Qualitative and Quantitative Comparison of Government and Industry Agility Metrics

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Government and industry have proposed various agility metrics in an effort to define and measure aircraft agility. Each of the agility metrics proposed measure different quantities related to aircraft performance and each, if designed to, would increase aircraft performance. The intent of this paper is not to choose the "best" or "most correct" agility metric but to compare their similarities and differences qualitatively and quantitatively compare their sensitivity to variations in agility-related design parameters.

Introduction

AGILITY is the most recent topic of discussion in the design and performance of current and future generation air combat fighters. Questions such as "What is agility, how significant is it, how is it measured, how can it be improved, and how much is enough?" are being asked by members of government and industry. Government and industry conferences on agility, including the Agility Metrics Conference hosted by the Air Force Flight Test Center (AFFTC) at Edwards Air Force Base, California, and the Aircraft Agility Workshop hosted by the Wright Research and Development Center at Wright-Patterson Air Force Base, Ohio, have tried to answer these questions. The result of these meetings has been a general agreement on the importance of agility and a general disagreement on what constitutes agility. The industry leaders have submitted their definitions of agility and, although the definitions are conceptually similar, no consensus has been reached concerning these similarities. By qualifying and quantifying their similarities and differences, a better understanding of each of the agility metrics can be achieved.

Advances in aircraft performance have been born from the inadequacies of past aircraft. As the tactical effectiveness of an aircraft declines due to technological advances or superior performance of threat aircraft, the fighter pilot's request of "give me more" becomes a design guideline. Aircraft performance measures of merit translate what the fighter pilot wants into a measurable quantity, allowing the engineer to iteratively design an aircraft. These measures of merit reflect the desires of the fighter pilot, the tactics employed, and the current capability of technology.

Figure 1 outlines a multistep approach to the study of agility. This approach consists of defining agility metrics, developing the tools and methodology capable of studying agility, relating agility to aircraft design, and determining the relationship between agility and air combat effectiveness. This paper focuses on the shaded area of Fig. 1 by attempting to facilitate a more comprehensive understanding of the proposed agility metrics. The quantitative comparison of the agility metrics described in this paper was accomplished using the advanced vehicle flight dynamics model listed in Fig. 1 and described in a companion paper.[1] The relationship of agility to aircraft design and air combat effectiveness is currently being studied and is the subject of future papers.

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Emphasis on Agility

The growing importance of agility can be traced to a combination of several developments in air combat including the advent of all-aspect missiles and the enhanced maneuverability of current generation fighters combined with the physiological limitations of the human pilot. Maneuvering air combat is dominated by the superior ability of one aircraft to maneuver into a position of advantage vs an opponent. The limited aspect capability of guns and early air-to-air missiles required an aircraft to maneuver into and maintain a position of advantage. The emergence of all-aspect missiles provides a point-and-shoot capability that stresses maximum instantaneous rates to secure a pointing advantage as opposed to the maximum sustainable rates required to achieve a positional advantage. This point-and-shoot capability reduces air combat engagement times, thereby increasing the importance of how quickly maximum instantaneous rates can be achieved.

Concurrent with the development of all-aspect missiles, the increasing maneuverability of current generation fighters has pushed maximum instantaneous g capability to the human limit. As conventional measures of performance become limited, transient performance becomes increasingly important. To make an analogy, in European countries where, as on the German Autobahn, there is no speed limit, an automobile's performance is measured by its maximum speed. In the United States, where the maximum speed is limited by law to 55 or 65 mph, an automobile's performance is measured by how quickly it can accelerate from 0 to 60 mph. Similarly, as the performance of fighter aircraft increases and the pilot continues to be the limiting factor, the measure of merit evolves from how many gs an aircraft can pull to how quickly it can achieve this limit.

Agility Metric Definition

The absolute definition of agility is a subject of debate. Each of the definitions of agility proposed by members of government and industry represent different quantities measuring the performance capability of an aircraft. The four most widely recognized agility definitions have been proposed by General Dynamics, Eidetics International, Messerschmitt-Boelkow-Blohm (MBB), and the AFFTC. A summary of each of the definitions is presented in Fig. 2.

General Dynamics has qualitatively defined agility as the ability to point the aircraft quickly, continue pointing the aircraft, and accelerate quickly.[2–4] It is a function of maneuverability, as represented by force equations, and controllability, as represented by moment equations. Using this definition, a highly agile aircraft would be characterized by a highly maneuverable aircraft with exceptional response and control characteristics. General Dynamics' definition is quantified in the form of a dynamic speed turn (DST) plot, an example of

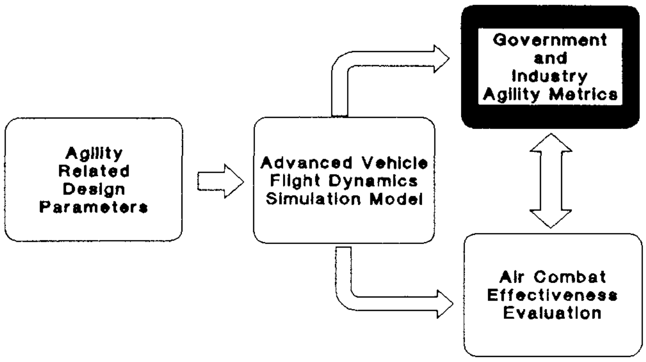

Fig. 1 Aircraft agility design and evaluation process.

