ARTICLE NO. 80-4077

C 80-100

Future Fighter Technologies

00006

W.B. Herbst*
Messerschmitt-Bölkow-Blohm GmbH, München, W. Germany

In Central Europe there is a need for a new fighter aircraft to be introduced in the 1990 time period. Can sufficient improvement of operational capabilities be expected from new technologies in order to justify the development of a new weapon system? This paper describes a fighter concept which is based upon recent advancements in aerodynamics and control technology of delta wings and upon "supermaneuverability," a blend of post-stall and side-slipping maneuvers or direct force control, respectively. This concept would satisfy diverging requirements for high-speed performance, low-speed maneuverability, and short field performance against a superior number of hostile aircraft at less cost than existing conventional fighters. The concept is backed by extensive wind-tunnel testing and manned as well as model air combat simulations. It constitutes a basis for a new development at the expense of some remaining risk.

I. Introduction

THE design of fighter aircraft used to be a race for performance. There was the race for maximum speed, followed by the aim for maximum climb performance, and eventually concluded with the emphasis on sustained turn capability. As a result, the installed thrust-to-weight ratio (T/W) continuously increased and has now exceeded the value of 1. Unfortunately, there is a progressive effect of T/W on weight and cost and even an asymptotic limit.[1] Though this limit is shifting with airframe technology, more thrust per engine has to be paid for by more cost per unit of thrust, thus further accelerating the price for increased performance. The analysis of war games[1] indicates that the cost-effectiveness of a fighter fleet would suffer from the introduction of aircraft employing T/W ratios of more than 1.2. In Fig. 1, fleet deterioration is presented against increasing vehicle performance at constant budget, e.g., against decreasing fleet size. Beyond a performance level equivalent to $T/W=1.2$, the red fighters—assumed to employ a T/W of 0.7—would outnumber the higher performance blue aircraft. This performance level, however, is already achieved by current fighter aircraft. The race for energy-performance has reached its limits.

There is also competition to the airframe designer by the new generation of medium range missiles (MRM) to be introduced soon. MRM's plus multi-target and shoot up/down capabilities of radar weapons may even tend to make the classical fighter concept questionable.

II. Requirements

In Central Europe there is a need for a new fighter concept which would have to satisfy the following three largely contradicting requirements: 1) interception of intruders under all-weather conditions beyond visual range with MRM's, 2) air superiority against a superior number of maneuvering offensive targets with short-range weapons, and 3) short field performance for base survival. Largely because of the cost constraint, there is a tendency to use existing engines. This reduces the degree of freedom for the designer.

The driving airframe parameter to satisfy requirement 1 turns out to be high-speed maneuverability in particular. In a MRM environment with multi-target capability on both sides, supersonic performance is important to achieve an advantageous first launch opportunity, outrun the opponent's missile, and be able to reattack.

Figure 2 summarizes the results of multiple intercept combat engagements[2] employing AMRAM-type MRM's of blue fighters against escorted red intruders. A typical $M=1.6$-fighter with marginal SEP at medium supersonic speed is compared against a typical $M=2.2$-fighter with good turn and acceleration capability around $M=1.8$. As a result, the faster aircraft would suffer fewer own losses, and consequently, red losses and mission aborts would increase. According to Fig. 2, better supersonic performance would improve the overall exchange ratio by a factor of 2 in an engagement of 2 interceptors against 4 intruders being escorted by 2 fighters. Figure 3 represents a time history averaging a statistical number of such engagements. It shows that in addition to the effectiveness advantage, the faster interceptor would achieve the same mission success in less time. This is extremely important in view of the excessive fuel consumption at afterburner power settings.

The air superiority requirement 2 leads to a requirement for superior close combat capability with short-range weapons, e.g., for subsonic maneuvers performance. Unfortunately, there is that contradicting problem with conventional aircraft which achieve their maximum rate of turn at a speed very different from that constituting a smallest turn radius. Also, it is well known from many manned and unmanned combat simulations that it takes about 3 deg/s rate of turn advantage to be superior; however, the current level of about 25 deg/s (maximum sustained) is very difficult to exceed by conventional means.

Without any thrust support, short field performance primarily is a matter of wing loading. Optimum maneuver and cruise performance prohibits low wing loadings for trapezoidal wing aircraft (Fig. 4). Low-aspect ratio delta wings lend themselves to, and are even dependent upon, considerably low wing loadings. However, a low wing loading may constitute a problem for low-level high-speed penetration missions (ride quality).

III. Key Technologies

There are three technologies which offer a solution to the task of combining diverging requirements such as high supersonic speed, subsonic combat capability, and short field performance.

A. Digital Fly-by-Wire Control

This technology allows the control surface to move according to a commanded flight condition rather than to a control stick displacement, as in the case of a mechanical

Received Oct. 9, 1979; revision received Jan. 25, 1980.
Index category: Configuration Design.
*Head of Advanced Design, Military Aircraft Division.

