agility metric of 'blue' forces, then simulated combat for different initial orientations and numbers of combatants. Exchange ratios were compiled, and changes in agility metrics were compared in a general sense.

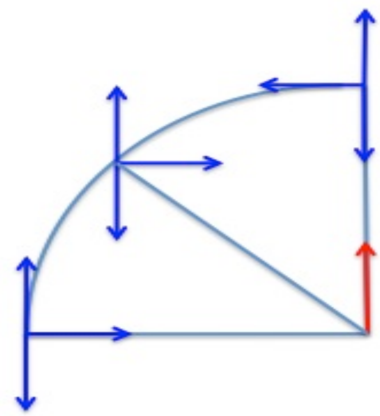

Figure 2: Hodgkinson's Starting Scenarios for AASPEM Simulation

While this study was telling when it came to the importance of agility, it did not provide the whole picture. What this set up fails to account for is that modern warfare is not attrition based, where general statistics will have an effect over a large sample size. It might tell designers whether or not the F-15 will outperform the MiG-29 in the long run, but it does little to help the individual pilot. In today's combat there are fewer participants and better radar, allowing for more selectivity when picking engagements. It would be beneficial for a pilot to know whether they are entering a skirmish with the advantage or not, factoring in both position and any concessions added by agility traits.

Combat Agility

While previous studies have compared the effects of enhanced agility traits on the combat environment, they often compared similar aircraft in a net-neutral range of scenarios.[3] While this may validate that greater agility is worth incorporating into future designs, it does little to help evaluate the combat effectiveness of current platforms. Of course if two aircraft are identical except for one augmented feature, the enhanced aircraft will have the advantage. What could be much more useful to tactical planning is if there were a way to study agility for an aircraft in an offensive or defensive fighting position. Which features, when enhanced, provide the greatest benefit to the pilot when they have the enemy in their sights? Which agility measures contribute most to evasiveness, and therefore the chance of survival? If one side has a numbers advantage, which traits will best allow for prolonged engagement?

Now that lots of agility metrics have been proposed and defined, they need to be tested. One method for examining this could be to use a comparable combat simulation & evaluation technique as Hodgkinson, but vary the initial set up and test for different results. Instead of testing each agility metric in a combined range of attacking, defending, and neutral starting positions, the metrics could be evaluated specifically in each category.

Offensive Agility

Aircraft agility that bolsters the attack capability could be considered as offensive agility. The measurement of offensive traits could be defined by their effect on the cone of lethality (width of the firing window), the time-to-kill from a position of advantage, or by exchange ratio.

A similar simulation to Hodgkinson could be run for a spread of neutral and offensive starting positions. The red force aircraft would begin in the same location and maintain the same flight characteristics throughout the test. A control group blue force (identical to the unaltered red aircraft) would determine the kill ratio without agility upgrades. Each testable agility metric of the blue forces aircraft could then be enhanced and the lethality measured.

Comparing the metrics' relative effects on lethality might reveal that certain elements of agility contribute far more than others when in an attack position. If any feature shows outstanding performance, it should be labeled as an offensive agility metric. This phase of combat will most likely favor quicker, transient moves that allow for point and shoot kills.

Defensive Agility

To test agility metrics for their contributions to evasiveness and survivability, this simulation could be run again, this time encompassing defensive and neutral starting positions. Using similar controls, each agility metric could be enhanced until a predetermined ‘acceptable’ level of survivability is reached. Survivability may be defined a number of ways, such as exchange ratio, ability to drawdown and flee successfully, or by measuring the width of the cone of lethality for the enemy combatant. A comparison between the necessary levels of improvement to each metric will provide valuable insight into which performance upgrades would most ensure the longevity of future aircraft. For example, it might be found that superior agility via the Lambda metrics will contribute to an aircraft evading an enemy far more so than a comparable upgrade to T_{90}, or that pitch agility is far more important than axial agility when dodging enemy fire. Whichever traits are most distinguished in this type of test would lay the groundwork for defining measures of defensive agility.

Other Agility Considerations

While defining offensive and defense metrics for agility could present great advantages for fighter pilots, there is further potential to explore this topic. It may be possible to determine the amount of influence each agility metric has, and combine them into an overall value for offensive and defensive ‘total agility.’ Performance charts such as those previously used for energy method studies could be assembled for each aircraft’s agility, presenting offense and defensive agility at different airspeeds and altitudes. This could lead to greater insight into what scenarios a pilot wants to get into in order to maximize tactical advantage over an enemy jet.

Additional variables not yet considered include varying altitude (i.e. red and blue forces do not start level), or asymmetric combat numbers. Altitude disparity might be the ideal scenario to demonstrate the effects of axial agility. Future wars also come with the prospect of a small force of expensive, technologically elite aircraft taking on a numerically superior force of older, less-sophisticated platforms. It may be incredibly beneficial to study how better aircraft performance (especially agility) allows a jet to take on multiple adversaries.

Initial studies on agility were also predicated on the belief that close range dogfighting is an inevitable part of air combat, despite the ability to acquire a missile lock, fire, and score a kill all before a pilot can see the adversary. The existence of beyond-visual-range weapons adds an entirely different element to what aircraft designers must consider if they want an aircraft to possess high levels of defensive agility during a range of possible engagements.

If agility becomes a defining measure of fighter aircraft performance, a similar method could be used to classify missile agility. An innovative generation of highly agile jets might require advanced weapons that can compensate for their target's newfound elusiveness. Do the same measures of offensive agility for aircraft apply to missiles? Is there a combined effect between the two that contributes to the overall combat effectiveness?

Conclusion and Looking Forward

Numerous definitions for aircraft agility have been proposed and studied extensively, but their situational effect on the results of air combat could still use in-depth analysis. One such manner to compare agility metrics would be to examine how they affect the ability of an aircraft in pursuit of or attempting to evade an enemy. Studying the contributions of agility metrics to specific offensive and defensive combat scenarios will better highlight their overall significance to the combat effectiveness of an aircraft. Advanced simulations have the potential to reveal the true nature of aircraft agility, which will allow for the exploitation of the battle space by current pilots and better understanding toward the design of future fighter jets.

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