Source	Qualitative	Quantitative
MBB	Rate of Change in Mnvr. State	$\ddot{V}$ $V\dot{\omega}+\omega\dot{V}$ $\ddot{\mu} - \ddot{\chi}\sin\gamma - \dot{\gamma}\dot{\chi}\cos\gamma$
Eidetics	Change of Accel., Pitch Rate, Turn of Lift Vector	$\Delta Ps / \Delta t$ Time to Δg T.R. / $t_{\phi=90}$
AFFTC	Change in Aircraft State	Pitch Capture Time Roll Capture Time
G.D.	Change in Maneuver State	Turn Rate vs. Bleed Rate

Fig. 2 Summary of government and industry agility metrics.

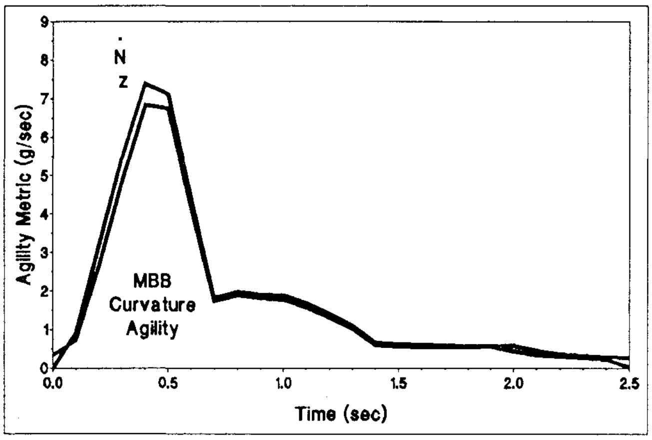

Fig. 3 Comparison of MBB's curvature agility metric and d($\dot{N}_z$)/dt.

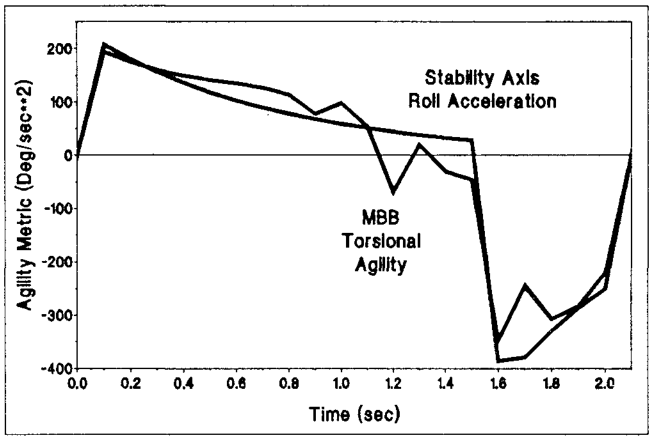

Fig. 4 Comparison of MBB's torsional agility metric and d($P_{\rm stab}$)/dt.

which is given later in the paper, in which turn rate is plotted vs acceleration. The DST plot can be derived by integrating specific excess power P_s over a typical combat cycle for a given Mach number vs turn rate performance plot. The manner in which this is presented facilitates conventional maneuverability performance comparisons between aircraft. The design goal of such a metric is to increase turn rates while increasing P_s.

Eidetics International defines agility as a higher order function of point performance and maneuverability.[5-7] Qualitatively, Eidetics separates agility into three components representing 1) acceleration/deceleration along the flight path, 2) symmetrical turning perpendicular to the flight path, and 3) rolling about the velocity vector to reorient the flight path. Eidetics is a pioneer in the study of agility and has hosted conferences devoted to the discussion of the subject. Under company-funded and government-contracted activities, they have collected a large body of data utilizing historical flight test data and man-in-the-loop simulation capabilities to define agility characteristics for current U.S. Navy and Air Force fighter aircraft.

Eidetics' original definition of agility consisted of a time-averaged extrapolation on the energy maneuverability-based specific excess power vs turn rate representation of aircraft performance.[5] The resultant "dynamic energy maneuverability" plots energy rate, as measured by the change in P_s divided by the elapsed time from idle thrust to maximum afterburner, vs turn agility, as measured by turn rate divided by the time it takes to achieve a 90-deg bank angle change at this turn rate. A highly agile aircraft would therefore be characterized as having the highest energy rate and greatest turn agility. The maximization of energy rate entails an increase in maximum thrust or minimization in drag combined with the minimization of transient engine response. The maximization of turn agility entails the maximization of turn rate combined with increased roll/yaw authority at high angle of attack. Dynamic energy maneuverability can be used for the basis of the comparison of time-related changes in conventional aircraft performance measures of merit. Eidetics has recently added an agility metric in the pitch axis to measure aircraft control and response in the lift plane consisting of a time to pitch up to and stop at a specified g level and unload to and capture 0 g.[6,7]

MBB defines agility as the derivative of the maneuver vector.[8,9] Unlike other proposed metrics that define agility in terms of time-related changes in conventional performance measures of merit or control response in the aircraft body axis, MBB has approached the study of agility mathematically in relation to the velocity vector. They have developed agility metrics by mathematically deriving the "agility vector" from the second derivative of the velocity vector as defined in the Frenet-Serret[10] system. The agility vector is divided into three separate components measuring 1) longitudinal agility, in the direction of the velocity vector; 2) curvature agility, in the direction of the maneuver plane; and 3) torsional agility, representing the rotation of the maneuver plane about the velocity vector. The metric for each component is defined as the peak measured value of the component vs time for a given maneuver.