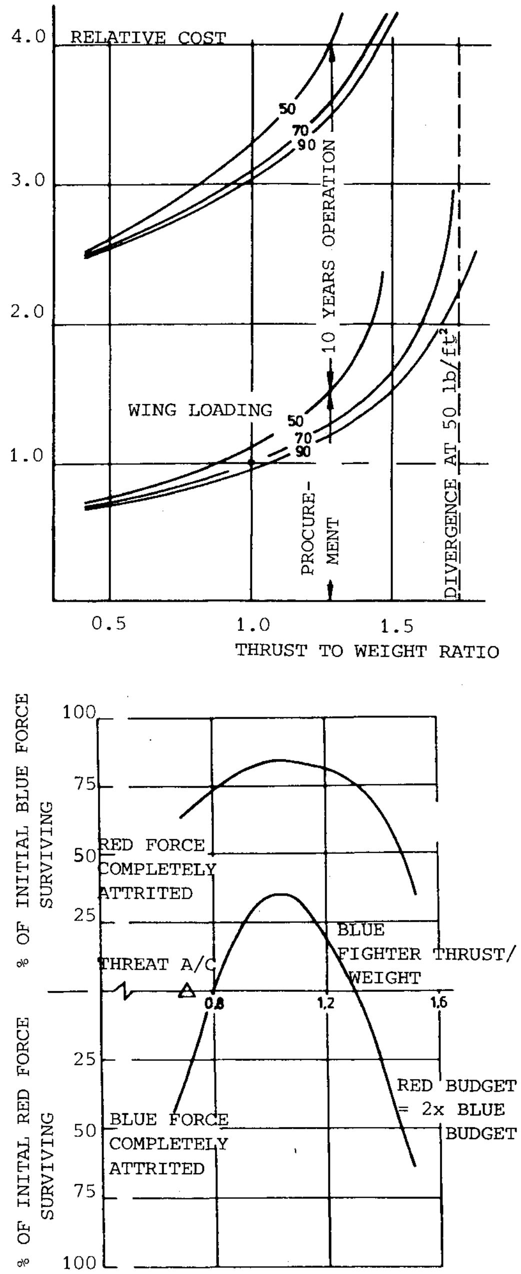

Fig. 1 The limits of the race for performance (Ref. 1).

system. Furthermore, the digital system, as compared to an electrical analog system, allows command and control to dedicated mission-oriented flight modes and even provides the basic stability of the aircraft. Digital electronic control technology is becoming state of the art. However, there is still the problem of accounting for system malfunctions. Malfunctions of electronic components, unfortunately, are still well within expectation, and therefore, are usually taken care of by systems redundancy. Redundancy in terms of parallel systems, however, is questionable and may not even satisfy safety requirements because the system would still be subject to systematic failures such as environmental impacts, production tolerances, wrong maintenance, and even software mistakes. Other redundancy principles such as functional or dissimilar redundancy are currently being developed, the success of which will be important to new fighter concepts.

B. Delta Wings

A tailless delta wing takes more advantage from CCV-technology than any other wing configuration. Flaps can be

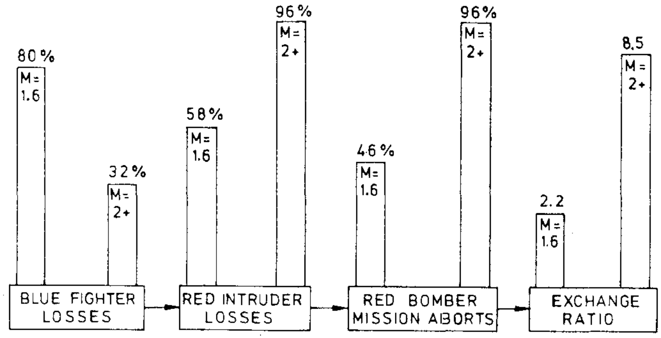

Fig. 2 The tactical value of high-speed performance in a medium-range and multi-target environment (Ref. 2).

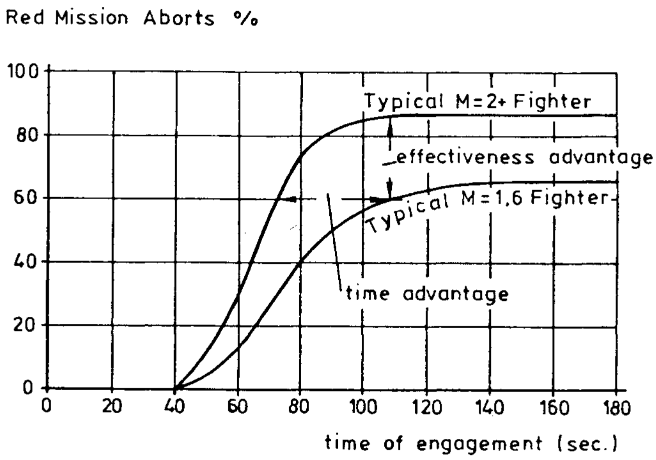

Fig. 3 Higher speed capability leads to faster mission success.

