JOURNAL OF AIRCRAFT
Vol. 30, No. 6, Nov.–Dec. 1993

Measurement and Improvement of the Lateral Agility of the F-18

David P. Eggold,* John Valasek,* and David R. Downing‡
University of Kansas, Lawrence, Kansas 66045

Abstract

THIS synoptic highlights parameters which affect the lateral agility of a modern fighter aircraft. This is accomplished using a generic, nonreal-time simulation of the F-18 to study lateral agility as measured by the time to roll through 90-deg metric, T_{TR90}. Specific, simple modifications which improve the existing agility of this aircraft are shown, and are easily applicable to other aircraft. A sensitivity study on the effects of modified actuator rates and roll and yaw control powers, employed both singly and in combinations, demonstrate that a 10–30% improvement in lateral agility, as measured by the T_{TR90} metric, can be achieved. Additionally, coordinating the wind axis roll acceleration by slowing the aileron input rate yields a further improvement in T_{TR90}. This modification reduces adverse sideslip and improves the character of the roll response.

Contents

The T_{TR90} metric is tested using the University of Kansas Flight Research Laboratory's nonlinear, nonreal-time six degree-of-freedom generic computer simulation of the F-18.[1] The program is high fidelity, containing full flight control system (FCS), engine, and aerodynamic models. Values for T_{TR90} are measured by commanding the aircraft to pitch-up to some specified angle of attack α with the wing level, and then rolling through a bank angle of 90-deg while holding aft stick constant. The bank angle is measured with the parameter Φ_{wind}, which is defined as

$$\Phi_{\text{wind}} = \int P_{\text{wind}}\, \mathrm{d}t \tag{1}$$

where P_{wind} is wind axis roll rate. Rudder pedal inputs are not to be used, and for this aircraft are not required due to the full authority rolling-surface-to-rudder interconnect. Although a nonreal-time simulation cannot include all of the effects of flying qualities, and the pilot stick inputs are an idealized representation of what a pilot might actually use, this method does evaluate both airframe and FCS performance.

To determine parameters which affect lateral agility, the roll performance of the baseline generic F-18 is quantified using the T_{TR90} metric. Figure 1 shows T_{TR90} vs the average value of α and the maximum value of sideslip angle β during the roll through $\Phi_{\text{wind}} = 90$ deg. The reduction of roll performance is not due not to FCS scheduling, but rather to surface deflection limits. The most β is generated during rolls in the range 10 deg $< \alpha <$ 20 deg for all the Mach numbers tested. The shape of the curve is a result of FCS scheduling of surface deflections with α. The FCS commands the rudders and the roll control surfaces to provide a coordinated roll ($\beta = 0$) in response to a lateral stick input. In the range 10 deg $< \alpha <$ 20 deg, and with a full deflection lateral stick input, the rudders become saturated and the roll is less coordinated than at other α. For $\alpha >$ 20 deg, roll control surface deflections are limited so as to better coordinate the roll.

Having determined the parameters which affect the lateral agility of the baseline generic F-18, simple modifications are investigated to improve lateral agility and roll coordination at medium to high α. The modifications considered are limited to simple changes that do not affect the functioning of the FCS or the validity of the simulation as being representative of a modern fighter aircraft. The three key parameters addressed are 1) rudder saturation, 2) rudder actuator rates, and 3) roll control surface deflection limiting at high α. Each of these parameters are considered individually and in unison.

To reduce rudder saturation, the control power of the rudders is increased by applying factors of 1.1 and 1.2 to the forces and moments due to rudder deflection. The preliminary design methods of Ref. 2 indicate that rudders of 30% chord and 90% span on the same vertical tails can provide a 20% increase in control power; the baseline generic F-18 rudders are of 20% chord and 67% span. Rudder actuator rates are increased above the no-load rate of 61 deg/s for the baseline generic F-18 to 100 and 140 deg/s. The time constant of the rudder actuator is not changed. A rudder actuator capable of producing 140 deg/s surface rate with hinge moments 20% larger than the baseline generic F-18 is within the capabilities of existing hardware. The roll command limiters are modified (enlarged) to take advantage of the now increased rudder power and rate. For the aileron and differential stabilator command limiters factors of 1.1, 1.3, 1.5, and 2.0 are applied. This permits the ailerons and the differential stabilators to deflect further than they would with the baseline FCS. To implement these changes requires only a software change to the FCS. The impact of these changes on the weight and inertias of the generic F-18 is assumed to be small enough to