At first glance, the equations that MBB utilizes to quantify airframe agility can be intimidating.[11] It must be realized, though, that the quantities measured are velocity vector Euler-angle-dependent interpretations of commonly measured and understood quantities. For example, Fig. 3 depicts a plot of $\dot{N}_z$ and the MBB curvature agility metric A_k vs time for a maximum performance 1–6 g level pull in the horizontal. As can be seen, the general trends established by $\dot{N}_z$ and A_k are identical; $\dot{N}_z$ and A_k vary only in absolute magnitude. A similar pattern emerges in Fig. 4 when stability axis roll acceleration $\dot{P}_{stab}$ and the MBB torsional agility metric A_t are compared for a 180-deg, 6-g loaded roll. The MBB longitudinal agility metric A_l is equivalent to $\dot{N}_x$. Qualifying MBB's agility metrics using these commonly known quantities, a highly agile aircraft can then be characterized as having the ability to effect high pitch rates, large roll accelerations, and fast engine response transients.

The AFFTC defines agility as "The rate of change of aircraft state with precision and control."[12] This reflects the AFFTC's desire to relate agility metrics to tactical tasks such as the fine tracking required for weapons solution. The AFFTC has been a leader in measuring the agility of current U.S. Air Force inventory aircraft. Although the majority of work has been accomplished using real-time, man-in-the-loop simulations, the AFFTC is currently conducting agility flight testing of the F-16.[13] As such, they have defined standard agility maneuvers in order to standardize the amount and type of information required to characterize airframe agility.[14]

The AFFTC has defined two types of agility known as functional and transient agility.[13,15] An explanation of the distinction between functional and transient agility is illustrated by Fig. 5. Figure 5 represents a change in aircraft state characterized by an acceleration onset at time t_0, attainment of a steady-state rate limit at time t_1, deceleration onset at time t_2, and capture of the desired state at time t_3. Transient agility refers to the accelerating, from time t_0 to t_1, and decelerating, from time t_2 to t_3, portions of Fig. 5. Functional agility refers to the ability to achieve the final desired state and can be measured as the time from t_0 to time t_3. This distinction allows transient agility to be associated with maximum angular accelerations whereas functional agility can be related more closely to maximum angular rates. This further allows the classification of certain agility metrics, such as MBB's torsional agility metric, as a measurement of transient agility and others, such as Eidetics' turn agility, as representative of functional agility.

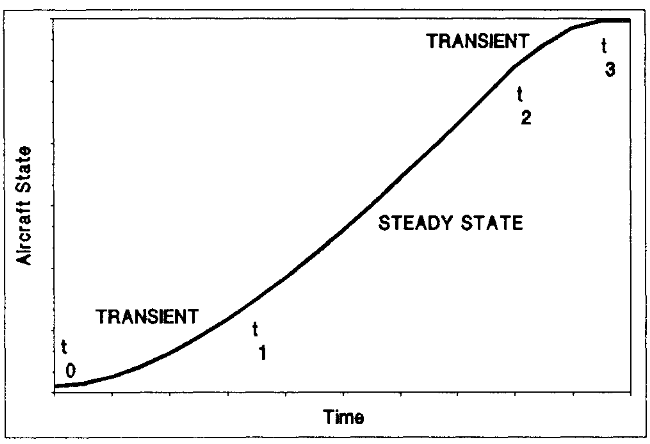

Fig. 5 Definition of transient agility.

The AFFTC has also recognized, as has Eidetics and MBB, that agility can be separated into three components[9] that quantify 1) pitch agility, as represented by time to capture body axis heading or pitch angle, Ψ or θ, vs initial load factor; 2) lateral agility, as represented by time to bank vs airspeed and load factor; and 3) axial agility, as represented by time to final airspeed vs initial airspeed and load factor. A highly agile aircraft would therefore be characterized by high sustainable g and g-onset rates, large roll rates at elevated g, large positive P_s values throughout its operating envelope, and fast engine response transients.

Qualitative Comparison

Although each definition of agility is quantitatively different, there are many conceptual similarities. Agility is, regardless of which definition is used, a representation of the transient performance capability of an aircraft. Agility is generally considered to be a combination of conventional maneuverability and controllability. Although it would be beneficial to represent airframe agility as a single number for the purpose of comparison, it is generally agreed that agility is measured separately in the three components consisting of 1) longitudinal/axial agility in the direction of the velocity vector, 2) pitch/curvature agility in the direction of the lift/maneuver plane, and 3) roll/torsional agility representing the rotation of the lift/maneuver plane about the velocity vector. It is also generally agreed that the design of a highly agile aircraft consists of a highly maneuverable aircraft that has exceptional control and response characteristics through its operating envelope.