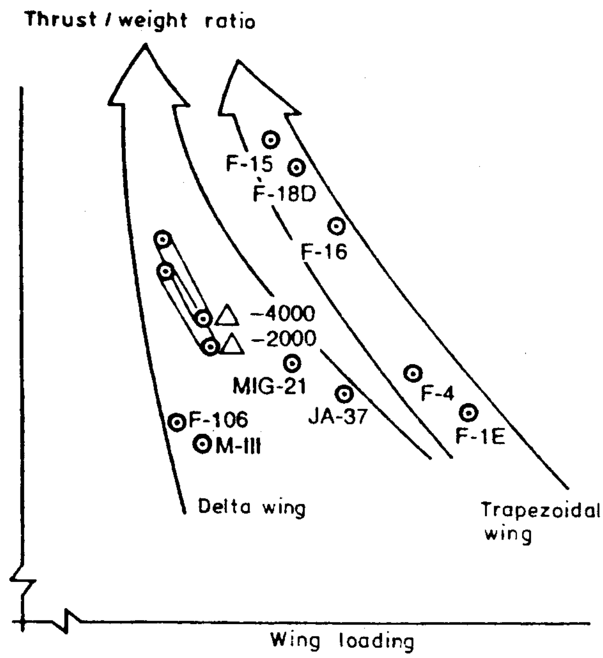

Fig. 4 Delta wing leads to lower wing loading.

designed to deflect in accordance with the commanded maneuver (down for uplift, up for downlift). As a result:

1) The aircraft is responding faster and more precisely to a control input.

2) Maximum lift coefficients are improved considerably.

3) Angle of attack in a high-lift configuration is reduced, which permits exploitation of the lift potential more efficiently for takeoff and landing.

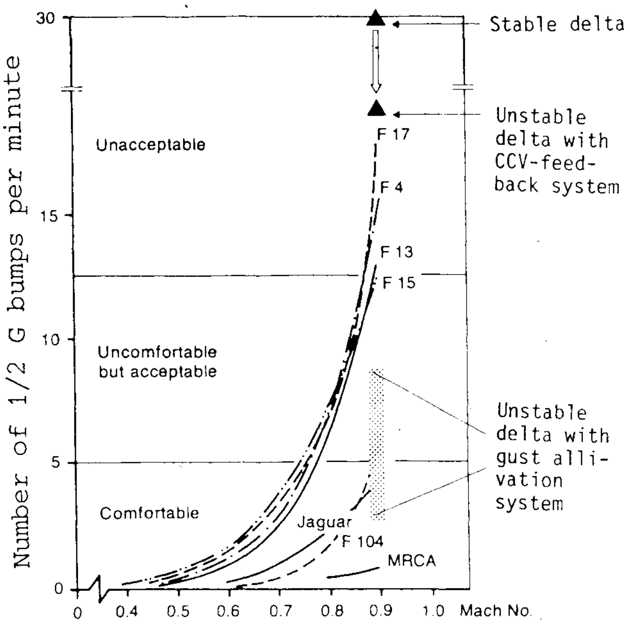

Fig. 5 Gust alleviation potential of an aircraft with DFM-capability (Ref. 12).

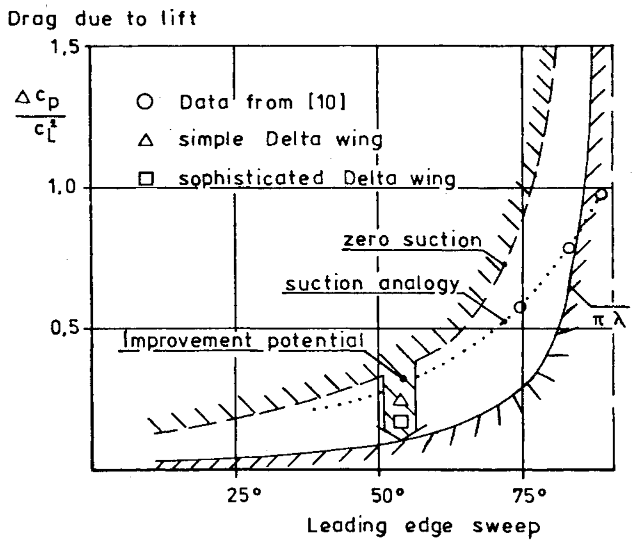

Fig. 6 The potential performance improvements of delta wings.