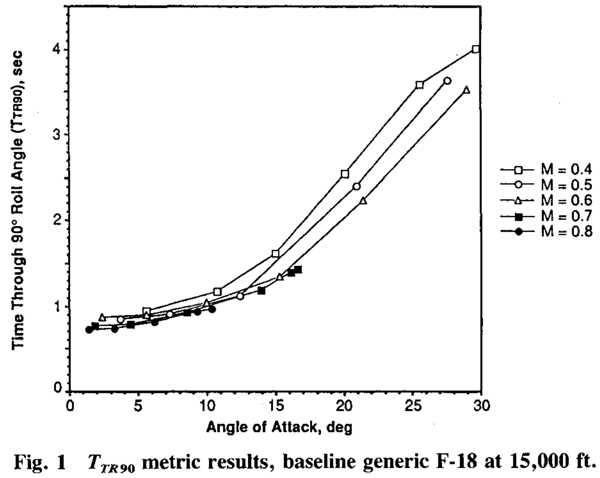

Fig. 1 T_{TR90} metric results, baseline generic F-18 at 15,000 ft.

Presented as Paper 91-2880 at the AIAA Atmospheric Flight Mechanics Conference, New Orleans, LA, Aug. 12–14, 1991; received Sept. 3, 1991; synoptic received Aug. 15, 1992; accepted for publication Aug. 15, 1992. Full paper available from AIAA Library, 555 West 57th Street, New York, NY 10019.

*Graduate Research Assistant, Flight Research Laboratory, University of Kansas Center for Research, Inc., 2291 Irving Hill Drive. Member AIAA.

‡Professor and Chair, Department of Aerospace Engineering, 2004 Learned Hall. Associate Fellow AIAA.

not appreciably change the aircraft's dynamics for this investigation.

The modified generic F-18 is tested at four flight conditions (see Ref. 3), but only the results of the α = 28 deg, Mach = 0.6 case are displayed here (Fig. 2). The vertical axis shows the effect of the modifications on the T_{TR90} metric, expressed as a fraction of the T_{TR90} of the baseline generic F-18; the horizontal axis shows the effect of the modifications on roll coordination. The effect of larger roll surface deflections is to drive T_{TR90} and maximum β in the direction of arrow "A" in Fig. 2. For this flight condition a roll command multiple of 2.0 can be used without inducing more than 10 deg of β from kinematic coupling. The effect of increased rudder power is in the direction of arrow "B." Installing a larger rudder on the same vertical tail reduces adverse yaw, increases P_{wind}, and reduces T_{TR90} for all the flight conditions tested. The effect of increased rudder rate is in the direction of arrow "C." It is seen that rudder power and rate have a large effect on the value of T_{TR90}, chiefly by increasing yaw acceleration and improving roll coordination. Maximum rudder rates faster

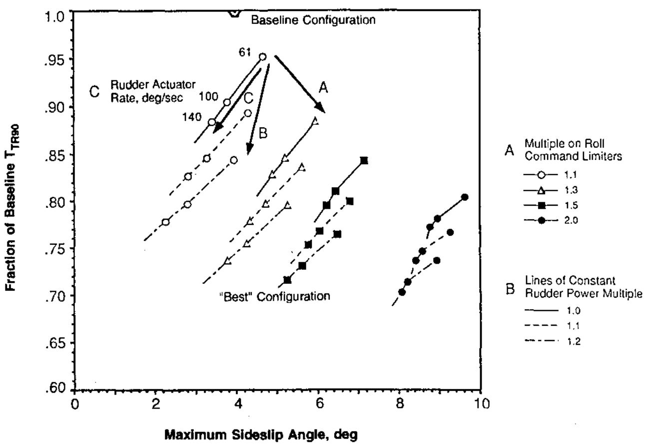

Fig. 2 Effects of rudder and roll command changes on T_{TR90}, generic F-18 at 0.6/15k, 28 deg angle of attack.