A missing component in the study of agility is the ability to discuss the various metrics in similar terms. A common language is required to more comprehensively explain the similarities and differences between each of the agility metrics. Retaining the idea of three-axis agility as described above and borrowing from Eidetics' "Analogy to Calculus,"[6] the relationship between agility, maneuverability, and state variables can be defined as shown in Fig. 6 with maneuverability being the derivative of aircraft state and agility being the derivative of aircraft maneuverability. The agility parameters shown in Fig. 6 define a working definition of agility created to more clearly describe the similarities and differences between the proposed metrics.

Relating the idea of three-axis agility to the state variables shown in Fig. 6 define an aircraft's 1) speed V; 2) velocity vector direction, as defined by the velocity vector heading and pitch angles χ and γ; and 3) lift plane orientation, as defined by the bank angle μ.

AXIS	STATE	MANEUVERABILITY	AGILITY
LONGITUDINAL (AXIAL)	V	$\dot{V}$	$\ddot{V}$
CURVATURE (PITCH)	γ, χ	ω	$\dot{\omega}$
TORSION (ROLL)	μ	P_{stab}	$\dot{P}_{stab}$

Where: $\omega = \sqrt{\dot{\gamma}^2 + \dot{\chi}^2 \cos^2\gamma}$ & $\dot{\mu} \approx P_{stab}$

Fig. 6 Working definition of agility.

AXIS	STATE	MANEUVERABILITY	AGILITY
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CURVATURE (PITCH)	γ, χ	ω	$\dot{\omega}$
TORSION (ROLL)	μ	P_{stab}	$\dot{P}_{stab}$

Where: $\omega = \sqrt{\dot{\gamma}^2 + \dot{\chi}^2 \cos^2\gamma}$ & $\dot{\mu} \approx P_{stab}$

Fig. 7 General Dynamics' agility metrics.

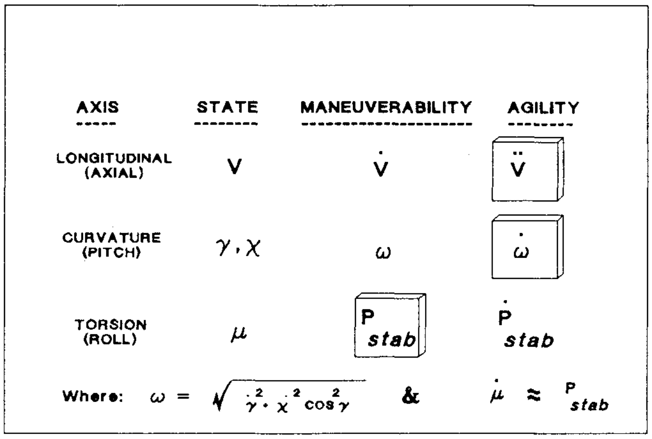

Fig. 8 Eidetics' agility metrics.

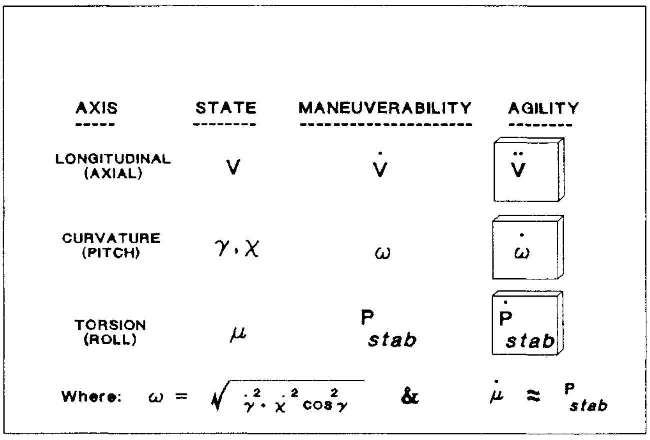

Fig. 9 MBB's agility metrics.

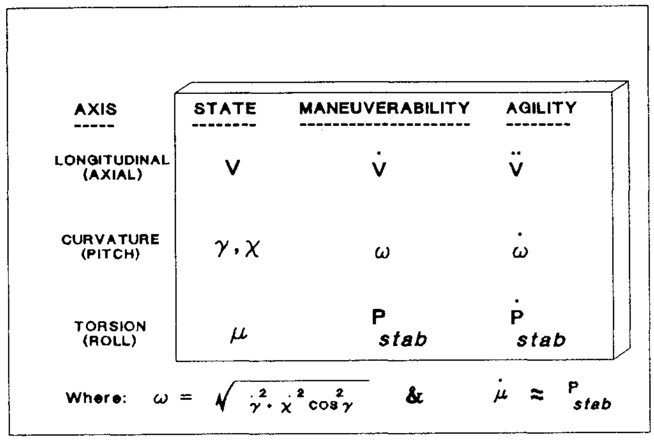

Fig. 10 AFFTC's agility metrics.