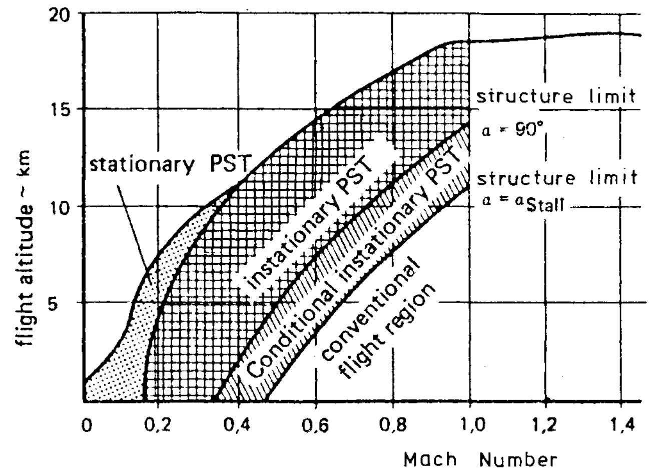

Fig. 7 Flight regime of supermaneuverability (PST).

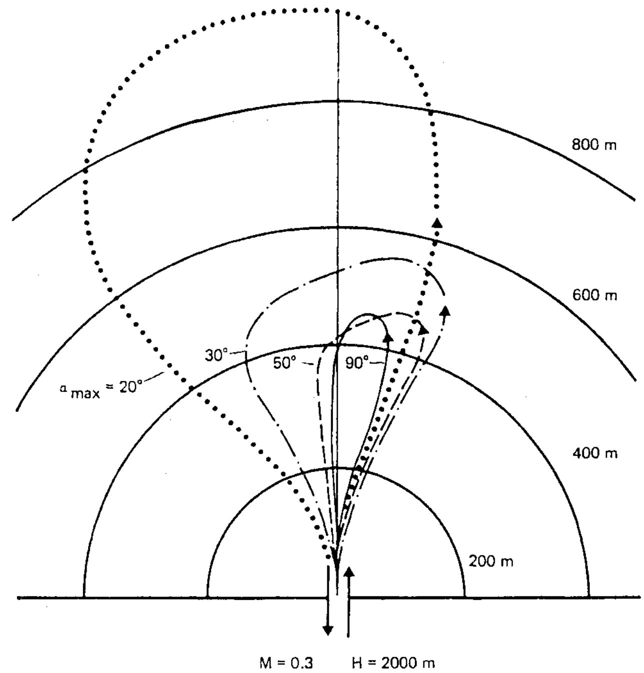

Fig. 8 Thrust supported minimum time maneuvers (Ref. 6).

4) There is less drag due to lift at any flap setting which improves the basic maneuver performance, particularly at high lift.

The combination of a delta wing with a properly designed and integrated close-coupled canard furthermore improves maximum lift with less penalties of canard-wing interaction.[11] At the same time, a canard can be used as a control device for optimum lift to drag throughout the flight envelope. A delta-canard configuration also allows[12] to superimpose an effective gust alleviation system (Fig. 5). This, in turn, permits the wing loading to keep as low as necessary for optimum SEP-performance. Wing loading would be as low as about 40 lb/ft^2 at combat, which suits optimum air combat capability at 1.2 T/W (see Ref. 1). It reduces approach speed to values as low as 80 knots and eliminates the need for high-lift systems, thrust reversers, and brake chutes at ground run distances of less than 1200 ft.

There is a considerable basic aerodynamic potential in terms of lift to drag improvements in delta wings. Theoretical tools are available now to refine the wing planform, profile, and twist distribution. In particular, the leading edge suction can be improved considerably by means of a proper leading edge profile,[10] thus improving drag due to lift, the weakness of any highly swept wing. Figure 6 shows drag due to lift dependent on the slenderness of the wing in terms of leading edge sweep. There is a maximum value under the assumption of zero leading edge suction. Most of the existing delta-wing vehicles are close to this line. There is a minimum value given by the ideal potential flow and optimum spanwise lift distribution. It has been demonstrated in wind-tunnel tests that this line can be approached fairly closely by a properly designed delta wing.

In summary, there is a revival of the delta wing. With the help of an electronic digital control system, properly designed with modern aerodynamic tools and suitably equipped with a canard control surface, a delta wing could be designed to maintain its classically good supersonic performance without sacrificing cruise and subsonic performance compared to a more conventional trapezoidal wing. The inherently low wing loading does not need to be considered a disadvantage, but contributes to short field performance and a low approach speed. As a separate issue, it lends itself particularly well for the application of post-stall maneuverability, as described in the following section.