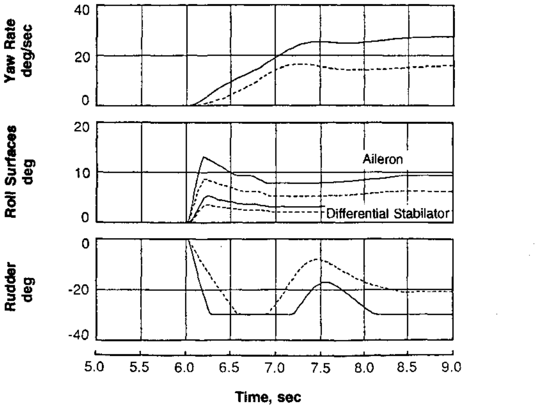

Fig. 3 Comparison of modified and baseline generic F-18 configurations in a time through roll angle maneuver, 0.6/15k, 28 deg angle of attack.

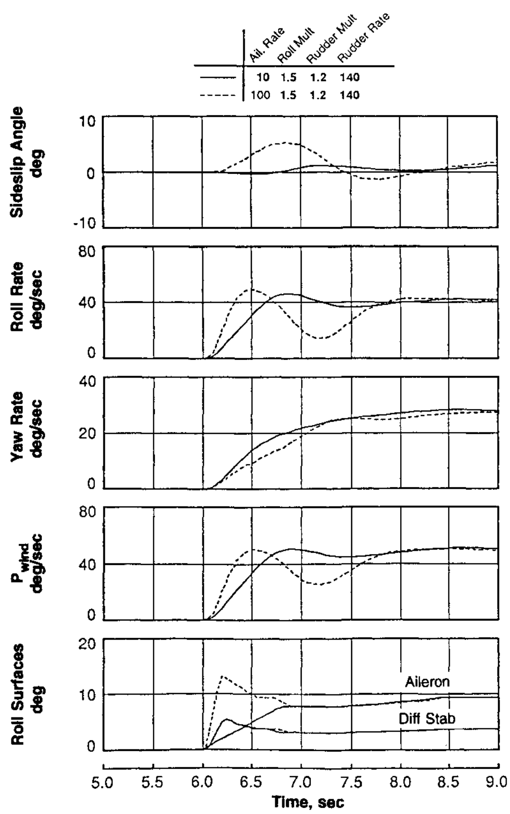

Fig. 4 Effect of a slow aileron actuator on generic F-18 configurations in a time through roll angle maneuver, 0.6/15k, 28 deg angle of attack.

than about 140 deg/s provide little additional improvements in T_{TR90} and roll coordination.[3] A "best" modified configuration with a roll command multiple of 1.5, a rudder power multiple of 1.2, and a rudder rate of 140 deg/s reduces T_{TR90} by 0.95 s, which is 28.5% less than the baseline generic F-18.

Figure 3 is a time history comparison of the best modified configuration and the baseline generic F-18. Even with the rudder deflecting to its deflection limit at 140 deg/s, body axis roll rate P builds too fast for the yaw rate R that is generated. However, when P approaches its steady-state value after 8 s, it is well-coordinated with R. Just as P and R need to be proportioned correctly for steady-state rolls, body axis roll and yaw accelerations need to be proportioned correctly during roll acceleration. The high α roll command limiters, which were designed for steady-state coordination, do not address this problem.

An effective method to improve the coordination of body axis roll and yaw accelerations is to reduce the aileron actuator rate. Figure 4 demonstrates that reducing the aileron actuator rate from the baseline 100 deg/s to 10 deg/s slows the initial body axis roll acceleration. The resulting improvement in roll coordination reduces adverse β from 5 deg to only 1 deg. The oscillation in P_{wind} is eliminated, and T_{TR90} is reduced from 2.4 to 2.3 s, an improvement of 4.2%. With less kinematic coupling, the character of the roll response is improved, which slightly improves T_{TR90}.

References

[1]Valasek, J., "SIM-II F-18 Flight Simulation Program Documentation," Univ. of Kansas Flight Research Lab., KU-FRL-831-1, Lawrence, KS, June 1990.

[2]Roskam, J., *Airplane Design, Part VI: Preliminary Calculation of Aerodynamic, Thrust and Power Characteristics*, Roskam Aviation and Engineering Corp., Ottawa, KS, 1987, pp. 461, 462.

[3]Eggold, D. P., "The Assessment and Quantification of Lateral Agility Metrics Using an F-18 Simulation," Univ. of Kansas Flight Research Lab., KU-FRL-831-4, Lawrence, KS, Sept. 1990.