AGILITY COMPONENT	GENERAL DYNAMICS	AFFTC	EIDETICS	MBB	WORKING DEFINITION
LONGITUDINAL (AXIAL)	DYNAMIC SPEED TURN	TIME TO FINAL AIRSPEED	ENERGY RATE	A_l	$\dot{N}_x$
CURVATURE (PITCH)		TIME TO CAPTURE Θ OR Ψ	TIME TO PITCH	A_k	$\dot{N}_z$
TORSIONAL (ROLL)	P, Q, R AT HIGH α	TIME TO BANK	TURN AGILITY	A_t	$\dot{P}_{stab}$

FUNCTIONAL — TRANSIENT

MANEUVERABILITY ◄ ► AGILITY

Fig. 11 The agility spectrum.

The knowledge of these state variables in relation to an opponent and ownship aircraft performance define 1) speed in relation to opponent speed and ownship corner velocity, 2) ownship off angle in relation to the opponent, and 3) the alignment/disalignment of ownship and threat maneuver planes. These relationships help to define the tactical choices available to a pilot.

The ability to affect changes in these relationships defines the potential for success in maneuvering close-in air combat. Conventional maneuverability is the first-order term affecting these state variables and includes 1) P_s as defined by the change in velocity $\dot{V}$, 2) turn rate ω as related to the derivative of χ and γ defining the change in direction of the velocity vector, and 3) stability axis roll rate P_{stab} as defined by the change in the orientation of the lift plane.

Extrapolating on Eidetics' analogy to calculus and MBB's definition of agility as the derivative of the maneuver vector, agility can be thought of as a higher order term of maneuverability and defined as the derivative of maneuverability consisting of 1) the rate of change of acceleration/deceleration $\ddot{V}$, 2) turn rate onset/offset $\dot{\omega}$, and 3) stability axis roll acceleration $\dot{P}_{stab}$. The definition of maneuverability and agility as first- and second-order terms effecting aircraft state establish a basis for the qualitative comparison of the agility metrics.

Referring to Fig. 7, the quantification of acceleration and turn rate for the dynamic speed turn developed by General Dynamics is described by maneuverability terms in the axial and pitch axis. The merit of such a metric is that it relates static maneuverability measures of performance to a relevant combat task. Designing an aircraft to maximize the metric, by maximizing turn rate and thrust and minimizing drag, will increase its air combat effectiveness. Although the dynamic speed turn does not measure agility as previously defined, it is a useful metric because it provides the designers of fighter aircraft the ability to assess energy maneuverability in relation to air combat.

Figure 8 represents Eidetics' agility metrics in terms of the agility definition proposed in Fig. 6. Referring to the boxed quantities in Fig. 8, Eidetics' torsional agility metric, turn agility, would be described in terms of maneuverability. Turn agility, defined as turn rate divided by the time it takes to achieve a 90-deg bank angle change at that turn rate, is most closely related to maximum stability axis roll rate due to the dependence of time to bank on roll and yaw rate at high angle-of-attack conditions. Remaining with the working definition outlined in Fig. 6, turn rate and maximum stability axis roll rate are defined as maneuverability terms. Although this metric does not measure agility as defined, the turn agility metric is useful in assessing the ability of an aircraft to roll at elevated g conditions, a capability that is lacking in existing fighters and which is a requirement for air combat.

Eidetics axial and pitch agility metrics, energy rate and time to pitch, although they do not measure the rate of change of maneuverability as defined by the derivative of maneuverability parameters, do measure the transient capability of an aircraft to affect changes in maneuverability parameters.

MBB's agility metrics, A_k, A_t, and A_l, are almost identical with the terms in Fig. 9. As noted previously, the similarity of MBB's metrics with the commonly known and easily measurable values, $\dot{N}_z$, $\dot{P}_{stab}$, and $\dot{N}_x$, respectively, may lead to the alternative use of these known quantities for tasks such as the inflight measurement of agility parameters.

The box encircling the state, maneuverability, and agility variables shown in Fig. 10 represents the AFFTC's emphasis on the tactically relevant task of obtaining a desired final state. Defining a metric that uses the time to achieve a relative state change as a measure of performance incorporates the initial state conditions, the rates affected by maneuverability, and accelerations affected by agility. This global measure of merit, termed functional agility by the AFFTC, is best represented in the AFFTC's pointing spheres in which heading, pitch angle, speed loss, and time to maneuver are displayed on a color-coded sphere for a given initial speed and altitude condition. In this manner, the information can be made readily available to designers, analysts and, most important, operational fighter pilots.

The most important aspect of each of the government and industry's proposed metrics is that they assess aircraft performance in a manner that is unique. A summary of each of the agility metrics is shown in Fig. 11 in terms of the "agility spectrum" which defines aircraft performance on a scale from conventional maneuverability to functional agility to transient agility. The choice of which metric to use is made by the designer who is trying to maximize the aspect of aircraft performance that will dominate air combat. The assessment of which performance aspect, maneuverability or agility, that dominates air combat is still to be made. After this is accomplished, an optimal balance between agility and maneuverability can be struck utilizing the metrics identified.