C. Supermaneuverability

This is a term for combined post-stall (PST) and direct force (DFM) capability. PST represents the ability of the aircraft to perform controlled tactical maneuvers beyond maximum lift angle of attack up to at least 70 deg; DFM represents the ability of the aircraft to yaw and pitch independently of the flight path, or to maneuver at constant fuselage attitude.

DFM has been the subject of various analysis, design studies, simulations, and even flight tests. DFM has been developed by McAIR in conjunction with the vectored lift fighter (VLF) concept.[3] PST has been developed and analyzed by MBB.[4] PST and DFM are tactically related, supplement each other, and constitute a combined new and superior air combat feature.[5] The PST-flight regime (Fig.7) is limited by control constraints to the low-speed side and with respect to altitude, and by structural strength at $C_{L\max}$, to the high-speed side. Depending on the amount of net thrust available, there is a line left of which steady state PST-conditions could be maintained. At higher dynamic pressure, the vehicle would lose speed and/or altitude, and PST-maneuvers in this regime would be of short duration. The condition of maximum structural strength at a 90-deg angle of attack constitutes a line right of which PST-maneuvers would be angle-of-attack limited. It has been found in extensive manned and computerized combat simulations that tactical PST-maneuvers are confined to the instationary and conditionary instationary regime. There are no precisely definable DFM-flight regime limits; however, tactical usage confines DFM to the medium to high subsonic regime. PST and DFM regime overlap to a large extent.

The tactical advantage of PST lies in a trade of energy vs positional advantage. Figure 8 shows the trajectories of a high T/W-ratio fighter aircraft aiming to return to a point of departure at minimum time and to arrive at that point at the same altitude and speed and with an opposite heading.[6] With increasing angle-of-attack limits beyond maximum lift, the aircraft is able to maneuver in less air space and to complete the maneuver in a shorter time. Figure 9 is a time history of this maneuver in terms of angle of attack and airspeed as compared to the same aircraft being limited to a 20-angle of attack. It shows the typical feature of any PST-maneuver: a rapid pitch up to even 90-deg, maintaining this condition for only 2-3 s, followed by a fast return to normal flight. During the PST-phase, speed drops to low values and, not shown in the plot, some altitude is gained. There is an analogy to the power slide turns of racing cars.[7] If the front wheels are turned excessively and exceeding the limits of ground friction during a short time period at initiation of the maneuver, and if adequate power is applied to the back wheels, then a turn can be performed faster and with a much smaller turn radius. Both vehicles successfully sacrifice energy gaining an overall tactical advantage, as the speed plot in Fig. 9 indicates.

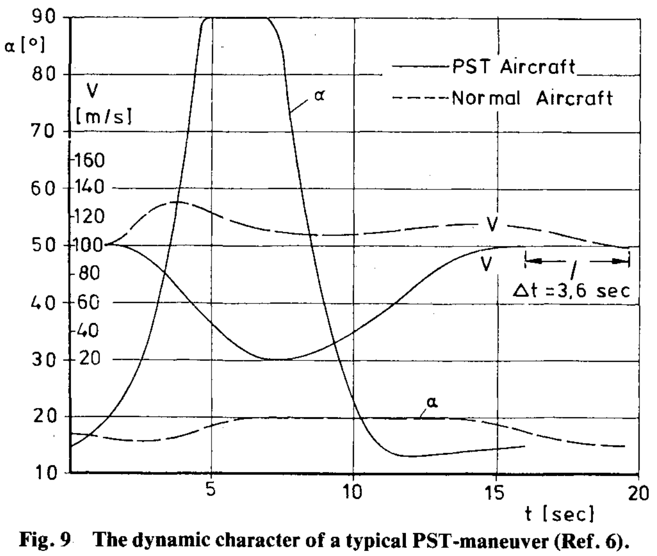

Fig. 9 The dynamic character of a typical PST-maneuver (Ref. 6).

A conventional fighter aircraft could not perform a tactical PST-maneuver. As the airflow separates from the wing surface at maximum life angle of attack, the center of pressure moves backwards along with the neutral point with respect to the center of gravity. At the same time, conventional control surfaces would lose their efficiency, and consequently, the aircraft would encounter trim and stability problems just at a time when maximum and precise control is required. The plot of required angular control acceleration throughout the turn maneuver in Fig. 8 indicates (Fig. 10) that the demand for control power is increasing with angle of attack beyond maximum lift. In particular, high yaw rates and high pitch down rates are required to perform PST-maneuvers of tactical value. The analysis of available aerodynamic control power, even considering an aircraft configuration designed for PST-maneuvers, is plotted in Fig. 11 against control power requirements experienced in many manned combat simulations employing PST. Beyond about a 30-deg angle of attack, an additional reaction control system becomes necessary at least for pitch and yaw. The most suitable solution would be the deflection of engine thrust, e.g., a vectored nozzle, since any PST-maneuver is flown at high-power settings.

PST capability is primarily used for maneuvering the aircraft into a position of advantage. Any limitation of its angle-of-attack capability and/or its controllability at high incidence constitutes a limitation of its offensive and defensive air combat capability. According to a parametric variation of such limits,[9] the capability of maneuvering at angles of attack up to at least 50 deg is required (Fig. 12) to achieve a substantial improvement in kill/loss rate. The most difficult design problems prevail in the 30-50-deg angle-of-attack regime. Beyond 50 deg, flight and control conditions are primarily ruled by thrust rather than aerodynamic support or disturbances.

DFM-capability in air combat maneuvers is primarily used for aiming the fuselage for longer and more precise firing solutions independently of the flight path. This advantage pertains particularly for the gun if the radar-operated fire control system is automatically coupled to the flight control system of the aircraft. This feature makes the gun an all-aspect weapon which can most successfully be used head on. Combat simulations[8] indicate (Fig. 12) that an elevation aiming potential of at least 6 deg and an azimuth aiming range of about 4 deg would be desirable for attacking the opponent from the rear hemisphere. For front hemisphere attacks, increased azimuth aiming potential is more important, and elevation aiming could partly be accomplished by normal load factor control. Conventional aircraft would have to use their wing flaps in conjunction with elevator deflection to generate elevation aiming; however, the resulting aiming range usually

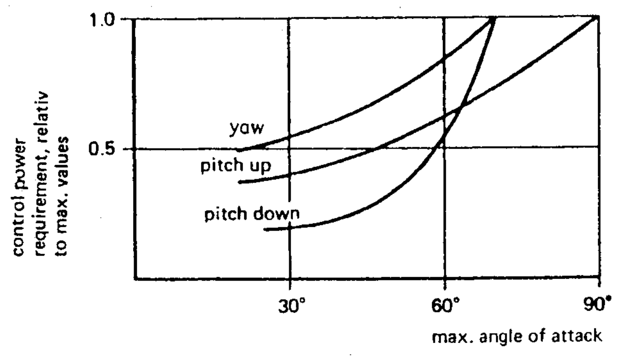

Fig. 10 The demand for more power to perform the PST-maneuver in Fig. 8.

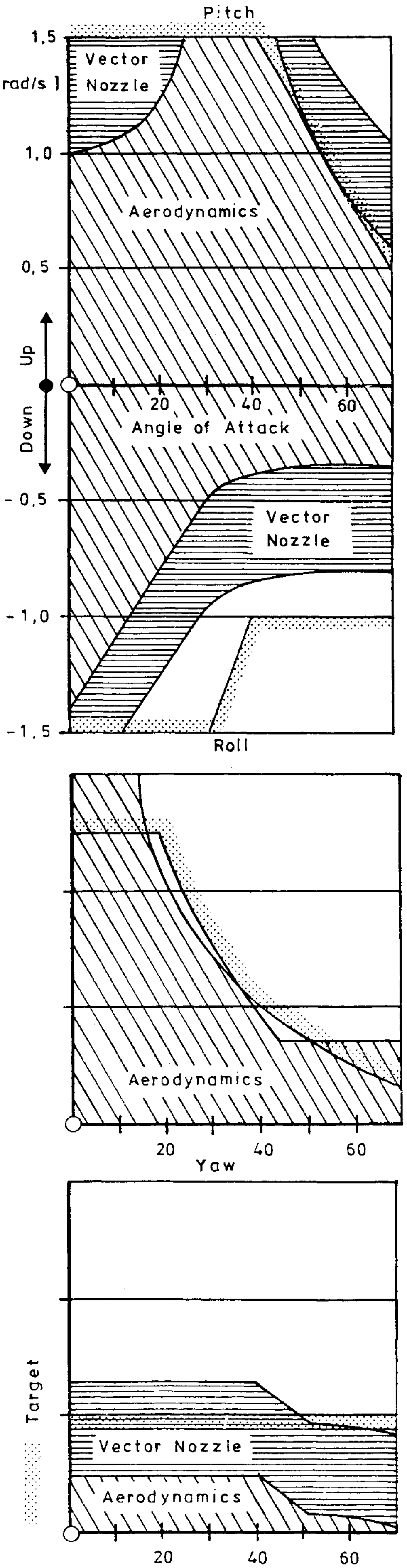

Fig. 11 The necessity of an additional reaction control system for tactical PST-maneuvers (vectored nozzle with 10-deg pitch and yaw deflection).