Quantitative Comparison

Under a company-funded effort, Rockwell has developed a high-fidelity, six-degree-of-freedom advanced vehicle flight dynamics simulation model by which agility metrics can be measured.[1] The model provides the capability to quantify the effect of the variation of design parameters, such as pitch and roll rates and accelerations, rate limits, thrust-vectoring capability, and aerodynamic performance characteristics on airframe agility. The model utilizes an analytical controller that emulates a perfect flight-control system which is sensitive to established handling-qualities criteria. In this manner, total airframe agility potential can be measured.

Each of the recognized agility metrics presented is quantified for AFFTC standard agility maneuvers.[14] The AFFTC standard agility maneuvers are designed to measure pitch, roll, and axial agility. The pitch-agility maneuver, run 41 from Ref. 14, consists of a 1-*g* roll to 90 deg of bank at 350 KCAS at 20,000 ft altitude followed by a full aft stick pull to capture 6 *g*. The roll-agility maneuver, run 82 from Ref. 14, consists of a 180-deg loaded roll at 6 *g* at 350 KCAS at 20,000 ft. The axial-agility maneuver consists of a 1-*g* acceleration maneuver from 0.5 Mach to maximum level speed at 20,000 ft with 0-deg speed brake deflection. Each of the maneuvers described are designed in order to isolate the specific agility metric to be measured.

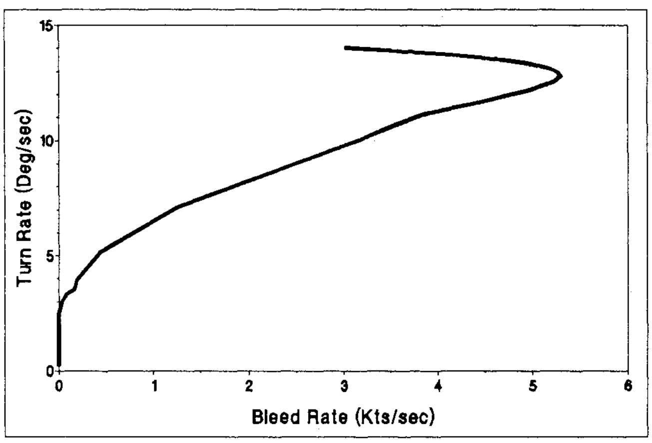

Fig. 12 Dynamic speed turn plot.

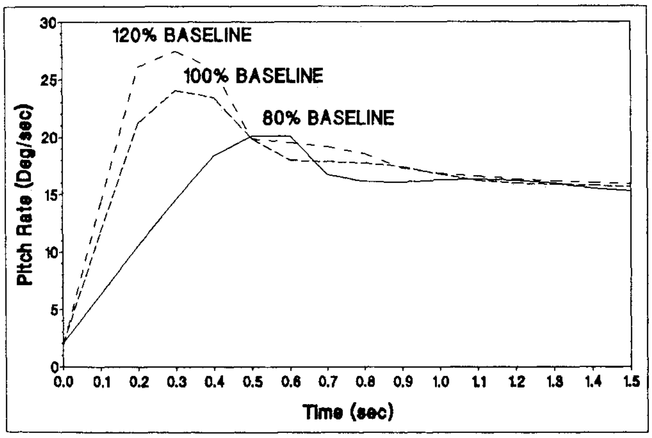

Fig. 13 Effect of variation in pitch rate overshoot ratio on pitch rate.

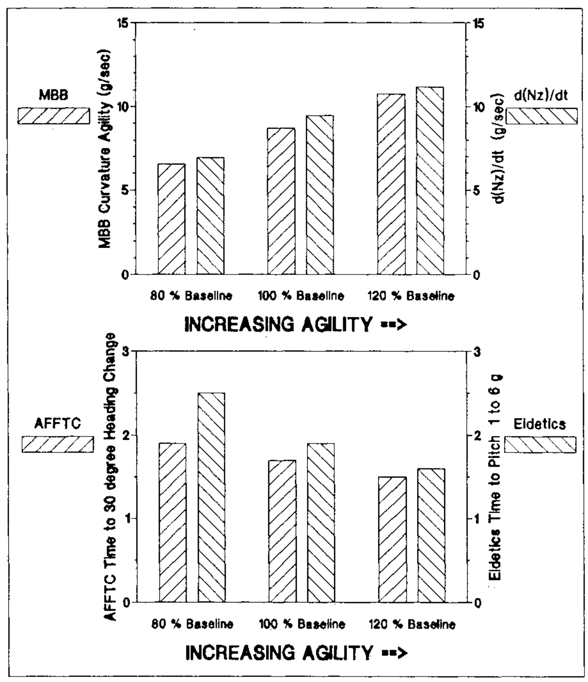

Fig. 14 Effect of variation in pitch agility on pitch-axis agility metrics.