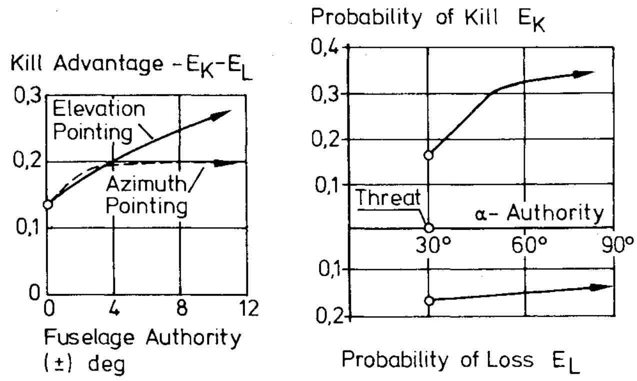

Fig. 12 The improvement of air combat effectiveness by independent (decoupled) fuselage aiming (Ref. 8) and by post-stall capability (Ref. 9).

is small, in the order of 2 deg. Azimuth aiming requires special control surfaces and cannot be achieved by conventional configurations.

Both PST- and DFM-maneuvers require a digital electronic control system. The most suitable control laws are still to be explored in simulations and in actual flight testing. Simulations have been successfully accomplished with an angle-of-attack feedback for PST and the roll control stick displacement commanding roll around the velocity vector rather than the body axis. DFM-aiming control has to be automatic in conjunction with the aircraft fire control system. For example, after target lock on and upon pilots stick pull command, the aircraft accordingly moves up, but pitches down at the same time. Similarly, upon a pedal input to the right, the aircraft would move to the right side but makes a left hand yaw. A deceleration would be accomplished by means of an appropriate combination of control surface deflections providing more deceleration power than conventional speed brakes. Of course, such a modulation of drag would have to be blended into the overall aircraft control by means of an appropriately designed electronic control system mechanization and a suitable control surface concept.

There is the question of load factor tolerance from the pilots point of view. First of all, it has been demonstrated in simulations and actual flights that the increased performance of contemporary fighters has shifted the peak load factor occurrence to lower values. This is because an F15 can sustain lower speed turns as compared to an F4. Air combat simulations employing PST consistently show a further relaxation of the pilots *g*-loading-level in the PST-aircraft as compared to its opponent of equal conventional flight performance (Fig. 14).

The tactical advantage of supermaneuverability has been successfully demonstrated in a series of manned and unmanned (digital computer) air combat simulations[5,9] with guns and all aspect short-range missiles, and even against multiple targets. Up to now, 15 operational fighter pilots have flown more than 1500 air combat engagements. Some of the most important findings are summarized in Fig. 13. As an overall result, air combat capability against a threat of the same conventional performance can be improved by a factor of 2 using all aspect missiles and by a factor of 10 using guns. With guns and missiles and counting first hits without counter hits, a suitably designed supermaneuverability fighter would win 5 out of 6 engagements against a threat of identical conventional performance.

The same level of air combat capability could not be achieved by any feasible increase in conventional maneuver performance. In Fig. 15, such performance is expressed in terms of wing loading and power installation, and then translated in relative air combat capability. The F15 is taken as reference representing a typical design for maximum SEP-performance. Then, the asymptotic limits from the upper diagram in Fig. 1 are used as end points of each wing loading

o Technical characteristics
- 5 sec. average duration of a PST maneuver
- 10 % of total engagement time in PST
- 50° angle of attack as a minimum requirement
- 15 % firing opportunities at PST conditions
- lower g-level by about 1△g
- lower average maneuvering speed by about 0.1△M

o Tactical characteristics
- PST and DFM equally contributing
- Quicker into firing postion maneuvering
- Longer a firing position maintaining
- More first shoot opportunities
- Less counter hits
- Easier and quicker to switch alternate targets
- Dictating tactics throughout entire speed regime
- More missiles deployable

o Exchange ratio of 2:1 with missiles
o Exchange ratio of 10:1 with guns
o 3:1 exchange ratio with guns and missiles
o 5 wins out of 6 fights (hits without counter hits)
o Withstands two conventionally equal threats

Fig. 13 The tactical advantage of supermaneuverability. Manned air combat simulation results (Refs. 4,5, and 9).

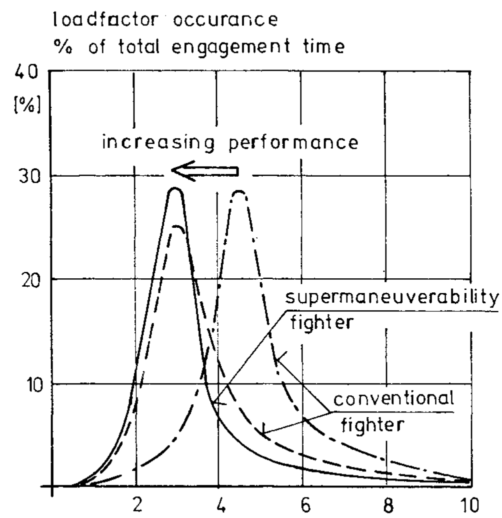

Fig. 14 Relaxation of g-forces by higher sustained turn performance. Reduction of g-level by supermaneuverability (Refs. 1 and 9).