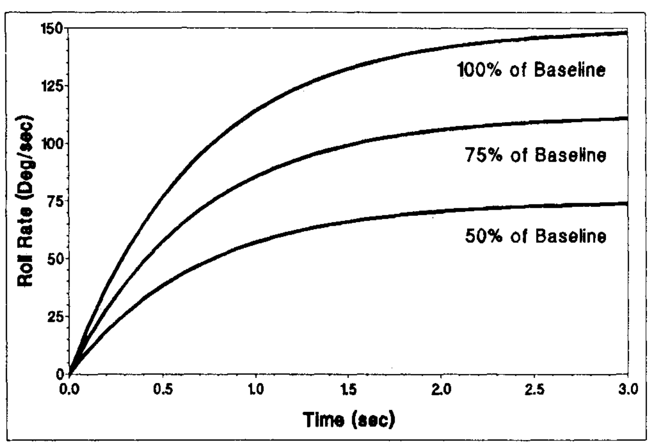

Fig. 15 Effect of variation in maximum roll rate.

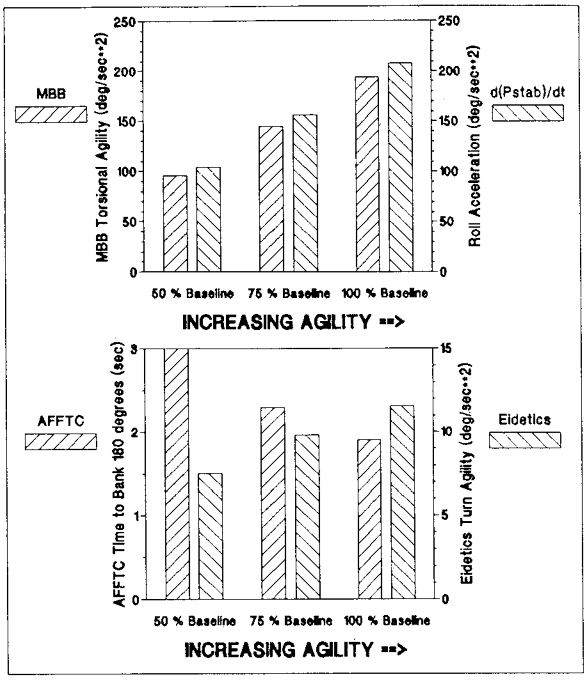

Fig. 16 Effect of variation in roll agility on roll-axis agility metrics.

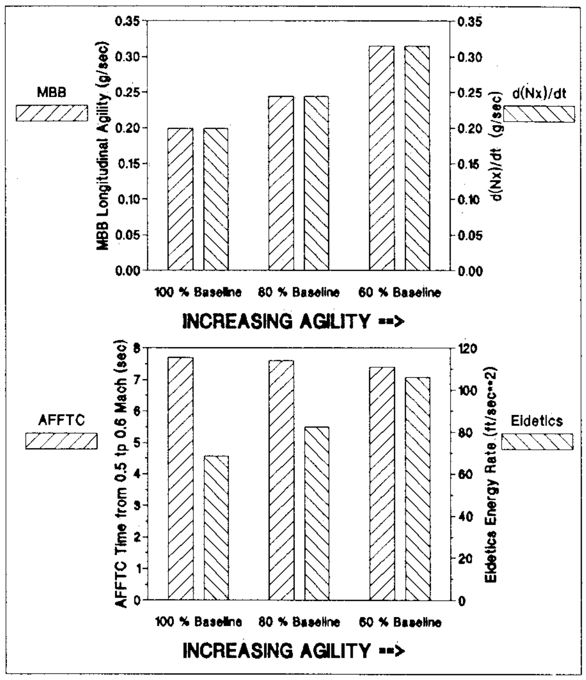

Fig. 18 Effect of variation in axial agility on longitudinal agility metrics.

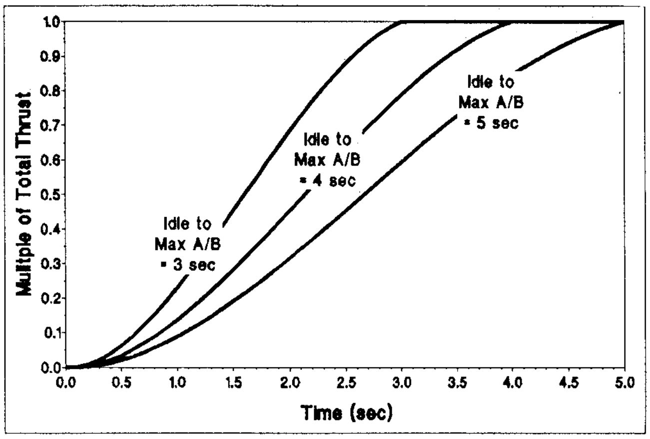

Fig. 17 Effect of variation in engine transient response.

AGILITY COMPONENT	MANEUVERABILITY	TRANSIENT AGILITY: WORKING DEFINITION	TRANSIENT AGILITY: MBB	FUNCTIONAL AGILITY: FLIGHT TEST	FUNCTIONAL AGILITY: PILOTS
LONGITUDINAL (AXIAL)	DYNAMIC SPEED TURN (GENERAL DYNAMICS)	$\dot{N}_x$	A_l	TIME TO FINAL AIRSPEED	POINTING SPHERES (AFFTC)
CURVATURE (PITCH)		$\dot{N}_z$	A_k	TIME TO CAPTURE Θ OR Ψ	
TORSIONAL (ROLL)	TURN AGILITY (EIDETICS)	$\dot{P}_{stab}$	A_t	TIME TO BANK	

MANEUVERABILITY + TRANSIENT AGILITY = FUNCTIONAL AGILITY

Fig. 19 Systems approach to aircraft design for agility.