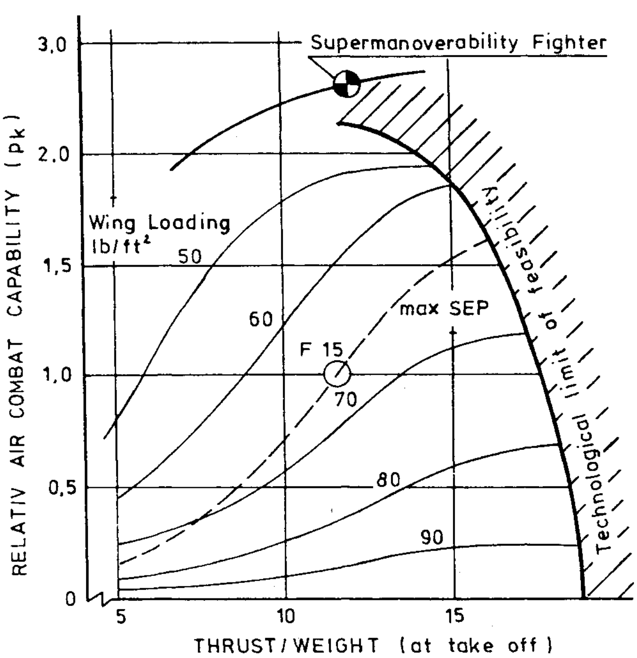

Fig. 15 Levels of air combat capability equivalently achievable by conventional performance and supermaneuverability (Refs. 1 and 9).

line not to be exceeded for a given level of airframe and engine technology. The connection of these end points constitutes a technological limit of air combat capability for conventional fighter aircraft. A fighter of the F15 performance level, however employing supermaneuverability, would have to be plotted beyond that limit.

IV. Summary

The design of a new fighter has become more challenging since a pure increase of conventional performance does not seem to pay off any more. However, a new concept evolves from the combination of three key technologies: electronic digital control, the aerodynamic advancements of delta wings, and "supermaneuverability." Such fighter concept would feature excellent supersonic performance, thus improving the use of future MRM's, a conventionally unachievable level of short-range air combat capability, and extremely short field performance combined in one design.

References

[1] Herbst, W.B., and Krogull, B., "Design for Air Combat," AIAA Paper 72-742, AIAA 4th Aircraft Design, Flight Test and Operations Meeting, Los Angeles, Calif. Aug. 7-9, 1972.

[2] Polis, R. and Frenzl, W., "Mehrfachzielbekämpfungsfähigkeit Luft/Luft," MBB Report FE1/TKF/R/6 Band 3, Teil 1, 1979.

[3] "Advanced Fighter Technology Integration (AFTI)," Executive Summary, Tech Rept. AFFDL-TR-75-86, 1975.

[4] Ross, H., "Taktische Auswirkungen von Post-Stall-Manövern im Luftkampf," MBB Rept. UF 1498, 1977.

[5] Herbst, W.B., "Zur Beurteilung des taktischen Nutzens von PST/DFM für die Luftkampffähigkeit eines zukünftigen TKF," MBB Rept. UF 1477, 1978.

[6] Well, K.H., "Optimale dreidimensionale Steuerungen von Hochleistungsflugzeugen mit Post-Stall-Eigenschaften," MBB/DFVLR, Rept. A552-78/2, 1978.

[7] Witte, "Rechnerische Untersuchung von 180° Wendekurven," Pt. 4, MBB/Porsche AG Report 928.000.021.0B, 1979.

[8] Guthrie, C.H., "Advanced Fighter Technology Integration (AFTI)," Pt. 4, Tech Rept. AFFDL-TR-75-86, 1975.

[9] Polis, R. and Frenzl, W., "Untersuchung des Einflusses von Flugzeug- und Waffensystemen sowie Supermanövrierbarkeit im 1 vs 1 Luftkampf mit dem digitalen Luftkampfmodell STRALU," TN-BT13-88-22/79, MBB, Oct. 1979.

[10] Lamar, J.E., and Luckring, J.M., "Recent Theoretical Developments and Experimental Studies Pertinent to Vortex Flow Aerodynamic with a View towards Design," NASA Langley Research Center, *AGARD Conference Proceedings No. 247*, 1978.

[11] Lacey, D., "Aerodynamic Characteristics of the Close-Coupled Canard as Applied to Low-to-Moderate Swept Wings, Vol. 2: Subsonic Speed Regime, David W. Taylor Naval Ship Research and Development Center, Rept. DTNSRDC-79/002, 1979.

[12] Becker, J., "Untersuchung über Böenabminderung bei einer Delta-Canard-Konfiguration," MBB, 1979.