General Dynamics, as stated previously, defines agility as a combination of maneuverability and controllability. General Dynamics' measure of maneuverability, the dynamic speed turn plot, is quantified, as shown in Fig. 12, for the standard pitch-agility maneuver. General Dynamics' measure of controllability is represented by fast pitch response, rapid loaded rolls, and quick engine response.[2] General Dynamics' measure of controllability is characterized by variations in the agility-related input design parameters used for this analysis.

To determine the effect of variations in pitch/curvature agility vs the proposed metrics, the pitch axis handling-qualities input to the advanced vehicle flight dynamics model was varied. Pitch overshoot ratio, as defined by maximum pitch rate divided by final desired steady-state pitch rate, was set at 80 and 120% of baseline to effect the change in pitch-axis agility. The resultant effect on pitch rate as a function of time for the three levels of pitch agility is shown in Fig. 13 for the AFFTC standard pitch-agility maneuver. Figure 14 demonstrates the effect of these variations for the MBB, Eidetics, and AFFTC pitch-axis agility metrics as well as the peak measured value of $\dot{N}_z$. As illustrated in Fig. 14, the MBB A_k metric increases with increasing pitch agility along with $\dot{N}_z$, whereas the AFFTC and Eidetics metric of time to achieve a 30-deg heading change and time from 1–6 g, respectively, decrease with increasing pitch agility.

The effect of variation in roll/curvature agility was determined by varying maximum stability axis roll rate to 50 and 75% of baseline. By increasing maximum stability axis roll rate, stability axis roll acceleration increases for a given roll mode time constant. Figure 15 illustrates the resultant effect on roll rate as a function of time for the three levels of roll agility. The effect of variations in roll agility is shown in Fig. 16 for the MBB, Eidetics, and AFFTC roll axis agility metrics and the peak measured values of stability axis roll acceleration $\dot{P}_{stab}$. As calculated, the MBB A_t metric, Eidetics turn agility, and $\dot{P}_{stab}$ increase with increasing roll agility, whereas the AFFTC metric of time to achieve a 180-deg bank angle change with increasing roll agility.

Longitudinal/axial agility was increased by reducing engine transient response, as defined by time from idle power to maximum afterburner, to 60 and 80% of baseline. The resultant effect on thrust as a function of time for the three levels of axial agility is shown in Fig. 17. The effect of variations in axial agility for the MBB, Eidetics, and AFFTC axial agility metrics and the peak measured value of $\dot{N}_x$ is shown in Fig. 18. As shown in Fig. 18, the MBB A_l metric, Eidetics energy rate, and $\dot{N}_x$ increase with increasing axial agility, whereas the AFFTC metric of time, at 1-g level flight, from an initial to final airspeed decreases as a function of the input.

Conclusions

The initial investigation into the quantification of the proposed agility metrics demonstrates that they can be used to quantify the ability of aircraft design parameters to influence the agility, maneuverability, and desired state of an aircraft. Each of the agility metrics proposed measure an aspect of aircraft performance in a manner in which it has not been previously measured. Conventional maneuverability is measured by the General Dynamics DST plot, uniquely tied to a relevant combat task. Functional agility is measured by the AFFTC's "time to" metrics thereby satisfying their objective of developing an agility metric that is easily measurable in flight test and easily interpreted, in the form of pointing spheres, by pilots. Eidetics' agility metrics provide design guidance by measuring quantities that represent aircraft capabilities that are required for success in air combat, such as high stability axis roll rates at elevated g, and are lacking in current generation fighters. The MBB agility metrics are uniquely capable of measuring transient agility during air combat by measuring the rate of change of maneuverability as opposed to measuring a time-related change in maneuverability for a specific task. The "working definition" of agility, as defined by commonly known and understood quantities, can be used to facilitate the measurement of aircraft transient agility during flight testing. A comprehensive systems approach to aircraft design would utilize each of these metrics, as shown in Fig. 19, along with classical energy maneuverability measures of performance to design future fighter aircraft. By maximizing aircraft maneuverability and transient agility, a more agile aircraft, in terms of functional agility, can be designed.

Agility is an interdisciplinary subject involving aerodynamicists, flight-control engineers, pilots, and operations analysts. The utility of each of the agility metrics discussed is their ability to measure a unique aspect of aircraft performance and therefore provide design guidance. The importance of each of the metrics is how it can influence the design process and what it means in the context of total weapon system air combat effectiveness. The next step in the comprehensive study of agility is to merge the vehicle dynamic simulation methodology developed with current air combat simulation models to quantify the impact of increased agility on air combat effectiveness. Until the relationship of agility to aircraft design and air combat effectiveness is identified, the study of agility is not complete.

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